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PLANNING

PLANNING PROCEDURES AND PRINCIPLES



Chapter 2

PLANNING PROCEDURES AND PRINCIPLES

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Part II

PLANNING

Chapter 2

PLANNING PROCEDURES AND PRINCIPLES

2–01 SCOPE. These instructions relate to the procedures of planning new permanent installations and of the re-planning or conversion of wartime Army installations to permanent postwar use. In the Continental United States, due to the fact that the facilities constructed for the World War II Army are in excess of those required for training, operating, and maintaining the peacetime Army, few if any entirely new installations are likely to be constructed. For the most part, therefore, planning in the Continental United States will relate to the conversion and further development of existing installations and to the disposal of excess facilities. Oversea construction will include a larger majority of new construction, with some expansion of existing facilities. These instructions do not cover construction in occupied areas.

2–02 PLANNING AT EXISTING INSTALLATIONS. Upon receipt of advice that an existing installation has been designated for prolonged or permanent use, a planning board is established through command channels in conformity with AR 210–20, 24 January 1947, subject: Posts, Camps, and Stations—Master Planning of Installations, which describes the composition, duties and functions of the Board in detail. WD Memorandum 210–20–1, 10 September 1946, subject: Master Planning and Construction Programming at Postwar Installations in Continental United States and Overseas, correlates existing instructions and implements AR 210–20 by specifying in detail the procedures to be followed in preparing master plans and construction programs. It describes, further, the purposes and contents of the master plan to be prepared and recommended by the planning board for the orderly future development of the installation. The procedures of planning call for the preparation of (1) basic information maps, (2) and analysis of existing facilities, and (3) future development plans. Description of (1) and (2) is given in paragraphs 12 and 13 of above-referenced WD Memorandum 210–20–1, and of (3) in paragraph 14 thereof. Accomplishment of the first two items presents less difficulty than that of the third which may be complicated in the extreme. Paragraphs 2–04 and 2–07 below give broad general principles and one method of approach to future planning as used by professional planners. In the case of small installations, this method of approach should enable the planning board to produce comprehensive, efficient plans for future development with their own resources, while at large or complicated installations, the assistance of qualified planning consultants may be found desirable. Procedures and channels for submission of master plans are given in table 1, AR 210–20.

2–03 PLANNING AT NEW INSTALLATIONS. Upon receipt of directives authorizing advance planning or construction at an approved site, the appropriate district engineer or other construction authority will proceed with the preparation of plans following procedures which prevailed generally during wartime construction as follows. Based on the requirements of the using service as defined in the advance planning or construction directive and upon reconnaissance surveys (contour interval of 5 feet) at convenient map scale, not larger than 1″=400′ nor smaller than 1″=1,000′, preliminary site studies as described in paragraph 2–05 below are prepared with a view to establishing a final approved site lay-out. Upon approval by the using service and the Chief of Engineers of a final lay-out mutually acceptable to all interested parties, detailed planning will proceed. Normally, a new project will require the preparation of the same types of plans as are required for existing installations, as described in paragraph 14 of above referenced WD Memo-

randum 210–20–1, the essential difference being that, at existing installations every effort must be made to retain, utilize, and take maximum advantage of existing facilities (roads and utilities), while at new installations, lay-out design is not affected by this factor.

2–04 BROAD PLANNING PRINCIPLES. The preparation of any comprehensive plan for future development must follow the process of analysis and synthesis: The analysis of existing conditions and future requirements and their synthesis into a unified whole, the execution of which will provide all the required facilities in the most economical and functional manner.

a. Sound planning. The preliminary site lay-out of a new installation or the general site plan of a master plan of an existing installation must be based primarily upon the principles of sound land planning. These embrace the necessary allotment, proper arrangement, and efficient correlation of both land areas and structures and their functional and economical organization and integration to serve a specific purpose—the mission of the installation as at present understood. Such planning demands complete knowledge of the function of the installation, broad vision, thorough knowledge of ground forms and their possible manipulation and use, and the proper adjustment of structures and groups of structures to the land and to each other.

b. Flexibility and expansion. While it is desirable to have complete knowledge of the function or mission of an installation before planning is begun, in many cases this will be impossible, especially in the case of air force installations, where the very vehicle of operation and training—the airplane—is undergoing frequent changes in size, operating characteristics, and function. Therefore, in addition to fulfilling immediate program requirements as to area to be allotted to troop housing, family housing, training facilities, and other functions, the installation must be planned with an eye to flexibility of use and future expansion. The dire results of permitting posts to "grow like Topsy" are due largely to lack of foresight, to making *small plans* and not allowing for future needs. It is in the preliminary stages of planning for future development, as described in the following paragraphs, that this difficulty can best be circumvented, for it is easiest at this stage to set the control for the long distance future by establishing (1) the uses to which different land areas may best be put and correlated to produce a thoroughly coordinated, economical, and efficiently operative installation and (2) the alternative land uses, which change of mission or other eventualities may dictate, which would still produce the same result.

c. Plans for future development. Reference is made to paragraph 14, above-referenced WD Memorandum 210–20–1, with particular reference to the completion of preliminary studies prior to the inception of plans for future development.

2–05 PRELIMINARY STAGE PLANNING. Whether at an existing installation being master-planned for future development or at a new site being planned for immediate construction, the preliminary stage of planning should take the form of a skeleton lay-out to include the following:

a. Approximate allocations of land areas to the various functions and activities of the installation, such as troop housing, family housing, training aids, ranges, and drill areas; administrative, operational, service, recreational, and hospital areas; runway systems, approach zones, and parking aprons; including adequate indication of the functional relationship of each to the other and adequate provision for expansion of each area.

b. Circulation between these areas, indicating proposed network of main arteries and secondary roads, including any existing roads to be retained and improved; also, the location of existing rail spurs and any future proposed relocations or expansions thereof.

c. Such a preliminary site study will normally *not* show the detailed locations of structures, except important special buildings, the locations of which within the different use-areas, may have been important in motivating the size and shape of the areas or in determining their locations in relation with other areas.

Such a "land-use-area study", though in comparatively preliminary form, is analogous to the zoning map of a city, and, as such, must look as far into the future as possible; it should be con-

fined to broad rather than detailed considerations. Preliminary submission of a master plan, referred to in paragraph 10, WD Memorandum 210–20–1 may take the form of such a skeleton plan.

2–06 PURPOSES OF PRELIMINARY PLANNING. Among the purposes of the preliminary planning described above are:

a. Determination of the location and necessary number of blocks of troop housing (battalion, battery, squadron, regimental, group) needed to house the peacetime complement based on approved space allowances. *In the case of new installations* where planning is not restricted by the existence of road and utilities networks which every effort must be made to retain, the lay-out of housing areas is determined largely by the economical fitting of structures and groups of structures to topography and by the necessary efficient relationship of housing to operational areas. *In the case of existing installations* there is the added problem of determining which of the already developed areas should be retained and converted to permanent construction and, by stage development, the priority of areas designated for such conversion. Normally, the first blocks to be converted would be those in closest juxtaposition to operational or training areas. This determination can best be made and recorded in the stage 1 study described in paragraph 2–07 below. At this stage also, determination is made as to which blocks of existing housing should be retained in mobilization type construction for use by UMT troops (see paragraph 2–09*b*, below) and which blocks have no use in the foreseeable future and may therefore be recommended for disposal or for retention on standby status.

b. Determination of areas to be assigned to permanent family housing for both officers and noncommissioned officers and to local recreation, shopping centers, and school grounds as given in detail in paragraph 2–15.

c. Determination *at new installations* of appropriate areas to set aside for operational and for training uses to satisfy the criteria and requirements of the using service; *at existing installations*, determination of the existing operational and training facilities to be retained as they are because of their suitability, adequacy, and efficiency, as determined from the analysis of existing facilities prepared in conformance to paragraph 13, WD Memorandum 210–20–1; determination of changes or revisions to be recommended in the event that the analysis indicates the unsuitability, inadequacy, or inefficiency of any existing facilities or areas or of their relationship one to the other.

d. Determination of locations and acreage to be set aside for outdoor recreation. In this matter, conclusions will be easier to reach at new projects than at existing installations where athletic areas of the extent required (see par. 2–15 below) to accommodate units of different sizes will be difficult to find in close proximity to the existing housing areas. The nearest available open spaces should be allocated for these purposes provided they do not interfere with or obstruct the normal use of the installation from a training or operation viewpoint. Parade grounds may be used for recreation purposes, except for facilities requiring construction of backstops or other obstructions to the use of the grounds for reviews.

2–07 SAMPLE OF PLANNING TECHNIQUE. Figures 1 to 4 inclusive (plans 18.2–4, –5, –6, –7) show four possible stages in the development of a "plan for future development" and represent one method of procedure often used by planners in establishing a scheme for the physical development of large projects. Stages 1 and 2, though rough studies, are valuable forerunners of stage 3. Stage 3 represents the form and degree of development considered desirable for the preliminary submission of lay-out plan referred to in paragraph 10, above-referenced WD Memorandum 210–20–1, while stage 4 answers the requirement of a general site and building use plan, as called for by paragraph 14*c* of the same memorandum. The four stages of planning show a logical process of development as follows:

Stage 1. Over a print of the topographic survey, any number of rough studies are made on tracing paper with a soft pencil to produce finally (fig. 1) a relationship of elements of the installation plan. These elements are shown by simple curvilinear outlines, representing areas of different land usage. At this stage the areas are not necessarily in proper relative size, for this stage of study aims only to produce efficient relationships of areas one to another and to the topography. If dictated by the topography to the optimum extent, the lay-out produced will not only meet the requirements of housing, training, administration, operation, and service, in a functional and economical manner, but also will produce more attractive living conditions than if topography had been disregarded in favor of some arbitrary pattern of development, such as a gridiron lay-out or other stiffly rectilinear design. Arrows on the study show where it is considered important to have easy access from one area to another or where areas should definitely be in juxtaposition by reason of their proposed uses. Thus, at this stage, opportunity is given to assure, for example, that access from the troop housing areas to training areas is adequate and efficient and that traffic between troop housing areas and nearby cities and towns need not be through the family housing areas but, rather, by-passed around them.

Essentially the same principles, relationships of elements, and study procedures apply in the conversion of existing temporary cantonments to permanent posts, the greatest difference being that in the case of existing installations, the study is influenced to a marked degree by the advisability and economy of saving former roads and utilities so far as is practical. The size and shapes of the outlines will be more rectangular and definitive due to the existing road and block lay-out.

Stage 2. The second step (fig. 2) in the evolution of the post plan develops to a more realistic degree the size and shape of the curvilinear outlines. To the original outlines are applied certain criteria for allocation of space for different land uses, such as: troop housing, 100 men per acre; troop recreational areas, 12 acres per battalion or 1,000-man complement; officer family housing, 4 to 5 families per acre; noncommissioned officer family housing, 6 to 7 families per acre. It is observed that, through the use of these space allocation criteria applied to land use areas, the curvilinear outlines of stage 1 become somewhat more definitive in stage 2, but that the over-all relationships between areas still follow stage 1 fairly closely.

Stage 3. The third stage (fig. 3) transmutes the irregular curving area outlines of stage 2 into the different types of housing "blocks" and other use areas and defines the street circulation between them. The organizational area relationships remain to a large extent, as in the preceding studies, but the sizes and shapes of the outlines take a more realistic form.

Stage 4. The final stage (fig. 4) refines the road alinements; shows the housing spacings in the four different types of "blocks" (troop units, officer and noncommissioned officer family units, family apartment units, and bachelor apartment units); locates and defines outlines for important structures and groups of structures (commercial area, warehouse area, administrative area, etc.); gives foliage outlines to define open areas for recreation and screens for privacy or protection (such as between troop housing areas, between warehouse and housing areas, etc.).

2–08 REGIONAL STUDY. No such preliminary stage studies as are described above should be undertaken until the regional plan, called for by paragraph 14*a* of referenced WD Memorandum 210–20–1 has been given at least preliminary study as well. Outside (off-post) influences may be far reaching in their effect upon the future development of an installation. The installation must be given consideration as an integral part of the community in which it is located and of the region within a 50-mile radius from installation headquarters. At least the following factors should receive consideration prior to starting the preliminary master plan:

a. Transportation. The adequacy of access roads from nearby population centers and from public highway networks and to off-reservation maneuver areas, airfields, existing or proposed recreation centers and parks; elimination of traffic hazards (narrow roads, narrow or weak bridges, dangerous intersections); desirability of new circumferential expressways to alleviate congestion; adequacy of rail facilities for supply and troop movement; interference with civil airlanes.

b. Training areas. Desirability of establishing needed off-reservation training areas (water courses for engineer training, maneuver areas, special target areas) and access to them.

c. Health and morals. Elimination of off-reservation mosquito-breeding or other unsanitary nuisances; protection through local zoning or building regulation against intrusion on surrounding private land of influences affecting morals of troops.

d. Flooding. Extent of necessary corrective measures (Army, State, or Federal) against flooding due to off-reservation high water.

e. Civilian housing. Need of public housing, recreation, and commercial facilities for civilian workers to be employed on the installation.

f. Recreation. Development of public reservoir, lake, or park facilities which might be shared by military personnel for recreation purposes.

2–09 MISSION AND STRENGTH AS BASIS OF PLANNING. Volume I of section 3–D, Progress Report, "Program of Installations," Service, Supply and Procurement Division, WDGS, establishes the existing installations at which master planning is required, in addition to which certain stations may from time to time be designated for "prolonged use" at which master plans will be developed in conformance with AR No. 210–20. Volume II of the same publication gives *mission* of the installations in the form of a break-down of units assigned and *strength* in the form of two tabulations, Active Forces and Reserve Forces. Active Forces are composed of Regular Army, UMT trainers and UMT trainees; Reserve Forces, of National Guard and Organized Reserve. The basic requirements of installations, in the form of missions and strengths, will be made available to the installation planning boards by the appropriate higher authorities. This information will assist the planning boards in determining areas and facilities and types of construction to be allocated to the different components of the installations, as follows:

a. Regular Army—permanent construction. Paragraph 7*b* (1), above-referenced WD Memorandum 210–20–1, gives the objective of the War Department that "elements and activities of the Regular Army shall be housed in permanent type construction by 30 June 1957* for the Continental United States and by 30 June 1952* for overseas areas exclusive of areas of occupation."

b. UMT—existing mobilization-type construction. Until such time as it becomes War Department policy to provide UMT complements with permanent facilities, it will be assumed for planning purposes that these troops will be provided with existing mobilization-type facilities. Structures in general will retain their present function, but groupings of barracks in relation with messes, supply, and recreation buildings will change, due to the necessity of complying with the space allowances established by WD Memorandum 100–46, 2 April 1946, Space Allowances at Permanent Installations; as, for example, the necessity for providing 72 square feet per enlisted man, grade 6 or 7, in barracks where the original lay-out was based on 60 square feet per man.

c. Reserve Forces—"Site facilities". These troops need only be provided with "site facilities" (kitchens, messes, administration and recreation buildings, roads and utilities, and terrain for training), shelter being provided by use of tents, except in those cases where mobilization-type facilities are still available.

Note. For Reserve Forces, if the area assigned is at present in theater of operations construction, barracks and/or hutments will be recommended for early disposal to obviate high maintenance costs; balance of structures will be retained as "site facilities" for as long as they will stand without abnormal maintenance, after which it is expected that they will be replaced by permanent construction.

From the above, it is evident that, for present planning purposes, the "plans for future development" may show areas of one or more of three different types of construction, depending upon the mission of troops assigned: areas of *permanent construction* for Regular Army troops, areas of *mobilization-type* for UMT trainers and trainees, and *"site facilities"* of whatever construction type is available, for Reserve Forces.

*Revised by Change No. 2, 4 Feb. 1947, to 30 June 1962 and 30 June 1960.

2–10 PLANS FOR FUTURE DEVELOPMENT.

a. General plans and detailed site plans. Paragraph 14 of above-referenced WD Memorandum 210–20–1 describes the phase of the master plan known as "Plans for Future Development." Paragraph 2–08 above describes the need for at least preliminary study on the Regional Plan, the first item under Plans for Future Development. The other items described are plans which are general in nature, normally at as small a scale as 1″=400′, except for the detailed site and building use plan, normally at a scale of 1″=50′, 1″=100″, or rarely 1″=200′. While general in nature, these plans must be carried to a sufficient degree upon which to base the preparation of the construction program as called for by the tabulation of total required and existing facilities in paragraph 15, WD Memorandum 210–20–1.

b. Other detailed plans. It is not contemplated that other detailed plans for future development (par. 14*k* of same memorandum) than the detailed site and building use plan will be required until funds have been allocated for definite construction projects when they may be needed to serve as a guide for the preparation of actual construction plans or project plans and specifications.

c. Labor-saving device in plan preparation. Particular attention is drawn to the last sentence of the opening paragraph of paragraph 14, WD Memorandum 210–20–1: "In many cases it will be feasible and advisable and is permissible to prepare the plans for future development on reproducible prints of the corresponding basic information maps." In the case of the general site and building use plan of the future development plans (par. 14*c*, WD Memorandum 210–20–1), for example, it will save labor in study and reference back and forth from one plan to another, if the general site and building use map of the basic information maps (par. 12*c*, WD Memorandum 210–20–1) is printed on the reverse of the sheet to be used for the future development plan. (See par. 14*c*.) Existing roads will show through and the proposed construction readily fitted into the pattern of existing circulation.

2–11 DEVELOPMENT BY STAGES.

a. Stages of construction program. The long-range construction program can be shown on a set of prints of the future development plans by appropriate use of a different color or symbol for each year's part of the total program. Crayon is suggested as preferable to inked-on symbols (in the form of different types and directions of cross-hatching), since changes will have to be made from year to year, due to the fact that items approved for construction for a given year may not coincide exactly with items recommended for that year. Items recommended but not approved may be transferred to the next year's program (by change of color on the print), provided their priority is still considered high by the planning board; or, if not, may be relegated to a later year's program. In any case, it is important to record the complete fifteen-year program by different colors by year, in order that constantly changing personnel on the planning boards may have the benefit of previous planning.

b. Progress prints. For use by the planning board and as record of accomplishment year by year and of the status of post development at all times, reproducible prints may be prepared, *in reverse*, of all the basic information maps called for by paragraph 12, Memorandum 210–20–1, and, *on the front side of each sheet*, "as built" new construction added in its proper place.

2–12 TYPES OF BUILDING CONSTRUCTION.

Standards of construction will be in accordance with War Department policy as defined in WD Memorandum 100–46, 4 March 1946, Standards of Construction at Permanent Installations.

2–13 SPACE ALLOWANCES IN BUILDINGS.

Space allowances in buildings will be in accordance with War Department policy as defined in WD Memorandum 100–46, 2 April 1946, Space Allowances at Permanent Installations, and subsequent directives as issued and interpreted in the form of standard architectural drawings.

2–14 SPACING BETWEEN BUILDINGS. Spacing between buildings will be determined by the provision of proper and adequate light and air in the buildings and by the requirements of fire protection.* Reduction in fire hazard is attained:

a. By providing fire breaks 250 feet in width between every 1,000 feet* (approx.) of built-up area where "mobilization type", "ordinary construction" (masonry walls, wooden windows, trim, eaves, floors, and roof), or "partly fire-resistant construction" (masonry walls, metal sash with plain glass, fire-resistant roof; classified as "incombustible but damageable"), is retained or planned. Where completely fire-resistant and/or fireproof construction (masonry walls, metal sash with wire glass, fire-resistant roof) is retained or planned, firebreaks may be omitted.

b. By providing the following minimum spacing between buildings of the following construction types:

Frame construction:	Feet
Between one-story buildings, "Mobilization Type"	40
Between one- and two-story buildings, "Mobilization Type"	50
Between two-story buildings, "Mobilization Type"	50
Between isolated warehouses, "Mobilization Type" (not including platforms)	80

(It is preferable to have 100 feet separation between the sides of warehouses which do not face railroad loading platforms.)

Partly fire-resistant construction. Spacing between structures may be reduced to 30 feet in the case of barracks and other structures in housing areas, provided they are not more than one-story in height, but should not be reduced below the above criteria in the case of warehouses or other large "industrial" structures. For adequate light and air, two-story structures should normally not be closer together or to one-story structures than 40 feet apart; three-story structures should not be closer together or to structures of fewer stories than 60 feet. Greater spacings, within the limits of economical construction costs, will increase the dignity and setting of the higher structures.

Completely fire-resistant or fireproof construction. Spacing between buildings will be determined by the requirements of light, air, and suitable setting. (See reference to two- and three-story structures in *b* above.)

2–15 SPACE ALLOWANCES BY LAND AREA. For the allocation of land to different functions, buildings, and group of buildings, for use in preliminary studies and in subsequent future development plans, the figures given below may be used as general guides.

a. For preliminary study, broad-scale allocation of space:

Troop housing	75 to 100 men per acre.
Family housing:	
Officers	4 to 5 families per net acre, exclusive of roads; assume 75% of assigned officers to be married.
Noncommissioned officers, first 3 grades.	6 to 7 families per net acre, exclusive of roads; assume 60% of assigned noncommissioned officers to be married.
Recreation (as authorized by WD Memorandum 210–46, 12 June 1946):	
1,000-man unit or battalion	Approx. 12 acres each.
3,000-man unit or regiment (In addition to above)	Approx. 7 acres each.
Division-type unit (In addition to above)	Approx. 30 acres.
Posts of less than Division strength	Vary with size of post.

*See paragraphs 7–06 *b* and 7–15 *c* of Chapter 7, Part II, for special spacings in family housing areas.

Regimental facilities..... Approx. 7 acres.
(Administration, infirmary, post exchange, gymnasium, and chapel)
Parade Ground (At division-type post)... 130–175 acres.

b. For structures and groups of structures. See attached table of space allocations for major buildings. This tabulation gives a rough figure of acreage to be allotted to structures of different functions, sizes, and capacities. It also shows the number of cars to be accommodated at different types of structures in one of the following forms: actual number of cars, percentage of total complement to be provided parking space, percentage of civilian personnel to be accommodated (as at bakeries, laundries, etc.), percentage in terms of seating capacity (as in theaters, auditoriums, chapels, etc.).

2–16 GROUPING OF BARRACKS. Groupings of permanent barracks are shown on figure 5

a. Barrack sizes. The three different sizes of barracks shown are based on the determination that a great majority of *table of organization units* can be housed in three sizes of barracks: 105-man 165-man, and 225-man units. Definitive drawings for these three types are in preparation.

b. Barracks groupings. Groupings of barracks shown are based on the determination that a majority of *table of organization units* can be accommodated in two main types of groupings:

Type I:
3 225-man units.
1 165-man unit.
1 105-man unit.

Type II:
5 105-man units.
2 165-man units.

Other combinations of the three sizes of barracks can be developed to cover such table of organization units as would not be economically accommodated in the two types of groups listed above.

c. Non-table of organization units. For such units it has been determined that a majority of needs will be satisfied by 40-man squad rooms grouped in units of 200 men, 500 men, or 1,000 men, served by a central mess. Definitive drawings for these types are in preparation. Possible groupings are shown on figure 6.

d. Adaptation to topography. Figure 5 also shows the desirability and, often, the necessity of avoiding the use of symmetrical, balanced grouping of structures in order to fit the topography economically. Figure 5a shows original (existing) barracks of mobilization-type construction and, superimposed in heavier lines, barracks of permanent-type construction. The shorter mobilization-type structures were placed on the topography in regular rectilinear blocks; the longer permanent buildings require adjustment to contours to avoid excessive cuts and fills, resulting in the irregular lay-outs shown. Figure 5b shows mobilization-type construction accommodating an armored division and, superimposed in heavier lines, an infantry division in permanent-type construction with structures adapted to topography in a similar manner.

2–17 FAMILY HOUSING. For criteria and standards in connection with the lay-out of family housing, reference is made to chapter 7 of this part.

2–18 RECREATION. For criteria and standards, reference is made to

a. WD Memorandum 210–46, 12 June 1946, Athletic, Religious, and Recreation Facilities.
b. O. C. E. Folder, Series 18.3, March 1946, subject: Athletic Facilities.
c. Chapter 1, part XV, Engineering Manual, Recreation, Military Construction.

TABLE I

SPACE ALLOWANCES FOR MAJOR BUILDINGS AND FACILITIES

	Per building		3,000-man instln.		5,000-man instln.		10,000-man instln.		15,000-man instln.		20,000-man instln.	
	Parking for—	Acreage	Parking	Acreage	Parking	Acreage	Parking	Acreage	Parking	Acreage	Parking	Acreage
Bakery					25% Civ. Emp.	1.25	25% Civ. Emp.	1.25	25% Civ. Emp.	1.5	25% Civl Emp.	2.0
Bank*						.2		.3		.5		.5
Barrack					See Data on Barrack Plan (fig. 5)							
Chapel—300 Seats w/Cl. Rm	200 cars	4.0										
Chapel—300 Seats w/o Cl. Rm	75 cars	2.5										
Civilian Cafeteria (Cap. 200)	15% cap	1.0										
Civilian Cafeteria (Cap. 500)	15% cap	2.0										
Civilian Cafeteria (Cap. 1,000)	15% cap	3.0										
Commissary*					1% Tot. St	1.5	1% Tot. St	2.25	1% Tot. St	2.75	1% Tot. St	3.5
E. M. Service Club					2% Tot. St	3.5	2% Tot. St	5.0	2% Tot. St	7.0	2% Tot. St	7.0
Field House incl. Adjacent Athletic Facilities					6% Tot. St	22.0	6% Tot. St	26.0	6% Tot. St	30.0	6% Tot. St	37.0
Fire Station—Type I 4 Stall		1.5										
Fire Station—Type II 3 Stall		.66										
Guard House					½ Guards	1.5	½ Guards	2.5	½ Guards	3.0	½ Guards	4.5
Gymnasium				1.5								
Headquarters and Admin			0.3% Tot. St	1.3	0.3% Tot. St	1.75	0.3% Tot. St	2.0	0.3% Tot. St	3.0	0.3% Tot. St	3.5
Infirmary			½ of Staff	.5								
Laundry and Dry Cleaning			30% Civ. Emp.	2.25	30% Civ. Emp.	3.25	30% Civ. Emp.	4.75	30% Civ. Emp.	5.5	30% Civ. Emp.	6.5
Library					50% Seat. Cap.	1.0	50% Seat. Cap.	2.0	50% Seat. Cap.	2.0	50% Seat. Cap.	3.0
NCO Serv. Club					17% NCO St.	7.0	17% NCO St.	11.0	17% NCO St.	13.0	17% NCO St.	16.0
Officers Club					20% Off. St.	4.0	20% Off. St.	7.0	20% Off. St.	8.5	20% Off. St.	10.5
Post Exchange (E. M.)				.75								
Post Exchange—Main*					2% Tot. St.	2.5	2% Tot. St.	5.0	2% Tot. St.	7.0	2% Tot. St.	9.0
Post Office*					10 Cars	1.0	20 Cars	1.5	20 Cars	2.0	25 Cars	2.0
Refrig. Bldg. and Ice Plant					25% Civ. Emp.	.5	25% Civ. Emp.	.75	25% Civ. Emp.	.75	25% Civ. Emp.	.75
School—Elementary (500 P)	15% Aud. Seat. Cap.	7.0										
School—Jr.-Sr. High (500 P)	15% Aud. Seat. Cap.	20.0										
School—Combined (500 P)	15% Aud. Seat. Cap.	25.0										
Shops—Motor Repair 2nd Echelon		.3										
Shopping Center: PX, Commissary, Bank, Post Theater, and Post Office.					3% Tot. St. 1+5% Theat. Seat. Cap.	8.0	3% Tot. St. +15% Theat. Seat. Cap.	15.0	3% Tot. St. +15% Theat. Seat. Cap.	17.0	3% Tot. St. +15% Theat. Seat. Cap.	18.0
Storehouse—P. X						.5		.5		1.0		1.0
Storehouse—Post						4.0		6.0		9.0		12.0
Theater—500 Seat Cinema	15% Seat. Cap.	1.5										
Theater—1,000 Seat Cinema	15% Seat. Cap.	2.5										
Theater, Stage—500 Seat*	15% Seat. Cap.	1.5										
Theater, Stage—1,029 Seat*	15% Seat. Cap.	2.5										
Utility Yard—Post Eng					20 Cars	7.0	25 Cars	7.0	35 Cars	8.0	35 Cars	8.0

*If isolated from Shopping Center.

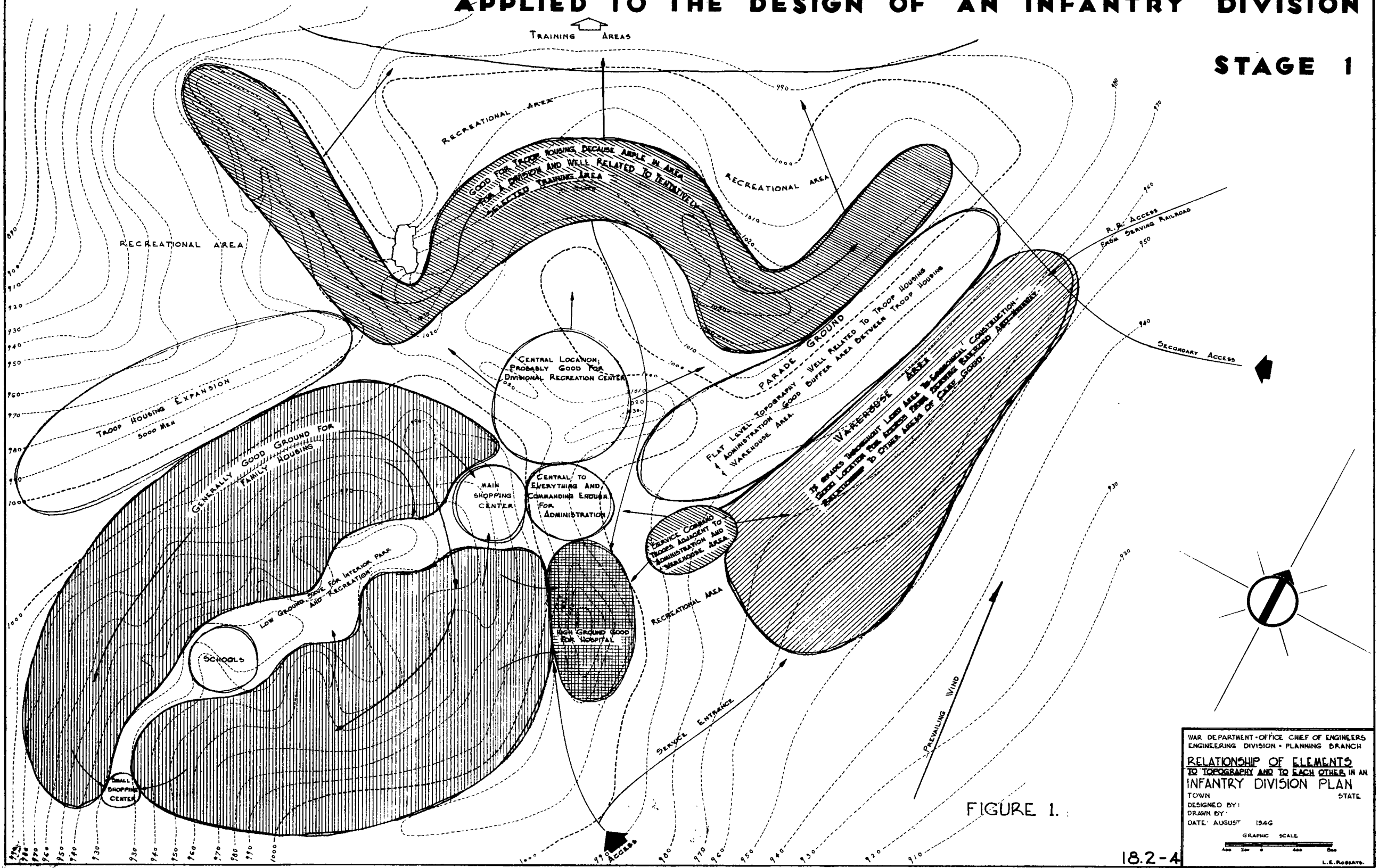
Aud. Seat. Cap.=Auditorium Seating Capacity.
Civ. Emp. =Civilian Employees.
Cl. Rm. =Class Rooms.
NCO St. =NCO Strength.
Off. St. =Officer Strength.
Seat. Cap.=Seating Capacity.
Theat. Seat. Cap.=Theater Seating Capacity.
Tot. St. =Total Strength.

U. S. GOVERNMENT PRINTING OFFICE: 1947

PRINCIPLES OF SITE PLANNING

APPLIED TO THE DESIGN OF AN INFANTRY DIVISION

STAGE 1



WAR DEPARTMENT - OFFICE CHIEF OF ENGINEERS
ENGINEERING DIVISION - PLANNING BRANCH

RELATIONSHIP OF ELEMENTS TO TOPOGRAPHY AND TO EACH OTHER IN AN INFANTRY DIVISION PLAN

TOWN STATE

DESIGNED BY:

DRAWN BY:

DATE: AUGUST 1946

GRAPHIC SCALE

L.E. ROBERTS.

FIGURE 1.

18.2-4

TO ACCOMPANY ENG. MAN. PART II CHAPTER 2.

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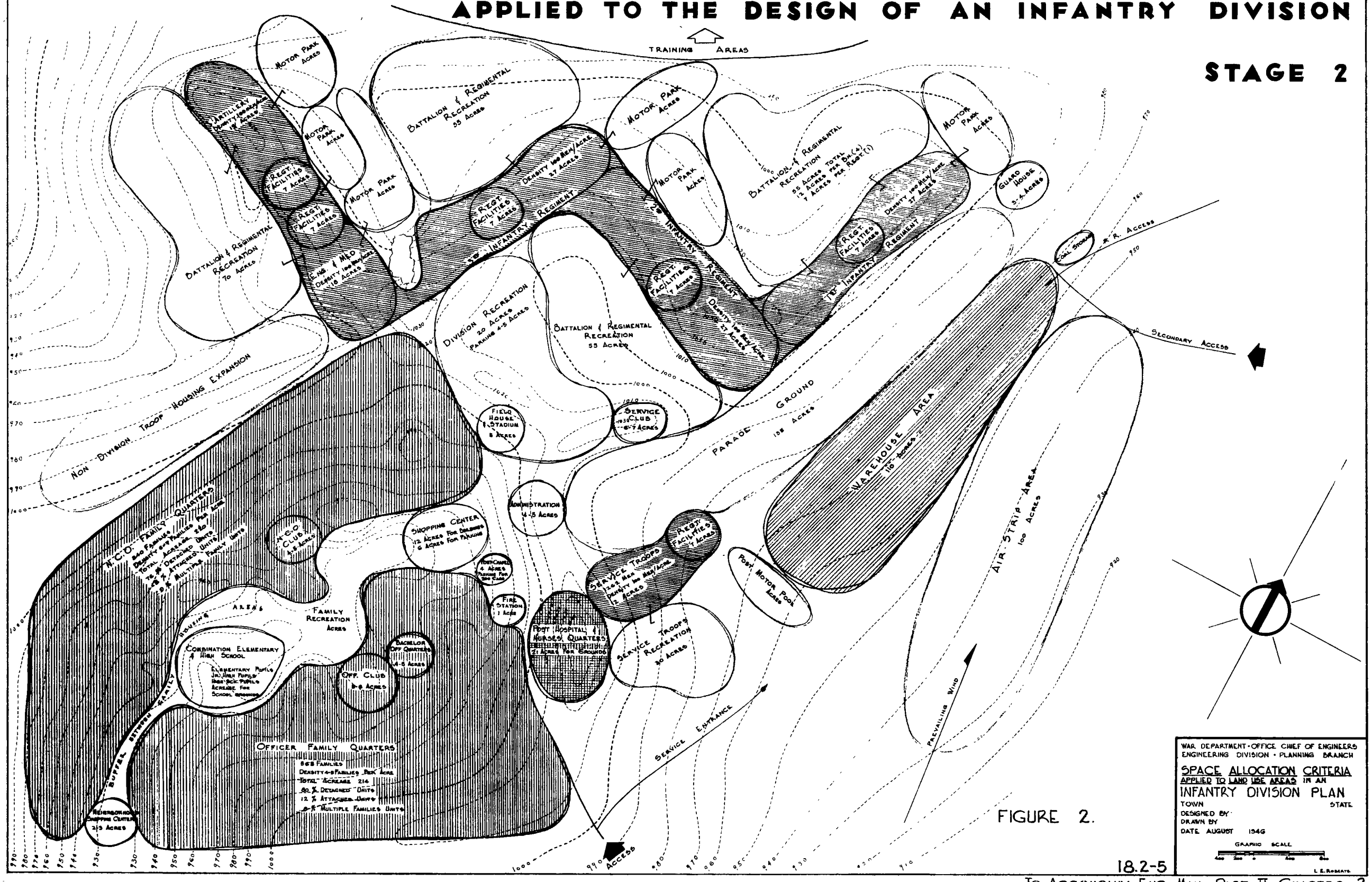
Inside Back Cover No. 1

PRINCIPLES OF SITE PLANNING

APPLIED TO THE DESIGN OF AN INFANTRY DIVISION

STAGE 2


TRAINING AREAS
MOTOR PARK AREAS
ARTILLERY (DIVISIONAL) 14 ACRES
REGT'L FACILITIES 7 ACRES
BATTALION & REGIMENTAL RECREATION 55 ACRES
DENSITY 100 REM/ACRE 27 ACRES
1ST INFANTRY REGIMENT
2ND INFANTRY REGIMENT
3RD INFANTRY REGIMENT
BATTALION & REGIMENTAL RECREATION 70 ACRES
E-MS & MED. DENSITY 100 PERS/ACRE 18 ACRES
DIVISION RECREATION 20 ACRES PARKING 4-5 ACRES
BATTALION & REGIMENTAL RECREATION 55 ACRES PER BN.(A) 12 ACRES PER BN.(T) 7 ACRES PER REGT.(T)
GUARD HOUSE 3-4 ACRES
COAL STORAGE
R.R. ACCESS
SECONDARY ACCESS
N.C.O. FAMILY QUARTERS
800 FAMILIES / / /

PRINCIPLES OF SITE PLANNING

APPLIED TO THE DESIGN OF AN INFANTRY DIVISION

STAGE 3

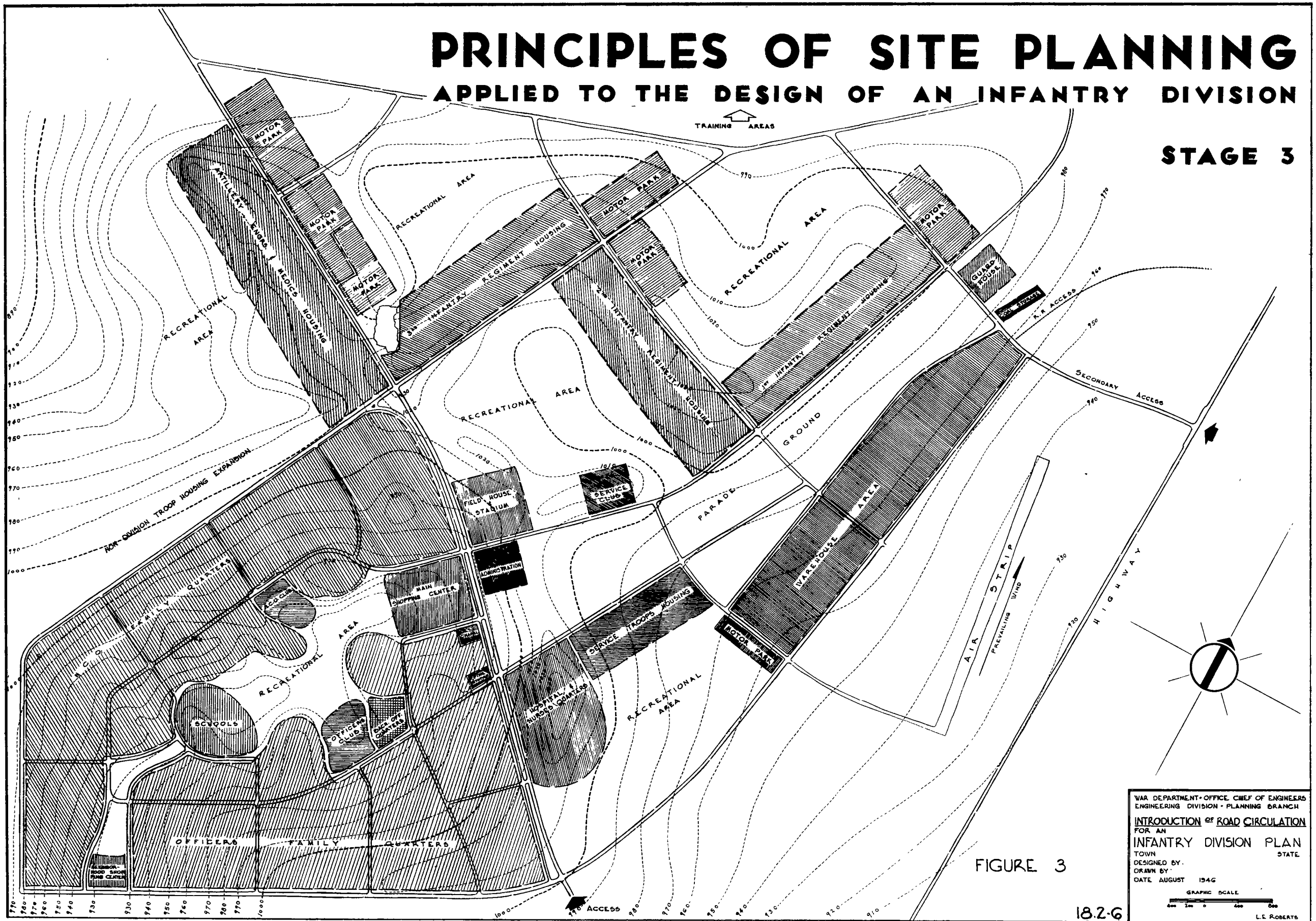


FIGURE 3

18.2-6

WAR DEPARTMENT • OFFICE CHIEF OF ENGINEERS
ENGINEERING DIVISION • PLANNING BRANCH

INTRODUCTION of ROAD CIRCULATION
FOR AN
INFANTRY DIVISION PLAN
TOWN STATE
DESIGNED BY.
DRAWN BY
DATE AUGUST 1946
GRAPHIC SCALE
L.E. ROBERTS

TO ACCOMPANY ENG. MAN. PART II CHAPTER 2.

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PRINCIPLES OF SITE PLANNING

APPLIED TO THE DESIGN OF AN INFANTRY DIVISION

STAGE 4

PREPARED BY THE PLANNING BRANCH
ENGINEERING DIVISION . . . . . .
OFFICE OF THE CHIEF OF ENGINEERS

SEPTEMBER 1946

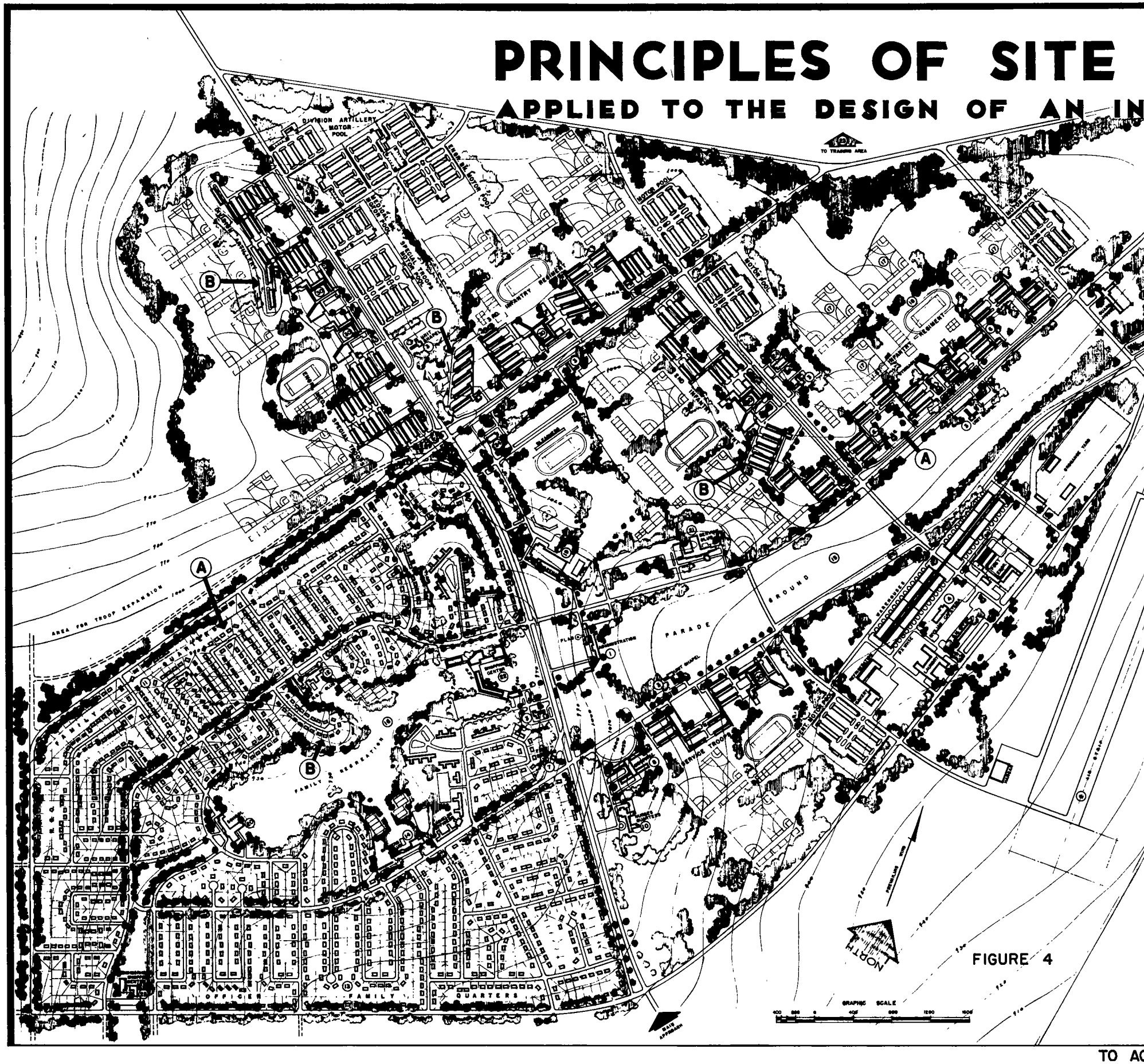

FIGURE 4

1. ADMINISTRATION — OCCUPIES COMMANDING SETTING CENTRAL TO ENTIRE POST ON DIRECT ROAD FROM MAIN ENTRANCE WITH ACCESS TO ALL PARTS OF THE POST BY DIRECT ROUTES.
2. AIR STRIP — WHERE AUTHORIZED WILL BE LOCATED AS CLOSE TO POST AS REQUIRED CLEARANCES AND SUITABLE TOPOGRAPHY WILL PERMIT AND IN SUCH A LOCATION THAT THE FLIGHT PATTERN WILL NOT BE DIRECTLY OVER BUILT UP AREA.
3. CHAPELS — CENTRALLY LOCATED IN UNIT AREAS FOR WHICH THEY ARE PROVIDED. THE POST CHAPEL IS NEAR THE FAMILY AREA IN A SETTING COMMENSURATE WITH ITS IMPORTANCE.
4. CIVILIAN CAFETERIA — PLACED CENTRALLY IN THE WAREHOUSE AREA WHERE THE MAJORITY OF CIVILIAN WORKERS WILL BE EMPLOYED.
5. COAL STORAGE — PLACED TO LEEWARD OF BUILT UP AREA.
6. ENLISTED MEN'S AUTO PARKING — PROVIDE IN OPEN PARKING COMPOUNDS AS CLOSE TO BARRACK BUILDINGS AS POSSIBLE.
7. FIRE STATIONS — NOT MORE THAN ⅝ MILE RUN TO HOSPITAL, 2 MILES TO WAREHOUSE AREA, AND NOT MORE THAN 3 MILES TO EITHER FAMILY HOUSING OR BARRACKS AREA.
8. HOSPITAL — OCCUPIES A CENTRAL LOCATION NOT CLOSER THAN 1000 FEET TO A MOTOR STORAGE AREA, NOR CLOSER THAN 3000 FEET TO ARTILLERY OR TANK TRAFFIC, NOR CLOSER THAN ONE MILE TO THE FIRING POINTS OF RANGES
9. MOTOR STORAGE — AS CENTRAL AS POSSIBLE TO LEEWARD OF BARRACKS AND ON SIDE TOWARD RANGES AND TRAINING AREAS.
10. NURSES QUARTERS — NEAR THE HOSPITAL WITHIN ½ MILE OF SHOPPING CENTER AND OFFICERS CLUB IF POSSIBLE.
11. N.C.O. FAMILY QUARTERS — PROVIDE ON BASIS OF SIX TO SEVEN SINGLE FAMILY UNITS PER NET ACRE. HIGHER DENSITY DEVELOPMENTS (APARTMENTS, DUPLEX UNITS) SHOULD BE LOCATED CLOSER TO SHOPPING CENTER THAN SINGLE-FAMILY UNITS.
12. N.C.O. CLUB — CENTRAL TO N.C.O. FAMILY HOUSING AREA AND IN CLOSE RELATIONSHIP TO ADEQUATE RECREATIONAL FACILITIES
13. OFFICER FAMILY QUARTERS — PROVIDE ON BASIS OF FOUR TO FIVE SINGLE FAMILY UNITS PER NET ACRE. HIGHER DENSITY DEVELOPMENTS (APARTMENTS, DUPLEX UNITS) SHOULD BE LOCATED CLOSER TO SHOPPING CENTER THAN SINGLE-FAMILY UNITS.
14. OFFICERS CLUB — RELATED TO OFFICER PORTION OF FAMILY HOUSING AREA WITH ADEQUATE OPEN SPACE FOR RECREATION FACILITIES
15. PARADE GROUND — LOCATE CENTRALLY AND ADJACENT TO POST ADMINISTRATION WITH SPACE ADEQUATE TO ACCOMODATE REGIMENTAL MANEUVERS. LARGER PARADE REQUIREMENTS WILL BE TAKEN CARE OF OUTSIDE OF BUILTUP AREA.
16. RECREATION, FAMILY AREAS — ADEQUATE OPEN SPACE AT THE SCHOOLS AND CLUBS SHOULD BE PROVIDED AS AN INTEGRATED UNIT OF EACH ACTIVITY.
17. RECREATION, BATTALION AREAS — SUFFICIENT OPEN SPACE AS CLOSE AS POSSIBLE TO EACH BATTALION HOUSING UNIT TO PROVIDE FOR THE DEVELOPMENT OF FACILITIES AUTHORIZED BY W.D. MEMO. 210-46.
18. RECREATION, REGIMENTAL AREAS — SUFFICIENT OPEN SPACE AS CLOSE AS POSSIBLE TO EACH REGIMENTAL HOUSING UNIT TO PROVIDE FOR THE DEVELOPMENT OF FACILITIES AUTHORIZED BY W.D. MEMO 210-46.
19. RECREATION, DIVISIONAL — SPORTS ARENA LOCATED CENTRALLY TO THE ENTIRE POST AND ON DIRECT ROAD FROM THE MAIN ENTRANCE WITH SUFFICIENT ADJACENT OPEN AREA FOR ALL DIVISION RECREATION AS AUTHORIZED BY W.D. MEMO. 210-46
20. SCHOOLS — LOCATED IN THE FAMILY HOUSING AREAS, REDUCE TO A MINIMUM THE CROSSING OF MAIN STREETS BY PUPILS GOING TO AND FROM SCHOOL. ELEMENTARY SCHOOLS NOT MORE THAN ½ MILE AND JUNIOR AND SENIOR HIGH SCHOOLS NOT MORE THAN 2 MILES DISTANT FROM FARTHEST PUPIL SERVED.
21. SERVICE CLUB AND GUEST HOUSE — CENTRAL TO THE MAJORITY OF TROOP HOUSING AREAS BUT AWAY FROM TROOP MOVEMENT ACTIVITY AND IF FEASIBLE, NOT MORE THAN ½ MILE FROM POST ADMINISTRATION, SHOPPING CENTER, AND DIVISIONAL RECREATIONAL ACTIVITIES.
22. SHOPPING CENTER — CENTRALLY LOCATED BETWEEN FAMILY AND TROOP HOUSING AREAS. WHERE FAMILY HOUSING COVERS A LARGE AREA SMALL NEIGHBORHOOD SHOPPING CENTERS SHOULD BE PROVIDED NOT MORE THAN ½ MILE FROM FAMILY UNITS SERVED
23. SMALL ARMS RANGES — WITHIN 30 MINUTES MARCHING TIME OF ALL TROOPS USING THEM.
24. THEATERS — CENTRAL TO THE AREAS WHICH THEY SERVE MAIN POST THEATER LOCATED IN OR NEAR SHOPPING CENTER
25. TROOP HOUSING — LOCATE TO TAKE ADVANTAGE OF SUN, PREVAILING WINDS AND TOPOGRAPHY WITH PROPER RELATIONSHIP TO RECREATION FACILITIES, MOTOR STORAGE, RANGES AND TRAINING AREAS. THE BUILDING ARRANGEMENT WILL BE ADAPTED TO FIT NATURAL FEATURES SUCH AS TERRAIN, TREE GROUPS, ROCKS AND WATER AREAS.
26. TROOP LOADING AND UNLOADING TRACKS — WHERE AUTHORIZED NEAR THE WAREHOUSE AREA WITH ADEQUATE SPACE AROUND THEM FOR EFFICIENT OPERATION.
27. TREES AND OTHER PLANTING — EVERY EFFORT SHOULD BE MADE TO PRESERVE EXISTING TREES AND PLANTING.
28. WAREHOUSE AREA — CENTRAL AS POSSIBLE TO THE ENTIRE LAYOUT YET ON THE PERIMETER OF THE POST NEAREST THE SERVING RAILROAD. ACCESS TO THE AREA FROM OUTSIDE SHOULD BE DIRECT AND NOT THROUGH THE POST PROPER.
29. BUILDING LOCATION DESIGN — BUILDINGS SHOULD UTILIZE EXISTING TOPOGRAPHY TO GREATEST ADVANTAGE AND BE PLACED IN PROPER RELATIONSHIP TO ROADS, OPEN SPACES, SUNLIGHT AND AIR, AND GROUPED WITH OTHER BUILDINGS IN PLEASING COMPOSITIONS.
30. UNIT FACILITIES — FACILITIES FOR 3000 MAN UNIT AREAS INCLUDE GYMNASIUM, P.X., INFIRMARY, ADMINISTRATION AND STORAGE.

A → SHOWS A NORMAL ARRANGEMENT OF HOUSING WHERE TOPOGRAPHY IS NOT A STRONG INFLUENCE IN LAYOUT.

B → SHOWS IRREGULAR LAYOUTS IN WHICH STANDARD GROUPINGS ARE REARRANGED TO FIT IRREGULARITIES OF TOPOGRAPHY.

THIS PLAN IS BASED ON Y0 AND E 7 AS REVISED TO 1 JULY 1946.

E.W. GROLL & L.E. ROBERTS.

18.2-7

TO ACCOMPANY ENG. MAN. PART II CHAPTER 2.

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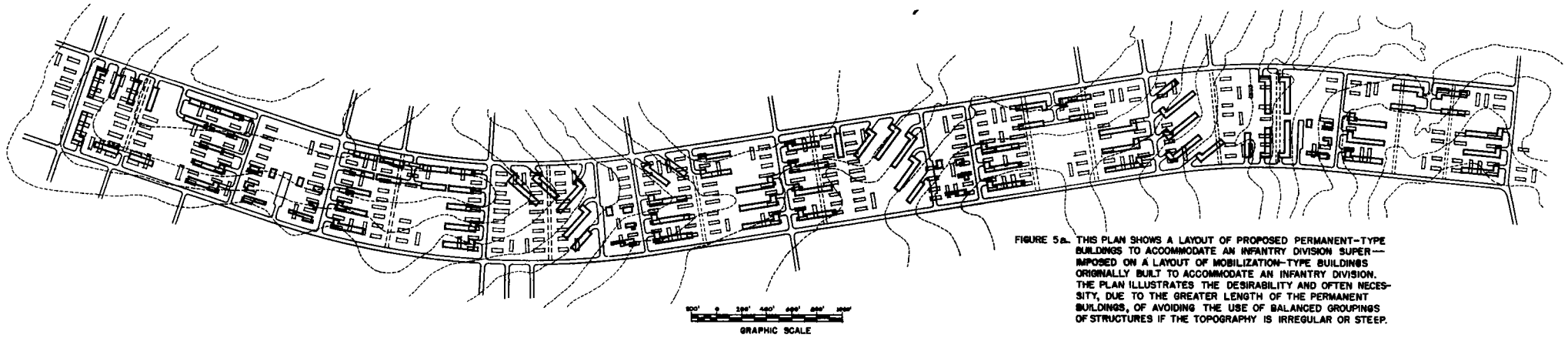


GRAPHIC SCALE

FIGURE 5a. THIS PLAN SHOWS A LAYOUT OF PROPOSED PERMANENT-TYPE BUILDINGS TO ACCOMMODATE AN INFANTRY DIVISION SUPERIMPOSED ON A LAYOUT OF MOBILIZATION-TYPE BUILDINGS ORIGINALLY BUILT TO ACCOMMODATE AN INFANTRY DIVISION. THE PLAN ILLUSTRATES THE DESIRABILITY AND OFTEN NECESSITY, DUE TO THE GREATER LENGTH OF THE PERMANENT BUILDINGS, OF AVOIDING THE USE OF BALANCED GROUPINGS OF STRUCTURES IF THE TOPOGRAPHY IS IRREGULAR OR STEEP.

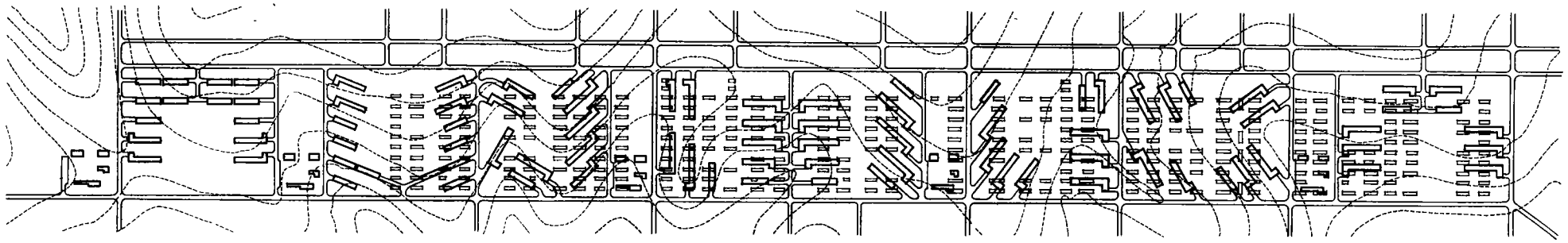


FIGURE 5b. THIS PLAN SHOWS A LAYOUT OF PROPOSED PERMANENT-TYPE BUILDINGS TO ACCOMMODATE AN INFANTRY DIVISION SUPERIMPOSED ON A LAYOUT OF MOBILIZATION-TYPE BUILDINGS ORIGINALLY BUILT TO ACCOMMODATE AN ARMORED DIVISION. THE PLAN ILLUSTRATES THE DESIRABILITY AND OFTEN NECESSITY, DUE TO THE GREATER LENGTH OF THE PERMANENT BUILDINGS, OF AVOIDING THE USE OF BALANCED GROUPINGS OF STRUCTURES IF THE TOPOGRAPHY IS IRREGULAR OR STEEP

BASIS FOR BUILDING SIZES AND GROUPINGS

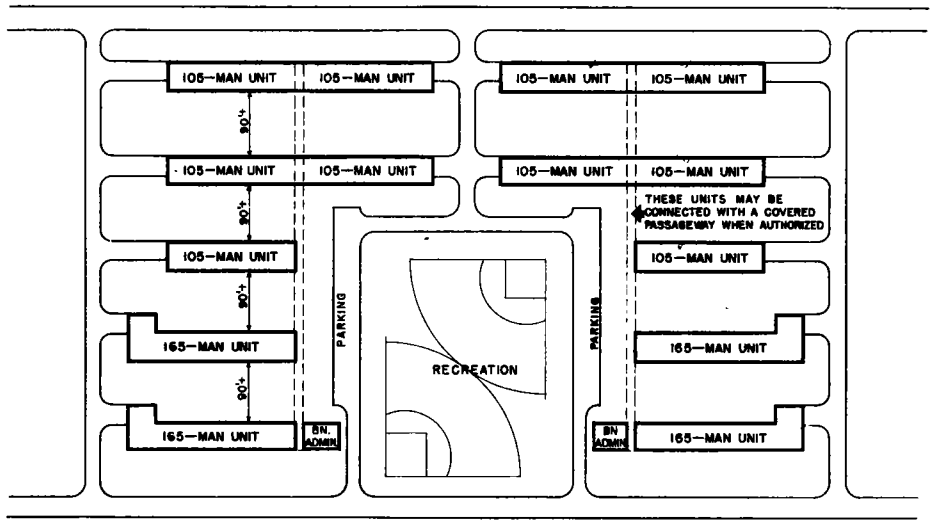
BARRACK SIZES ARE BASED ON THE DETERMINATION THAT A GREAT MAJORITY OF TABLE-OF-ORGANIZATION UNITS CAN BE HOUSED IN THREE SIZES OF BARRACKS: 105-MAN, 165-MAN, AND 225-MAN UNITS.

BARRACK GROUPINGS ARE BASED ON THE DETERMINATION THAT A MAJORITY OF TABLE-OF-ORGANIZATION UNITS CAN BE ACCOMMODATED IN TWO MAIN TYPES OF GROUPINGS

TYPE I 3-225-MAN UNITS
1-165-MAN UNIT
1-105-MAN UNIT

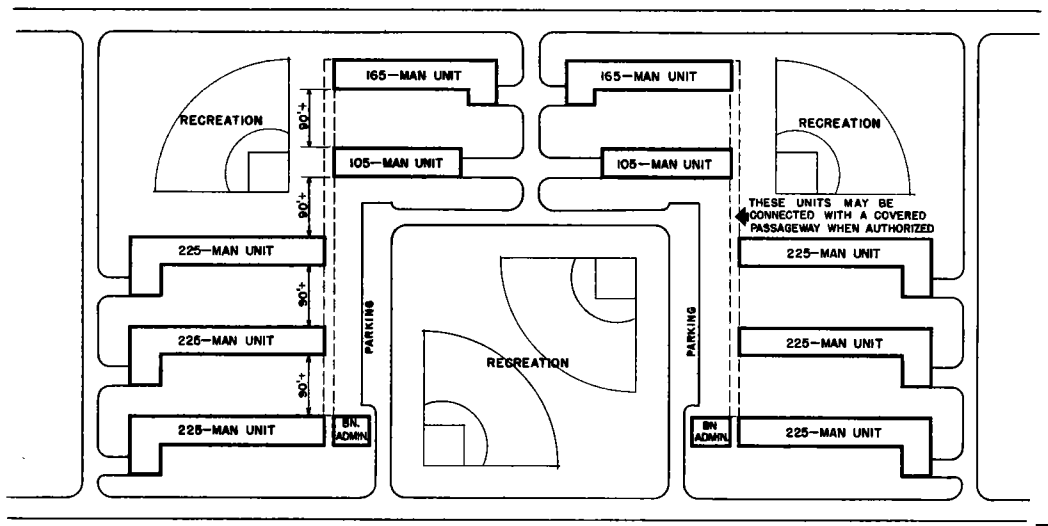
TYPE II 5-105-MAN UNITS
2-165-MAN UNITS

FOR NON-TABLE-OF-ORGANIZATION UNITS IT HAS BEEN DETERMINED THAT A MAJORITY OF NEEDS WILL BE SATISFIED BY 40-MAN SQUAD ROOMS GROUPED IN UNITS OF 200 MEN, 500 MEN, AND 1000 MEN SERVED BY A CENTRAL MESS.



TYPE II

TYPICAL ARRANGEMENT SHOWING TWO BARRACK GROUPS, EACH CONSISTING OF TWO 165-MAN UNITS & FIVE 105-MAN UNITS



TYPE I

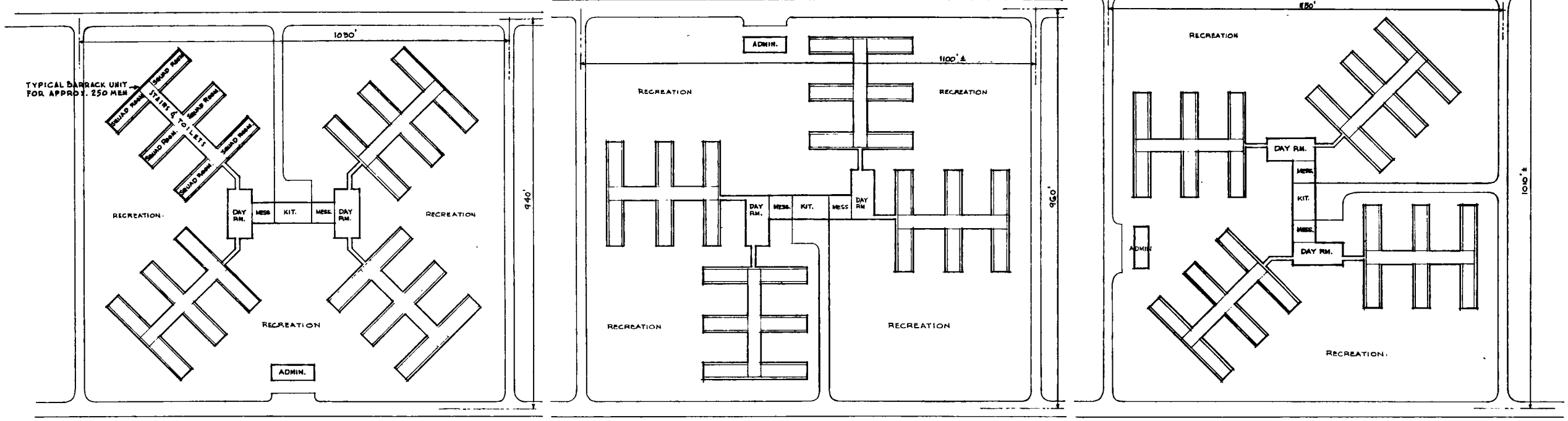
TYPICAL ARRANGEMENT SHOWING TWO BARRACK GROUPS, EACH CONSISTING OF THREE 225-MAN UNITS & ONE 105-MAN UNIT & ONE 165-MAN UNIT.

100 0 100 200 300 400 500

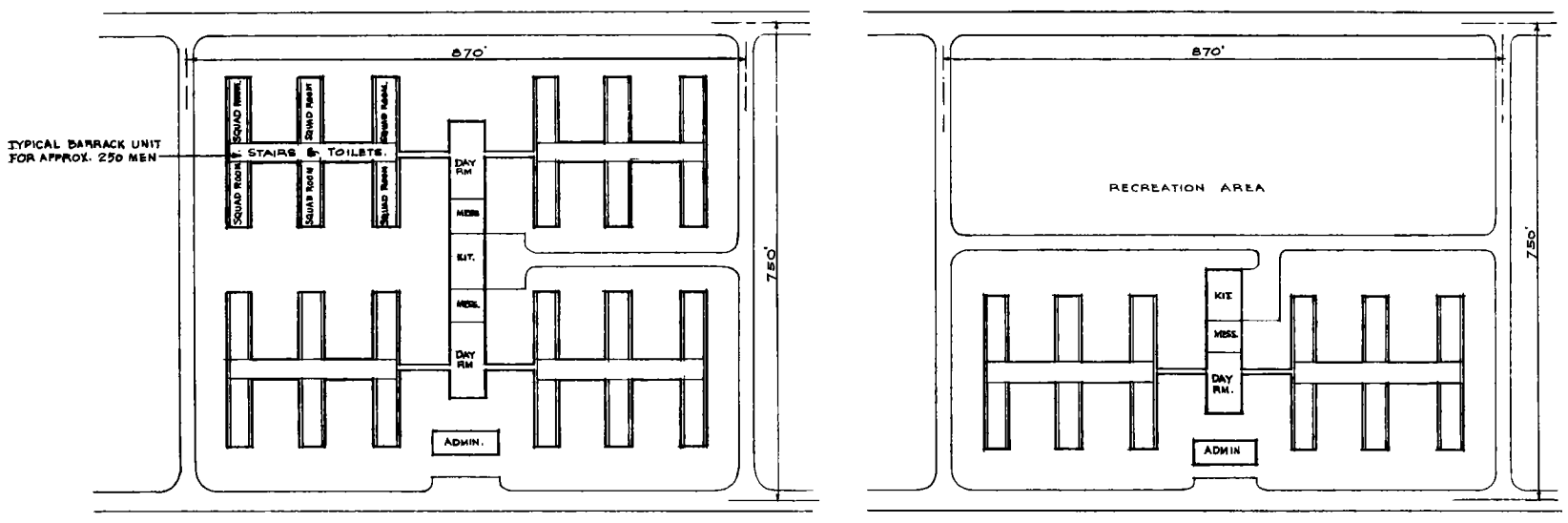
GRAPHIC SCALE

FIGURE 5

WAR DEPARTMENT OFFICE OF THE CHIEF OF ENGINEERS DIRECTOR OF MILITARY CONSTRUCTION ENGINEERING DIVISION WASHINGTON, D. C.	
DRAWN BY: C. WATKINS	BARRACK GROUPINGS FOR TABLE OF ORGANIZATION UNITS
TRACED BY: C. WATKINS	
CHECKED BY:	
SUBMITTED: CHIEF DESIGN SECTION	
APPROVED: CHIEF PLANNING BRANCH	APPROVED: COL. U.S. CHIEF ENGR. DIVISION DATE: 29 OCT. 1942
APPROVED FOR DATE:	SCALE SPEC. NO. DRAWING NUMBER SHEET OF



LAYOUTS SHOWING POSSIBLE VARIATIONS OF BARRACK GROUPINGS FOR 1000-MAN UNITS TO FIT TOPOGRAPHICAL CONDITIONS AT NEW PROJECTS WHERE LAYOUT IS NOT LIMITED BY THE EXISTENCE OF ROAD AND UTILITY NETWORKS.



LAYOUTS SHOWING ARRANGEMENT OF BARRACK GROUPINGS FOR 500-MAN & 1000-MAN UNITS WHERE EXISTING ROADS AND UTILITIES ARE TO BE PRESERVED TO THE GREATEST PRACTICABLE EXTENT.

0' 100' 200' 300' 400'
GRAPHIC SCALE

FIGURE 6

FOR NON-TABLE OF ORGANIZATION UNITS IT HAS BEEN DETERMINED THAT THE MAJORITY OF NEEDS WILL BE SATISFIED BY APPROXIMATELY 40-MAN SQUAD ROOMS GROUPED IN UNITS OF 200+-MEN, 500-MEN AND 1000-MEN, SERVED BY A CENTRAL MESS.

REVISION	DATE	DESCRIPTION	BY

WAR DEPARTMENT
OFFICE OF THE CHIEF OF ENGINEERS
DIRECTOR OF MILITARY CONSTRUCTION ENGINEERING DIVISION
WASHINGTON, D.C.

DRAWN BY W.E.H.
TRACED BY W.E.H.
CHECKED BY
SUBMITTED
CHIEF DESIGN SECTION
APPROVED
CHIEF PLANNING BRANCH
APPROVED FOR
DATE —

· BARRACK · GROUPINGS ·
FOR
· NON-TABLE-OF-ORGANIZATION-UNITS ·

APPROVED
COL. C.E. CHIEF ENGINEERING DIVISION
DATE 29 OCT. 1946
SCALE 1" = 100' SPEC NO
DRAWING NUMBER
SHEET OF

FIG. 6 TO ACCOMPANY ENGINEER MANUAL PART II CHAPTER 2

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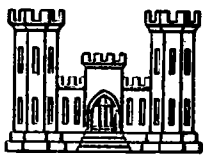
PLANNING

PLANNING OF STORAGE DEPOTS



WAR DEPARTMENT
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

U.S. Army.

Chapter 6

PLANNING OF STORAGE DEPOTS

6–01 PURPOSE

6–02 DEPOT FUNCTION

6–03 SERVICES REQUIRING STORAGE

6–04 REQUIREMENTS
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- *b.* Statement of requirements

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6–06 SITE

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- *b.* Open sheds
- *c.* Open storage

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6–09 DIMENSIONS

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Part II

PLANNING

Chapter 6

PLANNING OF STORAGE DEPOTS

6–01 PURPOSE. These instructions are intended to cover the major requirements for the lay-out, arrangement, and design of storage depots for War Department services. They will apply to major expansion of present facilities, new construction, and, where justified by economy of operation, to the improvement of existing lay-outs. They will not apply to remodeling present warehouses. Information as set forth is intended to aid in economical and serviceable use of land, and to contribute to economies of construction and efficiency of operation. Details of design for buildings and untilities will conform to applicable chapters of this manual.

6–02 DEPOT FUNCTION. The function of a depot is to accumulate, store under satisfactory conditions, process, prepare for shipment, distribute, and regulate the flow of War Department supplies, equipment, and materials. A depot includes, in addition to storage facilities, the necessary accessory facilities used in connection with the storage operation.

6–03 SERVICES REQUIRING STORAGE. The services requiring storage facilities are Army Air Forces, S. S. and P. Forces, including Adjutant General, Chemical Corps, Corps of Engineers, Medical Corps, Ordnance Department, Quartermaster Corps, Signal Corps, and Transportation Corps. In addition, intransit depots are required for accumulation and temporary storage of export materials and temporary storage of cars under load. Special storage facilities are also required for ammunition, volatile liquids, and coal.

6–04 REQUIREMENTS. *a. General requirements.* Depot requirements are determined and justified by the using services and include all facilities for complete storage and operation. These requirements are based primarily on storage space, number of personnel, and type and quantity of operating equipment. The net storage area is that on which material may be stored. The operating area is the total developed area and includes aisles, work space, and offices. The ratio of operating area to storage area is about 1.5 for warehouses, and 2.0 for open storage.

b. Statement of requirements. The following data should be furnished by the using service: Net storage area required, closed, covered, and open. Net storage area heated and temperature requirement. Net area of refrigeration. Requirements for special air-conditioning. Estimated personnel, both office and operating. Estimated number and type of operating equipment.

6–05 LOCATION. The location of the depot should be on traffic lines between areas of production and distribution. Intransit depots should be located at or back of ports in locations which will permit the use of storage-in-transit freight rates. For other depots the average unit volume of shipments is greater between production and storage than between storage and distribution, and to permit minimum freight rates the depot should be located as near points of distribution as practicable. There should be little or no backhaul.

6–06 SITE. Requirements of the site are that the terrain should be even, preferably slightly sloping but not greater than will require maximum grades as hereinafter specified without excessive

grading; that the soil shall be of stability and character to support superimposed loads both of buildings and open storage; that so far as possible natural drainage is available.

6–07 TYPES OF STORAGE. There are three general types of materials to be stored:

a. Warehouses. Commodities requiring protection from moisture and adverse temperature which are stored in completely inclosed warehouses. These include packaged goods and some types of wheeled equipment. The former require a warehouse with floor at car-floor level, while the latter should be stored in warehouses with floors at ground level.

b. Open sheds. Commodities which are adversely affected by rain or snow but not otherwise by weather, which are normally stored in sheds with floors at ground level. Commodities generally consist of wheeled or track-laying equipment. Sheds may be inclosed if complete protection from rain or snow is required.

c. Open storage. Materials which are neither seriously affected nor will deteriorate by exposure to the elements and those which can be readily protected by tarpaulin or other means and which are stored in the open.

6–08 WAREHOUSES. Only single-story warehouses with floors at car-floor and truck-body level are considered in this manual. Where multiple-story buildings are required on account of high cost of ground or restricted area, they will be designed to meet War Department construction policy and each building planned to meet its particular requirements.

6–09 DIMENSIONS. For single story warehouses the standards of construction for both permanent and emergency buildings are determined by War Department policy. Since a warehouse is one unit of a depot, the dimensions should be as great as practicable. Column spacing should be such that there will be little obstruction as possible, consistent with economical structural design, since the loss of storage and operating efficiency varies inversely with the number of columns in a given area. However, the column spacing should not be increased in either direction over that shown in the figures accompanying this chapter. Width is determined by the economy of use of various types of handling equipment, percentage of space in aisles, and the location of aisles. In general, a width of 200 feet is economical considering the capacity of storage space and economic hauling distances. The length of the warehouse should be not less than 1,000 feet. Standard fire walls should be located at intervals which will limit the storage area to that required for fire prevention as defined in part XI, chapter 1, Engineering Manual. A greater length, limited only by fire regulations, economy of railroad operation and road circulation is acceptable. Inter-warehouse movement will be reduced proportionally with the increase in warehouse length.

6–10 SPACE REQUIREMENTS. *a. Work space.* In warehouses, space is required for inspection, packing, crating, and open stock or bin storage and operation. Work space should be near the center of gravity of material to be handled. This space should have access from both road and railroad sidings for delivery of material and safe access on the road side for personnel. Normal processing operations should be in warehouses and not in separate buildings.

b. Personnel space. Each warehouse will require one office including toilet facilities for storekeepers and locker space for personnel. This space assignment will conform to War Department standards. Office space for the clerical forces of storage and transportation offices, and various services in general depots, should not be on storage floors of warehouses. Warehouse space requires a type of structure not satisfactory for general offices, and includes transportation facilities and utilities, the value of which is lost when large sections of storage floors are assigned to personnel. Although second floor construction for such personnel would be acceptable, it is generally preferable to provide such office space either in the Administration Building or a separate building designed

for the purpose, near the warehouse area. Cafeterias and other personnel facilities may be incorporated in such buildings.

c. Consolidation space. Each depot requires space for assembling, packing, and shipping in L. C. L. lots. This space should be centrally located with respect to the depot, and adjacent to the open stock or bin storage. The location and dimension of this space should be established in determining requirements. Adequate road and railroad facilities are essential to this space. On the road side, and end, if an end section is used for consolidation, sufficient door openings should be provided for receipt of packing material, inbound and outbound shipments by rail or truck. A ramp, preferably at the end, is necessary for receipt of materials from other warehouses. For railroad shipments, the capacity of the house tracks should be such that the setting of cars may be undisturbed during a working shift. To accomplish this, additional spurs with cars spotted to permit trucking through them may be constructed. The running track in the three-track lay-out should be spaced to permit the construction of the additional spurs.

d. Open stock. Open stock or bin storage is required at all depots. This requires no special building design, except adequate lighting, but should be located near the consolidation space.

e. Depot supplies. Space for depot supplies which must be warehoused should be provided in a section of a warehouse nearest the point of use.

6–11 DESIGN REQUIREMENTS. *a. Doors.* To insure minimum average movement of goods, doors on the track side should be spaced close enough to permit full use, when necessary, of railroad frontage with cars spotted directly opposite doors. Doors on the road side should be spaced at intervals which will best serve the functions of the warehouse, whether for storage only, or for storage and processing. Either of two types of entrance may be used: recesses 60 to 80 feet wide at intervals of two or three warehouse sections, with inside platforms, or doors on the building line at the same intervals with canopied platforms in front of openings. In either design, the distance between platforms of opposite warehouses should be not less than 142 feet.

b. Platforms. With doors on the railroad side at approximately car length intervals, wide platforms with canopies are not essential for normal operation. In new construction the area occupied by the platforms can be inclosed at little or no increase in cost, and consideration should be given to this type of design. A car length platform at the end of a warehouse can provide for handling the small percentage of packages which require a crane for loading or unloading. Continuous platforms on the road side are not essential. Ramps opposite doors at ends of buildings are essential.

c. Light and ventilation. Windows should not be installed in exterior walls in storage areas, but should be confined to offices and toilet rooms. Monitors are not warranted either for lighting, ventilation, or to permit a greater height of storage. Some roof ventilation is essential using improved forms of roof ventilators. Efficient lighting can be provided economically to assure illumination of the proper amount where and when required, and may be readily modified to suit changing conditions. Density of lighting should conform with requirements of part XI, chapter 2, Engineering Manual.

d. Obstructions in storage space. Fire hose, standpipes, fire alarm boxes, electric switches, conduit boxes, and all fixtures which require access should be located near doors to eliminate the necessity for access aisles to such equipment.

6–12 OPEN SHEDS. Open or inclosed sheds are differentiated from warehouses principally by the lower type of construction with floors at ground level, while warehouse floors are at car-floor level. The type of materials to be stored is outlined in paragraph 6–07. Shed dimensions normally will be the same as those of warehouses. This criterion need not apply for storage of wheeled equipment which requires wide aisles for movement. Unit buildings of width equivalent to normal

storage space between aisles, so located that the spaces between buildings serve as aisles, are satisfactory. Floors of sheds should be substantial and permanent, preferably of concrete. Roof drainage should be through gutters and downspouts to underground storm sewers, or to adequate open ditches. Sheds require standard fire walls to meet fire prevention requirements.

6–13 OPEN STORAGE. Materials which are stored in the open are of two classes, those which must be lifted and those which travel on running gear. Both classes vary greatly in size and weight, and the former may be uncrated or crated. Three types of handling equipment are in normal use:

a. Locomotive cranes. Locomotive cranes operate on fixed railroad tracks and normally handle heavy lifts. Their use requires a two-track system, and they can be used for some car shifting in connection with their lifting uses although movement is slow. The storage area is limited to an area between the railroad clearance line and the limits of boom reach.

b. Crawler and truck-mounted cranes. These operate from craneways alongside the railroad track. They have greater areas of operation and are much more flexible than locomotive cranes, but require a higher type of operating surface than is necessary in the net storage areas.

c. Fork-lift trucks. These operate over the entire storage area and solid-tired trucks require a smooth operating surface. Their effective use is limited by the shape and size of packages, and to box car loadings, unless some other type of equipment is used to transfer material from car to truck. For efficient operation they require car-floor level platforms in moving material from box cars. These platforms, in order not to interfere with the use of other operating equipment must be located a considerable distance apart. This reduces economy of operation unless certain areas with surface at car-floor level can be assigned for use of fork-lift trucks handling palletized materials.

6–14 GENERAL ARRANGEMENT. Depot lay-outs are designed for both rail and truck service. Economy of design requires minimum movement of both railroad and road equipment with no interference. The following principles apply to lay-outs:

a. Warehouse lay-outs. Terrain permitting, warehouses should be laid out in rows with tracks and roads alternating between rows. In no case should the track and road be on the same side of a warehouse, nor should the track area be paved. The length of the lay-out is determined by efficiency of road and railroad operation, and the amount of necessary inter-warehouse movement. Space should be available for reasonable expansion, and to conserve space in original planning, expansion should be longitudinal. A warehouse area less than approximately 3,300 feet long can be operated efficiently by spur railroad tracks, and with storage properly planned, with little inter-warehouse movement. When longitudinal expansion is necessary, double-ended rail connections are advisable.

b. Space between buildings. The space between buildings on the track side should meet minimum established fire prevention requirements, or be sufficient for two house tracks, a third track to facilitate switching operations, a single-lane road for fire fighting apparatus and utility lines. A width of 100 feet will meet these requirements. The space between buildings on the road sides should meet minimum established fire prevention requirements but this space should be not less than that required to accommodate trucks or truck-trailer combinations on aprons at doors of opposite warehouses clear of the traffic lanes of the adjacent street. The longitudinal space between buildings should be sufficient for a two-lane road between ramps from each building, or for cross-overs between tracks or spur connections with standard railroad clearances throughout the lengths of the buildings. A space of 150 feet will meet these requirements.

c. Open storage. Open storage areas are preferably located parallel and adjacent to covered storage areas, and are normally served by rail. The widths of storage areas between tracks should be limited to boom reach of equipment used. A storage width of 50 feet from railroad track

clearance for locomotive crane operation, and from the craneway for crawler crane operation, satisfies this requirement. For all material except wheeled vehicles, additional width requires rehandling and more than doubles the cost of the storage operation. Double-track lay-outs should be provided with cross-overs at intervals of 1,000 to 1,500 feet. Single-track lay-outs over 1,000 feet long should normally have access at both ends.

d. Vehicle storage. Storage, both open and covered for vehicles and track-laying equipment does not require direct rail service, since such equipment can be moved economically by tractor up to 500 feet. Each depot which stores vehicles should be provided with end ramps and side loading platforms, advantageously located in the storage area for handling this equipment. Platforms should be 3 feet 9 inches above top of rail, 14 to 16 feet wide and of aggregate maximum length to accommodate the number of cars which can be normally loaded in 4 hours. Where the traffic warrants, multiple units are advisable, but with platforms on only one side of tracks. Platforms between tracks should be wide enough to accommodate simultaneous handling on both tracks. The grades of ramps should not exceed 10 percent. For handling heavy equipment, a preferable design is an earth-filled platform confined by a retaining wall on the track side. The track should be depressed about 2 feet and the surface sloped gradually throughout the length of the platforms to the storage area elevation. Adequate drainage must be provided for the track.

e. Typical plans. Figures 1 and 2 show typical storage depot lay-outs. Figure 3 shows typical space lay-outs in a warehouse. Figure 4 shows typical gasoline drum storage.

6–15 RAILROAD TRANSPORTATION. Economical railroad operation is essential in depot operation. The track lay-out should conform in general to the requirements of part X, chapter 2, Engineering Manual. In planning, the following principles should be considered:

a. Warehouse service. An efficiently operating track lay-out at warehouses in double rows consists of two house tracks and a single operating track with connections at required intervals, generally at the ends of buildings. An exception to this is at the consolidation station, where there should be sufficient trackage to accommodate all cars which will be loaded in a single working shift. This can be accomplished by additional spurs. Cars are spotted with doors opposite to permit trucking through them. A single row of warehouses will require a house track and an operating track. House tracks should be provided on only one side of a warehouse.

b. Open storage service. Open storage areas will require single or double tracks, depending on the type of handling equipment, and the length of the storage area as outlined in paragraph 6–14*c*.

c. Yards. Railroad yards should be designed to meet the mission of the depot. Preferred designs include receiving, sorting, delivery, and forwarding tracks arranged to permit operation with minimum switching movement. The yards should be easily accessible to both the serving railroad and points of delivery. In general, yard tracks should be connected to leads at both ends. The yard capacity is not determined by the storage capacity of the depot, but by traffic, amount of car storage required, the number and size of classifications. Receiving and forwarding tracks with capacities equal to maximum single deliveries should be provided. Outbound classification yards are not essential.

d. Grades and curvature. Grades and curvature will conform to part X, chapter 2 of this manual. An excessive amount of curvature should be avoided. This should be considered in planning the depot lay-out, since operation over curves delays movements, is more subject to derailments, and maintenance costs are higher.

6–16 ROADS. Project roads should provide for circulation of vehicular traffic to all areas, for delivery and shipment by truck. They should be constructed to meet all traffic requirements. Grades, widths, and type of construction are specified in part X, chapter 1, Engineering Manual.

6–17 UTILITIES. Heat, refrigeration, and power requirements will be established by the using service. Design of utilities, including water supply, fire prevention, electricity, sanitary sewerage, and drainage will conform to appropriate chapters of this manual.

6–18 HOUSING. Each depot will be provided with housing for commissioned and noncommissioned officers assigned to the depot. Depots requiring enlisted personnel or those where civilian help is not available locally, may be provided with troop or civilian housing, but only on instructions from the office, Chief of Engineers.

6–19 ACCESSORY CONSTRUCTION. In addition to storage facilities, the following accessory buildings are essential, all of which should conform with War Department standards of construction and space requirements:

a. Offices. Executive and administrative offices should be in separate buildings designed for office personnel. Checkers' offices in open storage areas should be in portable buildings.

b. Cafeterias. Cafeterias for office personnel are preferable in Administration Building; cafeteria for operating personnel in a separate building.

c. Dispensary.

d. Engine shelter. This may be combined with yardmaster's office and railroad maintenance buildings.

e. Fire house. Preferably located within the envelope of the Administration Building.

f. Equipment maintenance and repair facilities. These are preferably so located that all operating equipment maintenance and repairs may be accomplished in one general location and under one authority.

g. Post engineer facilities. These will consist of office, storehouse, essential shops, covered storage for equipment, and lumber yard. The lay-out should be compact with the storehouse and transportation facilities in the immediate vicinity of shops. The size of the shops will in general be governed by an orderly arrangement of shop equipment, with adequate work space, rather than by the size of the depot.

h. Equipment processing and boxing building. When required, these will be designed to meet particular requirements of the using service.

i. Special purpose storage buildings. When required, these will be designed to meet particular requirements of the using service.

6–20 INFLAMMABLE STORAGE. Inflammable liquids and materials subject to spontaneous combustion are stored in separate warehouses. The space and interior arrangements are established by the using service. Engineering requirements are fire-resistant construction with floors at car-floor level and buildings segregated as required in part XI, chapter 1, Engineering Manual.

6–21 OUTSIDE STORAGE IN DRUMS. Sites for open storage of combustible liquids in drums should be isolated by at least 250 feet from all other storage areas or buildings, on ground which permits drainage away from the storage area.

a. Lay-out. Drums will be stored in double rows, stacked three drums high, with the lowest tiers restricted to 51 drums, limiting the number of drums in a double row to 300. Aisles not less than 3 feet nor more than 4 feet wide will be maintained between the double rows. There will be not more than 12 double rows in a section, limiting the section to 3,600 drums. Sections will be separated by 30-foot spaces, with a drainage ditch in each space. The number of sections will be limited to 9, permitting a total storage of 32,400 drums in a block. Blocks will be spaced 150 feet apart.

b. Utilities. Adequate fire protection should be provided. Access by road is essential for

all storage and rail access advisable. Where rail connections are provided, the lay-out should permit storage and removal of drums without rehandling.

c. Surfacing. The storage area should have an impervious surface. Driveways will conform to requirements for roads of similar traffic density.

6–22 COAL STORAGE. Coal will not be stored in depots except for local use. Storage facilities will conform to requirements of part IX, chapter 3, Engineering Manual.

6–23 AMMUNITION STORAGE. Explosives and ammunition, except small arms ammunition, are stored in standard arch-type earth-covered (igloo) magazines. Small arms ammunition is stored in standard above-ground magazines of fire-resistant material. Construction will conform with the following criteria:

a. Building types. Standard plans, current at the time of construction, will be followed for all igloos and magazines. Number 652–686 series are current standard plans for igloos.

b. Barricades. When protected by barricades at the door end, standard earth-covered igloos are considered fully barricaded, and "barricaded distances" to inhabited buildings, public roads, and railroads will apply. When not protected by such barricades, "barricaded distances" will apply in all directions except between lines drawn from the door at 30° angles with a line through the long axis of the igloo. The covered sides and end of an igloo are considered barricaded. In an igloo area, the igloos should be so located that barricades will not be required for inter-igloo protection.

c. Clearances. Clearances between igloos and magazines and between explosives storage and habitations, public roads, and railroads will conform with current quantity distance tables in the Ordnance Safety Manual. Studies of current full-scale experiments may result in changes in clearance requirements, which, if made, will be available through manual revisions or bulletins.

d. Railroad Lay-out. It is not the policy to provide rail service to individual igloos. Ammunition is handled between railroad car and igloo by truck from a loading platform along a railroad siding. Sidings and platforms should be so located that the average truck haul to an igloo area does not exceed 1½ miles. There is no restriction in safety distance between the access line to an igloo area and igloos, but sidings and platforms should meet the "safety distances" prescribed for igloos. The railroad classification yard should clear the nearest igloo by 1,800 feet.

e. Roads. The road system will consist of primary class A roads for access to igloo areas and loading docks; secondary class A roads around each igloo block (maximum 100 igloos); tertiary class B roads within igloo blocks to serve each igloo; and tertiary class C patrol roads. Road classification and construction types shall conform with design criteria outlined for project roads in part X, chapter 1 of this manual.

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ENGINEERING MANUAL

FOR WAR DEPARTMENT CONSTRUCTION

PART II
CHAP. 7

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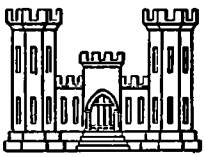
PLANNING

PLANNING OF FAMILY HOUSING AT ARMY INSTALLATIONS



WAR DEPARTMENT
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

Chapter 7

PLANNING OF FAMILY HOUSING AT ARMY INSTALLATIONS

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Part II

PLANNING

Chapter 7

PLANNING OF FAMILY HOUSING AT ARMY INSTALLATIONS

7–01 SCOPE. These instructions relate to the planning of permanent family housing facilities at permanent Army installations.

7–02 PLANNING ASSUMPTIONS AND DEFINITIONS. It is assumed for planning purposes that 75 percent of the officer and warrant officer strength and 60 percent of the noncommissioned officer strength of the top three grades will be married and entitled to family quarters; it may be assumed that 25 percent of the officers are in bachelor status and that 40 percent of the N. C. O.'s of the top three grades are bachelors.

a. Family housing. Officer, warrant officer, and top grade N. C. O. families will be housed in single-family dwellings, detached or semidetached, apartments, or row houses as local conditions of topography or congestion dictate or as appropriated funds permit. Present economy measures indicate the necessity for a substantial percentage of apartment or row-house types for company grade and top grade N. C. O. families.

b. Civilian family housing. Where housing for civilian specialists is authorized, the housing provided will be of a type comparable to that provided for military personnel of like responsibility and pay; and will not be segregated, but will be appropriately located—depending on responsibility, pay, or type of work—within either the officer or N. C. O. family housing area.

c. Bachelor housing. All officers in bachelor status will be provided with quarters in bachelor housing, and, where authorized, all bachelor N. C. O.'s of the top three grades who are not already housed with troops in barracks will be provided with bachelor quarters. Bachelor quarters will have group mess and recreation facilities and preferably will be located in the vicinity of the respective officers' or N. C. O. club.

d. Single house. A single house, detached, for use by one family.

e. Double (semidetached, duplex) house. Two single houses, one-story or two-story, joined by a blank party wall and each having separate exterior entrances.

f. Row houses. Three or more houses in a row, separated from each other by blank party walls, and each house having separate exterior entrances. A row shall not exceed eight houses.

g. Apartment houses. Suburban or garden-type (not to exceed three stories in height nor nine apartments per unit) with one exterior entrance per unit into a stairhall serving a maximum of three apartments per floor. Grouping of units shall not exceed three units (27 apartments), joined by blank party walls.

h. Family size (average). For planning purposes each family unit should be figured as four persons.

i. School children. For planning purposes school children should be figured on the basis of 0.75 per family unit, of which approximately one-third will be of high-school age and approximately two-thirds will be of grade-school age.

7–03 GENERAL PLANNING CONSIDERATIONS. In general, the planning of family housing facilities at Army installations should be in accord with established principles and proce-

dures for the planning of better-type civilian residential communities. Planning with end results of this nature will be more readily attainable in family housing areas than in troop housing areas due to (1) the smaller size of the building units and (2) the fact that there will be no necessity for "efficiency of military operation" comparable to that in troop housing areas. Each housing project must be designed to fit closely the topography of its site. The economy and efficiency possible as a result of the recognition and full acceptance of the topography as an inspiration and controlling factor in the design of a housing project cannot be overemphasized. The economy, convenience, and safety of the road pattern; the economy, convenience, ease of access, and pleasant arrangement of buildings of various sizes; the economy in construction of utilities; the attractiveness of outlook and surroundings; the avoidance of monotony; the comfort and general welfare of the occupants; and the many other amenities resulting from careful study and adaptation of the several elements of the project to the topography will be recognized as being of the greatest importance.

The standards set forth in the following paragraphs are desirable minimum requirements which have been established for the purpose of governing the lay-out of an economical and at the same time livable and attractive development. Where conditions of topography, vegetation, or existing lay-out of roads indicate the desirability of and justify increases in the minimum standards, such increases will be considered proper.

7–04 RELATION OF FAMILY HOUSING TO EACH OTHER AND TO RELATED AREAS. In the interest of efficiency, officer and N. C. O. family housing areas will be separate and distinct from each other although accessible by road to each other and to the balance of the post, that is, to the community area, troop housing area, training area, warehouse area, and hospital area. In order that common use may be made of such facilities as children's schools, shopping centers, post theaters, and chapel, the two housing areas normally will be adjacent to each other but separated and interrelated by an open area suitable for common family recreation, as shown on figure 4, chapter 2, part II, Engineering Manual.

7–05 AREA ALLOWANCES. (For planning purposes and housing density control.) (See fig. 1.)

a. Officer family housing area. The area assigned to single-family dwellings (detached or semi-detached) normally will be developed on the basis of 4 to 5 families per net acre exclusive of streets, curbs, utility strips, and sidewalks. The area allotted for a single-family dwelling (detached or semi-detached) will be approximately 9,800 square feet, comprising an area approximately 70 feet in width and 140 feet in depth. Where climatic or topographical conditions or approved floor plans dictate and to the extent where such practice can be fully justified, the width of the allotted area may be increased to a maximum of 95 feet. It should not be overlooked, however, that the accumulated increase in lot width will lengthen utilities and roads disproportionately, which might be avoided by turning the long side of the house at right angles to the road thus permitting the use of the normal 70-foot lot width.

The areas in which row-house or apartment-house types are used will be developed on the basis, respectively, of approximately 8 and 15 families per net acre.

b. N. C. O. family housing area. The area assigned to single-family dwellings (detached or semi-detached) normally will be developed on the basis of 6 to 7 families per net acre exclusive of streets, curbs, utility strips, and sidewalks. The area allotted for a single-family dwelling (detached or semi-detached) will be approximately 7,200 square feet, comprising an area approximately 60 feet in width and 120 feet in depth. Where climatic or topographical conditions or approved floor plans dictate and to the extent where such practice can be fully justified, the width of the allotted area may be increased to a maximum of 75 feet.

The areas in which row-house or apartment-house types are used will be developed on the basis, respectively, of approximately 9 and 15 families per net acre.

Note.— The topography, the street lay-out, and the orientation of the buildings will often determine the shapes of the allotted area; they will not necessarily be rectangular and, due to special circumstances, as for example, if they are located at intersections of streets, may exceed sizes given in *a* and *b* above.

7–06 BUILDING AND AREA RELATIONSHIP (Site Plan of Individual Buildings). For planning purposes, each area allowed for a building site is divided into front yard, side yard or side yards, rear yard, and the bulk building area. (See fig. 1.)

a. Front yard. In locating the house on the site, unless unusual topographic conditions dictate, the bulk of the building will have a minimum set-back of 50 feet from the center line of the pavement and 35 feet from the street curb. The street facade of the house need not necessarily be placed parallel to the road nor will it always be necessary to maintain a uniform set-back of all houses along the street. A variation of the set-back line of adjacent houses may often be desirable in informal settings, such as wooded areas or areas of varied topography. Varied building lines also may be effectively used to create interest on long straight streets. (See fig. 3.)

b. Side yard or yards. These areas will be reserved for garages, carports, drying areas, playgrounds, and service features. (See fig. 2.) The minimum side yard will be 10 feet making a normal minimum clearance of 20 feet between houses. In the case of detached garages a minimum clearance between garage and house will be 10 feet. (See fig. 1, also pars. 7–15 below.) Laundry areas should provide for a minimum of 60 linear feet of clothesline per family, preferably in two 30-foot sections. Revolving clothes reels may be used if indoor storage for them is provided. Adequate provision should be made for the delivery of supplies and for the collection of waste and garbage, preferably by using the garage driveway for these services. Appropriate concealment of ash and garbage receptacles should either be provided for in original construction or planned for by provision of screens of planting or fences. The entrance walk normally should not be used for service purposes.

c. Rear yard. This area should be reserved entirely for outdoor living, for family recreational use, and for play area for children; it should not be encroached upon by driveways, service roads, or service entrances. (See fig. 2.) Utility roads in the rear of houses are undesirable and costly and normally will not be provided. The desirable minimum depth of the rear yard will be approximately 50 feet; in most cases the depth will be in excess of this minimum which is a desirable condition. A surface slope of less than 10 percent is desirable.

d. Bulk-building area. This refers to the area covered by actual dwelling exclusive of open steps, porches, or car shelters.

Each individual house should be located on the site so that the living areas, inside and outside, will not look directly upon service areas of adjoining houses or other unsightly features. On corner lots this occasionally may be a problem, and can often be overcome by placing the house diagonally on the site.

Row-house types will be controlled by the same requirements as above with respect to minimum distances in relation to the adjacent street, side yard, and rear yard.

7–07 CAR SHELTERS. Planning should anticipate the eventual provision of garages or car ports for one car per family unit, including appropriate access driveways. The facilities will range from attached and detached garages or carports for single-family dwellings to multiple garages or carports as integral parts of multiple-family dwellings or as separate structures for protective housing of cars in garage groups or compounds. A two-car garage or carport will serve conveniently and economically two adjoining family houses. Garage or car-shed space will be

planned for on the basis of 100 percent of the bachelor officers housed and, when authorized, normally will be provided in group garage facilities located in close proximity to the quarters. Garages and carports usually will not be constructed at the same time as the dwellings; however, in all cases, space must be allowed for the future location of the garage or carport in order to avoid undue damage and construction as to grades, planting, service facilities and openings of windows and doors.

Where garages are not provided at the time the house is built, off-street parking may be provided by constructing a part (a minimum of 25 feet inside the sidewalk line) of the future garage drive. This area will also facilitate service into the dwelling.

The proper location of the garage and the driveway will aid in the lay-out of the service facilities indoors and outdoors, such as kitchen, service entrance, drying yard, fuel delivery, and garbage disposal. (See fig. 1.)

The location of car shelters, especially group garages, multiple garages, or compounds, at a distance beyond which it will not be practical or convenient for occupants to use them is to be avoided. Experience indicates that a group garage normally will not be used if it is farther than 150 feet from the dwellings it is meant to serve.

7–08 FAMILY HOUSING AREAS, GENERAL SITE PLAN. (See fig. 4, Ch. 2, Part II, Engineering Manual.) Except in those rare instances where the existing topography is so flat that a rectangular, "gridiron" street pattern is the most reasonable solution, it is well to avoid a pattern of straight streets which places buildings in parallel lines and at right angles or in long, monotonous rows. Blocks of varied lengths up to 1,750 or even 2,000 feet will be permissible. However, study must assure that the streets on the long sides of this type block are so designed that they do not become through-traffic streets. In almost all cases a careful study of the topography, which will vary from gently rolling to very broken, will indicate the many economies and amenities to be secured by the use of angular or curvilinear street alinements. Great care should be exercised, however, to insure that the street pattern is not jumbled or confusing and that it is neither unnecessarily nor unreasonably curvilinear. Privacy can be enhanced and monotony avoided by arranging dwelling units in small groups on courts or cul-de-sacs. A center of interest in such groups may be obtained by using a two-story building as a terminus to a cul-de-sac of one-story houses; by a restrained variation of construction materials or paint; or by a variation in the set-back line of adjacent buildings. It is well to avoid "open end" compositions of buildings which look out on nothing or toward objectionable views. It is desirable to provide vistas to good views of water, hills, or other distant objects worthy of such recognition (towers, church steeples, mountain peaks, etc.). In order to avoid flat, "paper" design it is necessary, during the early planning studies, to visit the site often to assure that the design is taking full advantage of the third-dimensional aspects of the existing ground forms. In some sections climatic conditions may become a controlling factor which should be carefully considered in the street lay-out and in the orientation of the house. For example, in hot humid areas the orientation of the house should strive to minimize the effects of the heat by obtaining maximum shade and cool breezes in the living areas.

7–09 RECREATIONAL AREAS. The recreation facilities to be provided in the family housing areas will include facilities for women and for the play of children of all age groups. For children of preschool age, adequate play areas may be obtained by arranging the houses in such a manner that open courts and moderately large areas in yards are available for this purpose. For children of school age, playgrounds adjacent to the schools will be provided and, where necessary, in other central and convenient locations. It may well be that such playgrounds will also contain facilities

for adult recreation. The necessity for children to cross traffic arteries to reach play areas should be avoided so far as practicable. Facilities for organized sports in family housing areas are not contemplated since it is assumed that school athletic fields and gymnasiums will be adequate for this purpose.

7–10 STREETS, CURBS, WALKS, UTILITIES STRIPS, STEPS, AND PARKING AREAS.

a. Roads and streets. The general street pattern for traffic circulation is discussed in paragraph 7–08 above. Recommended street gradients and pavement types are given in chapter 1, part X, Engineering Manual. Normally the class of traffic using streets within the housing areas should be accommodated on streets constructed in accordance with the criteria given for Class "C" roads in chapter 1, part X, Engineering Manual. The design of the road lay-out should be such as to avoid inviting outside traffic and "through traffic" through the family housing areas. Service streets or alleys will not be provided except where their use can be fully justified.

b. Curbs. Curbs should be planned for generally along streets and around parking areas. See chapter 1, part X, Engineering Manual.

c. Utilities strips. The utility strip is an unpaved area left between the curb and the sidewalk to receive underground utilities. The desirable width of this strip is 8 to 10 feet.

d. Walks. An appropriate system of sidewalks will be planned for. A 4-foot width, adequate to allow two persons to walk abreast or to pass each other, is normally ample, except in areas of concentrated pedestrian traffic (as in shopping centers).

e. Steps. Steps in walks are to be avoided whenever possible. Single risers are dangerous and should be avoided. A gradient as steep as 15 percent may be used in preference to steps, provided that the length of such a gradient is short and that a handrail is constructed along walks having a gradient steeper than 10 percent. Where steps are necessary, 6-inch risers and 15-inch treads are recommended as providing one of the best outdoor riser-and-tread relationships.

f. Parking areas. Parking areas will be required to serve stores, theaters, community centers, clubs, schools, and churches. Their location and design should be carefully studied to insure that they are (1) conveniently related to the buildings which they are intended to serve, (2) adequate in size but not overdesigned, and (3) suitably laid out to permit easy entrance and exit, maneuvering, and safe parking of vehicles. Criteria for pavements, curbs, bumper rails, etc., for parking areas are given in chapter 1, part X, Engineering Manual.

7–11 CONSERVATION OF EXISTING VEGETATION AND NEW PLANTING.

a. General considerations. General considerations relative to planting design and the preservation of existing vegetation, the planting of trees, and the establishment of ground cover at Army installations are contained in part XIV, Engineering Manual. In addition to these, careful consideration will be given to the following factors which are particularly applicable to family housing areas:

b. General. The effect to be desired as a result of the conservation of existing trees and grass and all new planting of trees, shrubs, and lawns is that the construction of the housing area will appear to have been accomplished *without disturbing in any way the preexisting natural landscape* and that, largely for this reason, the structures of all types will appear to have been located in an attractive and fortuitously suitable natural environment. From this, it will be clear that, for all new planting, indigenous plant material is to be preferred and that all exotic plant material is to be generally avoided. For similar reasons, all plants having odd or highly colored foliage, or unusual habits of growth, should be avoided.

c. Style. While a naturalistic, or informal, arrangement of trees, both singly and in groups, will probably be desirable for the over-all planting and appearance of the housing area, the formal

or regular arrangement of trees in certain sections and about certain buildings (shopping areas, theaters, community centers, schools, churches, etc.) and along the streets, particularly straight streets, may be utilized to augment the importance of these areas or structures. Where street planting is used, the trees should be placed on the inside of the sidewalk, leaving the strip between the sidewalk and the curb free for underground utilities.

d. Windbreaks and snowbreaks. In localities where heavy winter winds and much snow can be expected, the preservation of tree masses as windbreaks and snowbreaks is recommended for careful consideration.

e. Shade. In localities where the summers are long and hot, shade trees should be used more generously than in localities where more moderate climatic conditions prevail.

f. Special topographic features. On hills or knolls, in low-lying areas, along streams and around the edges of water bodies, where the land is not well adapted to any particular use, the preservation of existing ground cover or appropriate planting of trees usually will be desirable.

g. Planting design. Other than the specific recommendations outlined in *a* to *f* above, the principles which will be followed in designing the planting for housing areas are described in part XIV, Planting, Engineering Manual.

7–12 GRADING AND DRAINAGE. Provisions for adequate surface drainage facilities in the early planning stage will effect many economies in the length of time required for construction, in the cost of construction of subgrade and base courses for pavements, and in general over-all expense. The problem of grading and drainage of building areas should not be treated independently of road-drainage requirements or vice versa. Over-all grading should be considered in preliminary planning in order that deep cuts and fills may be avoided. The principal design factors to be considered and assured in connection with the grading of housing areas are (1) a minimum disturbance of existing ground forms, (2) a reasonable balance of cut and fill, (3) avoidance of fills which will add to the height of the building foundations, (4) avoidance of wavy profiles in streets and walks, (5) avoidance of earth banks wherever possible, (6) elimination, so far as possible, of steps in walks, (7) meeting satisfactory ground levels at existing trees which it is desired to preserve, (8) keeping finished grades as high as practicable where rock will be encountered close to the surface, in order to reduce the cost of utility trenching. For the purpose of discharging surface drainage directly into the streets to the greatest feasible extent and in order to limit the need for storm water sewers, the lay-out should be such that lawns and planted areas may be sloped toward streets, driveways, and other suitable areas. Adequate continuous slopes should be given to all parts of the site not occupied by buildings. Flow of drainage across walks, service areas, and playgrounds should be avoided. Surface water should flow away from all buildings with continuous foundations. The ground surface under buildings supported by piers should be so graded as to eliminate depressions in which water may collect. Where warranted a suitable system of storm-water sewers, with necessary inlets, catch basins, etc., will be included in the planning. For detailed discussion, see part XIII, Drainage and Erosion Control, Engineering Manual.

7–13 UTILITIES.

a. Water Supply. For detailed discussion and requirements, see part VII, Water Supply, Engineering Manual.

b. Sewage and waste disposal. For detailed discussion and requirements, see part VIII, Sewage and Waste Disposal, Engineering Manual.

c. Power and light. For detailed discussion and requirements, see part VI, Electrical Design, Engineering Manual.

d. Gas distribution. For detailed discussion and requirements, see part IX, Fuel Distribution and Storage, chapter 1, Gas Distribution, Engineering Manual.

e. Mechanical. See part V, Mechanical Design, Engineering Manual.

f. Garbage disposal. Containers should be odor-proof and inaccessible to scavengers, such as dogs, cats, and rodents. The capacity and type of facilities should be adequate for the period between regular removals and sufficiently sturdy to allow for hard use and outdoor weather. Unsightliness is to be avoided by proper screening or concealment.

7–14. FIRE PREVENTION. The minimum clearances between family dwellings established in the above paragraphs are not covered in the Engineering Manual, part XI, chapter 1, Fire Prevention, Policy, October 1946. However, these established minimum clearances are within the limits of the presently approved Fire Prevention Policy for permanent family housing, providing the following conditions are met:

a. That the buildings are located within the maximum running distances for motorized firefighting apparatus of organized army fire departments or paid municipal fire departments. (See part XI, chapter 1, paragraph 1–03*g*, Engineering Manual.)

b. That the construction of the buildings is equal to or better than the limits set forth in part XI, chapter 1, paragraph 1–02*c*, Engineering Manual.

c. That garages be constructed of noncombustible material.

If the construction of the buildings is not equal to the limits set forth in part XI, chapter 1, paragraph 1–02*c*, Engineering Manual, the clearances between buildings will be governed by the spacings as given in part XI, chapter 1, paragraph 1–03*a*, Engineering Manual.

Firebreaks of 100 feet should be provided at approximately 2,000-foot intervals. The normal 100-foot clearance between buildings on both sides of a street, as provided by the 50-foot set-back from the center line of the street, will ordinarily satisfy the firebreak requirement.

7–15 TYPES OF BUILDINGS AND MINIMUM DESIGN REQUIREMENTS. Minimum requirements for dwelling design, general structural requirements, minimum loads, types of buildings, and kinds and amounts of furnishings are contained in part III, Architectural Design, Engineering Manual.

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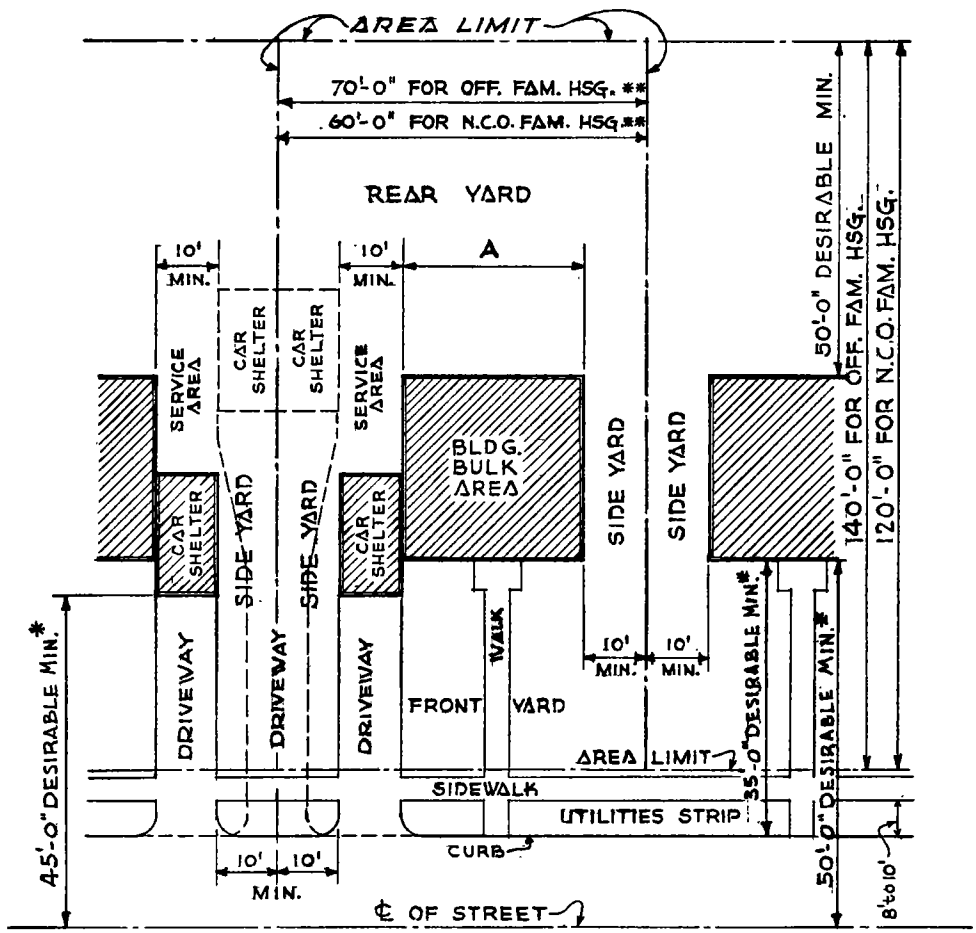


HOUSING AREA ALLOWANCE

OFFICER FAMILY UNIT
70'-0" X 140'-0"
9800 SQUARE FEET

DENSITY:
4 TO 5 FAMILIES PER NET ACRE

N.C.O. FAMILY UNIT
60'-0" X 120'-0"
7200 SQUARE FEET

DENSITY:
6 TO 7 FAMILIES PER NET ACRE

NOTE: ALTERNATE LOCATIONS OF GARAGES INDICATED IN DOTTED LINE.

* FOR CONDITIONS UNDER WHICH THESE MINIMUMS MAY BE CHANGED SEE PARAGRAPH 7-06 a, CHAPTER 7, PART II, ENGINEER MANUAL.

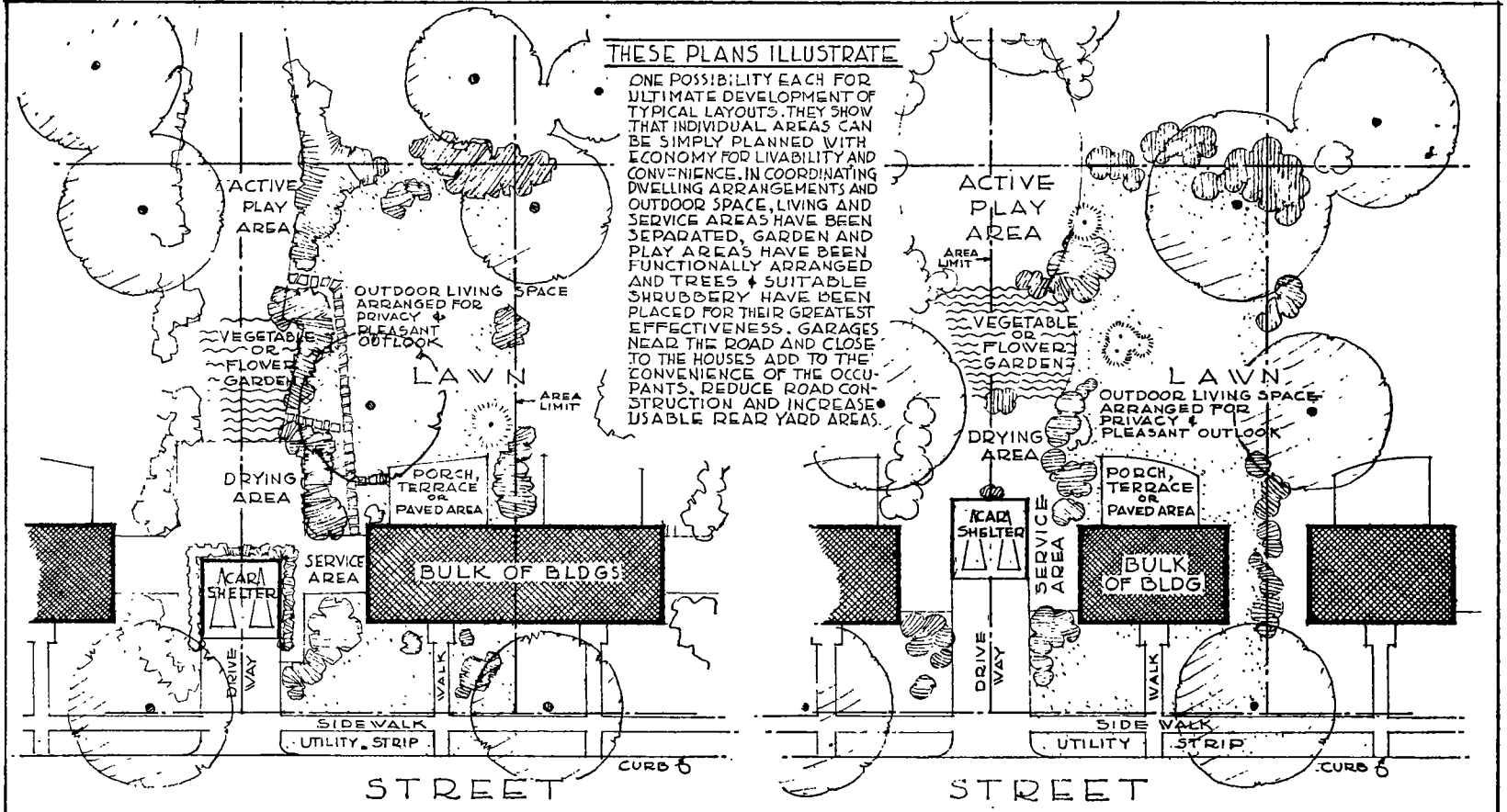
** THIS DIMENSION MAY REASONABLY BE INCREASED BY THE AMOUNT WHICH DIMENSION A IS IN EXCESS OF 40 FEET IN THE CASE OF OFFICER UNITS OR 30 FEET IN THE CASE OF N.C.O. UNITS.

23 MAY 1947

FIG. 1.

C.R.W.
E.F.M.

FIG. 1 TO ACCOMPANY ENG. MAN. PART II CHAPTER 7



PLAN
FOR SEMIDETACHED DWELLINGS

PLAN
FOR DETACHED DWELLINGS

E.F.MENKE

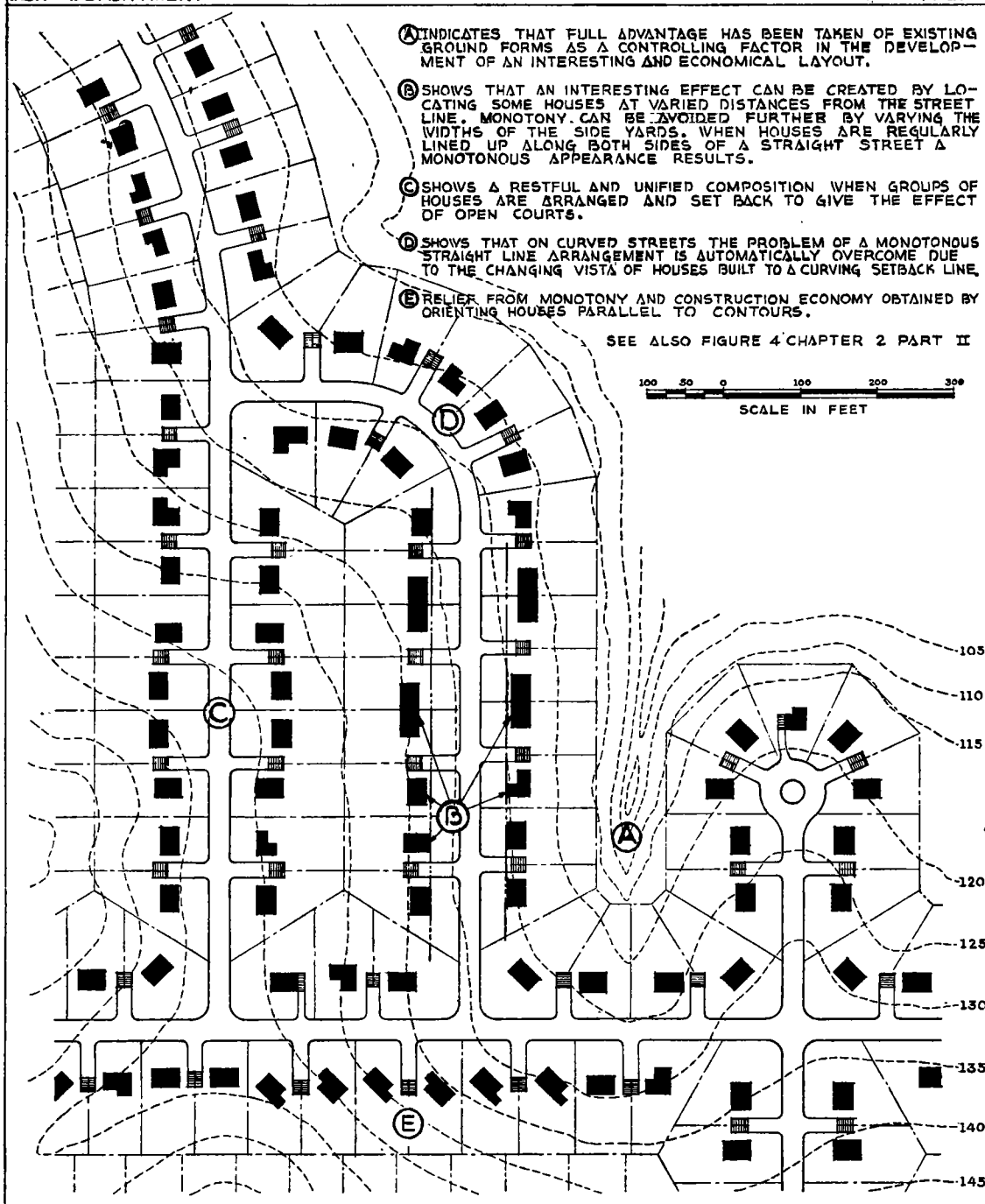
DEVELOPMENT PLANS FOR TYPICAL AREA LAYOUTS

SINGLE-FAMILY DWELLINGS IN OFFICERS AND N.C.O. HOUSING AREAS

1 FEBRUARY, 1947 DIAGRAMMATIC NO SCALE

FIG. 2

TO ACCOMPANY ENGINEERING MANUAL, PART II, CHAPTER 7



SECTION OF FAMILY HOUSING LAYOUT

SHOWING SOME DIFFERENT TYPICAL HOUSE ARRANGEMENTS

23 MAY 1947

FIG. 3

C.R.W.

TO ACCOMPANY ENGINEERING MANUAL, PART II, CHAPTER 7

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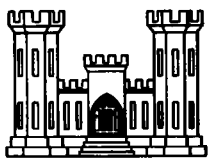
STRUCTURAL DESIGN
LOAD ASSUMPTIONS FOR BUILDINGS



ARMY SERVICE FORCES
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VI

CHAPTER 1

LOAD ASSUMPTIONS FOR BUILDINGS

1-01 SCOPE

1-02 DESIGN LOADS

1-03 DEAD LOADS
- a. Dead Load of Structural Members
- b. Partition Loads

1-04 LIVE LOADS
- a. On Floor Areas
- b. On Roof Areas
- c. On Areas Subject to Wind Loads
- d. Combined Wind and Live Loads
- e. Elevators
- f. Cranes and Monorails

1-05 LIVE LOAD REDUCTION

1-06 LOADS IMPOSED BY EARTHQUAKE

1-07 DESIGN ANALYSIS

PART IV

STRUCTURAL DESIGN

CHAPTER I

LOAD ASSUMPTIONS FOR BUILDINGS

1-01 SCOPE. The instructions in this chapter relate to the load assumptions which shall be used in the design of buildings.

1-02 DESIGN LOADS. The structural elements of buildings shall be designed for the dead loads of the structure and for the live loads established herein.

1-03 DEAD LOADS. Dead loads shall include all of the material composing the structure and all equipment which is fixed in position on floors or roof. These loads should be accurately appraised, based on the weights of materials and equipment.

a. Dead Load of Structural Members. In the design of a member, the dead load assumed in the design should be revised and the design corrected where the variation from the assumed section is excessive.

b. Partition Loads. Provision shall be made for partition loads in accordance with Figure 1. Partition loads shall be assumed in addition to the live loads given below.

1-04 LIVE LOADS. Live loads in pounds per square foot shall be assumed as follows:

a. On Floor Areas.

Ordinary living quarters, squad rooms in barracks, wards in hospitals, small mess halls and small assembly rooms	40
Supply or storage rooms in above buildings (See Note)	100
Miscellaneous rooms in theaters, gymansiums, hospitals, chapels, etc. (See Note)	40
Rooms used for office purposes. (See Note)	50
Operating rooms and similar spaces in hospitals (See Note)	60
Dance floors	100
Mess halls or assembly rooms with fixed seats	60
Mess halls or assembly rooms with removable seats and other floor areas used for dancing or assemblages	100
Gymnasium floors	100
Kitchens (See Note)	40
Theaters and Chapels, including balconies -	
Having sloping floors or level floors with fixed seats	60
Having level floor with removable seats	100
Stage floor	150
Projection rooms and machine rooms (See Note)	100
Post offices and post exchanges (See Note)	100
Warehouses and storehouses -	
Light storage and stores	125
Heavy storage and stores (See Note)	250
Attic floors, in addition to any superimposed dead and live roof loads -	

Nonstorage 25

Accessible through hatchways only but with headroom for storage .. 40

Accessible by stairs or elevators (See Note) 75

Telephone exchange and rooms for radio equipment (See Note) 100

Corridors and porches of buildings such as barracks, hospitals, etc., in which room areas are designed for 40 pounds 60

Corridors and porches, except as noted above, lobbies and stairs.... 100

Garages -

Passenger cars only 75

Trucks, with load, less than 3 tons 100

Trucks, with load, 3 to 10 tons 150

Trucks, with load, above 10 tons 200

Loading platforms and ramps - same load as areas which they serve

NOTE: If special conditions of usage are indicated for these areas the necessity for heavier loadings should be investigated. The adequacy of the adopted load in providing for any equipment must also be investigated.

b. On Roof Areas.

Live loads on horizontal projection, for zones indicated in Fig. 2.

Zone A 40

Zone B 30

For roof slopes of more than 15 degrees the above loads may be reduced one-third pound per degree, with a maximum reduction of 10 pounds for slope of 45 degrees.

Zone C 20

Roofs surfaced with quarry tile or similar purpose finish, having an area greater than 800 square feet and accessible by stairs or elevators 100

c. On Areas Subject to Wind Loads.

Wind on vertical projection of buildings not in excess of 300 feet in height above ground level 20

Wind on chimneys or stacks, multiplied by shape factor listed below 30

Square or rectangular	1.00
Hexagonal or octagonal	0.80
Round or elliptical	0.60

Special wind-load specifications shall be formulated locally for areas that are definitely known to be subject to hurricanes or tornadoes.

Wind on buildings of a temporary nature with an anticipated usage of not more than five years and not intended for purposes of assembly may be reduced to not less than 10

Wind on interior side if exterior wall and roof surfaces, in addition to external wind loads above stipulated:
for buildings that are nominally airtight, pressure or suction..... 4.5

for buildings with 30% or more of the wall surface open or subject to being open
- pressure 12
- suction 9

for buildings with openings varying from 0 to 30% of the wall surface, increasing uniformly from
- pressure ..... 4.5 to 12
- suction ..... 4.5 to 19

These wind loads on interior side of exterior wall and roof surfaces are to be used only for the design of these surfaces and their attachments and are not to be included in the design of the structural framing.

Wind on flat roofs, suction 12

Wind on windward side of sloping roofs:
- for slopes under 20°, suction 12
- for slopes between 20° and 30°, suction decreasing uniformly from ..... 12 to 0
- for slopes between 30° and 60°, pressure increasing uniformly from ..... 0 to 9
- for slopes between 60° and 90°, pressure 9

Wind on leeward side of sloping roofs, for all slopes in excess of 0°, suction 9

Wind on roofs that are not in excess of 300 feet in height above ground line, and are rounded or may be represented roughly by a circular arc passing through the two springings and the ridge:
- for windward quarter of arc of roofs springing from ground level with rise ratio between 0.00 and 0.60, pressure increasing uniformly from ..... 0 to 11.4
- or windward quarter of arc of roofs on elevated vertical supports with rise ratio not in excess of 0.20, suction 12
  - with rise ratio between 0.20 and 0.60, pressure increasing uniformly from ..... 0 to 12
  - with rise ratio between 0.20 and 0.35, suction decreasing uniformly from ..... 12 to 0
- for central half of arc of roofs starting from ground level, for all rise ratios, suction 11
- for central half of arc of roofs on elevated vertical supports, with rise ratio between 0.00 and 0.60, suction increasing uniformly from ..... 11 to 20
- for leeward quarter of arc of all roofs, for all rise ratios in excess of zero, suction 9

The wind load need not be divided into pressure and suction in proportioning the wind bracing of tall buildings. The wind load on vertical surfaces shall be divided into 60% pressure and 40% suction on the windward and leeward sides, respectively, for structures with rounded roofs on elevated vertical supports and for mill or other buildings with large open interiors or with walls in which large openings may occur.

These wind loads are based on the recommendations in the Final Report of Sub-Committee No. 31, American Society of Civil Engineers, published in the Transactions of the Society, Number 105, 1940, page 1713. This report should be consulted for wind loads on tall buildings and for other special conditions.

d. Combined Wind and Live Loads. Roofs shall be designed for the combination of dead load and the live and wind loads stipulated above. Allowable working stresses on materials may be increased as permitted for wind loads in accordance with the provisions in the chapters on the several materials, but resulting sections shall not be smaller than required for dead load and full live load.

e. Elevators. Loads from elevators should receive early attention in building design as the magnitude and disposition of reactions, together with the required arrangement of carrying beams, have a decided influence on the framing of columns and adjoining members. Working stresses in support beams shall be as set forth in the chapters on the several materials.

f. Cranes and Monorails. Unless otherwise indicated by manufacturer, loads imposed on the structure shall be:

Vertical loads - Maximum wheel loads, plus 25% for impact.

Horizontal loads - Parallel to crane rails and applied at top of the rails - 20% of maximum wheel loads distributed equally between both rails. At right angles to rails - 20% of the sum of lift capacity and weight of crane trolley, the total to be equally distributed between both rails and applied at top of rails.

1-05 LIVE LOAD REDUCTION. No reduction shall be made in live load on roofs. For live loads of 100 pounds or less per square foot, the design live load on any member supporting 150 square feet or more may be reduced at the rate of 0.08 percent per square foot of area supported by the member, except that no reduction shall be made for areas to be occupied as places of public assembly. The reduction shall exceed neither R as determined by the following formula nor 60 percent:

$$R = 100 \times \frac{D+L}{4.33L'}$$

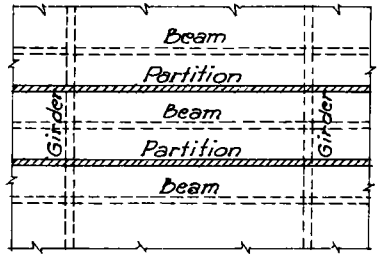
in which R = reduction in percent
D = dead load per square foot of area supported by the member
L = design live load per square foot of area supported by the member.

For live loads exceeding 100 pounds per square foot, no reduction shall be made, except that the design live loads on columns may be reduced 20 percent.

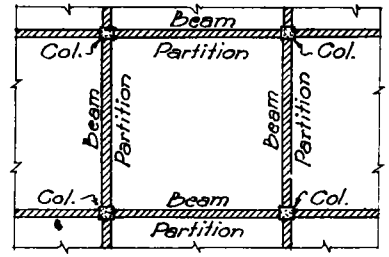
1-06 LOADS IMPOSED BY EARTHQUAKE. In regions where buildings are customarily designed to resist earthquake forces, the provisions of the Uniform Building Code of the Pacific Coast Building Officials Conference, current at the time, should govern the design of structures for these forces.

1-07 DESIGN ANALYSIS. Drawings showing structural designs other than O.C.E. standard designs shall be forwarded to the Office, Chief of Engineers, promptly upon completion, accompanied by design analyses, including stress diagrams for trusses, computations for design of typical truss members, beams, girders, columns, frames or bents and footings. Structural drawings shall have live loads clearly indicated thereon.

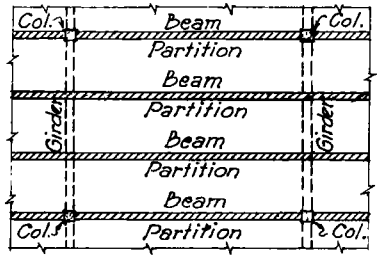
PROVISION FOR ASSUMED PARTITION LOADING



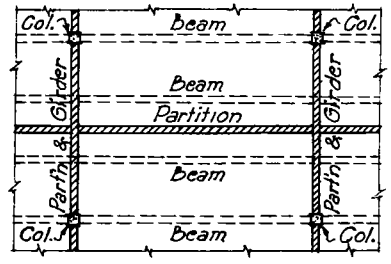
ONE-WAY SLAB- Assume partition load on center line of each slab for design of slab only, but do not carry to beams in slab reactions.



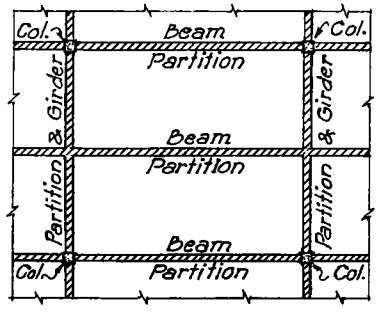
TWO-WAY SLAB- Assume partition load uniformly distributed - 30#/sq.ft. for 300#/ft. partition & 50#/sq.ft. for 500#/ft. partition. Carry partition load to beam in slab reactions. Assume partition load on each beam.



TWO BEAM BAY- Assume partition load on each beam, but do not carry to girders in beam reactions.



TWO BEAM BAY- Assume partition load on girder and on slab parallel to beams, half of the latter carried to girder by each parallel adjacent beam.



ONE BEAM BAY- Assume partition load on each beam and carry to girders in beam reactions. Assume partition load on girder in addition to those on beams.

This sheet shows provisions to be made in designing slabs, beams and girders for assumed partition loads. Attics and porches are to have no assumed partition loads and shall be designed only for those actually shown on plans.

In general, this assumed partition loading shall be used in designing framing for floors in buildings such as barracks, hospitals, etc., which are designed for light live load. It shall not be used when the live load is 100 lbs per square foot or greater.

Where actual partition loading is greater than the assumptions shown herein, the actual loads shall be used in designing.

Assumed partition load shall be as follows:-
Load per lineal foot of partition, 300 lbs, except where partitions are to be of glazed structural units. (See Note below). Partition loads are to be assumed in addition to the live and dead load requirements. In designing for critical loads, all partitions on interior framing are to be considered as live load.

Note:
For partitions of glazed structural units, use following loads:-
4" block, 11'-0" high, - 350 lbs per lineal ft.
6" " , 11'-0" " , - 500 lbs " " ft.

For columns and footings assume a partition load equal to one half the amount required under the heading ONE BEAM BAY. Partition load on columns and footings shall be treated as dead load.

Fig. 1

ROOF LIVE LOADING

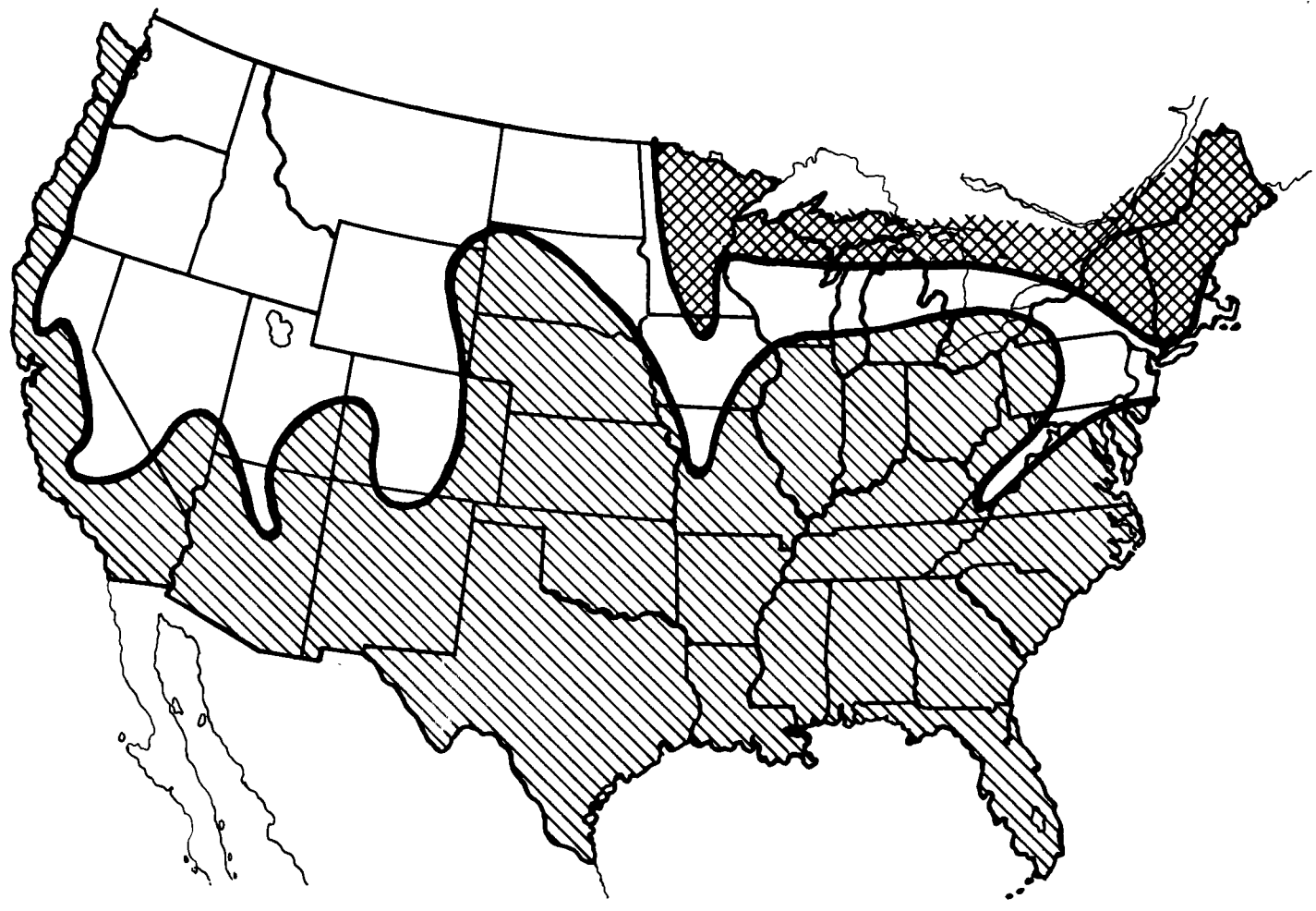


Figure 2

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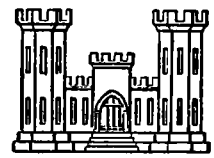
STRUCTURAL DESIGN

CONCRETE CONSTRUCTION FOR BUILDINGS

(Except Hydraulic Structures)



DEPARTMENT OF THE ARMY
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Chapter 2

CONCRETE CONSTRUCTION FOR BUILDINGS

(Except Hydraulic Structures)

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2–03 DESIGN LOADS
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- *b.* Dead loads
- *c.* Wind loads

2–04 STRESSES
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2–05 METHODS FOR MOMENTS AND SHEARS
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2–07 DETAILS OF DESIGN OF COLUMNS
- *a.* Eccentricities
- *b.* Number of bars

2–08 DETAILS OF DESIGN OF WALLS
- *a.* Lateral loads

2–09 DETAILS OF DESIGN OF FOOTINGS
2–10 EXPANSION AND CONSTRUCTION JOINTS
2–11 CONSTRUCTION DETAILS
2–12 OVERSEAS CONSTRUCTION

Part IV

STRUCTURAL DESIGN

Chapter 2

CONCRETE CONSTRUCTION FOR BUILDINGS

(Except Hydraulic Structures)

2–01 SCOPE. The instructions in this chapter relate to the design of plain and reinforced concrete construction for buildings (except hydraulic structures).

2–02 BASIS OF DESIGN. The basis of design is the issue of either the Report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete or the Building Code Requirements for Reinforced Concrete of the American Concrete Institute, current at the time the design is prepared, except as herein modified. These will be hereinafter referred to as the Code. In the event of conflict, the more recent publication is to govern.

2–03 DESIGN LOADS. The loads for which a structure is designed are the dead loads of the structure, the live loads which it is intended to support and wind loads.

a. Live loads. Live load assumptions are set forth in Part IV, Chapter 1, and unless requirements clearly indicate different load values, these assumptions are to be used. Live load reductions are to be in accordance with that chapter.

b. Dead loads. Dead loads affecting the stresses of members should be carefully appraised to the end that they will approximate the actual dead loads as nearly as possible. Provision for partition loads are set forth in Part IV, Chapter 1, Figure 1.

c. Wind loads. Wind loads acting on the structure are to be considered to the extent provided in Part IV, Chapter 1, when the character of the structure indicates that such loads will exert critical forces on it.

2–04 STRESSES. Allowable unit stresses to be used in proportioning all parts of buildings are as follows:

a. Permanent buildings. The stresses established by the Code.

b. Temporary buildings. For an expected useful occupancy not in excess of 5 years, the stresses are to be those established by the Code except as herein modified. The following unit stresses are in pounds per square inch:

Tension in flexural members

Structural grade steel bars	f_s=20,000
Intermediate grade steel bars and hard grade bars (billet steel, rail steel, or axle steel, and cold drawn wire)	f_s=24,000
Wire mesh or bars not exceeding ⅜ inch in diameter when used in one-way solid slabs of not more than 12 foot span—60 percent of minimum yield point but not to exceed	f_s=30,000

2–05 METHODS FOR MOMENTS AND SHEARS. Moments and shears in continuous slabs, beams, girders, and monolithic frames are to be computed in accordance with the theory of elasticity, preferably by the methods of moment distribution. The effects of critical loadings are to be recognized in the design, but approximate methods may be used as outlined in the Code.

2–06 DETAILS OF DESIGN OF BEAMS, GIRDERS AND SLABS. The details of the design of beams, girders and slabs should be accomplished as set forth in the Code, except as modified by the provisions of this chapter.

a. Minimum thickness of slabs. The minimum total thickness of slabs should be as follows:

One-way slabs for roofs (providing the reinforcement can be properly placed)	3″
Two-way slabs for roofs	4″
One-way and two-way slabs for floors	4″

Where a finish of 1½″ or more in thickness is to be applied over the structural slab or the design live load does not exceed 40 pounds per square foot, the minimum thickness for one-way floor slabs may be reduced to 3½″, providing the reinforcement can be properly placed.

b. Concrete joist construction. In concrete joist construction the minimum thickness of the concrete between joists is to be 2½″ for removable forms up to 30″. In ordinary roof construction, the minimum thickness may be 2″. Diaphragms not less than 4″ wide, with a ⅜-inch diameter bar top and bottom, are to be provided between joists where spans exceed 14 feet. Two lines of diaphragms are to be provided where spans exceed 24 feet and three lines where spans exceed 36 feet. Span of joists is taken as the clear distance between faces of stems, or faces of the monolithic tees, of the supporting beams or girders.

c. Bars in thin slabs. Straight bars only should be used for both positive and negative reinforcement in slabs 5″ or less in thickness. Standard hooks should be provided where necessary for anchorage.

d. Bars in thick slabs. Reinforcement in slabs over 5″ thick may be bent.

e. Deflection. Effects of deflection are to be investigated in members of unusually long span and provision for camber made if necessary.

f. Reinforcement in spandrel beams. Continuous bars top and bottom are recommended in all concrete spandrels. Bars should be as few in number as feasible but not less than four ⅝-inch diameter should be provided (2-top and 2-bottom). Spandrels are to be provided with ties throughout member spaced from 12 to 16 inches on center depending upon size of bars used and width and depth of member, unless shear requirements necessitate closer spacing.

g. Coordination of reinforcement at beam and girder intersection. To facilitate placing of steel, where concrete beams and/or girders of equal depth intersect at columns, provision is to be made for decreased effective depth of members in one direction and proper dimensions indicated on drawings. In beam and girder construction generally, the deeper beams at columns are to be designed and detailed so that the top bars come under the top bars of the shallower beams and adequate details, including the clear dimensions from upper and lower surfaces of concrete, indicated on drawings.

2–07 DETAILS OF DESIGN OF COLUMNS. The details of the design of columns should be accomplished as set forth in the Code.

a. Eccentricities. Unusually large eccentricities in columns should be avoided as much as possible. Where unavoidable they are to be recognized in the design.

b. Number of bars. To simplify placing of beam and girder reinforcement careful consideration should be given in design of columns to the number of bars used. The number should be as small as possible while retaining a reasonably uniform distribution of the reinforcement over the column section.

2–08 DETAILS OF DESIGN OF WALLS. Reinforced concrete walls in buildings are to be designed and detailed in accordance with the provisions contained in the Code. Retaining walls in excess of 6 feet in height not forming an integral part of a building are to be designed in accordance with the provisions of Part X, Chapter 9, of the Engineering Manual for Civil Works.

a. Lateral loads. Where building walls are subject to lateral pressure of any kind (fill, surcharge, floor live loads, wind loads, eccentric loads, etc.), a careful analysis is to be made and walls and footings designed accordingly. The method of determining lateral forces due to earth fill and surcharge is set forth in Part X, Chapter 9, of the Engineering Manual for Civil Works. In general, passive resistance of earth on side opposite retained material is not to be taken into account.

2–09 DETAILS OF DESIGN OF FOOTINGS. Overburden, or weight of backfill, should be considered in design of footings when the resulting load becomes appreciable. Weight of floor slab and the floor live load should be treated as overburden where slabs rest on grade.

2–10 EXPANSION AND CONSTRUCTION JOINTS. Careful consideration should be given to the location, arrangement and details of expansion and construction joints. The provisions of the Code should be used as a guide. Special consideration should be given to expansion joints at junctions of wings or at points of abrupt change in size.

2–11 CONSTRUCTION DETAILS. Typical reinforcement details showing standards for stirrups, ties, and hooks, for placing of wall reinforcement and column verticals and for construction joints are included in Corps of Engineers Guide Specifications, CE–204, Concrete. Other details of construction are specified therein, based on the design practices outlined in this chapter.

2–12 OVERSEAS CONSTRUCTION. In overseas construction, where for economy or other considerations local materials are to be used which are of grades other than those for which working stresses are established by the Code, the working stresses to be used in design are to be modified as required by the characteristics of the materials.

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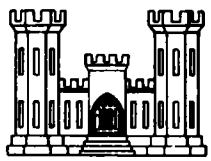
STRUCTURAL DESIGN
MASONRY CONSTRUCTION FOR BUILDINGS



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CHAPTER 3

MASONRY CONSTRUCTION FOR BUILDINGS

3-01 SCOPE

3-02 BASIS OF DESIGN

3-03 DESIGN LOADS
- a. Live Loads
- b. Dead Loads
- c. Wind Loads

3-04 STRESSES FOR BEARING WALLS AND PILASTERS
- a. Brick Masonry
- b. Clay Tile and Concrete Block Masonry

3-05 STRESSES FOR COLUMNS
- a. Brick Masonry
- b. Solid Concrete Block and Concrete Filled Hollow Units

3-06 REQUIREMENTS FOR BEARING WALLS
- a. Brick Walls
- b. Clay Tile and Concrete Block Walls
- c. Maximum Openings Permitted in Bearing Walls
- d. Design of Walls and Pilasters Subject to Lateral Loading

3-07 REQUIREMENTS FOR COLUMNS

3-08 REQUIREMENTS FOR PARTITIONS

3-09 OVERSEAS CONSTRUCTION

PART IV

STRUCTURAL DESIGN

CHAPTER 3

MASONRY CONSTRUCTION FOR BUILDINGS

3-01 SCOPE. The instructions in this Chapter relate to the design of masonry of brick, clay tile or concrete block units for permanent buildings.

3-02 BASIS OF DESIGN. The basis of design shall be as set forth herein.

3-03 DESIGN LOADS. The loads for which a structure is designed shall be the dead loads of the structure and the live loads which it is intended to support.

a. Live Loads. The loads to be used for live load assumptions shall be as set forth in Chapter 1 of this Part except where requirements clearly indicate different load values should be used.

b. Dead Loads. Dead loads affecting the stresses of members should be carefully appraised to the end that they will approximate the actual dead loads as nearly as possible.

c. Wind Loads. Wind loads shall be considered as acting on the structure to the extent provided in Chapter 1 of this Part when the character of the structure indicates that such loads will exert critical forces on it.

3-04 STRESSES FOR BEARING WALLS AND PILASTERS. Masonry shall be treated as incapable of developing tensile stress. The allowable unit compressive stresses on gross area shall be as follows:

a. Brick Masonry. Bricks with an average compressive strength of not less than 4500 pounds per square inch, laid in Portland cement mortar, with rigid supervision to assure that all vertical and horizontal joints are completely filled, 300 pounds per square inch. Bricks with an average compressive stress of not less than 3000 pounds per square inch, laid in Portland cement mortar, 250 pounds per square inch, in cement-lime mortar, 200 pounds.

b. Clay Tile and Concrete Block Masonry. Units laid in Portland cement mortar: Structural clay tile with cells vertical, 125 pounds per square inch, with cells horizontal, 70 pounds; hollow concrete block, 75 pounds, solid concrete block, 150 pounds. Units laid in cement-lime mortar: Structural clay tile with cells vertical, 100 pounds per square inch, with cells horizontal, 60 pounds; hollow concrete block, 65 pounds, solid concrete block, 125 pounds. The above values for hollow units are for those conforming to requirements of Federal Specifications for load bearing units of hollow clay tile or concrete. The values for solid units are for those having a minimum ultimate compressive strength of 1500 pounds per square inch.

3-05 STRESSES FOR COLUMNS. Columns shall be solid masonry. Units shall be solid or, if hollow, they shall be laid with cells vertical and the cells filled with concrete. The allowable compressive stresses for concentrically loaded columns with ratios of length to least side not in excess of 10 shall be as given below. It is contemplated that masonry columns with larger ratios will not be used. Where the design requirements cannot be met within this ratio, reinforced concrete or steel columns shall be used.

a. Brick Masonry. Stresses shall be as given in paragraph 3-04 a.

b. Solid Concrete Block and Concrete Filled Hollow Units. Stresses shall be as given in paragraph 3-04 b for solid concrete block.

3-06 REQUIREMENTS FOR BEARING WALLS. Wall bearing construction shall be limited to buildings three stories or less in height. Careful consideration shall be given to the advantages of skeleton construction, the type which is preferred for such buildings.

a. Brick Walls. Exterior bearing walls above the basement story shall be not less than 12 inches thick for clear heights not exceeding 13 feet. This thickness may be reduced to 8 inches for one-story structures or the top story in other buildings provided the clear height does not exceed 10 feet and no horizontal thrust is imparted to the walls by the roof framing. Limitations of openings in such walls shall be as set forth in subparagraph 3-06 c. Unless walls are braced laterally by intersecting walls or other means pilasters shall be provided at center to center distances not exceeding 24 times the wall thickness. This requirement may be modified if the clear story height does not exceed 10 times the wall thickness. Load bearing pilasters shall be provided under the bearing of beams of other concentrated loads.

Interior bearing walls shall be not less than 12 inches thick for clear heights not exceeding 15 feet. This thickness may be reduced to 8 inches for one-story structures or the top story in other buildings provided the clear height does not exceed 12 feet.

b. Clay Tile and Concrete Block Walls. The thicknesses and limitations set forth for brick walls shall apply also to walls constructed of these units except that the maximum allowable wall heights shall be 2 feet less than for brick walls.

c. Maximum Openings Permitted in Bearing Walls. The area of openings in any horizontal section of wall shall not exceed 50 percent of the gross sectional area. This percentage may be increased to 75 percent by increasing the wall thickness 4 inches for each 15 percent or fraction thereof of increased opening area

d. Design of Walls and Pilasters Subject to Lateral Loading. Masonry shall be treated as incapable of developing tensile stress. Where tensile stresses would otherwise result, reinforcing steel shall be provided. Walls and pilasters may be designed as a series of vertical beams when adequately supported at top and bottom or as cantilever beams when proper restraint is developed at the bottom. Support at top and bottom is considered adequate if positive anchorage exists at the wall and the floor system has sufficient rigidity to transmit the forces to cross walls capable of carrying the load into the foundation.

3-07 REQUIREMENTS FOR COLUMNS. The dimensions of masonry columns shall be not less than 12 inches by 12 inches. Openings and chases will not be permitted within the required area of the column.

3-08 REQUIREMENTS FOR PARTITIONS. Non-bearing partitions should have, unless otherwise required for fire resistance, a minimum thickness of 3 inches up to 12 feet in height, 4 inches from 12 to 16 feet in height, 6 inches from 16 to 20 feet in height and 8 inches from 20 to 24 feet in height. Partitions should be wedged or otherwise given lateral support at ceiling or roof and should be bonded to masonry walls against which they may abut. Where partitions

cannot be supported laterally at the top, the maximum unsupported height for 4 inch, 6 inch and 8 inch partitions shall be 12 feet, 16 feet and 20 feet, respectively. The height of partition walls may be increased where they are laterally braced by cross walls or other means.

3-09 OVERSEAS CONSTRUCTION. In overseas construction, where for economy or other considerations local materials are to be used which are of grades other than those herein specified, the working stresses to be used in design and the other stipulations of this chapter shall be modified as required by the characteristics of the materials.

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PART IV
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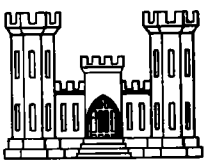

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CHAPTER 4

STRUCTURAL STEEL FOR BUILDINGS

4-01 SCOPE

4-02 BASIS OF DESIGN

4-03 LOAD ASSUMPTIONS

4-04 UNIT STRESSES
- a. Permanent Buildings
- b. Temporary Buildings
- c. Members Supporting Elevator Loads

4-05 DETAILS OF DESIGN
- a. Minimum Connections
- b. Reversal of Stress
- c. Combined Rivets and Bolts
- d. Rivets in Tension
- e. Slab as Support of Compression Flanges
- f. Lateral Stability of Purlins and Trusses
- g. Tension Bracing
- h. Bearing Plates on Masonry
- i. Unrestrained Members in Welded Construction
- j. Plate Girders of Welded Construction
- k. Lacing Members in Welded Construction

4-06 OVERSEAS CONSTRUCTION

PART IV

STRUCTURAL DESIGN

CHAPTER 4

STRUCTURAL STEEL FOR BUILDINGS

4-01 SCOPE. The instructions in this Chapter relate to the design of structural steel for buildings.

4-02 BASIS OF DESIGN. The basis of design shall be the issues of the Specification for the Design, Fabrication and Erection of Structural Steel for Buildings of the American Institute of Steel Construction and the Code for Arc and Gas Welding in Building Construction of the American Welding Society, current at the time the design is prepared, except as herein modified.

4-03 LOAD ASSUMPTIONS. Live load assumptions should be as set forth in Chapter 1 of this Part.

4-04 UNIT STRESSES. Allowable unit stresses to be used in proportioning all parts of buildings shall be as follows:

a. Permanent Buildings. For permanent buildings the stresses shall be those established by the Specification and Code referred to in Paragraph 4-02, except as modified in this subparagraph and in subparagraph c below. The following unit stresses are in pounds per square inch:

Tension

Bolts and other threaded parts, on nominal area at root of thread

Rolled threads 20,000

Cut threads 17,000

b. Temporary Buildings. For temporary buildings with an expected useful occupancy not in excess of five years the stresses shall be those established by the Specification and Code referred to in Paragraph 4-02, except as modified in this subparagraph and in subparagraph c below. The following unit stresses are in pounds per square inch:

Tension

Structural steel, net section 24,000

Butt welds, section through throat 20,000

Bolts and other threaded parts, on nominal area at root of thread

Rolled threads 24,000

Cut threads 20,000

Compression

Butt welds, section through throat (crushing)..24,000

Bending

Tension on extreme fibers of rolled sections, plate girders, and built-up members 24,000

Compression on extreme fibers of rolled sections, plate girders, and built-up members, for values of $\frac{l}{b}$ not greater than 40 ..... $\frac{25,500}{1+\frac{l^2}{1400\ b^2}}$

with a maximum of 24,000, in which l is the laterally unsupported length of the member and b is the width of the compression flange, both in inches.

Fiber stresses in butt welds, due to bending, shall not exceed the values prescribed for tension and compression, respectively.

Shearing

Rivets 17,000

Pins and turned bolts in reamed or drilled holes..... 17,000

Unfinished bolts 12,000

Webs of beams and plate girders, gross section 14,000

Weld metal

On section through throat of fillet weld, or on faying surface area of filled plug or slot weld..... 15,000

(Stress in a fillet weld shall be considered as shear on the throat for any direction of the applied stress. Neither filled nor fillet-welded plug or slot welds shall be assigned any values in resistance to stress other than shear).

On section through throat of butt weld 14,000

Except as noted below allowable values of all unit stresses established under this subparagraph shall be increased 30 percent, but not to exceed 27,000 pounds per square inch, for members subject to stresses produced by wind forces alone or in combination with other loads, provided the sections thus determined are not less than those required for the combination of loads without wind.

c. Members Supporting Elevator Loads. The allowable tensile or compressive unit stress in bending for beams supporting elevator machine or sheave beams shall be 12,000 pounds per square inch.

4-05 DETAILS OF DESIGN. The details of design shall be accomplished as set forth in the Specification and the Code cited in paragraph 4-02, except as herein modified.

a. Minimum Connections. Except for lacing, sag bars, and girts, connections carrying calculated stresses shall be designed for a minimum of 10,000 pounds if welded or shall have no fewer than two rivets or bolts if riveted or bolted.

b. Reversal of Stress. Members subject to loads (other than wind loads) producing alternating tensile and compressive stresses shall be proportioned as follows: To the net total compressive stress and to the net total tensile stress add 50 percent of the smaller of the two and proportion the member to resist each of these increased stresses. Connections shall be proportioned to resist the larger of the two increased stresses. In welded construction if the reversal may be expected to occur over 100,000 times in the life of the building, the unit stresses in the connecting welds shall not exceed 75 percent of the basic unit stresses for the various types of welds.

c. Combined Rivets and Bolts. The combined use of rivets and bolts in the same face of any connection shall not be permitted.

d. Rivets in Tension. Wherever possible the use of rivets in direct tension shall be avoided in important connections.

e. Slab as Support of Compression Flanges. For ordinary construction, beams which have compression flanges embedded in a concrete slab at least 3/4" shall be considered laterally supported for full length of such embedment.

f. Lateral Stability of Purlins and Trusses. The effectiveness of sag rods, bracing systems and roof decking in providing lateral support for purlins and trusses should be as set forth on Figure 1.

g. Tension Bracing. Tension bracing, other than vertical, should be proportioned in accordance with Figure 2.

h. Bearing Plates on Masonry. Bearing plates, set on grout at least 1/2" thick, and adequate anchors shall be provided for all beams and girders supported on masonry.

i. Unrestrained Members in Welded Construction. Beam, girder and truss connections should generally be treated as unrestrained, that is, as simple or free-ended and be designed for the reaction shears only. Connections should permit the ends of the beam to rotate sufficiently to accommodate its deflection by providing for a horizontal displacement of the top flange determined as follows:

$e = .007d$ if the beam is designed for full uniform load and for deflection not exceeding 1/360th of the span

or, $e = \frac{f \times L}{3{,}625{,}000}$ if the beam is designed for full uniform load producing the unit stress f at mid span,

where e = the horizontal displacement between the top and bottom of beam at its end, in inches

f = the flexural unit stress in the beam at mid span, in pounds per square inch

d = the depth of the beam, in inches

L = the span of the beam, in feet.

j. Plate Girders of Welded Construction. Each flange of welded plate girders shall, in general, consist of a single plate rather than two or more plates superimposed. The single plate may comprise a series of shorter plates, laid end to end and butt welded at their junctions. Bearing stiffeners shall be designed as columns subject to the provisions for compression members, assuming the column section to comprise a pair of stiffeners and a centrally located strip of the web the length of which is equal to not more than 25 times its thickness at interior stiffeners or not more than 12 times its thickness when the stiffeners are located at the end of the web. The column length shall be taken as not less than 3/4 of the length of the stiffeners in computing the ratio, ℓ/r. Only that portion of the stiffener outside of the flange-to-web welds or the angle fillet shall be considered effective in bearing. Intermediate bar stiffeners employed to stay the web plate against buckling, and not for the transfer of concentrated loads from flange to web, shall be of a section not less than that required by the formula,

$$I_s = 0.00000016\ h^4, \text{ in which}$$

h = total depth of web.

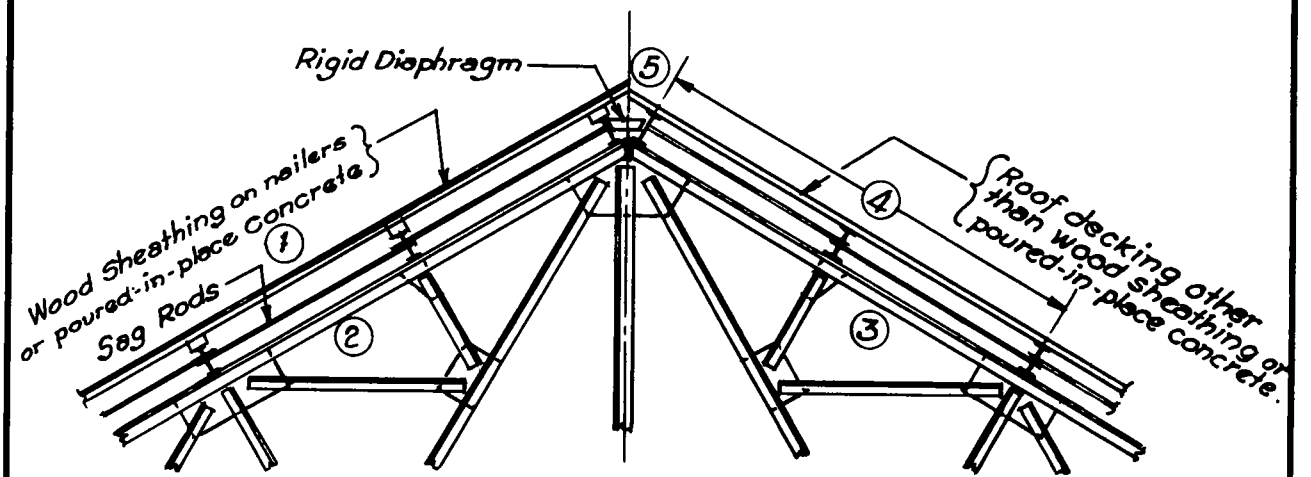
I_s = moment of inertia of the stiffeners or stiffener (figured with a common axis at the centerline of web for stiffeners in pairs and with the axis at the interface between stiffeners and web for single stiffeners).

If the girder is subjected to substantial fluctuations in loading, the stiffeners shall not be welded to the tension flange, except at points where the maximum flange stress is less than half the allowable. Webs shall be spliced with a complete penetration butt weld. If the flanges are spliced, the splices shall either develop the full effective strength of the material or they shall develop the strength required by the total stresses produced by dead loads and by the live and impact loads increased 15 percent, but in no case shall the strength developed be less than 50 percent of the effective strength of the material spliced.

k. Lacing Members in Welded Construction. Lacing members in welded construction shall be arranged in single system and have an 1/r ratio not exceeding 100.

4-06 OVERSEAS CONSTRUCTION. In overseas construction, where for economy or other considerations local materials are to be used which are of grades other than those for which working stresses are established by the Specification and Code referred to in Paragraph 4-02, the working stresses to be used in design shall be modified as required by the characteristics of the materials.

STRUCTURAL STEEL FRAMING
($\frac{L}{r}$, $\frac{L}{b}$ FOR PURLINS AND UPPER CHORDS OF TRUSSES)



1.- For roof pitches of 1½" to 12" and greater, use sag rods, unless poured-in-place concrete roof slabs are used.

2.- One inch wood sheathing, laid diagonally, or 2" tongue and groove wood sheathing fastened to nailers bolted to purlins shall be considered to fix the top flanges of the purlins which in turn fix the top chords of trusses. Where top flange of purlin is embedded at least ¾" or otherwise adequately tied into poured-in-place concrete roof slab, the purlin shall be considered as fully stayed.

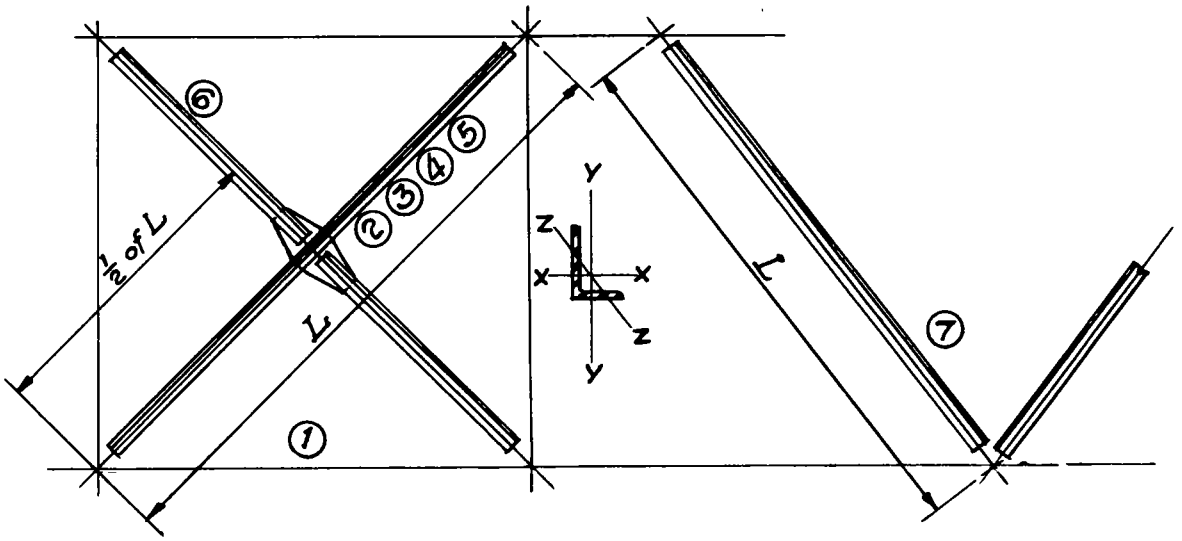
3.- For all types of roof decking other than wood sheathing or poured-in-place concrete, sag rods may be considered to fix purlins for purposes of computing $\frac{L}{b}$ and $\frac{L}{r}$ provided sag rods are properly stayed and the number of panels between such stayed panels or other rigid struts is reasonable.

4.- Except as stated above, $\frac{L}{r}$ values for upper chord members of trusses shall be based on lengths between panel points fixed by some positive system of diagonal bracing.

5.- Double purlins at ridge connected by rigid diaphragms at lines of sag rods shall be considered sufficiently stiffened to permit L to be taken as distance between diaphragms or between diaphragms and end of purlins.

Fig. 1

STRUCTURAL STEEL FRAMING
TENSION BRACING (OTHER THAN VERTICAL PLANE)



1.- Cross bracing should always be used in preference to single line tension bracing unless conditions are such as to make the use of the former impracticable.

2.- The through member in the cross bracing should be designed for $\frac{L}{r}$ not to exceed 300.

3.- In calculating $\frac{L}{r}$ for the horizontal axis (X-X), the length "L" should be taken as the total nominal length of the member, center to center of working points.

4.- In calculating $\frac{L}{r}$ for the vertical axis (Y-Y), the length "L" should be taken as half the total length.

5.- $\frac{L}{r}$ about the diagonal axis (Z-Z) need not be considered for cross bracing.

6.- Both members should be of the size required by $\frac{L}{r}$ of the through member unless the size of one must be increased to provide for definitely calculated stresses.

7.- Single line tension bracing, where used, should be designed for $\frac{L}{r}$ not over 300 about any axis, taking "L" as the total length center to center of working points.

8.- Buildings subject to extraordinary vibration conditions should be the subject of special study.

Fig. 2

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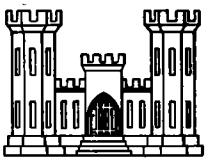
WOOD CONSTRUCTION FOR BUILDINGS



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CHAPTER 5

WOOD CONSTRUCTION FOR BUILDINGS

5-01 SCOPE

5-02 BASIS OF DESIGN

5-03 GRADES OF LUMBER

5-04 COMPRESSION MEMBERS
- a. Composition of Members
- b. Members Carrying Combined Stresses
- c. Design of Compression Chords of Connector-Joined Trusses
- d. Bracing of Compression Chords of Trusses

5-05 OVERSEAS CONSTRUCTION

PART IV

STRUCTURAL DESIGN

CHAPTER 5

WOOD CONSTRUCTION FOR BUILDINGS

5-01 SCOPE. The instructions in this chapter relate to the design of wood used for structural purposes in buildings.

5-02 BASIS OF DESIGN. The basis of design shall be the National Design Specification for Stress Grade Lumber and Its Fastenings, published by the National Lumber Manufacturers Association, current at the time the design is prepared, except as modified herein. It will be hereinafter referred to as the Specification. Design stresses for permanent buildings shall be as set forth herein. These allowable stresses shall be increased 50% for dead and full live loads without any additional increases for snow, wind or other short time loads for those portions of temporary buildings which are subjected to intermittent, non-continuous loading. No increase shall be made in modulus of elasticity. For the purpose of this paragraph, a temporary building is defined as one with an anticipated usage of not more than five years.

5-03 GRADES OF LUMBER. The grades of wood, except as provided herein, to be used for structural purposes shall be those identified and established as stress grades. Grades selected shall be suitable for the intended usage. In buildings or portions of buildings not requiring fastenings other than nailing and designed for live loads not in excess of 40 lbs. per square foot, No. 1 Dimension Douglas Fir as defined in Standard Grading and Dressing Rules, West Coast Bureau of Lumber Grades and Inspection, or the equivalent in other species, may be used as stress grade wood when an extreme fiber stress in bending not in excess of 1000 lbs. per square inch is used and no increase in stress is allowed for temporary loads such as wind and snow.

5-04 COMPRESSION MEMBERS. Compression members shall be designed in accordance with the provisions of the Specification, modified by the assumptions and methods set forth herein.

a. Composition of Members. Compression members carrying large loads and those supporting important parts of structures such as trusses or heavy girders shall be simple solid columns consisting of a single piece, pieces properly glued together to form a single member, or split-ring connector-joined spaced columns.

b. Members Carrying Combined Stresses. Compression members subjected to combined axial compression and flexure shall be designed in accordance with Paragraph 403 of the Specification except that members supporting permanent side loads producing flexure, such as earth or water pressure, shall be designed by the more accurate formulas contained in Appendix B of the Specification.

c. Design of Compression Chords of Connector-Joined Trusses. When compression chords of connector-joined trusses are braced laterally at the panel points only, by purlins or other members, the ℓ/d ratio shall be computed by using the distance between panel points as ℓ and the least breadth of the individual members of the chord as d. The allowable unit compressive stress shall be computed as provided for spaced columns. When compression chords of such trusses support purlins, rafters or joists, the ℓ/d ratio shall be computed by using the distance between panel points as ℓ and the least depth of individual members as d, and the distance between supported members as ℓ and the least breadth of individual members as d. The allowable unit compressive stress shall be computed for a simple solid column using

the larger of the two values of τ/d as determined above. Chord members shall be designed for combined compressive and bending stresses where purlins, rafters or joists rest on the chord between panel points. Trusses should be detailed so that spacer blocks between the individual pieces of top chord members will occur adjacent to the supported members nearest to midpoints of the panels, extend above the tops of the chord and be securely fastened to those members.

d. Bracing of Compression Chords of Trusses. Bracing in the plane of the top chord of trusses may generally be omitted when 1" wood sheathing, laid diagonally, or 2" tongue-and-groove wood sheathing is used. When other types of sheathing are used, diagonal bracing shall be installed, applied on the underside of purlins, rafters or joists and fastened thereto.

5-05 OVERSEAS CONSTRUCTION. In overseas construction, where for economy or other considerations local materials are to be used which are of grades other than those for which working stresses are established by the Specifications and by subparagraph 5-03 a above, the working stresses to be used in design shall be modified as required by the characteristics of the materials.

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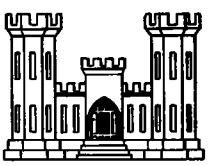
STRUCTURAL DESIGN
STRUCTURES OTHER THAN BUILDING



ARMY SERVICE FORCES
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CHAPTER 6

STRUCTURES OTHER THAN BUILDINGS

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PART IV

STRUCTURAL DESIGN

CHAPTER 6

STRUCTURES OTHER THAN BUILDINGS

6-01 SCOPE. The instructions in this chapter relate to the design of structures other than buildings.

6-02 HIGHWAY BRIDGES. The specifications of the highway department of the State in which the bridge is located shall be used as the basis of design for such structures but in the event no such specifications are applicable, the Standard Specifications for Highway Bridges of the American Association of State Highway Officials shall be used. These specifications shall be modified where conditions indicate such necessity.

6-03 RAILWAY BRIDGES. The specifications of the railroad on whose line the bridge is located shall be used as the basis of design for such structures but in the event no such specifications are applicable, the manual on design and practices of the American Railway Engineering Association shall be used. These specifications shall be modified where conditions indicate such necessity.

6-04 ELEVATED STEEL TANKS, STANDPIPES AND RESERVOIRS. The standard specifications of the American Water Works Association shall be used as the basis of design for elevated steel water tanks, standpipes and reservoirs except where conditions indicate the necessity for modifications.

6-05 TOWERS. Radio and transmission towers shall be designed for wind load of not less than 30 pounds per square foot of exposed surfaces, on both windward and leeward sides, in addition to other applicable loading. Special wind-force specifications shall be formulated locally for areas that are definitely known to be subject to hurricanes or tornadoes. In calculating the surfaces exposed to the wind, no shielding of the leeward portions of the tower by the windward frames shall be assumed. Stresses shall be in accordance with provisions of Chapters of this Part applicable to the structural materials used.

6-06 STEEL STACKS. Steel stacks shall be designed for the wind load stipulated in Chapter 1 of this Part. The maximum unit stresses in pounds per square inch shall be 14,000 in tension in the net section of the plate with rivet holes deducted and 12,000 in compression on the gross section. These stresses are based on no allowance being made for corrosion. The maximum unit stresses for rivets shall be 21,000 and 10,500, respectively, for bearing and shear.

6-07 BRICK STACKS. Brick stacks shall be designed for the wind load stipulated in Chapter 1 of this Part. The maximum unit tensile stress in pounds per square inch shall be 10 for ordinary brickword and 35 for radial brick construction. The maximum unit compressive stress shall be as set forth in Chapter 3 of this Part for ordinary brickwork and 350 for radial brick construction.

6-08 PRESTRESSED CONCRETE TANKS. Prestressed concrete tanks shall be designed in accordance with the best practice current at the time design is prepared. The prestress in band bars shall not exceed 62.5% of yield-point stress of the bars for tanks buried in damp ground or used for water storage nor 68.5% for other tanks. Specifications for band bars shall require steel with a phosphorous content not in excess of 0.05% and a minimum yield-point stress of not

less than 40,000 pounds per square inch. The compressive concrete stress after completion of the prestressing shall not exceed 550 pounds per square inch.

6-09 RETAINING WALLS Retaining walls not forming an integral part of a building shall be designed in accordance with provisions of Part X, Chapter 9 of the Engineering Manual for Civil Works.

6-10 MISCELLANEOUS STRUCTURES. Structures not identified with any groups or types for which there are existing recognized coeds or specifications shall be designed under the provisions in the Chapters of this Part applying to structures which they most nearly resemble. Those to which no portions of this Part are applicable shall be designed in accordance with the best current practice.

6-11 DETAILS OF DESIGN. Structures that are exposed to outside weather conditions should have all surfaces sloped for drainage. Intersecting surfaces forming angles or pockets that may retain water should be arranged to provide drainage. Members, especially of structural steel or wood, should be so designed that they will drain and not retain moisture; when in pairs or multiples, should be so designed and detailed that water or moisture will not be held between them. Elements of structures such as expansion plates, rockers, joints and surfaces intended to permit movement should be so designed that they are protected from contact with water or condensation and should also be so arranged and detailed that water will readily drain away from them. Surfaces and members should be so designed that water will drain away from points where steel enters concrete or masonry or is in contact with any such materials. Contact between masonry and wood or metal in exposed conditions should be prevented wherever feasible. At times the most efficient method of providing drainage for steel members is through the use of weep holes where they do not affect the strength of the members too adversely. In important exposed structures where steel is used, thickness of metal should be increased above that necessary for computed requirements in order to provide for possible deterioration from rust scale. In the design of exposed concrete structures or portions of structures such as towers or piers for towers, adequate coverage for reinforcement should be provided; specifications should require such practices of proportioning, mixing and placing the concrete as will insure maximum surface density and minimum shrinkage, particularly long-time shrinkage and expansion caused by alternate periods of wetting and drying. Relatively close spacing of expansion joints in retaining walls, bridges and similar structures is helpful in preventing excessive cracking. Where a structure of steel or wood rests on masonry or on concrete footings, the masonry or footings should extend above the ground surface approximately 24 inches in order that the metal or wood junction with the footing will be above the splash zone.

6-12 DESIGN ANALYSES. Structural drawings shall have design live loads clearly indicated thereon. Drawings showing major structural designs for other than standard plans prepared in the Office, Chief of Engineers, shall be accompanied by design analyses including stress diagrams for trusses and computations for design of typical truss members, slabs, beams, girders, columns, frames, bents and footings as these various elements may be utilized in the structure.

6-13 OVERSEAS CONSTRUCTION. In overseas construction, where for economy or other considerations local materials are to be used which are of grades other than those for which working stresses are established by the requirements of this chapter, the working stresses to be used in design shall be modified as required by the characteristics of the materials.

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ENGINEERING MANUAL
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PART V
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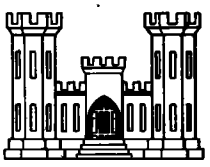
MECHANICAL DESIGN
HEATING, VENTILATION, AND AIR CONDITIONING



ARMY SERVICE FORCES
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

U S Army

CHAPTER 1

HEATING, VENTILATION, AND AIR CONDITIONING

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PART V
MECHANICAL DESIGN

CHAPTER 1
HEATING VENTILATION, AND AIR CONDITIONING

HEATING

1-01 SCOPE OF THESE INSTRUCTIONS. These instructions cover the major requirements for the design of space heating and utility steam heating systems, central heating plants, ventilation and air conditioning, as required in connection with Permanent Construction. Good engineering practice, as recommended by the latest edition of the American Society of Heating and Ventilating Engineers Guide, should be followed in regard to special conditions and problems and to items not covered specifically by these instructions.

1-02 INSIDE DESIGN TEMPERATURES. The following inside design temperatures should be used, unless otherwise directed:

Living Spaces	70°	
Offices	70°	
Toilets	70°	
Showers	70°	
Baths (with tubs)	80°	
Kitchens	50°	
Food Preparations	70°	
Dishwashing	50°	
Operating and Maternity Sections (in which patients are exposed)	85°	
Hydrotherapy, X-ray and similar rooms	80°	
Wards	70°	
Laundries	50°	
Shops	50°	and higher
Paint Shops	80°	
Drying	80°	and higher
Drying Parachute	100°	maximum
Storage (if heated)	40°	and higher
Issue	60°	
Hangar Lean-tos	70°	in all zones
Hangar Proper	50°	in zero & -20° zones

In general, heat is considered unnecessary in certain types of hangars in the +20° zone and higher. However, if for functional reasons heat is considered essential in these zones by the Commanding Officer of any field, request for the installation should be made through prescribed channels on the basis of plans and cost estimate obtained from the District Engineer.

NOTE: Temperatures for spaces other than the above, or changes in the above, will be determined by the District Engineer or by the Using Service.

1-03 OUTSIDE DESIGN TEMPERATURES The outside design temperature used in computing the heat loss from a building is seldom taken as the lowest temperature ever recorded in a given locality. Such temperatures are usually of short duration. It is, therefore, evident that a temperature somewhat higher than the lowest on record properly may be assumed in making heat loss calculations. The outside temperature generally assumed in the design of a heating system is ordinarily not more than 15 degrees above the lowest temperature recorded in a given locality during the preceding ten years as reported by the Weather Bureau or other official weather reporting station. In the case of well insulated buildings in localities where the minimum does not prevail for more than a few hours or where the lowest recorded temperature is extremely unusual, more than 15 degrees above the minimum may be allowed. Outside design temperatures for heating for stations within the continental United States should be in accordance with those established by the American Society of Heating and Ventilating Engineers. These data are incorporated in table "Climatic Conditions Compiled from Weather Bureau Records", as contained in the current issue of the Heating, Ventilating and Air Conditioning Guide. Where a particular location is not listed, local weather reports should be obtained. If such reports are not available, the reports for the station nearest the locality should be used. Where temperatures obtained do not appear to be representative of the site, the matter should be submitted to the Office of the Chief of Engineers for decision. Outside design temperature for heating for stations located outside of the continental limits of the United States should be based on the average minimum temperature prevailing at the particular station during the preceding ten years. Prevailing temperatures should be obtained from official weather reporting stations.

1-04 BUILDING HEAT LOSSES. Building heat losses should be computed as follows:

a. Heat Losses through Floors, Walls and Ceilings: Heat losses through floors, walls, and ceilings should be computed by the method outlined in the American Society of Heating and Ventilating Engineers Guide. Heat losses through ceilings having closed unheated attic space should be calculated by using the combined ceiling and roof coefficient as outlined in the Guide. The total temperature difference to be used in calculating the heat loss through floors above closed unheated spaces should be determined by using one-half (1/2) the algebraic difference between the inside and outside design temperatures.

b. Infiltration Losses. Infiltration losses, i. e., losses due to leakage of air, should be computed by the "Crack" method as outlined in the American Society of Heating and Ventilating Engineers Guide. For large spaces, such as hangars and shops, infiltration calculated on the air change method, also contained in the Guide above referred to, may be used. If there is any uncertainty as to the number of air changes that should be used, the matter should be referred to the Office of the Chief of Engineers.

1-05 TYPES OF HEATING SYSTEMS. In general, types of heating systems for various buildings should be in accordance with the following:

a. Officers' Quarters.

Temperature zone	
Below zero	Steam
Zero to $+20^{\circ}$ F.	Forced hot water
Above $+20^{\circ}$ F.	Forced warm air

b.	N.C.O. Quarters.	
	Temperature zone	
	Below zero	Steam
	Zero to $\pm 20^{\circ}$ F.	Forced hot water
	Above $\pm 20^{\circ}$ f.	Forced warm air
c.	Barracks.	Forced warm air or steam
d.	Warehouses, Shops, Hangars and Similar Buildings.	Steam unit heaters or forced warm air
e.	Theatres.	Forced warm air with air conditioning
f.	Schools.	Forced warm air
g.	Administration Buildings.	Steam or forced hot water
h.	Radio Receiving and Transmitter Buildings.	Forced warm air
i.	Chapels.	Forced warm air with heating and ventilating cabinets
j.	Gymnasium.	Forced warm air
k.	Apartment Houses.	Steam or forced hot water

1-06 FUEL. The type of fuel to be used for stations located within the continental United States will be determined by the Office of the Chief of Engineers. For other areas the type of fuel will be established by the Division Engineer.

1-07 BOILER SELECTION. After determining the total heat loss from a building, and if an individual heating plant is to be provided, the capacity of the boiler to be used in square feet of radiation or Btu output should be determined in accordance with the following procedure:

a. Cast-iron, Coal- and Oil-fired Boilers. Cast-iron, coal- and oil-fired boilers should be selected on the basis of Heating, Piping and Air Conditioning Contractors National Association "net load" ratings. Where the capacity is stated on standard plans as "standing" or "installed" radiation, these figures should be taken as "net load". Where capacities on standard plans are given as E.D.R., the net load should be taken as 75% of the "E.D.R." capacity for hand-fired boilers, and as 60% for mechanically fired boilers. E.D.R. is the Equivalent Direct Radiation, including standing radiation, piping loss, and allowance for pick-up.

b. Cast-iron, Gas-Fired Boilers. Cast-iron, gas-fired boilers should be selected on the basis of American Gas Association "output ratings" determined as follows:

If the system is of the steam type, the AGA output rating is obtained by multiplying the square feet of installed radiation by 1.33 if the steam pressure is automatically controlled and by 1.66 if the steam pressure is not automatically controlled.

If the system is of the hot water type and designed for a heat emission of 200 Btu per square foot, the AGA output rating, at 150 Btu per square foot, is obtained by multiplying the square feet of installed radiation, at 200 Btu per square foot, by 1.78 for systems where the water temperature is automatically controlled and by 2.22 where the water temperature is not automatically controlled.

c. Horizontal Firebox Boilers. Horizontal firebox boilers should be selected on the basis of Steel Heating Boiler Institute ratings.

d. Hot Air Furnaces. Hot air furnaces having a capacity less than 294,000 Btu per hour at the bonnet should be sized according to the formula

established by the National Warm Air Heating Association in Technical Code 1940, using a combustion rate not in excess of seven and one-half (7-1/2) pounds of coal per square foot of grate area per hour at an efficiency not in excess of 65%. This is known as the Standard Code Rating. The size of all furnaces having a capacity in excess of 294,000 Btu at the bonnet should be based on this formula, but with a combustion rate not in excess of ten (10) pounds of coal per square foot of grate area per hour at an efficiency not in excess of 70%. However, no furnace having a Standard Code rating of 294,000 Btu output at the bonnet, or less, should be approved for a capacity in excess of 294,000 Btu output.

1-08 COAL-FIRED BOILERS. Where coal is the established fuel in individual heating plants, boilers should be hand-fired unless the saving in the cost of fuel and operating personnel over a three-year period will justify the use of stokers, in which case the installation of stokers is authorized.

1-09 RADIATION. In general, the use of free-standing cast-iron radiation should not be considered for quarters. Convectors should be used in lieu thereof. They should be recessed, if possible, in the walls of the building with the front flush with the wall. Capacities of convectors should be as determined by the National Bureau of Standards.

1-10 RADIANT HEATING. Where the installation of a hot water heating system is being contemplated and the type of building is suitable for its use, consideration may be given to a system of the Radiant type. With this type of system hot water coils are generally embedded in the floor construction with the floor temperature limited to a maximum of 85° F.

a. Coils. Careful consideration should be given to the desired uniformity of heating. If temperature variations from point to point are kept at a minimum, this requires close spacing of pipe and the use of lower water temperatures. If, on the other hand, even floor temperatures are deemed less impirtant, and lower cost is desired, then smaller pipe, wider spacing and higher water temperatures should be chosen. A compromise must usually be made. If coils are spaced more than twenty-four (24) inches apart, it is difficult to maintain satisfactory uniform temperature distribution. A coil spacing of eighteen (18) inches or less will generally provide a satisfactory installation. In special cases, such as rooms with excessively large heat loss with a small floor area, it may be necessary to supplement the floor coil by providing extra coil surface in adjacent rooms so that normal air circulation through the building will supply the deficiency. Another method which may be considered is to place a warm panel in the ceiling or in a wall. Fig. 4, contained in the APPENDIX, shows the rate at which these panels will give off heat when maintained at different temperatures. Depending on the ceiling height, ceiling panels can be operated at between 105° and 130° Fahrenheit while wall panels are usually held to a temperature of 100° Fahrenheit or less. It will be seen by an inspection of these curves that ceiling and wall panels operated at relatively high temperatures may be used as effective supplements to the floor coils.

b. Floor Coverings. Floor coverings have their effect on the operation of the system. In estimating the water temperature for a concrete floor

covered with a thin felt pad and carpet, it is suggested that about a forty (40) degree increase in water temperature be anticipated. This figure is an approximation, but it may indicate the order of magnitude of the change to be made. Linoleum has relatively less effect and a twenty (20) degree allowance would be reasonable.

c. Floor Construction. Fig. 5 contained in APPENDIX shows some of the methods of floor construction which are commonly used. Detail "A" illustrates the system most commonly employed in residential projects. Over the compacted soil a layer of gravel or broken stone four (4) to six (6) inches deep is placed and the pipe coils are laid out so that they will just be covered by the gravel. Cinders should never be used in place of the gravel, owing to the large amount of sulphur contained therein. Sulphur will cause endless trouble due to corrosion. Of all the available fill materials, limestone is to be preferred, but coarse gravel may be used. Over the coils and gravel a concrete slab is poured. Heat is conducted from the pipe through the concrete. In some instances the pipe is embedded directly in the concrete and, since the pipe and concrete expand at the same rate, no difficulty should be encountered. The broken stone or gravel is spread and tamped before the coils are laid out on top of the gravel and the concrete is then poured. Since the pipe is surrounded by solid masonry, heat transfer is facilitated, quicker response to changes in temperature is achieved, and some reduction in heat loss downward may be expected. In order to achieve further reduction in the downward heat loss, strips of rigid insulation board are sometimes bedded into the gravel under the pipe as shown in detail "C". Another method of installing the coils consists in placing them on hollow tile, which not only retards heat flow to the ground but eliminates any possibility of moisture seepage as well. This construction is shown in detail "D".

1-11 UNIT HEATERS. Unit heaters should be interpreted as equipment used to transmit heat from steam or hot water to air, utilizing a fan for air circulation. They should be sized so that the outlet air temperatures do not exceed 145° Fahrenheit or fall below 120° Fahrenheit depending upon the mounting height and function of the heated space. The location and number of units should be such that there are provided sufficient air circulations without objectionable drafts. For large buildings, such as hangars where unit heaters or direct fired heaters are used, the total capacity of the fans should be sufficient to provide approximately four (4) recirculations of air per hour. This requirement should not be interpreted as being four (4) air changes per hour.

1-12 AUTOMATIC CONTROLS. For the control of heating apparatus equal consideration should be given to both electrically and pneumatically operated equipment. Where the installation costs can be justified by the saving of fuel over a three-year period, consideration should be given toward the use of automatic temperature control equipment. Controlling the temperature inside the building by the outside temperature has proven to be a very satisfactory method.

1-13 INSTALLATION. In general, where steam, hot water, or warm air heating systems are installed, all piping and duct work should, if possible, be run concealed in the building structure.

1-14 STACKS. The design of stacks should be in accordance with the following procedure:

a. Stack Heights. Correction in stack size for elevations 1000 feet above sea level and higher should be made according to TABLE III, CORRECTION FOR ALTITUDE, as outlined in paragraph 1-24.

b. Cast-Iron Boilers. Stacks for cast-iron boilers, coal-or oil-fired, should be sized in accordance with the recommendations of the Heating, Piping and Air Conditioning Contractors' National Association.

c. Steel Boilers. Stacks for steel boilers should be sized as recommended by the boiler manufacturer at one hundred (100) percent rating.

d. Gas-Fired Boilers. Stacks for gas-fired boilers should be installed in accordance with the American Gas Association standards, and the top of the stack should be, in no case, less than three (3) feet above the highest point of the roof, unless otherwise indicated on standard plans.

e. Furnaces. Stacks for furnaces should be sized in accordance with the recommendation of the National Warm Air Heating Association.

1-15 FIRE PREVENTION. In order to reduce fire hazards to a minimum, installations of various items of equipment such as ranges, hot water heaters, smoke pipe and hot air ducts, hoods, steam and hot water pipes, and masonry chimneys should be made in accordance with Part XI, FIRE PREVENTION.

1-16 DESIGN ANALYSIS. In accordance with the provisions of par. 740.09 of Orders and Regulations, plans and specifications for heating installations submitted to higher authority for approval will be accompanied by design analysis.

CENTRAL HEATING PLANTS

1-17 LOCATION. Central Heating Plants should be designed for the particular load conditions required for the facilities to be served. The plant should be located to permit efficient distribution of steam and easy access for the delivery and storage of fuel. The plant design should be as simple as possible consistent with safety and operating economy.

1-18 RECOMMENDED USES. Central Heating Plants are recommended for hospital areas for the supply of steam for space heating and utility purposes. They are also recommended for groups of buildings xxxxxx located in close proximity to one another for supplying steam for space heating, domestic hot water, cooking and other utility purposes. Central heating plants for other than hospital areas should be of such capacity that they can be operated by not to exceed two (2) men per shift. The installed capacity for such a plant is 750 horsepower, viz., three 250 horsepower water tube boilers designed for 200% rating. The total load for such a plant should not exceed 1000 horsepower. If gas or oil is the established fuel, central heating plants should not be used for other than hospital areas.

1-19 FIRE TUBE BOILERS. Steel firebox boilers should be utilized where the capacity of individual units does not exceed 304 horsepower. Steel firebox boilers may be either the refractory lined type or standard steel firebox type and should be sized in accordance with the Steel Heating Boiler Institute Code. Boilers of this type should be sized so that in case of an emergency or in the event one boiler is out of service, the remaining boilers can be operated at not to exceed 125% rating in order to carry the load.

1-20 WATER TUBE BOILERS. Water tube boilers should be utilized where the capacity of individual units exceed 304 horsepower or where it is desired to

operate a boiler of less horsepower at 200% rating. Boilers should be so sized that the load can be carried when all boilers are being operated at not to exceed 150% rating. In the event one boiler is out of service, the remaining boilers should be capable of carring the load when being operated at 200% rating.

1-21 DESIGN PRESSURE. Water tube boilers are generally designed for a minimum steam pressure of 160 pounds per square inch as compared with 125 pounds or 150 pounds per square inch for fire tube boilers.

1-22 LOAD FACTORS. When establishing boiler capacities the following load factors should be utilized unless local conditions and the project being considered is of such nature that these factors would not be applicable, in which case other factors will be locally established.

a. Heating. Not automatically controlled 100%
b. Heating. Automatically controlled 80%
c. Utility Steam. Domestic hot water, cooking, etc. 65%

1-23 BOILER CAPACITIES. When establishing the boiler steam demand, the following tables giving the steam consumption of various items of equipment should be used. The items referred to are those indicated on standard plans.

a. Laundry Equipment.

ITEM	NAME	SIZE	POUNDS OF STEAM PER HOUR.
LE-4	Drying Tumbler	42" x 120"	699
LE-5A	Starch Cooker	25 Gal.	22.5
LE-5B	" "	50 Gal.	45
LE-6A	Two Girl Shirt Press Unit		2.6
LE-6B	" " " " "		9.3
LE-6C	" " " " "		34.5
LE-6D	" " " " "		17.25
LE-7A	Trouser Units		34.5
LE-7B	" "		9.3
LE-8A	Garment Press		34.5
LE-8B	" "		34.5
LE-9	Handkerchief Press		20
LE-10	Hosiery Unit		34.5
LE-12A	Flat Work Ironer	8-Roll 120"	550
LE-12B	" " "	6-Roll 120"	410
LE-12C	" " "	4-Roll 120"	275
LE-12D	" " "	2-Roll 120"	140
LE-17A	Four Girl Shirt Press Unit (Fully Automatic)		17.25
LE-17B	" " "		38.0
LE-17C	" " "		26.0
LE-17D	" " "		10.35
LE-17E	" " "		9.3
LE-17F	" " "		51.75
LE-17G	" " "		51.75
LE-18	Legger & Trouser Form		51.75
LE-19	Pocketeer		17.25
LE-22A	Drying Tumbler	Open End 36" x 30"	150.
LE-22B	" "	Open End 36" x 30" Reversible	150.

b. Kitchen Equipment.

ITEM	NAME	SIZE	POUNDS OF STEAM PER HOUR
KE-5	Bain Marie	72"x36"x10"	61
KE-5-1	" "	54"x36"x10"	46
KE-7-2	Veg. Steamer	36"x36"x66"	50
KE-9	Kettle	60 Gal.	69
KE-9-2	"	40 Gal.	52
KE-9-4	"	20 Gal.	28
KE-10	Dishwasher	64"x32"	60
KE-10-1	"	80"x32"	69
KE-10-4	"	28"x28"x60"	34
KE-10-5	"	46"x22"x32"	50
KE-10-6	"	64"x22"x32"	50
KE-13	Steam Table	87"x26"	27
KE-13-3	" "	54"x26"	17
KE-13-4	" "	66"x26"	20
KE-13-7	" "	72"x26"	22
KE-14	Scullery Sink (Pots)	108"x26"x16"	34
KE-14-20	Pot Washing Sink	72"x30"x20"	34
KE-19-4	Coffee Urn Battery	20/46/20 Gal.	136
KE-19-5	" " "	15/36/15 "	102
KE-19-10	Single Coffee Urn	6 Gal.	58
KE-19-11	Single Coffee Urn	8 Gal.	75
KE-19-12	Twin Coffee Urn	2-3 Gal.	75
KE-19-13	" " "	2-6 "	116
KE-19-14	" " "	2-8 "	153

c. Bakery Equipment.

ITEM	NAME	SIZE	POUNDS OF STEAM PER HOUR
KE-14	Scullery Sink (Pots)		34
BE-4	Fermentation Cabient	120"x96"x96"	52
BE-4-1	" "	156"x111"x96"	52
BE-4-2	" "	228"x111"x96"	52
BE-4-3	" "	228"x129"x96"	52
BE-4-4	" "	300"x147"x96"	52
BE-4-5	" "	300"x186"x96"	52
BE-5	Proofing Cabinet	89"x82"x84"	52
BE-5-1	" "	82"x131"x84"	52
BE-5-2	" "	89"x162"x84"	52
BE-5-3	" "	131"x162"x84"	52
KE-9	Steam Jacketed Kettle	60 Gal.	69
KE-9-1	" "	40 Gal.	52

d. Dry Cleaning Equipment.

ITEM	NAME	SIZE	POUNDS OF STEAM PER HOUR
DCE-2WM-A	Wash. Machine	30" x 30"	5
DCE-2WM-1	" "	54" x 70"	5
DCE-2SU-3	Still Unit	250 Gal.	300
DCE-2F-B	Filters		20
DCE-2F-E	"		70
DCE-5	Tumbler (End Door)	36" x 30"	150
DCE-6B	" (Reversible)	42" x 90"	500
DCE-10	Press-Mushroom		25
DCE-11	" -Utility		30
DCE-12	" -Trouser		35

e. Hospital Equipment.

ITEM	NAME	SIZE	POUNDS OF STEAM PER HOUR
S-1	Dressing Sterilizer	16""x 36"	50
S-1	" "	20" x 28"	60
S-1	" "	20" x 36"	75
S-1	" "	20" x 48"	90
S-2	Water Still	15 Gal.	180
S-2	" "	25 Gal.	300
S-3	Utensil Sterilizer	20"x20"x24"	100
S-4	Instrument Sterilizer	10"x12"x22"	40
S-5	" "	10"x20"	20
S-7	" "	9"x10"x20"	30

1-24 STACK HEIGHTS. Where conditions do not permit the use of a natural draft stack, an induced draft fan with shorter stack should be utilized to produce the required draft. Consideration should be given to the use of individual stub stacks with induced draft fans where such equipment appears desirable from the standpoints of operation, maintenance, initial and operating costs. Where natural draft stacks are utilized, stack diameters, stack heights, and correction for altitude should be in accordance with the following tables:

TABLE I STACK DIAMETERS IN INCHES

Diameter at top of Chimney computed for Brick Chimneys at Sea Level for a Friction Loss of One-Tenth Inch of Water per 100 Feet of Height

Square Feet of Boiler Heating Surface	Per Cent of Boiler Rating					Rated H.P. of Boiler Based on 10 Sq. Ft. of Heating Surface Per B.H.P.
	100	150	200	250	300	
500	21	24	27	29	31	50
1,000	24	32	34	36	41	100
1,500	31	36	41	45	48	150
2,000	36	42	45	52	55	200
2,500	38	44	48	55	60	250
3,000	41	48	53	58	64	300
4,000	48	54	61	67	72	400
5,000	53	60	68	74	80	500
6,000	55	65	72	77	86	600
7,000	62	69	78	84	92	700
8,000	65	74	82	89	98	800
9,000	67	78	85	93	103	900
10,000	72	81	91	98	106	1,000
12,000	74	88	98	104	112	1,200
14,000	79	92	104	110	120	1,400
16,000	86	98	110	118	128	1,600
18,000	92	104	114	124	134	1,800
20,000	96	108	120	128	140	2,000
25,000	104	118	128	140	150	2,500

DATA ON WHICH TABLE IS BASED

Efficiency *	68	68	68	65	63	
CO_2 *	9		10		11	
Stack Temp. ⁄	450		525		600	

* Very conservative figures are assumed so that the stack diameter selected will be ample.

⁄ Temperatures are "in the stack" for a group of boilers with considerable breeching.

TABLE II STACK HEIGHTS IN FEET

For Sea Level and 60° Outside Temperature and 0.1 Inch Friction Loss per 100 Feet

Total Draft (Inches) Required for Furnace, Boiler and Breeching	Per Cent of Boiler Rating				
	100	150	200	250	300
.3	56	-	-	-	-
.4	74	69	-	-	-
.5	93	86	81	-	-
.6	111	103	97	-	-
.7	130	120	113	108	-
.8	148	138	129	123	-
.9	-	155	145	139	132
1.0	-	172	161	154	147
1.1	-	190	177	170	162
1.2	-	-	194	185	176
1.3	-	-	209	200	191
1.4	-	-	226	216	206
1.5	-	-	-	231	221
1.6	-	-	-	-	236
1.8	-	-	-	-	265
Assumed Flue Gas Temp	500	550	600	650	700

TABLE III CORRECTION FOR ALTITUDE

Height Above Sea Level (Ft.)	Ratio Increase in Diameter	Ratio Increase in Height
0	1.000	1.000
1,000	1.015	1.046
2,000	1.030	1.097
4,000	1.063	1.205
6,000	1.096	1.321
8,000	1.130	1.456
10,000	1.165	1.612

1-25 HEATING PLANT ARRANGEMENT. The general interior plan arrangement should provide space for such special equipment as may be required and for performing normal maintenance tasks. Coal and ash handling equipment should be provided and should be as simple as possible. Coal and ash silos with necessary conveyors should be considered.

1-26 STOKERS. Stokers should be used for both water tube and fire tube boilers. Stokers for fire tube boilers should, in general, be of the underfeed ram type with side dump plates and fixed grates. Stokers for water tube boilers should be either an underfeed ram, side-dump type, or a spreader type, depending on the coal analysis. Where the ash content of the coal on a moisture free basis is in excess of eight (8) percent, or the ash fusion temperature is less than twenty-two hundred (2200) degrees F., spreader stokers should be used, and where the percentage of ash is lower, and the ash fusion temperature higher than the above figures, underfeed, side-dump stokers should be employed. Underfeed side-dump stokers with an overall width of eight (8) feet or more should be equipped with movable grates, providing positive lateral feeding of the coal from the central retort toward the side dump grates. Chain or traveling grate stokers should be considered if anthracite coal is used.

1-27 FLY ASH. When spreader type stokers are used, precautions should be taken to prevent the emission of fly ash from the stack by the installation of cinder traps or other similar equipment. Air or steam jets should also be provided to create a turbulence in the furnace to assist in reducing the amount of fly ash carryover.

1-28 INSTRUMENTS. Draft gages, CO_2 meters, recorders and other necessary operating instruments should be provided to assist the operators in the proper operation of the plant.

1-29 AUXILIARIES. An individual forced draft fan should be installed for each boiler when required. An open feed water heater of the deaerating type and a surge tank of adequate capacity for condensate returns should be installed where required for satisfactory operation. A simple combustion control system should be provided to regulate the fuel and air feed automatically in accordance with the demand for steam. Suitable means should also be provided for operating the boilers manually. The drives for station auxiliaries should be so divided between steam and electric that in the event of current failure, the plant can continue to operate. Exhaust from auxiliaries should be used for heating feed water and special effort should be made to prevent exhaust steam from being wasted. When an open type of feed water heater is used and high pressure returns are brought back to the plant, consideration should be given toward the use of a heat exchanger installed in the high pressure return line before connection is made to the feed water heater. The heat in the high pressure returns may be used for preheating the water to domestic hot water heaters or for other similar purposes.

1-30 STEAM DISTRIBUTION. Steam distribution systems for hospital areas should be run where possible under connecting corridors. Where corridors are not available, the piping should be run underground in a standard type of conduit. The distribution system for other than hospital areas should be run underground in a concrete trench, split tile or other form of standard underground construction. The manufacturer of the conduit should be required to make the installation.

1-31 BUILDING CONNECTIONS. When a building containing a hot water heating system is connected to a central steam plant, a hot water converter and circulating pump should be utilized. If the system in the building is of the forced warm air type, a steam coil and fan should be installed. A converter should be

used for the heating equipment and the condensate returned to the plant by pumps.

1-32 PUMPS. Condensate pumps located at advantageous points in the distribution system should be used for returning condensate to the plant. Where low pressure steam systems are installed vacuum pumps may be used.

1-33 FUEL. The type of fuel to be used will be determined as outlined in paragraph 1-06.

1-34 DESIGN ANALYSIS. Adesign analysis required by paragraph 740.09 of Orders and Regulations, should be prepared to accompany all plans and specifications for Central Heating Plants. The design analysis should set forth the basis for the determination of the heating load, the basis for the selection of the equipment to be provided, and the basis of design for each unit of the plan

VENTILATION

1-35 NEED FOR VENTILATION. The necessity for ventilation depends on the us to which the building or rooms are to be put. Wherever human beings are presen in closed quarters, the gaseous products of respiration should be removed as rapidly as possible and fresh air supplied. Likewise, in those cases where the gaseous products of combustion from chemical processes are given off, they should also be removed. Whether the ventilation should be accomplished by grav ity or by mechanical means is a problem that should be decided for each individual project.

1-36 ATTIC VENTILATION. In some instances attic fans are provided for use during the summer months to draw large volumes of outside air through a buildir and offer a means of using the comparative coolness of outside evening and nigh air to lower the inside temperature.

1-37 GRAVITY VENTILATION. Gravity ventilation should be accomplished by means of roof ventilators. The size of the ventilator is generally based on a four (4) mile outside wind velocity.

1-38 MECHANICAL VENTILATION. When mechanical ventilation is provided it should be in accordance with the following:

a. Fans. Fans for all ventilation uses should be rated and constructed in accordance with the National Association of Fan Manufacturers and should be selected in accordance with the standards of the American Society of Heating and Ventilating Engineers. Outlet velocities and fan tip speeds below the standards established by the American Society of Heating and Ventilating Engin. eers may be required in spaces where it is necessary to limit air movement or to maintain low sound level.

b. Air Filters. Air filters should be installed in all supply ventilating systems where dust or other foreign matter may be harmful to the function of the space, or as required by the Chief of Engineers. Filters or collectors may be required on exhaust systems in special cases where the fan discharge would create an objectionable condition in the immediate area.

c. Fire Dampers. Fire dampers with fusible links should be installed where and as recommended by the National Board of Fire Underwriters.

1-39 VENTILATION REQUIREMENTS. Where mechanical ventilation is provided, the following air changes per hour or C.F.M. per person are recommended:

a. Garages. Garages and other spaces subject to toxic, noxious, and explosive gases which cannot be ventilated by gravity means should be provided with exhaust or supply ventilation for year-round operation capable of suppling or exhausting a minimum of one cubic foot per minute per square foot of floor area.

b. Paint Shops. Paint Shops should be provided with both supply and exhaust ventilation for year-round operation. The system should be capable of producting twenty (20) air changes per hour and the capacity of the exhaust fan should equal the capacity of the supply fan.

c. Dishwashing Spaces. Dishwashing spaces when constructed as a separate room should be provided with exhaust ventilation capable of producting ninety (90) air shanges per hour under the hood when the dishwashing machine is so equipp equipped. The capacity of the fan should be based on the space from the floor to the hood over the dishwashing machine. The width and length of the hood should be included in the calculation for determining the volume of space on which the air changes are based. If the dishwashing machine is installed in a separate room and without a hood, not less than 60 air changes per hour should be provided for the entire room.

d. Barracks. 15 C.F.M. per man (fresh air).

e. Laundries. 30 air changes per hour.

f. Theatres. 10 C.F.M. per person (fresh air).

g. Chapel. 10 C.F.M. per person (fresh air).

h. Kitchen (Large Messes). 20 air changes per hour.

i. Attic Ventilation. 20 to 30 air changes per hour in northern areas and 60 in southern areas.

j. Toilets. 10 air changes per hour.

k. Mess Halls. 10 air changes per hour.

l. Hangar and Shops. 1/2 to 2 air changes per hour (consider as infiltration).

AIR CONDITIONING

1-40 DEFINITION. The term 'Air Conditioning' should be interpreted to mean the circulation of clean cooled air within a designated space. Humidification or dehumidification may be provided.

1-41 NEED FOR AIR CONDITIONING. Air conditioning systems should be installed only when climatic conditions make it absolutely essential for the proper functioning of facilities. In some instances they may be installed for the comfort of personnel, but in either case they will be provided only when authorized by the Office of the Chief of Engineers.

1-42 WHERE AND WHEN PERMITTED. Air conditioning installations should, in general, be provided only to the extent made mandatory by manufacturing and processing procedure. They are generally installed in connection with Bombsight Storage Rooms, Main Air Traffic Control Towers, Photographic Laboratories, Optical and Instrument Repair Shops, Link Trainer Buildings, Jam Handy Trainer Buildings, Celestial Navigation Trainer Buildings, Instrument Trainer Buildings, Low Pressure Chamber Buildings, various types of Hospital Buildings, and spaces housing synthetic training devices which by their nature require controlled atmospheric conditions.

1-43 PLANS AND SPECIFICATIONS. Plans and specifications should be prepared for each individual project. Conditions peculiar to each installation should necessarily influence the design. Designs should be as simple as possible and consistent with safety, economy, and performance.

1-44 INSIDE DESIGN TEMPERATURES. In general, the following inside design temperatures should be observed where air conditioning is to be provided.

a. Bombsight Storage Rooms. For Bombsight Storage Rooms in temperate regions, 75° dry bulb plus or minus 2°, and 40% relative humidity plus or minus 5% should be maintained. In tropical and subtropical regions 80° dry bulb plus

or minus 3° and 50% relative humidity should be maintained. Humidity conditions in both the temperate and tropical regions should be maintained throughout the year.

b. Aircraft Traffic Control Towers. For Aircraft Traffic Control Towers, dry bulb temperature not more than 15° below outside design temperature, with 50 to 55% relative humidity, should be used where air conditioning is prescribed.

c. Photographic Laboratories. For Photographic Laboratories, 70° F. dry bulb temperature and 60% relative humidity should be used.

d. Optical and Instrument Repair Shops. For Optical and Instrument Repair Shops from 50% to 60% relative humidity and from 70° f. to 75° F. dry bulb temperature should be used.

e. Link Trainer Buildings. For Link Trainer Buildings, a dry bulb temperature of 80° F. with 50% relative humidity should be used.

f. Jam Handy Trainer Buildings. For Jam Handy Trainer Buildings, a dry bulb temperature of 80° F. with 50% relative humidity should be used.

g. Celestial Navigation Trainer Buildings. For Celestial Navigation Trainer Buildings, a dry bulb temperature of 72°mF. plus or minus 2° F. with 55% relative humidity plus or minus 5% should be used.

h. Instrument Trainer Buildings. For instrument Trainer Buildings, a dry bulb temperature of 80° F. with 50% relative humidity should be used.

i. Low Pressure Chamber Buildings. For Low Pressure Chamber Buildings, a dry bulb temperature of 80° F. with 50% relative humidity should be used.

j. Theatres (Permanent Construction). For Theatres, a dry bulb temperature not more than 15° F. below outside design temperature with 50% relative humidity should be used. Outside design temperatures for stations within the continental United States should be in accordance with those established by the American Society of Heating and Ventilating Engineers and as outlined in the Guide. The design temperatures for stations outside of the continental United States will be established by the Division Engineer.

1-45 DESIGN CONSTANTS. The constants, coefficients, and methods used in computing heat transfer should be as set forth in the latest edition of the American Society of Heating and Ventilating Engineer Guide.

1-46 WATER SUPPLY. Special study should be made of the water supply, taking into consideration cost, hardness, and availability, in order to deter- whether evaporative condensers and water softening equipment will be required. The use of water for air conditioning when obtained from city supply should conform to local regulations. Specifications for cooling towers, condensers, air washers, and similar equipment should make provision for the treatment of water in circulating systems to remove acidity or other objectionable characteristics to prevent corrosion.

1-47 ACTIVATION HEAT. In dehumidification systems of the absorption types, particular attention should be given to the source and cost of activation heat. Activation heat is that generally obtained by the use of a gas burner for eliminating absorbed moisture in the dehydrating material.

1-48 COMPRESSORS. The use of standby compressors is not approved. However, for hospital systems, two (2) compressors, each of five-tenths to six-tenths of the total required capacity may be used to provide a partial standby in case of failure of one(1) compressor.

1-49 EVAPORATIVE COOLERS. Evaporative cooling involves the adiabatic exchange of heat between air and water-wetted surface. The water assumes the wet bulb temperature of the air. Cooling of the air occurs due to the temperature difference between the entering air and water at the wet bulb temperature. Evaporative coolers will be installed only on the specific authority of the Office

of the Chief of Engineers. They should be used in the desert areas where similar installations have proven satisfactory. Evaporative coolers installed in hospital patients' spaces, namely, Clinics, Infirmaries, Wards, Mess Halls, Recreation Rooms, Post Exchanges, and Libraries should be of the spray type. Coolers installed in all other permitted spaces, namely, Duty Personnel Mess Halls, Administration Buildings, Barracks, and Quarters should be of the standard drip type.

1-50 DESIGN CONDITIONS. The following design conditions should be observed in connection with authorized air conditioning installations:

a. By-Pass Design. The by-pass design should be such that no fresh air by-passes the cooling coil, except when 100% outside air is being circulated.

b. Vent Outlet. A suitable vent outlet should be provided if the system is to operate with 100% outside air at any time.

c. Duct Work. Duct work should be designed as recommended in the American Society of Heating and Ventilating Engineers Guide.

d. Fire Dampers. The system should be protected by suitable fire dampers.

e. Access. All equipment subject to the accumulation of dirt should have access provision for cleaning.

f. Controls. Controls may be electrically or pneumatically operated.

g. Equipment Rating. Equipment should be selected from manufacturers' published rating sheets and should be designed for the purpose intended.

h. Evaporative Condensers. Evaporative condensers should be served by cooled room exhaust air wherever practicable.

1-51 SPECIFICATION REQUIREMENTS. Specification requirements should be in accordance with the following:

a. Capacity. Equipment should be specified by its capacity in Btu per hour at its air, water, or refrigerant operating temperatures.

b. Cooling Coils. The face velocity, volume of air to be handled, and number of rows of coil, in the direction of air flow, should be specified for all finned type air cooling coils, excepting those in the package type of systems.

c. Operation Controls. The sequence of operation of the controls and the protection to be given by the safety devices should be clearly specified. In order to secure comparable control prices, the bid prices should include the furnishing and installing of equipment and wiring, complete in all respects. Bid prices for pneumatic controls should include the furnishing and installing of air piping and control and air compressing equipment complete in all respects for satisfactory operation.

d. Manufacturer's Guarantee. To insure a balanced installation, it is desirable to require that all equipment operating on any one refrigerant circuit, including compressor motors and starters, be provided by the compressor manufacturer who will guarantee the satisfactory operation of this equipment as a unit.

APPENDIX

SCOPE. The following problems and their solutions describe the method of calculating heat loss from buildings for the purpose of designing heating, ventilating, and air conditioning systems including the sizing of the required equipment to be used in connection therewith. All coefficients of conductivity and other similar information have been taken from the Guide of the American Society of Heating and Ventilating Engineers.

PROBLEM NO. 1 - HEAT LOSS CALCULATIONS. Calculate the heat loss from

a building located in Washington, D. C., as hereinafter described. Building is rectangular with no interior partitions. Dimensions are 100' x 75'. Ceiling height is 10'. The long walls have 10 windows each, and the short walls have 6 windows and one door each. Windows are double hung wood sash 2'-7"x4'-6". Doors are double with openings 5'-0" x7'-0". Building to be calculated for two types of frame construction; one with 1/2" rigid insulating board interior finish on walls and ceiling and with 4" concrete floor poured directly on ground; the other without any interior finish or floor. Building to be heated to 70 degrees F. with an outside design temperature of zero degrees F.

CONDUCTIVITY COEFFICIENTS

WALLS		
Uninsulated Building	Wood Siding, Building Paper 1" Sheathing	0.36
Insulated Building	Wood Siding, 1" Sheathing, 2"x4" Studs, 1/2" Rigid Insulation	0.19
ROOF AND CEILING		
Uninsulated Building	Roofing, 1" Sheathing	0.56
Insulated Building	Roofing, 1" Sheathing, Rafters, 1/2" Rigid Insulation	0.24
FLOOR		
Uninsulated Building	Exposed Ground Only the surface coefficient should be used	1.65
Insulated Building	4" Concrete on Ground	1.07
WINDOWS	Single Glass	1.13
DOORS	1-1/2" Wood	0.52
INFILTRATION	Windows assumed to be double hung wood of poor construction. Infiltration in C.F.H. per lineal foot of crack	69.0
	Doors assumed to be poorly fitted Leakage assumed to be twice that of a poorly fitted double hung window. Infiltration of C.F.H. per lineal foot of crack	138.0

HEAT LOSS CALCULATIONS

UNINSULATED BUILDING

PART OF STRUCTURE	NET AREA OR CRACK LENGTH	COEFFICIENT	TEMPERATURE DIFFERENCE	HEAT LOSS Btu/Hr	TOTAL Btu/Hr
Walls	3057 Sq. Ft.	0.36	70	77000	
Glass	373 " "	1.13	70	29505	
Doors	70 " "	0.52	70	2548	
Roof (Horizontal projection)	7500 " "	0.56	70	294000	
Floor	4350 " "	1.65	70/3	167236	
Infiltration Windows	541 Lin "	1.24	70)	28861	
Infiltration Doors	62 " "	2.48	70)		599150

INSULATED BUILDING

Walls	3057 Sq. Ft.	0-19	70	40656	
Glass	373 " "	1.13	70	29505	
Doors	70 " "	0-52	70	2489	
Roof and Ceiling	7500 " "	0.24	70	131267	
Floor	4350 " "	1.07	70/3	108450	
Infiltration Windows	541 Lin Ft.	1.24	70)	28861	
Infiltration Doors	62 " "	2.48	70)		341228

Floor losses are figured for an area 15 ft. in from outside walls. The temperature difference is taken as 1/3 of the difference between inside and outside temperatures.
Infiltration loss is taken as 1/2 the total loss for windows and doors. The coefficients 1.24 and 2.48 are obtained by multiplying the cubic feet of air per hour by the specific heat of air (0.24) and the density of air at 70° F.(0.075).

PROBLEM NO. 2 - RADIANT HEATING SYSTEM REQUIREMENTS. Select a Radiant type heating system for the insulated building described in Problem No. 1. Determine the size, spacing, lineal feet of pipe coil and capacity and head of circulating pump. System to be designed for a 20° F. temperature drop. Coil to be embedded in the concrete floor. Assume a loss of 30% into the foundation soil and floor to be uncovered.

Btu loss from building..... 341228
Btu loss from floor..... 108450
Btu loss for design of system..... 232778
Btu input to floor 232778 + 30%=302612

Btu output from floor per sq. ft. per hr. $\frac{232778}{7500 \text{ floor area}} = 31$

Btu input to floor per sq. ft. per hr. $31 + 30\% = 40.3$

For an output of 31 Btu Fig. 1 indicates that the floor would have a mximum temperature of 84° F.

Fig. 2 indicates a considerable number of possible combinations of pipe spacings and water temperatures from which to choose. One and one-quarter inch pipe on 18" centers with a water temperature of 110° F. will supply 40.3 Btu per hour per square ft. floor area.

Total heat input to floor $40.3 \times 7500 = 302612$ Btu

Quantity of water to be circulated $\dfrac{302612 \text{ Btu}}{20^\circ \text{ drop} \times 60 \text{ min.} \times 8.25 \text{ \# per gal.}} = 30.55$ G.P.M.

Lineal feet of 1¼" pipe -

Heat output from coil..... 302612 Btu

Btu per sq. ft. of floor..... $\dfrac{302612}{7500} = 40.3$

$40.3 \times \dfrac{18}{12} = 60.5$ Btu per sq. ft. of floor for pipe on 18" centers

Water temperature.....	110° F.
Room temperature.....	70° F.
Difference.....	40° F.

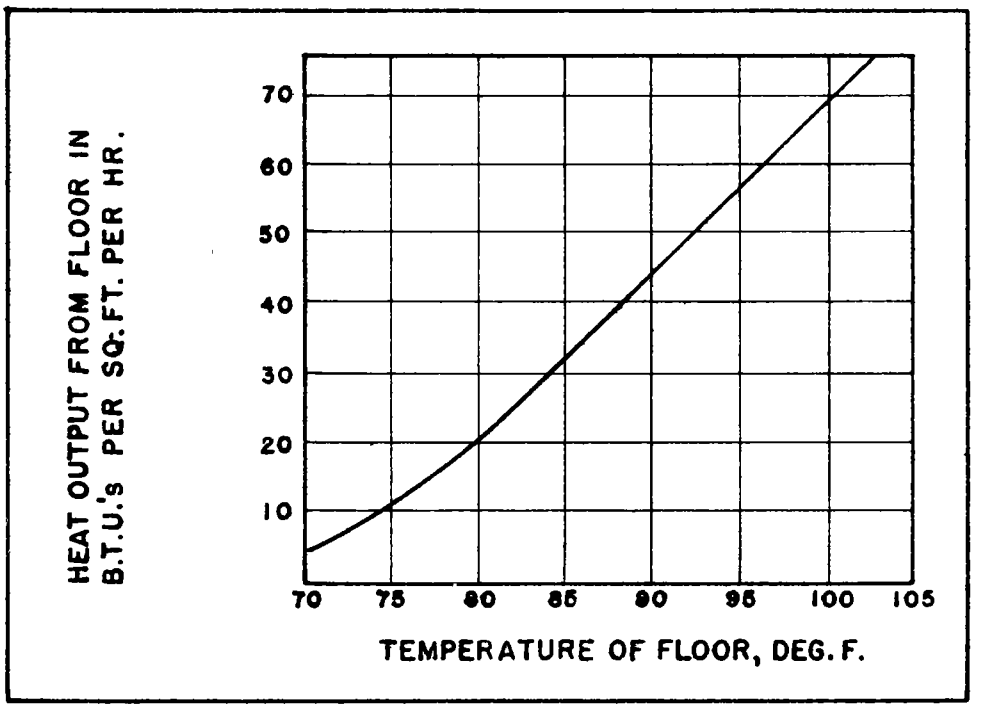


Fig. 1.

(BASED ON 70° F. ROOM TEMPERATURE)

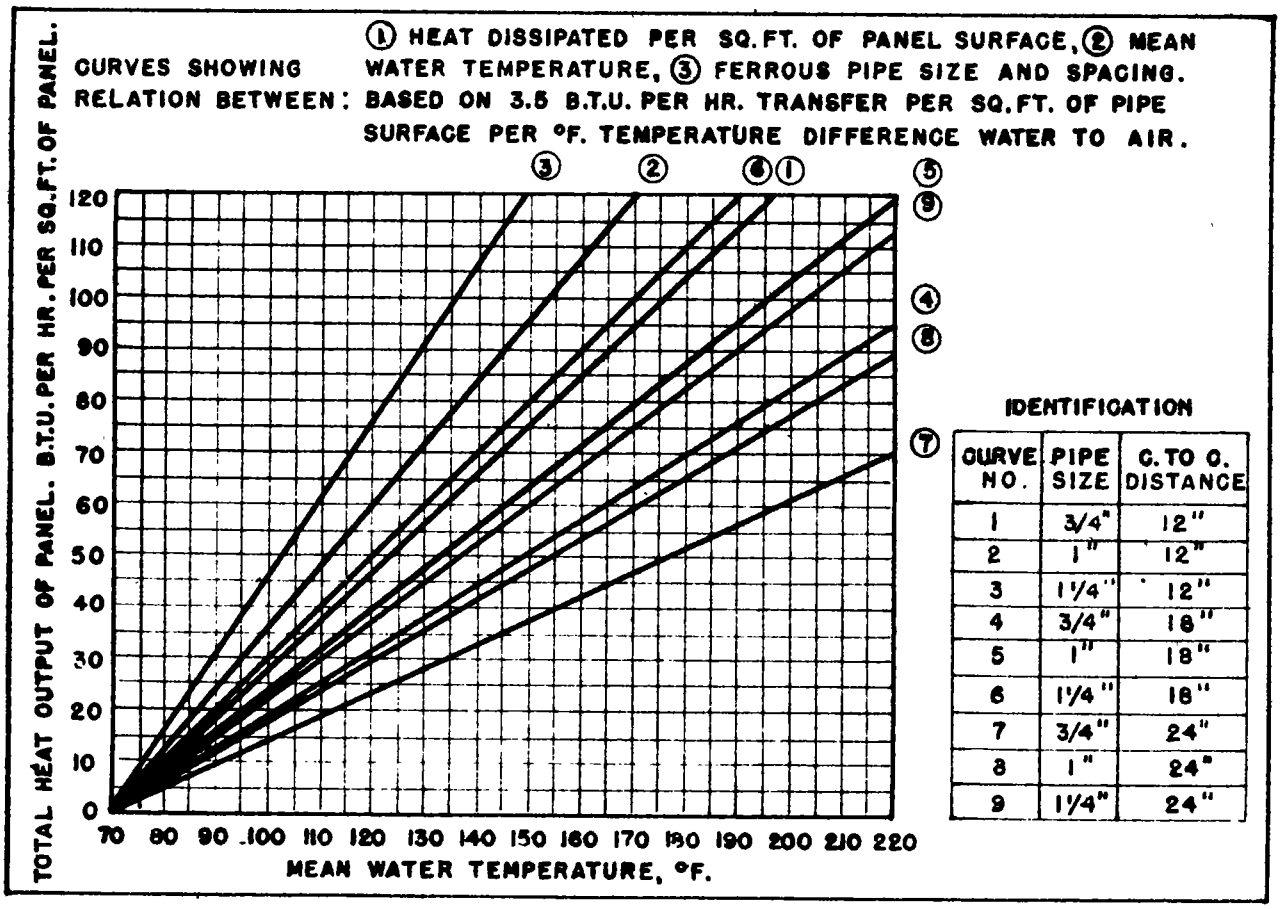

CURVES SHOWING RELATION BETWEEN: ① HEAT DISSIPATED PER SQ.FT. OF PANEL SURFACE, ② MEAN WATER TEMPERATURE, ③ FERROUS PIPE SIZE AND SPACING. BASED ON 3.5 B.T.U. PER HR. TRANSFER PER SQ.FT. OF PIPE SURFACE PER °F. TEMPERATURE DIFFERENCE WATER TO AIR.
TOTAL HEAT OUTPUT OF PANEL, B.T.U. PER HR. PER SQ.FT. OF PANEL.
0 10 20 30 40 50 60 70 80 90 100 110 120
70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220
MEAN WATER TEMPERATURE, °F.
IDENTIFICATION
CURVE NO. | PIPE SIZE | C. TO C. DISTANCE
1 | 3/4" | 12"
2 | 1" | 12"
3 | 1 1/4" | 12"
4 | 3/4" | 18"
5 | 1" | 18"
6 | 1 1/4" | 18"
7 | 3/4" | 24"
8 | 1" | 24"
9 | 1 1/4" | 24"

Fig. 2.

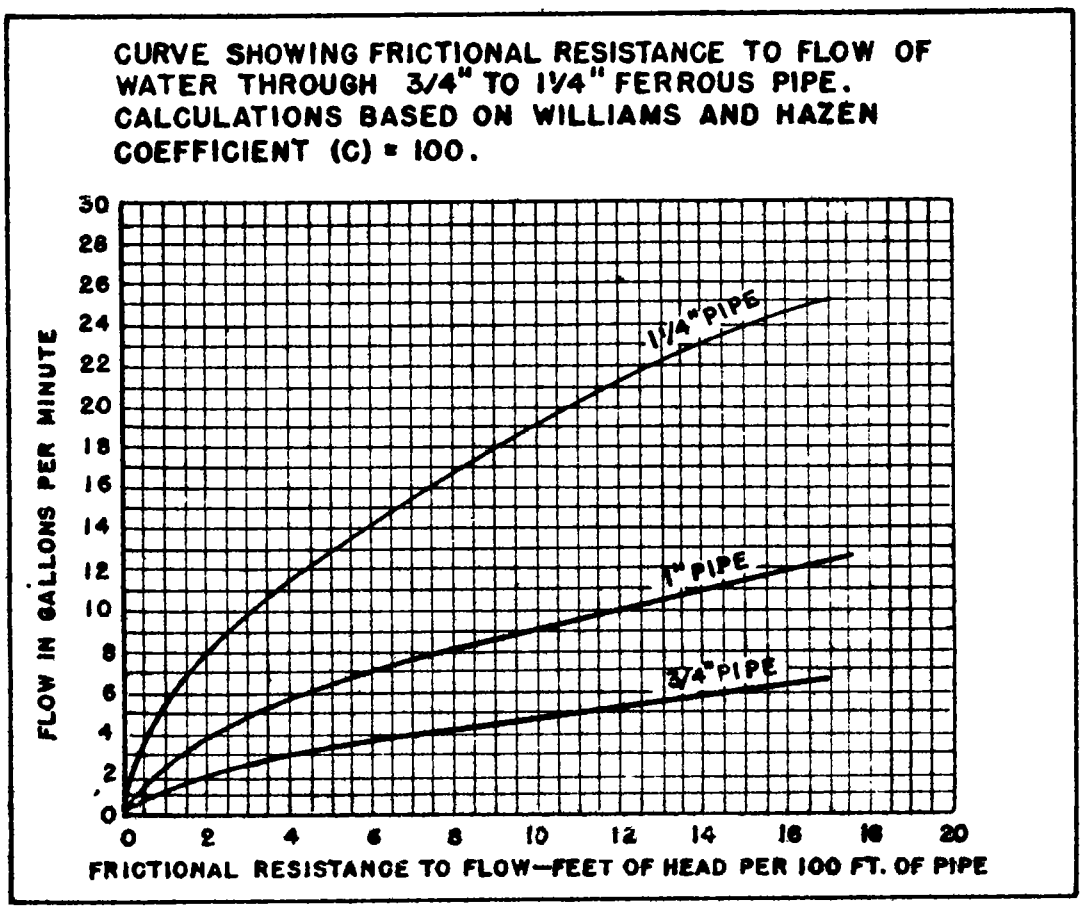
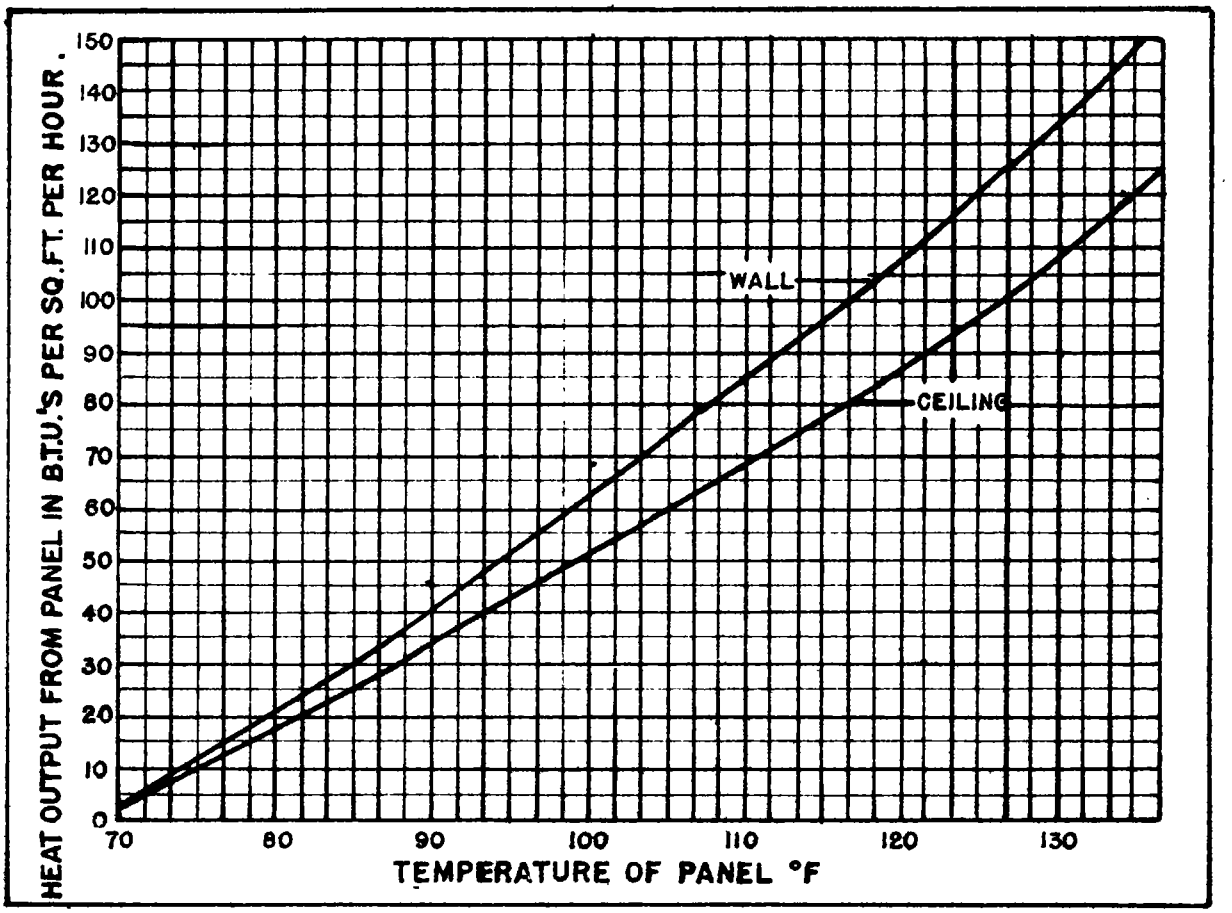

CURVE SHOWING FRICTIONAL RESISTANCE TO FLOW OF WATER THROUGH 3/4" TO 1¼" FERROUS PIPE. CALCULATIONS BASED ON WILLIAMS AND HAZEN COEFFICIENT (C) = 100.
FLOW IN GALLONS PER MINUTE
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
1¼" PIPE
1" PIPE
¾" PIPE
0
2
4
6
8
10
12
14
16
18
20
FRICTIONAL RESISTANCE TO FLOW—FEET OF HEAD PER 100 FT. OF PIPE

Fig. 3.



CALCULATED HEAT OUTPUT FROM WALL AND CEILING PANELS AT VARIOUS TEMPERATURES, WITH 70° F. AIR TEMPERATURE AND OTHER SURFACES IN ROOM AT 65° F.

Fig. 4.

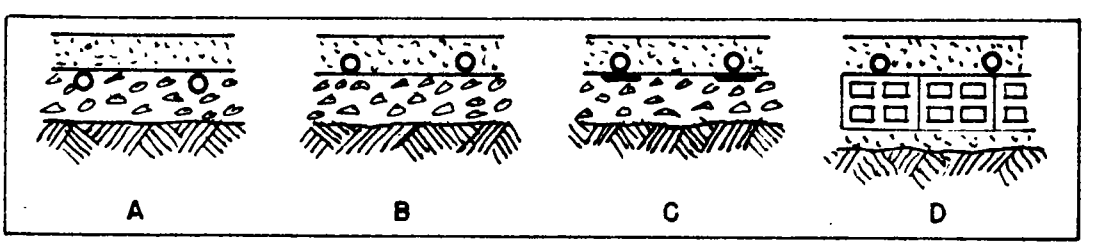


Fig. 5— Cross Sections of Floor Construction

$\frac{60.5}{40}$ = 1.51 Btu per sq. ft. of pipe on 18" centers.

Each foot of pipe on 18" centers must release 1.51 Btu per degree temperature difference water to air.

With pipe release of 3.5 Btu per sq. ft. of pipe surface per degree difference, 1¼" pipe having an area of .434 sq. ft. will transfer -

3.5 x .434 = 1.519 Btu per ft. per degree temperature difference.

Temperature difference 40° x 1.519 = 60.7 output per ft. from 1¼ pipe on 18" centers.

$$\frac{302612 \text{ Btu required}}{60.7} = 4980 \text{ ft. pipe}$$

On the assumption that the coil will be divided into four (4) zones with a pump for each zone, the feet of pipe for each coil and head for each pump will be -

$$\text{Coil} - \frac{4980}{4} = 1245 \text{ ft. per zone}$$

$$\text{Pump} - \frac{30.55 \text{ total g.p.m.}}{4} = 7.63 \text{ gal. per pump}$$

From Fig. 3 the fractional resistance of 1¼" pipe carrying 7.63 gal. per minute is 1.7 feet per 100 ft. run. The operating head on each pump is -

$$1.7 \times 12.45 = 21 \text{ feet}$$

In determining the head on the pump no allowance has been made for friction due to return bends. This should be taken into consideration when the coils are designed.

For conditions other than above and for systems and calculations of a more complicated nature, reference should be had to the guide of the American Society of Heating and Ventilating Engineers.

PROBLEM NO. 3 - GAS CABINET AND GAS STEAM RADIATOR REQUIREMENTS. Select gas cabinets or gas steam radiators for the insulated building described in problem No. 1. The American Gas Association rates gas cabinets or gas space heaters in Btu input. Since all gas heaters are vented to atmosphere, some of the heat is lost in the products of combustion. Therefore, in order to obtain the required input, divide the desired output by 0.80. Using seven gas cabinets, the input capacity of each would be -

$$\frac{341,228}{7 \times 0.80} = 60,933 \text{ Btu}$$

Gas steam radiators are rated by the American Gas Association in square feet of equivalent steam radiation based on 240 Btu per sq. ft. Assuming 3 radiators are to be installed along each long side of building and 2 radiators along each short side of building, making a total of 10 radiators, the output capacity of each in sq. ft. of steam radiation would be -

$$\frac{341,228}{10 \times 240} = 142 \text{ sq. ft.}$$

PROBLEM NO. 4 - WARM AIR FURNACE REQUIREMENTS. Select a forced warm air furnace for the insulated building described in Problem No. 1. Assume 1-1/2 air changes per hour of fresh air, 120° delivery temperature at the grille or outlet and 5° loss of temperature in the duct system.

$$\text{Fresh Air (F.A.) (1-1/2 air changes per hour)} = \frac{\text{Vol. of bldg. x 1-1/2}}{60} = \text{CFM}$$

$$\frac{75 \times 100 \times 10 \times 1\text{-}1/2}{60} = 1875 \text{ CFM}$$

Where:

CFM = Cubic feet per minute.

$$\text{Total Air (T.A.) to be circulated} = \frac{\text{Total bldg. loss-infiltration}}{60 \times \text{Sp.} \times \text{D} \times (\text{Td} - \text{Tr})} = \text{CFM}$$

$$\text{T.A.} = \frac{341{,}228 - 28861}{60 \times 0.24 \times 0.075 \times (120 - 70)} = 5785 \text{ CFM}$$

Where:

60 = Minutes per hour
Sp = Specific heat of air (0.24)
D = Density of air at 70° F (0.075)
Td = Delivery temperature (120° F.)
Tr = Room temperature (70° F.)

$$\text{Temperature of Air entering heater (Te)} = \text{Tr} - \frac{\text{F.A.}}{\text{T.A.}} \times (\text{Tr.} - \text{To})$$

$$\text{Te} = 70 - \frac{1875}{5785} \times (70 - 0) = 47.3^{\circ} \text{ F.}$$

Where:

Te = Temperature of air entering heater
FA = Fresh air (1875 CFM)
TA = Total air (5785 CFM)
To = Temperature of fresh air (0° F.)

$$\text{Temperature of Air leaving heater (Tf)} = \text{Td} + 5^{\circ}$$

$$\text{Tf} = 120^{\circ} + 5^{\circ} = 125^{9}$$

Where:

5° = Assumed duct loss
Tf = Temperature of air leaving heater

$$\text{Capacity of warm air heater required in Btu} = \text{T.A. (Tf - Te) Sp x D x 60}$$
$$= 5785 \ (125 - 47.3) \ 0.24 \times 0.075 \times 60$$
$$= 485{,}460 \text{ Btu per hour.}$$

Warm air furnace heating capacity would be 485,460 Btu. Fan capacity would be 5785 CFM when operating against the total resistance of the system, which includes furnace, filters, duct system, etc. Equipment would be selected from manufacturers catalog ratings.

NOTE. The resistance of the warm air heating system is the sum of the resistance of the component parts of the system and shall be computed in accordance with the following:

(1) Resistance of furnace, filters and fan housing is established by manufacturer of furnace. However, if filters are located in duct work external to the furnace their resistance shall be added to the resistance of duct work.

(2) Resistance of duct work shall be computed in accordance with the methods and data given in the latest edition of the "Guide" published by the American Society of Heating and Ventilating Engineers. When filters are installed in the duct work, their resistance whall be given by manufacturer for dirty filters.

PROBLEM NO. 5 - FORCED HOT WATER SYSTEM REQUIREMENTS. Compute capacities of radiators, circulator, and boiler required for a two-pipe forced hot water heating system for insulated building described in Problem No. 1.

Radiators. The total amount of radiation required (based on 200 Btu per sq. ft.) is -

$$\frac{341,228}{200} = 1706 \text{ sq. ft.}$$

Hot Water Circulator should be selected on the basis of a 20° temperature drop in the system.

Pumping Capacity of Hot Water Circulating (gallons per minute = G.P.M.)

$$= \frac{\text{Bldg. heat loss}}{60 \times 8.3 \times 20}$$

$$= \frac{341,228 \times 1.25}{60 \times 8.3 \times 20} = 42.7 \text{ GPM}$$

Where:

60 = Minutes per hour
8.3 = Pounds per gallon
20° = Temperature drop in system
1.25 = Line Loss

Boiler. Boiler would be selected on the basis of 150 Btu per sq. ft. of radiation (which is the standard method rating hot water boilers by manufacturers).

$$\text{Boiler Capacity} = \frac{341,228}{150} = 2275 \text{ sq. ft. hot water radiation.}$$

Boiler would be selected in accordance with net load recommendation of Heating, Piping and Air Conditioning Contractors National Association.

PROBLEM NO. 6 - GRAVITY STEAM SYSTEM REQUIREMENTS. Compute capacities of radiators, condensate pump, and boiler required for a two pipe gravity steam heating system for insulated building described in Problem No. 1.

Radiators. The total amount of radiation required (based on 240 Btu per sq. ft.) =

$$\frac{341,228}{240} = 1422 \text{ sq. ft. of radiation}$$

Condensate Pump. Capacity of condensate pump in sq. ft. of steam radiation = Heating load + piping losses + domestic hot water loads = 1422 + 355 + 500 = 2277 sq. ft. equivalent direct radiation. Closest standard pump would be 2000 sq. ft.

Piping losses are assumed to be 25% of heating load 1422 x .25 = 355 sq. ft. of radiation.

Steam required to heat domestic hot water assumed to be equivalent to 500 sq. ft. of radiation.

Boiler. Low pressure cast-iron steam boiler would be selected on a net load basis in terms of sq. ft. of radiation based on 240 Btu per sq. ft.

Net load = heating load + domestic hot water load
= 1422 + 500 = 1922 sq. ft. of radiation

The net load rating should be in accordance with the net load recommendations of the Heating, Piping, Air Conditioning Contractors National Association.

PROBLEM NO. 7 - CENTRAL LOW PRESSURE STEAM REQUIREMENTS.

a. Boilers for Heating. Compute the capacities of low pressure boilers required to furnish steam for heating to a group of 10 insulated buildings as described in Problem No. 1. Duplex vacuum pumps shall be provided to return condensate to boilers.

Total Heating Load = sq. ft. of steam radiation per Bldg. x No. of Bldgs. x F or

1422 sq. ft. x 10 Bldgs. x 1.21 = 17,206 sq. ft. of steam radiation.

The factor (F) is used to compensate for pipe line losses 10% of which are assumed to be in the building and 10% ir the outside distribution system. (1.10 x 1.10 = 1.21).

Heating Boilers. Three low pressure cast iron boilers of equal size would be selected. Capacity of each would be

$\frac{17206}{3} = 5,735$ sq. ft. of steam radiation net load rating.

NOTE: Although the boilers furnished under the above net load rating have sufficient excess capacity to take care of normal piping losses, they are not rated to take care of additional outside losses. The 10% added for pipe losses in the buildings gives the boilers a small reserve capacity so that in emergencies any two of the three boilers could carry the load.

Duplex Vacuum Pumps. The heating load is 17,206 sq. ft. Each pump of duplex unit to have a capacity of 20,000 sq. ft. of radiation.

b. Utility Steam Boilers. Compute the capacities of utility steam boilers required to furnish 150 lbs. of steam per hour at 40 lbs. per sq. in., gage pressure to each of the 10 buildings for domestic hot water and sterilizers. Duplex condensate pumps shall be provided to return condensate to the boilers.

Total Utility Steam Load = lbs. of steam per Bldg. x No. of Bldgs. x Lf x F or -

150 x 10 0.65 x 1.21 = 1186 lbs. of steam per hour.

Where.

Lf = Load factor for utility steam (assumed 65%)
F = See total heating load above.

Utility Steam Boilers. Two hand-fired medium pressure steel firebox boilers each sized to handle 80% of total load. Capacity of each boiler would be

$\frac{\text{Total utility steam load x 0.80}}{34.5} = \text{Horsepower}$

or

$\frac{1186 \times 0.80}{34.5} = 27.5$ Horsepower

Where.

0.80 = 80% of load for each boiler
34.5 = lbs. of steam per horsepower.

NOTE: The utility steam boilers should be sized for 80% of the total load so that either boiler could be forced to enable it to handle the total load during an emergency.

Duplex Condensate Pumps. The capacity of condensate pumps should be based on maximum load on boilers which would be 1186 lbs. of steam per hour.

Equivalent load in sq. ft. of steam radiation =

$$\frac{\text{Load in lbs. of steam per hour}}{\text{lbs. condensate per sq. ft. of steam radiation}}$$

or

$$\frac{1186}{0.25} = 4744 \text{ sq. ft. of steam radiation}$$

Each pump of duplex unit would have a capacity equivalent to 4000 sq. ft. of radiation.

PROBLEM NO. 8 - MECHANICAL VENTILATION REQUIREMENTS. Provide (5) complete air changes per hour for ventilation of the building described in Problem No. 1.

Volume of Building = 75 x 100 x 10 = 75,000 cu. ft.

5 air changes = 75,000 x 5 = 375,000 cu. ft. hr.

$$\frac{375,000}{60} = 6250 \text{ cu. ft. per minute}$$

Fan capacity required would be 6250 CFM. Select fan with capacity nearest to the required CFM from manufacturers' catalogs. Fan should be capable of delivering specified CFM when operating against the resistance of the connected duct work, grilles and louvers.

See "NOTE" following the solution to Problem No. 4 for method of computing resistance in duct work.

PROBLEM NO. 9 - AIR CONDITIONING REQUIREMENTS. A building having the same dimensions, the same windows, and the same doors as building described in Problem No. 1, is to be summer air conditioned for the comfort of the occupants. The building is to be located in Washington, D. C., with one of the long sides facing due south. Construction of the building, as follows: Walls - 4" brick veneer, building paper, sheathing, 2" x 4" studs and 1/2" building board; Roof - 2" planks, pitch and slag; Floors - 4" concrete on ground. Windows will have buff-colored window shades. There will be 25 occupants doing moderately active office work. The connected lighting is assumed as being 2 watts per sq. ft. of floor space and power load, 15 horsepower. Desired inside conditions are 80° dry bulb and 50% relative humidity.

Outside design conditions. 95° dry bulb, 78° wet bulb.

City water temperature. Approximately 85° maximum.

Cooling load. Maximum assumed to be at 3 p.m. when roof load is greatest.

Sensible heat gain.

BUILDING PART OF STRUCTURE	NET AREA SQ. FT.	Btu PER SQ. FT.	HEAT GAIN Btu	TOTAL Btu
North Wall	884	2	1768	
North glass	116	21	2436	
East wall	680	4.75	3230	
East glass	70	21	1470	
South wall	884	3.75	3300	
South glass	116	74 x 0.68	5835	
West wall	680	2.25	1530	
West glass	70	195 x 0.68	9282	
Roof	7500	10.5	78750	
Floor		Neglected		107,601

Heat transmission, factors, sunload, and other data used were obtained from Chapter No. 7, 1942 issue of the "Guide", published by the American Society of Heating and Ventilating Engineers. (Laboratory Tests).
Doors included as part of wall.
Shades on windows on which sun is shining at 3 p.m. are assumed to be half drawn.

Internal Load (Sensible Heat).

25 people at 225 Btu per hr. = 5625 Btu
Lights (assume 1/2 lighted)

$\frac{75 \times 100 \times 2}{2} = 7500$ watts

7500 x 3.4 Btu per watt = 25,500 Btu
Power load 15 hp x 2950 Btu per hp = 44,250 Btu
Total (internal sensible heat) = 75,375 Btu

Total sensible heat load 107,601 + 75,375 = 182,976 Btu

Latent Heat Gain.

25 people at 265 Btu per hr. — 6625 Btu
Moisture Infiltration: Assume
1/2 air change per hr.
Moisture infiltration:

$\frac{75,000}{2} = 37,500$ cu. ft. per hr.

$\frac{37,500 \times 0.075 (112-76) \times 1047}{7000} = 15,150$ Btu

Total Latent Heat Gain = 21,775 Btu

Where:

0.075 = Density of air at 70°
112 = Grains of moisture at 95° D.B. and 78° W.B.
76 = Grains of moisture at 80° D.B. and 50% R.H.
1047 = Latent heat of vapor at 80°
7000 = Grains per lb. of water

Total load (sensible heat plus latent heat) = 204,751 Btu

Cubic feet of air per minute to be circulated (assume a 20° differential between air being introduced into room and room air) =

$$\frac{\text{Sensible load in Btu}}{60 \times Sp \times D \times T}$$

or

$$\frac{182,976}{60 \times 0.24 \times 0.075 \times 20^{o}} = 8471 \text{ CFM Use } 8470 \text{ CFM}$$

Where:

60 = Minutes per hour
Sp = Specific heat of air (0.24)
D = Density of air at 70° F (0.075)
T = Differential between room temperature and delivery temperature (assumed)

Fresh air to be introduced (assume 2 air changes of fresh air per hour)

$$\frac{\text{Volume of Bldg. x 2 air changes}}{60} = \frac{75,000 \times 2}{60} = 2500 \text{ CFM}$$

Dry Bulb Temperature of air entering cooling coil (Tm)

$$Tm = Tr + \frac{F.A.}{T.A.} \times (To - Tr)$$

$$= 80 + \frac{2500}{8470} \times (95 - 80)$$

$$= 84.42^{o} \text{ (Dry bulb temperature of air entering cooling coil)}$$

Where:

Tr = Room temperature (80° F)
F.A. = Fresh air (2500 CFM)
T.A. = Total air (8470 CFM)
To = Outside air temperature (95° F)
Tm = Dry bulb temperature of air entering cooling coil

Wet Bulb Temperature. Wet bulb temperature is computed from the enthalpy of saturated mixture of air and moisture at the wet bulb temperatures (same as total heat) (E_m).

$$E_m = E_r + \frac{F.A.}{T.A.} \times (E_o - E_r)$$

$$= 31.51 \ \frac{2500}{8470} \times (41.42 - 31.51)$$

$$= 34.43 \text{ Btu (total heat per lb. of saturated air at entering wet bulb temperature)}$$

Where:

E_r = Total heat per lb. of saturated air at inside wet bulb (31.51 Btu).

E_o = Total heat per lb. of saturated air at outside wet bulb (41.42 Btu).

E_m = Total heat per lb. of saturated air at entering wet bulb temperature.

Wet bulb temperature corresponding to 34.43 Btu total heat=70.54°F.

Dry bulb temperature of air leaving cooling coil (T_L).

$$T_L = T_r - \frac{Hs}{60 \times Sp \times D \times T.A.}$$

$$= 80 - \frac{182,976}{60 \times 0.24 \times 0.075 \times 8470}$$

$= 60.0^\circ$ F (dry bulb temperature leaving coil)

Where:

H_s = Total sensible heat load

T_L = Dry bulb temperature of air leaving coil

Wet bulb temperature of air leaving cooling coil (E_L)

$$E_L = E_r - \frac{Ht}{60 \times D \times 8470}$$

$$= 31.51 \quad \frac{204,751}{60 \times 0.075 \times 8470}$$

= 26.14 Btu (total heat per lb. of saturated air at leaving wet bulb temperature)

Where:

H_t = Total heat load (sensible plus latent)

E_L = Total heat per lb. of saturated air at leaving wet bulb temperature

Wet bulb temperature corresponding to 26.14 Btu total heat = 59.66° F.

NOTE: Except in special cases where reheat is required, the quantity of air to be passed through the coil should be chosen so that the condition of the air leaving the coil approaches saturation.

Total Refrigeration Capacity Required = (R)

$$R = T.A. \times 60 \times D \times (E_m - E_L)$$

$$= 8470 \times 60 \times 0.075 \times (34.43-26.14)$$

= 315,973 Btu per hr.

Expressed in tons of refrigeration

$$\frac{315,973}{\text{Btu per ton}} = \frac{315,973}{12,000} = 26.3 \text{ tons}$$

Equipment Selection.

Assume two air conditioning units, one located at each end of building. The entering air conditions to each unit would be 84.42° dry bulb and 70.54° wet bulb. Leaving air conditions would be 60° dry bulb and 59.66° wet bulb. Compressor capacity of each unit would be 315,973/2 = 157,986 Btu. Temperature of water available for condensing would be approximately 85° F. and maximum allowable water consumption would be 3 gallons per minute per ton. Air capacity of each unit would be 4,235 cu. ft. per minute. Compressors should be provided with step controller or cylinder cutouts to enable them to handle varying loads. All air passing through the air conditioning unit should be filtered.

NOTE: The preceding example is based on the use of mechanical refrigeration with direct expansion coils. Other types of systems may be installed and operated more economically depending on local conditions. For climates with low dew point temperatures, evaporative cooling may be used advantageously, and in some localities with cold well water available, the cooling could be accomplished directly with water coils.

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ENGINEERING MANUAL
FOR WAR DEPARTMENT CONSTRUCTION

PART V
CHAP. 2
SEPT. '45

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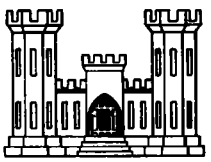
MECHANICAL DESIGN
REFRIGERATION



ARMY SERVICE FORCES
U.S. Army CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

CHAPTER 2

REFRIGERATION

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PART V
MECHANICAL DESIGN

CHAPTER 2

REFRIGERATION

GENERAL

2-01 SCOPE: These instructions cover the design of major equipment required for cold storage, meat cutting, ice manufacturing and ice storage facilities constructed under the supervision of the Chief of Engineers. The schedules contained in this chapter shall be consulted for information pertinent to the construction of permanent type facilities. Unusual conditions and special conditions not covered specifically by these instructions shall be referred to the Office, Chief of Engineers. Refrigeration equipment should be fabricated and installed in accordance with the applicable portions of Corps of Engineers Guide Specification No. 302.1, Refrigeration Systems. All equipment should be simple to install and operate. The control equipment should be as simple as possible consistent with the required control and should conform to the requirement of the Underwriters' Laboratories, Incorporated. Guarantee should be in accordance with the current specification referred to above.

COLD STORAGE PLANTS

2-02 GENERAL. A cold storage plant is a building containing one or more rooms used for the preservation of perishable items by controlled temperatures and humidities. Thermal insulation is used to assist in maintaining the desired storage conditions. Refrigeration equipment installed within the building is used to produce the desired storage conditions. Buildings are normally of masonry construction with the proper amount of insulation provided for maintaining the desired room temperatures. They should be so located that receipt and distribution of items may be made as expeditiously as possible; that dirt and contamination may be held to a minimum, and that future expansion may be provided without disruption of existing facilities.

2-03 STORAGE SPACES. The types of storage spaces, depending on the size of the installation, and the types of foodstuff stored are as described in the following paragraphs.

2-04 FREEZER STORAGE ROOMS. These rooms are used for the storage of previously frozen foods at those posts where normal population requires the distribution of frozen foods. The temperature to be maintained in these rooms should be approximately ten degrees Fahrenheit and should be accomplished by means of cooling surfaces consisting of steel plates or pipe coils. Capacity of coils should be such that entire product load may be pulled down from entrance to storage temperature in approximately 30 hours.

2-05 COOLER STORAGE ROOMS. Cooler storage rooms for the various classes of storage items are separated in order that objectionable odors, due to deterioration of one class of items, will not contaminate the others. These storage rooms are generally divided into the four classes described below, depending on the type of product to be cooled:

a. Meat Coolers. These rooms are used for the storage of fresh, corned and smoked meats for short periods only. These rooms are to be maintained at a temperature between thirty-one and thirty-five degrees F. Unit coolers with or without ducts should be provided for these rooms. Maximum air velocity from the unit cooler or from ducts connected to the unit cooler should not exceed one hundred feet per minute in order to prevent excessive dehydration of the meat products. In order to maintain the evaporator coils in the most efficient condition water spray defrosting is necessary.

b. Dairy Products Storage. These rooms are used for the storage of eggs, butter, milk and similar dairy products and are usually maintained at thirty-five degrees F. Air blower unit coolers either with or without ducts should be used. The outlet velocity of cool air from these units should not exceed one hundred feet per minute. Provision for water spray defrosting to keep evaporator coils at top efficiency is necessary.

c. Perishable Fruit and Vegetable Storage. These rooms are used for the storage of such fruits and vegetables as may be of a perishable nature; such as, lettuce, green and wax beans, peas, plums and peaches, and are to be maintained at a temperature of 35 degrees F. Unit coolers of the blower type are to be used for cool air distribution. Ductwork should be installed for proper air distribution in large rooms. Air outlet velocity should not exceed 100 feet per minute. Provision should be made to defrost the evaporator coils by means of a water spray.

d. Staple Fruit and Vegetable Storage. These rooms are used for the storage of staple fruits and vegetables; such as, apples, potatoes, onions etc., and are to be maintained at a temperature of 50 degrees F. Unit coolers are to be used for cool air distribution with connecting ductwork for large rooms. Consideration should be given for the installation of louvered openings in the walls of these rooms in order that advantage may be taken of the lower outside night air temperature in various localities.

2-06 RECEIVING AND ISSUE SPACE. Where the volume of such warrants, refrigerated receiving and issue space shall be provided to handle properly the incoming and outgoing products. Where authorized, the temperature of this type of

room shall be maintained at 40 degrees F. Cooling shall be by means of unit coolers with spray evaporator coil defrosters.

2-07 OFFICE SPACE. Office space for the purpose of keeping records of the products handled shall be incorporated as an integral part of the building. No cooling is to be provided for this room.

2-08 MACHINE ROOM Machine room shall be provided to house all the machinery necessary to maintain the proper temperature in the refrigerated rooms and to process such products as may be required.

2-09 SPACE ALLOCATION. The amount of space provided for the several types of storages listed in paragraph 2-03 depends upon the frequency of delivery, the lengths of storage period, and the population to be served. For populations of 7000 or less, the storage space as set forth in Table I is based on the delivery of all required items every three days with a three-day holdover period. For populations of 7001, and greater, the storage space as set forth in Table I is based on the delivery of all required items (except fruits and possibly vegetables) every seven days with a seven-day holdover period. In all cases the storage space for fruits and perishable vegetables is based on delivery every three days with a three-day holdover period. Space allocations given in Table I are not in exact proportion to the post populations served for the following reasons:

TABLE I

SPACE ALLOCATIONS FOR ROOMS
IN COLD STORAGE BUILDINGS
(IN SQ. FT.)

Population	10° F. Freezer Storage	31-35° F. Meat Cooler Storage	35° F. Fruits & Vegetables	35° F. Dairy Products	40° F. Receiving & Issue	45° F. Meat Cutting	50° F. Staple Fruits & Vegetables
1,000-2,000	-	315	315	315	-	-	-
2,000-3,000	-	450	450	450	-	-	-
3,001-5,000	-	1080	540	540	-	-	-
5,001-7,000	540	1080	540	540	-	-	-
7,001-10,000	1680	975	630	825	420	-	-
10,000-15,000	1680	975	630	825	600	-	1800
15,001-30,000	3120	1860	1200	1500	900	-	2540
30,001-45,000	4400	2800	1800	2120	1800	-	3820
45,001-60,000	5750	3540	2160	2700	2700	-	3860

a. Freezer Storage Rooms. Freezer storage rooms are not provided in cold storage buildings for populations of 5000 or less, as frozen foods are not ordinarily delivered to these smaller installations.

b. Staple Fruit and Vegetable Storage. Spaces for the storage of staple fruits and vegetables are not required for populations less than 10,000, since the total quantity of each delivery is not large and these items may be stored in the warehouse of which the cold storage is a part or in the individual messes.

c. Receiving and Issue Rooms. Receiving and issue rooms are not provided in cold storage buildings serving a population of less than 7,000, as the total of each delivery is not large enough to require special handling.

d. Space Proportioning. Architectural design features cause some variation in space allotments, but in general, the proportion of usable to total space increases with the size of the storage room.

2-10 INSULATION. Materials used for the insulation of cold storage and other refrigerated spaces should be either pressed vegetable corkboard or other approved insulation of a type used for cold storage work. Insulation should be provided in the storage and refrigerated spaces in an amount sufficient to maintain the specified temperatures without overtaxing the refrigeration equipment. For average climatic conditions the thickness of insulation should not be less than that listed in Table II.

TABLE II

MINIMUM THICKNESS OF INSULATION
(BASED ON CORKBOARD)

Room Temperature ^{o}F	Thickness of Insulation Inches
-20 to -10	8
-9 to -5	7
-4 to +10	6
+11 to +35	4
+36 to +45	3
46 and over	2

Materials other than corkboard shall be tested for comparison of thermal insulating value, using corkboard as a standard. No insulating material shall be used until it has been tested by the U. S. Bureau of Standards or other approved testing agency.

MEAT CUTTING PLANTS

2-11 GENERAL. A meat cutting plant is a structure or an addition to a cold storage plant, containing rooms for the processing of meat for ultimate consumption in the individual messes and for the rendering of fat.

2-12 MEAT CUTTING PLANT. Meat cutting plants should be of the same construction as the cold storage plant to which they are attached and refrigerated portions should be provided with the proper amount of insulation as indicated in Table II. The meat cutting plant should be an extension of a cold storage plant in order that the transportation of carcass meat from the cold storage rooms to the processing rooms, with its consequent exposure to outside temperature and contamination, may be held to a minimum.

2-13 WORK AND COLD STORAGE SPACES. In all meat cutting plants spaces should be provided for the following activities (See Table III).

a. Meat Holding Room. This room is used to hold carcass or unprocessed meat for immediate use by the meat cutters. Meat is brought into and out of this room by means of an overhead rail system, and is held in this room at a temperature of 32 degrees F. Suspended type unit coolers with water spray defrosting are used to maintain the proper temperature. Manually operated valves for controlling spray water should be located outside of this room so as to prevent freezing.

b. Meat Cutting Room. The meat cutting room is used for processing meat for distribution to the individual messes and is maintained at a temperature of 45 degrees F., winter and summer. Suspended type unit coolers with connected air distributing ducts are used to maintain the proper temperature.

c. Processed Meat Storage Room. Before distributing processed meat to the individual messes it is brought down to 28 degrees F. For this purpose a room is provided having access to both the meat cutting room and the platform. Suspended type unit coolers with water spray defrosters are used to maintain a temperature of 28 degrees F. in this room. The time required to pull down the processed meat load in this room is limited to twelve hours. Manually operated valves for controlling the spray water should be located outside of this room to prevent freezing.

d. Fat Rendering Room. A fat rendering room is provided in each meat cutting plant for the purpose of recovering fat products or fat which might otherwise be wasted. Ventilation shall be provided by means of a fan or blower exhausting air from a hood located over the kettles.

2-14 OTHER SPACES. In addition to the above mentioned work and storage spaces the following spaces shall form a part of the meat cutting plant:

a. Office. In all meat cutting plants an office shall be provided for the purpose of keeping records of the meat and products processed. No refrigeration is required for the room.

b. Storeroom. A room for the storage of spare tools, pans, clean linen and other small items of equipment shall be incorporated as an integral part of the plant.

c. Toilet and Locker Room. All meat cutting rooms designed to serve a population of over 7500 shall incorporate toilet and locker rooms for the use of meat cutting plant personnel.

TABLE III

SPACE ALLOCATIONS FOR ROOMS IN MEAT CUTTING PLANTS

No.	Population	Approximate Floor Areas - Square Feet				Authorized Personnel
		32 degree Meat Holding Room	28 degrees Processed Meat Stg.	45 degree Meat Cutting Room	Fat Rendering Rm.	
1	2500-4000	200	170	600	340	6
2	4001-7500	200	200	700	340	8
3	7501-15,000	325	340	1300	375	17
4	15,001-30,000	575	600	1900	600	30
5	30,001-50,000	800	1000	3100	850	44

2-15 SPACE ALLOCATIONS. The amount of space provided for the several types of meat cutting plants depends upon the population to be served. The amount of floor area allotted to each room shall be as indicated in Table III, which is based on the ability of each meat cutter to process 1000 pounds of carcass meat per shift of 8 hours. Place allotments for the office, storeroom, toilet and locker rooms shall be according to the best standard practice.

2-16 VENTILATION. Mechanical ventilation shall be provided for the meat cutting room and the fat rendering room as follows:

a. Meat Cutting Room. Fresh air shall be supplied to the meat cutting room in a basis of 10 cfm per man. This fresh air shall be supplied to the room by means of the unit cooler.

b. Fat Rendering Room. Air shall be taken from the fat rendering room by means of an exhaust fan on a basis of 12 air changes per hour for the entire room volume. The ventilating equipment for this room should be fabricated and installed in accordance with the applicable portions of Corps of Engineers Guide Specification No. 301.8, Mechanical Ventilation Systems.

2-17 REFRIGERATION EQUIPMENT. Refrigeration equipment should be fabricated and installed in accordance with the applicable portions of Corps of Engineers Guide Specification No. 302.1, Refrigeration Systems. All equipment should be simple to install and operate. The control equipment should be as simple as possible consistent with the required control and should conform to the requirements of the Underwriters' Laboratories, Incorporated. Guarantees should be in accordance with current specification referred to above.

2-18 STANDARD DESIGNS. Standard designs for meat cutting plants should be followed for all construction. Table IV indicates the proper selection for various populations to be served.

TABLE IV

STANDARD DESIGN - MEAT CUTTING PLANTS

No.	Population	Type	Plan No.
1	2500 - - 4000	Meat-A-M	700 - 4660
2	4001 - - 7500	Meat-B-M	700 - 4665
3	7501 - -15000	Meat-D-M	700 - 4680
4	15001 - -30000	Meat-E-M	700 - 4685
5	30001 - -50000	Meat-C-M	700 - 4670

ICE MAKING PLANTS

2-19 GENERAL. Ice making plants will be constructed only where authorized by the Chief of Engineers. Where ice is not available from commercial sources or the cost thereof is excessive, the District Engineer will make a survey and submit a report to the Office, Chief of Engineers, for use in determining the necessity of providing ice making facilities. In order to determine the advisability of constructing an ice making plant, the District Engineer's survey and report should include a list of commercial ice making plants within a radius of 50 miles, (depending on transportation facilities) from the site, together with information on each plant as follows:

(a) Daily Capacity: Maximum daily capacity.
(b) Sales of Ice: Maximum ice sales for three day period.
(c) Storage Capacity: Ice storage capacity.
(d) Condition of Plant: Physical condition of plant and its record for reliable and continuous operation.
(e) Transportation: Transportation facilities for ice deliveries to Post ice storage.
(f) Price: Price per ton at plant and price per ton delivered to Post ice storage building.

With the above information, the availability and cost of ice by direct commercial purchase can be accurately determined. In all cases where ice can be purchased as economically and reliably as it can be manufactured by the Government, an ice storage building will be provided in lieu of an ice making plant.

2-20 ICE MAKING PLANTS. An ice making plant is a structure containing rooms and equipment for the manufacture and storage of ice. Thermal insulation is used in the construction of the ice storage room to assist in maintaining the desired room,temperature. Refrigeration equipment installed within the building is used to produce the desired temperatures within the brine tank.

2-21 WORK AND STORAGE SPACES. In all ice making plants spaces should be provided for the following activities:

a. Machinery Room. This room contains the refrigerating machinery, the freezing tank and equipment for filling, empting and handling the ice cans.

b. Ice Storage Room. This room is used for the storage of ice before distribution. Four inches of insulation is required to maintain a temperature of 28 degrees. No refrigeration is required.

c. Office and Toilet. Office space is provided for keeping records. A toilet shall also be provided for the use of personnel in the ice making plant. No refrigeration is required for these rooms.

2-22 SPACE ALLOCATIONS. The amount of space required for the machinery and ice storage rooms should be based on the required amount of ice. The amount of space allowed for the machinery and ice storage rooms should be based on the equipment and storage required to manufacture 300 pound blocks of ice in the amount necessary to serve populations as set forth in the following paragraph.

a. Ice making plants located north of latitude 35 degrees should be designed for a capacity of 1.3 pounds of ice per person per day; plants located south of latitude 35 degrees should be designed for a capacity of 2 pounds of ice per person per day, while plants located in semitropical, tropical and desert areas should be designed for a capacity of 2½ pounds of ice per person per day.

b. The size of the ice storage room shall be based on a net storage capacity of three days output of the plant when operating at 100 percent.

2-23 INSULATION. Insulation should be provided in the ice storage room only and should conform to the requirements of paragraph 2-10

2-24 ICE STORAGE BUILDINGS. When ice can be bought as cheaply and as reliably as can be manufactured by the Government, ice storage buildings should be provided on a basis of 24 hours storage under normal conditions.

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Housing and Home Finance Agency
Office of the Administrator
LIBRARY

MECHANICAL DESIGN

COMPRESSED AIR



DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

U - 4 - 2

CHAPTER 3
COMPRESSED AIR

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PART V
MECHANICAL DESIGN
CHAPTER 3
COMPRESSED AIR

3–01. SCOPE

The following information and instructions are intended to cover the major requirements for compressed air. The criteria are based on the Trade Standards of Compressed Air Institute, a trade association comprising the principal manufacturers of air and gas compressors, pneumatic tools, and rock drills.

3–02. TEST STANDARDS

Tests, to determine the performance of air compressors and blowers and/or to establish compliance with performance guarantees, are of value only if conducted carefully and in strict conformance with accepted methods and standards prescribed by the A. S. M. E. Power Test Codes for Centrifugal Compressors, Displacement Compressors, Blowers, and Vacuum Pumps.

3–03. LOCATION OF AIR COMPRESSORS

Air compressors should be located in clean, well-lighted areas of sufficient size to permit cleaning, ready inspection, and any dismantling which may be necessary, such as removal of pistons, wheels, crankshaft, or inter-cooler tube nest.

3–04. FOUNDATIONS

Drawings should be prepared for foundations of appropriate mass and base area. To avoid transmission of vibration, the walls and floors of the compressor room should be insulated from the compressor foundation. It is well to surround the portion of the foundations that are below ground with 18 inches of coarse dry gravel, and to separate it from the adjacent building floor by a narrow air gap, or by vibration insulation material, such as asphalt.

3–05. AIR INTAKE

The intake of a compressor should be piped outside the building to obtain air as cool as possible. An increase in delivery of approximately 1 percent is gained for every 5 degrees reduction in intake temperature, since the density of air varies inversely as its absolute temperature, as indicated in table I. Where local requirements call for a minimum of noise, the air intake should be provided with a muffler. The air intake should be located as far away as possible from ash or coal bins or other dusty places. The piping should be as short and direct as possible, using long radius elbows. The size of piping should be full diameter of the intake opening of the air cylinder or, if longer than 12 feet, then the next larger size pipe should be used.

TABLE I.—*Effect of Initial or Intake Temperature on Delivery of Air Compressors*

Initial temperatures		Relative delivery	Initial temperature		Relative delivery
Degrees F	Degrees absolute F		Degrees F	Degrees absolute F	
−20	440	1. 18	70	530	0. 980
−10	450	1. 155	80	540	0. 961
0	460	1. 13	90	550	0. 944
10	470	1. 104	100	560	0. 928
20	480	1. 083	110	570	0. 912
30	490	1. 061	120	580	0. 896
32	492	1. 058	130	590	0. 880
40	500	1. 040	140	600	0. 866
50	510	1. 020	150	610	0. 852
60	520	1. 00	160	620	0. 838

Assume the indoor temperature to be 70° F. If the compressor takes in 1,000 cubic feet of free air, it will also deliver 1,000 cubic feet of free air, because the initial and final temperatures are the same.

Suppose the outside air averages 40° F. If the compressor is supplied with intake air from outdoors, only 943 cubic feet of free air will be required to deliver 1,000 cubic feet of free air at the indoor temperature, a direct saving of 5.7 percent. The cooler the climate, the more pronounced the effect becomes. The effect of the intake temperature on the final delivery is shown in table II.

TABLE II.—*Effect of Intake Temperature on Capacity*

[Intake volume required to produce 1,000 cu. ft. of free air at 70° F.]

Temperature of intake, ° F.	Relative intake volume required, cu. ft.	Percent H. P. saved
30	925	7. 5
40	943	5. 7
50	962	3. 8
60	981	1. 9
70	1, 000	. 0
80	1, 019	−1. 9
90	1, 038	−3. 8
100	1, 057	−5. 7
110	1, 076	−7. 6
120	1, 095	−9. 5

3–06. AIR DISCHARGE PIPE.

The discharge pipe should not be smaller than the full size of compressor outlet and should run directly to the aftercooler or air receiver. Piping connected to the compressor should be arranged with flanged fittings or unions close to the compressor to permit removal of the cylinder at any time without disturbing the piping. Overhead piping should be well supported to relieve the cylinders of incidental strains.

TABLE III.—*Cooling Water Recommended for Intercoolers, Cylinder Jackets and Aftercoolers*

	Gallons of water per hundred cu. ft. actual free air
Intercooler Separate	2.5 to 2.8
Intercooler and Jackets in Series	2.5 to 2.8
Aftercoolers:	
80–100 lbs. Two-Stage	1.25
80–100 lbs. Single-Stage	1.8
Two-Stage Jackets alone (both)	.8
Single-Stage Jackets:	
40 lbs	.6
60 lbs	.8
80 lbs	1.1
100 lbs	1.3

3–07. CIRCULATING WATER.

A liberal supply of cooling water for cylinder jackets, cylinder heads, intercoolers, and aftercoolers should be provided and the water supply should be turned on before the compressor is started. Where the cooling water is very cold, condensation may form in the air inlet passage of the high-pressure cylinder as the air passes through in coming from the intercooler, because the air may be much warmer than the water. If condensation forms, it will be carried into the air cylinder and destroy the lubricant, causing rapid cylinder and valve wear. To relieve this condition, it is advisable to pass the cold water through the intercooler first, in order to increase its temperature before going to the cylinder jackets, or to reduce the supply to the cylinder jackets so that the temperature of the discharge therefrom will be between 100° and 115° F. It is expected that the temperature of the air leaving the intercooler or aftercooler will be within 20° of the temperature of the water entering the cooler for ordinary working conditions, as shown in table III.

3–08. PIPING.

Compressed air piping should be indicated parallel with the lines of the building. Traps should be inserted in air lines at frequent intervals to remove condensed moisture. Automatic moisture traps are available for this purpose, or traps may be used made of pipe and fittings consisting of tees having a pipe leg hanging down with a drain connected at the bottom. Traps are effective only when the air has been cooled and the moisture has precipitated. Where the air is not allowed to stand unused for any period of time and there is, therefore, little opportunity for it to cool by radiation, an aftercooler should be used to cool the air before its moisture can be precipitated and removed. If an aftercooler is not employed, much of the trouble experienced with water in air lines can be overcome if small air receivers are put in the lines at frequent intervals to act as collecting tanks. Branches from compressed air mains should be taken off at the top to avoid picking up moisture. When a gate or globe valve is placed in the discharge line between the compressor and aftercooler or receiver, a safety valve should be placed in the pipe line between the cylinder and shut-off valve. The compressor at some time may be started with the stop valve closed and, if no safety valve is used, sufficient pressure may be built up to burst the cylinder.

a. **Loss of Air Pressure in Piping Due to Friction.** All data are based on nonpulsating flow and apply to clean and smooth pipe in graph I and tables V to VIII, inclusive, and are calculated

from the following formula by Professor E. G. Harris (University of Missouri Bulletin, vol. 1, No. 4, 1912):

$$p=\frac{cL}{r}\times\frac{Q^2}{d^5}$$

$$c=\frac{0.1025}{d^{0.31}}=\text{Coefficient for ordinary pipe}$$

Therefore $p=\frac{0.1025\ L}{r}\times\frac{Q^2}{d^{5.31}}$

Where p=Pressure drop due to friction, pounds per square inch.
L=Length of pipe, feet.
Q=Rate of flow of free air, cubic feet per second.
r=Ratio of compression (referred to atmosphere) at entrance of pipe.
d=Actual internal diameter of pipe, inches.
c=Experimental coefficient.

Substituting the value of c in the foregoing formula and changing the nomenclature—

$$\text{Then } p=\frac{Q^2\times F}{P} \tag{1}$$

Where p=Pressure drop due to friction per 100 feet of pipe, pounds per square inch.
Q=Rate of flow of free air, cubic feet per minute.
P=Initial pressure at the entrance to the pipe, pounds per square inch absolute.
F=Factor, which is a function of inside diameter of the pipe (d in inches), combined with the formula constant.

Its value is $\frac{0.04185}{d^{5.31}}$

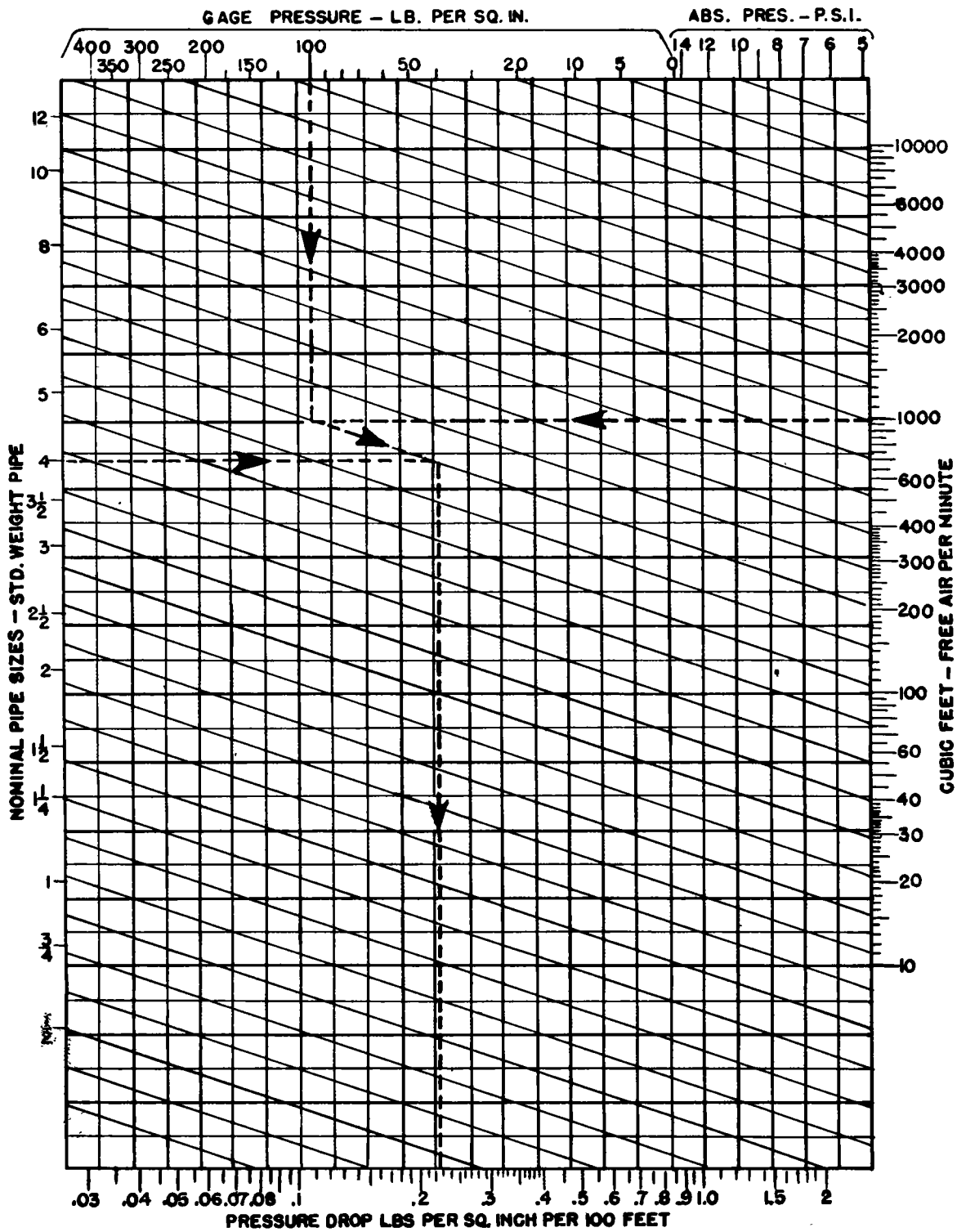
To facilitate the use of the formula, values of F for nominal pipe sizes are tabulated in table IV.

TABLE IV.—*Numerical Values of Factor "F".*

Nominal pipe size, inches	Standard weight pipe	Extra strong pipe
1¼	7. 568 x 10^{-3}	11. 375 x 10^{-3}
1½	3. 337 x 10^{-3}	4. 860 x 10^{-3}
2	885. 5 x 10^{-6}	1. 244 x 10^{-3}
2½	344. 7 x 10^{-6}	476. 4 x 10^{-6}
3	108. 7 x 10^{-6}	146. 7 x 10^{-6}
3½	50. 27 x 10^{-6}	66. 69 x 10^{-6}
4	25. 70 x 10^{-6}	33. 67 x 10^{-6}
5	7. 737 x 10^{-6}	9. 955 x 10^{-6}
6	2. 914 x 10^{-6}	3. 832 x 10^{-6}
8	678. 8 x 10^{-9}	865. 0 x 10^{-9}
10	202. 8 x 10^{-9}	260. 0 x 10^{-9}
12	80. 04 x 10^{-9}	103. 6 x 10^{-9}

GRAPH I

LOSS OF AIR PRESSURE IN PIPING DUE TO FRICTION



Graph I gives the pressure drop in pipes up to 12 inches in diameter, for capacities up to 10,000 cubic feet of free air per minute, and for initial pressures up to 400 pounds per square inch.

Tables V through VIII, inclusive, show the pressure drop in pipes to 6 inches in diameter, for capacities up to 1,000 cubic feet of free air per minute, and for initial pressures of 60, 80, 100 and 125 pounds.

For longer or shorter lengths of pipe the friction loss is proportional to the lengths, that is for 500 feet, one-half of the above; for 4,000 feet, four times the above, etc.

Example 1: One thousand cubic feet of free air per minute are to be transmitted at 100 pounds per square inch gage pressure through a 4-inch standard weight pipe. What will be the pressure drop due to friction?

Enter graph I at the top at the point representing 100 pounds per square inch gage pressure and proceed vertically downward to the intersection with a horizontal line representing 1,000 c. f. m., then parallel to the diagonal guide lines to the right (or left) to the intersection with a horizontal line representing a 4-inch pipe, then vertically downward to the pressure loss scale at the bottom of the graph, where it is observed that the pressure loss would be 0.225 pound per square inch per 100 feet of pipe.

Example 2: It is desired to find the loss in pressure due to friction in a 4-inch pipe 1,200 feet long, carrying 1,000 cubic feet free air per minute compressed to an initial gage pressure of 80 pounds per square inch.

Refer to table VI: the loss in 1,000 feet of four 4-inch pipe is 2.68 pounds per square inch. Multiplying this factor of 2.68 by 1,200 and dividing by 1,000 gives a loss of 3.22 pounds for the entire length of the pipe, or a terminal gage reading of 76.78 pounds.

TABLE V.—*Loss of Air Pressure Due to Friction, Pounds per Square Inch in 1,000 Feet of Pipe, 60 Pounds Gage Initial Pressure*

Free air, cu. ft. per min.	Equivalent compressed air, cu. ft. per min.	Nominal diameter, inches												
		½	¾	1	1¼	1½	2	2½	3	3½	4	4½	5	6
10	1. 96	10. 0	1. 53	0. 43	0. 10									
20	3. 94	39. 7	5. 99	1. 71	. 39	0. 18								
30	5. 89	89. 7	13. 85	3. 86	. 88	. 40								
40	7. 86		24. 7	6. 85	1. 59	. 71	0. 19							
50	9. 84		38. 6	10. 7	2. 48	1. 10	. 30							
60	11. 81		55. 5	15. 4	3. 58	1. 57	. 43							
70	13. 75		75. 8	21. 0	4. 87	2. 15	. 57	0. 22						
80	15. 72		99. 0	27. 4	6. 37	2. 82	. 75	. 29						
90	17. 65			34. 7	8. 05	3. 57	. 95	. 37						
100	19. 60			42. 8	9. 95	4. 40	1. 18	. 46						
125	24. 60			67. 0	15. 7	6. 90	1. 83	. 71	0. 14					
150	29. 45			96. 4	22. 4	9. 90	2. 64	1. 02	. 32	0. 15				
175	34. 44				30. 8	13. 40	3. 64	1. 40	. 43	. 20				
200	39. 40				39. 7	17. 60	4. 71	1. 83	. 57	. 27				
250	49. 20				62. 8	27. 5	7. 37	2. 85	. 89	. 42	0. 21			
300	58. 90				89. 3	39. 6	10. 55	4. 11	1. 30	. 60	. 31			
350	68. 8					54. 0	14. 4	5. 60	1. 76	. 82	. 42	0. 23		
400	78. 8					70. 4	18. 6	7. 30	2. 30	1. 06	. 53	. 30		
450	88. 4					89. 1	23. 7	9. 20	2. 90	1. 35	. 70	. 38		
500	98. 4						29. 7	11. 4	3. 60	1. 67	. 85	. 46	0. 26	
600	118. 1						42. 3	16. 4	5. 17	2. 40	1. 22	. 67	. 37	
700	137. 5						57. 8	22. 3	7. 00	3. 27	1. 67	. 91	. 50	0. 19
800	157. 2						75. 2	29. 2	9. 16	4. 26	2. 18	1. 20	. 65	. 25
900	176. 5						95. 5	37. 0	11. 6	5. 40	2. 76	1. 51	. 83	. 31
1,000	196. 0							45. 7	14. 3	6. 65	3. 40	1. 87	1. 02	. 39

TABLE VI.—*Loss of Air Pressure Due to Friction, Pounds per Square Inch in 1,000 Feet of Pipe, 80 Pounds Gage Initial Pressure*

Free air, cu. ft. per min.	Equivalent Compressed air, cu. ft. per min.	Nominal diameter, inches												
		½	¾	1	1¼	1½	2	2½	3	3½	4	4½	5	6
10	1. 55	7. 90	1. 21	0. 34										
20	3. 10	31. 4	4. 72	1. 35	0. 31									
30	4. 65	70. 8	10. 9	3. 05	. 69	0. 31								
40	6. 20		19. 5	5. 40	1. 25	. 56								
50	7. 74		30. 5	8. 45	1. 96	. 87								
60	9. 29		43. 8	12. 16	2. 82	1. 24	0. 34							
70	10. 82		59. 8	16. 6	3. 84	1. 70	. 45							
80	12. 40		78. 2	21. 6	5. 03	2. 22	. 59							
90	13. 95			27. 4	6. 35	2. 82	. 75							
100	15. 5			33. 8	7. 85	3. 47	. 93	0. 36						
125	19. 4			46. 2	12. 4	5. 45	1. 44	. 56						
150	23. 2			76. 2	17. 7	7. 82	2. 08	. 81						
175	27. 2				24. 8	10. 6	2. 87	1. 10						
200	31. 0				31. 4	13. 9	3. 72	1. 44	0. 45					
250	38. 7				49. 0	21. 7	5. 82	2. 25	. 70	0. 33				
300	46. 5				70. 6	31. 2	8. 35	3. 24	1. 03	. 47				
350	54. 2				96. 0	42. 5	11. 4	4. 42	1. 39	. 65	0. 33			
400	62. 0					55. 5	14. 7	5. 76	1. 82	. 84	. 42			
450	69. 7					70. 2	18. 7	7. 25	2. 29	1. 06	. 55			
500	77. 4					86. 7	23. 3	9. 0	2. 84	1. 32	. 67	0. 30		
600	92. 9						33. 4	12. 9	4. 08	1. 89	. 96	. 53		
700	108. 2						45. 7	17. 6	5. 52	2. 58	1. 32	. 72	0. 40	
800	124. 0						59. 3	23. 1	7. 15	3. 36	1. 72	. 95	. 51	
900	139. 5						75. 5	29. 2	9. 17	4. 26	2. 18	1. 19	. 65	
1,000	155. 0						93. 2	36. 1	11. 3	5. 27	2. 68	1. 48	. 81	0. 30

TABLE VII.—*Loss of Air Pressure Due to Friction, Pounds per Square Inch in 1,000 Feet of Pipe, 100 Pounds Gage Initial Pressure*

Free air, cu. ft. per min.	Equivalent compressed air, cu. ft. per min.	Nominal diameter, inches												
		½	¾	1	1¼	1½	2	2½	3	3½	4	4½	5	9
10	1. 28	6. 50	0. 99	0. 28										
20	2. 56	25. 9	3. 90	1. 11	0. 25	0. 11								
30	3. 84	58. 5	9. 01	2. 51	. 57	. 26								
40	5. 12	-----	16. 0	4. 45	1. 03	. 46								
50	6. 41	-----	25. 1	6. 96	1. 61	. 71	0. 19							
60	7. 68	-----	36. 2	10. 0	2. 32	1. 02	. 28							
70	8. 96	-----	49. 3	13. 7	3. 16	1. 40	. 37							
80	10. 24	-----	64. 5	17. 8	4. 14	1. 83	. 49	0. 19						
90	11. 52	-----	82. 8	22. 6	5. 23	2. 32	. 62	. 24						
100	12. 81	-----	------	27. 9	6. 47	2. 86	. 77	. 30						
125	15. 82	-----	------	48. 6	10. 2	4. 49	1. 19	. 46						
150	19. 23	-----	------	62. 8	14. 6	6. 43	1. 72	. 66	0. 21					
175	22. 40	-----	------	------	19. 8	8. 72	2. 36	. 91	. 28					
200	25. 62	-----	------	------	25. 9	11. 4	3. 06	1. 19	. 37	0. 17				
250	31. 64	-----	------	------	40. 4	17. 9	4. 78	1. 85	. 58	. 27				
300	38. 44	-----	------	------	58. 2	25. 8	6. 85	2. 67	. 84	. 39	0. 20			
350	44. 80	-----	------	------	------	35. 1	9. 36	3. 64	1. 14	. 53	. 27			
400	51. 24	-----	------	------	------	45. 8	12. 1	4. 75	1. 50	. 69	. 35	0. 19		
450	57. 65	-----	------	------	------	58. 0	15. 4	5. 98	1. 89	. 88	. 46	. 25		
500	63. 28	-----	------	------	------	71. 6	19. 2	7. 42	2. 34	1. 09	. 55	. 30	0. 17	
600	76. 88	-----	------	------	------	------	27. 6	10. 7	3. 36	1. 56	. 79	. 44	. 24	
700	89. 6	-----	------	------	------	------	37. 7	14. 5	4. 55	2. 13	1. 09	. 59	. 33	
800	102. 5	-----	------	------	------	------	49. 0	19. 0	5. 89	2. 77	1. 42	. 78	. 42	
900	115. 3	-----	------	------	------	------	62. 3	24. 1	7. 6	3. 51	1. 80	. 99	. 54	0. 20
1,000	126. 6	-----	------	------	------	------	76. 9	29. 8	9. 3	4. 35	2. 21	1. 22	. 66	. 25

TABLE VIII.—*Loss of Air Pressure Due to Friction, Pounds per Square Inch in 1,000 Feet of Pipe, 125 Pounds Gage Initial Pressure*

Free air, cu. ft. per min.	Equivalent compressed air, cu. ft. per min.	Nominal diameter, inches												
		½	¾	1	1¼	1½	2	2½	3	3½	4	4½	5	6
10	1. 05	5. 35	0. 82	0. 23										
20	2. 11	21. 3	3. 21	. 92	0. 21									
30	3. 16	48. 0	7. 42	2. 07	. 47	0. 21								
40	4. 21		13. 2	3. 67	. 85	. 38								
50	5. 26		20. 6	5. 72	1. 33	. 59								
60	6. 32		29. 7	8. 25	1. 86	. 84	0. 23							
70	7. 38		40. 5	11. 2	2. 61	1. 15	. 31							
80	8. 42		53. 0	14. 7	3. 41	1. 51	. 40							
90	9. 47		68. 0	18. 6	4. 30	1. 91	. 51	0. 20						
100	10. 50			22. 9	5. 32	2. 36	. 63	. 25						
125	13. 15			39. 9	8. 4	3. 70	. 98	. 38						
150	15. 79			51. 6	12. 0	5. 30	1. 41	. 55	0. 17					
175	18. 41				16. 3	7. 2	1. 95	. 75	. 24					
200	21. 05				21. 3	9. 4	2. 52	. 98	. 31					
250	26. 30				33. 2	14. 7	3. 94	1. 53	. 48	0. 22				
300	31. 60				47. 3	21. 2	5. 62	2. 20	. 70	. 32				
350	36. 80					28. 8	7. 7	3. 00	. 94	. 44	0. 22			
400	42. 10					37. 6	10. 0	3. 91	1. 23	. 57	. 28			
450	47. 30					47. 7	12. 7	4. 92	1. 55	. 72	. 37	0. 20		
500	52. 60					58. 8	15. 7	6. 10	1. 93	. 89	. 46	. 25		
600	63. 20						22. 6	8. 8	2. 76	1. 28	. 65	. 36	0. 20	
700	73. 80						30. 0	11. 9	3. 74	1. 75	. 89	. 49	. 27	
800	84. 20						40. 2	15. 6	4. 85	2. 28	1. 17	. 64	. 35	
900	94. 70						51. 2	19. 8	6. 2	2. 89	1. 48	. 81	. 44	
1,000	105. 1						63. 2	24. 5	7. 7	3. 57	1. 82	1. 00	. 55	0. 21

b. **Flow of Compressed Air in Pipes.** In considering the flow of compressed air in pipes, solve for the value of Q, volume of cubic feet per minute from formula (1) as follows:

$$Q=\sqrt{\frac{p\times P}{F}}$$

c. **Air Consumption.** The air consumption for various tools and equipment expressed in cubic feet of free air per minute is listed in tables IX, X, and XI. Discharge of air through orifices, indicated in cubic feet of air per minute measured at absolute pressure of 14.7 pounds per square inch and 70° F., is listed in table XII. Multipliers for determining volumes of air compressed and delivered at various pressures when capacities are expressed in cubic feet of free air at atmospheric pressure and at constant temperature are listed in table XIII.

TABLE IX.—*Air Consumption of Shop Tools and Equipment*

Tools or equipment	Size or type	Air pressure, pounds per sq. in.	Air consumed, cu. ft. of free air per min.
Blow gun		70–90	3
Bus or truck lift		70–90	10
Car lift		70–90	6
Car rocker		70–90	6
Drills, rotary	Weight 10 lbs	70–90	15
Engine, cleaning		70–90	5
Grease gun		70–90	4
Grinders, hand	Weight 17 lbs	70–90	20
Grinders, hand	Weight 24 lbs	70–90	30
Paint sprays	Production gun	40–70	20
Paint sprays	Touch up gun	40–70	30
Paint sprays	Small hand	70–90	2–7
Riveters, hand	Weight 13 lbs	70–90	18
Riveting machines	Reach 12–30	70–90	5
Riveting machines	Reach 36–45	70–90	6½
Spring oiler		70–90	3
Surfacers	Weight 35 lbs	70–90	30–40
Surfacers	Weight 65 lbs	70–90	60–70
Tire changer		70–90	½
Tire inflater		70–90	1½
Tire spreader		70–90	½
Valve grinder		70–90	2

TABLE X.—*Air Requirements for Pneumatic Pumping Systems*

Pump capacity, g. p. m.	Compressed air required, cu. ft. of free air per min.
25	1. 5
45	2. 5
80	4. 5
150	7. 5
170	11. 0

TABLE XI.—*Air Consumption for Laundry Machinery*

Equipment	Size	Cu. ft. of air compressed and delivered at 70 p.s.i.
2-operator shirt unit		0. 933
4-operator shirt unit		2. 195
Garment or utility presses	2–(50″x15″x8″)	. 678
Linen coat unit	2–(54″)	. 678
Trouser unit or nurses uniform unit		. 519
General Laundry press	37″x12″x7″	. 273
Coat and shirt press	37″x18″x18″	. 565
Shirt press	37″x18″x18″	. 565
Wearing apparel press	50″x15″x8″	. 339
Linen and duck coats	52″x18″x18″	. 339
Shirt sleeve press	21″x10½″x10½″	. 182
Oval shaped buck press	21″x9″	. 09
Shirt yoke press	19″x11″	. 098
Collar press	21″x6½″	. 093
Cuff press	13″x8½″	. 093
Starch collar press	21″x12½″	. 339
Cuff and gusset press	10½″x6½″	. 124
Handkerchief press	20″x20″	. 5
Handkerchief and napkin press	25″x25″	. 5
Unloading washer		. 2
Unloading extractor		. 15
Conditioning tumbler and conveyor		. 09

TABLE XII.—*Discharge of Air Through Orifice*

[Cubic feet of air per minute measured at absolute pressure of 14.7 pounds per square inch and 70° F.]

Gage pressure before orifice, pounds per sq. in.	Diameter of orifice, inches										
	1/64	1/32	1/16	1/8	1/4	3/8	1/2	5/8	3/4	7/8	1
	Discharge of free air, cubic feet per minute										
1	0.028	0.112	0.450	1.80	7.18	16.2	28.7	45.0	64.7	88.1	115
2	.040	.158	.633	2.53	10.1	22.8	40.5	63.3	91.2	124	162
3	.048	.194	.775	3.10	12.4	27.8	49.5	77.5	111	152	198
4	.056	.223	.892	3.56	14.3	32.1	57.0	89.2	128	175	228
5	.062	.248	.993	3.97	15.9	35.7	63.5	99.3	143	195	254
6	.068	.272	1.09	4.34	17.4	39.1	69.5	109	156	213	278
7	.073	.293	1.17	4.68	18.7	42.2	75.0	117	168	230	300
9	.083	.331	1.32	5.30	21.2	47.7	84.7	132	191	260	339
12	.095	.379	1.52	6.07	24.3	54.6	97.0	152	218	297	388
15	.105	.420	1.68	6.72	26.9	60.5	108	168	242	329	430
20	.123	.491	1.96	7.86	31.4	70.7	126	196	283	385	503
25	.140	.562	2.25	8.98	35.9	80.9	144	225	323	440	575
30	.158	.633	2.53	10.1	40.5	91.1	162	253	365	496	648
35	.176	.703	2.81	11.3	45.0	101	180	281	405	551	720
40	.194	.774	3.10	12.4	49.6	112	198	310	446	607	793
45	.211	.845	3.38	13.5	54.1	122	216	338	487	662	865
50	.229	.916	3.66	14.7	58.6	132	235	366	528	718	938
60	.264	1.06	4.23	16.9	67.6	152	271	423	609	828	1,082
70	.300	1.20	4.79	19.2	76.7	173	307	479	690	939	1,227
80	.335	1.34	5.36	21.4	85.7	193	343	536	771	1,050	1,371
90	.370	1.48	5.92	23.7	94.8	213	379	592	853	1,161	1,516
100	.406	1.62	6.49	26.0	104	234	415	649	934	1,272	1,661
110	.441	1.76	7.05	28.2	113	254	452	705	1,016	1,383	1,806
120	.476	1.91	7.62	30.5	122	274	488	762	1,097	1,494	1,951
125	.494	1.98	7.90	31.6	126	284	506	790	1,138	1,549	2,023

Table is based on 100 percent coefficient of flow.
For well-rounded entrance, multiply values by 0.97; for sharp-edged orifices, multiply by 0.65.

TABLE XIII.—*Multipliers for Determining Volumes of Air Compressed and Delivered at Various Pressures When Capacities Are Expressed in Cubic Feet of Free Air at Atmospheric Pressure and at Constant Temperature*

Pressure	Multiplier	Pressure	Multiplier	Pressure	Multiplier	Pressure	Multiplier
Pounds		*Pounds*		*Pounds*		*Pounds*	
1	0. 9363	26	0. 3612	51	0. 2237	76	0. 1621
2	. 8802	27	. 3525	52	. 2204	77	. 1603
3	. 8305	28	. 3443	53	. 2171	78	. 1586
4	. 7861	29	. 3364	54	. 2140	79	. 1569
5	. 7462	30	. 3289	55	. 2109	80	. 1552
6	. 7101	31	. 3217	56	. 2079	81	. 1536
7	. 6774	32	. 3148	57	. 2050	82	. 1520
8	. 6476	33	. 3082	58	. 2022	83	. 1505
9	. 6203	34	. 3018	59	. 1995	84	. 1489
10	. 5951	35	. 2958	60	. 1968	85	. 1474
11	. 5720	36	. 2899	61	. 1942	86	. 1460
12	. 5506	37	. 2843	62	. 1917	87	. 1445
13	. 5307	38	. 2789	63	. 1892	88	. 1431
14	. 5122	39	. 2737	64	. 1868	89	. 1418
15	. 4949	40	. 2687	65	. 1844	90	. 1404
16	. 4788	41	. 2639	66	. 1822	91	. 1391
17	. 4637	42	. 2593	67	. 1799	92	. 1378
18	. 4495	43	. 2548	68	. 1778	93	. 1365
19	. 4362	44	. 2504	69	. 1756	94	. 1352
20	. 4236	45	. 2462	70	. 1736	95	. 1340
21	. 4118	46	. 2422	71	. 1715	96	. 1328
22	. 4005	47	. 2382	72	. 1696	97	. 1316
23	. 3899	48	. 2344	73	. 1676	98	. 1304
24	. 3798	49	. 2308	74	. 1657	99	. 1293
25	. 3703	50	. 2272	75	. 1639	100	. 1282

Example 3: One hundred cubic feet of free air represents the output of the compressor at atmospheric pressure. What will be the output of the compressor when the air is compressed and delivered at 70 p.s.i. at constant temperature?

The multiplier for pressure at 70 p.s.i. is 0.1736.

Therefore, $100 \times 0.1736 = 17.36$ cubic feet.

3–09. AIR RECEIVERS

The air pressure or tank should be placed as close to the compressor as possible so as to keep the discharge pipe short.

All receivers should be provided with a drain cock near the bottom and drained from time to time. They should also be provided with a safety valve which should be tested occasionally by lifting the lever or raising the pressure to that required to operate the valve.

TABLE XIV.—*A. S. M. E. Standard Air Receivers*

Size		Actual compressor capacity for which receiver is suited, cu. ft. free air per minute*	Volume, cubic feet	Safety valves		Size of drain valves	Types of opening for cleaning
Diameter, inches	Length, feet			Number	Diameter, inches		
14	4	60	4½	1	¾	Size of drain should meet requirements of A. S. M. E. code for unfired pressure vessels.	Openings for inspection and cleaning are required and should meet specifications of A. S. M. E. code for unfired pressure vessels.
18	6	95	11	1	1		
24	6	185	19	1	1½		
30	7	305	34	1	2		
36	8	450	57	1	2½		
42	10	640	96	1	3		
48	12	1, 275	151	2	3		
54	14	1, 900	223	3	3		
60	14	3, 000	275	3	3		
66	18	4, 500	428	3	3		

Table XIV is for discharge pressures up to 125 pounds per square inch.

*For automatic start-and-stop service, extra large receivers are recommended to avoid starting too frequently.

All receivers up to 42 x 120 inches inclusive have screw openings; 48 x 144 inches and larger have flanged inlet and discharge openings with companion flanges.

Receivers are furnished complete with safety valves, pressure gage, hand holes or manhole, drain valve and nipple, and base for vertical receivers.

3–10. DESIGN ANALYSIS

Design analysis in accordance with paragraph 4106.13 of Orders and Regulations should be submitted with plans and specifications.

APPENDIX

DEFINITIONS: Compressed air terms in common use are defined as follows:

Absolute Pressure is the total pressure measured from absolute zero, that is, from an absolute vacuum. It equals the sum of the gage pressure and the atmospheric pressure corresponding to the barometer (gage pressure, expressed in pounds per square inch).

Absolute Temperature equals the degrees Fahrenheit plus 459.6 or the degrees Centigrade plus 273. These values are referred to as degrees Rankin and degrees Kelvin, respectively.

Adiabatic Compression of a gas is effected when no heat is transferred to or from the gas during the compression process. In compressor practice, this definition refers only to the reversible adiabatic, or isentropic, compression process. The characteristic equation relating pressure and volume during adiabatic compression is—

$$pv^k = C$$

where "k" is the ratio of the specific heat at constant pressure to the specific heat at constant volume.

Air Indicated Horsepower is the horsepower calculated from compressor indicator diagrams. The term applies only to displacement type compressors.

Brake Horsepower or Shaft Horsepower is the measured horsepower input to the compressor. It should be noted that horsepower, either indicated or brake, for any displacement compressor varies with compression ratio as well as absolute intake and discharge pressures. Performance guarantees are expressed in terms of horsepower per cubic foot capacity. In comparing test results with performance guarantees, corrections should be made for any deviation from specified values of absolute intake pressures and ratio of compression.

Capacity (actual delivery) of an air or gas compressor is the actual quantity of air or gas compressed and delivered, expressed in cubic feet per minute at conditions of total temperature, total pressure, and composition prevailing at the compressor inlet. The capacity is always expressed in terms of air or gas at intake conditions rather than in terms of standard air or gas.

Capacity of a Positive Displacement—Type Compressor working under a given ratio of compression is not affected by barometric pressure or temperature at the compressor intake.

Compression Efficiency (Adiabatic) is the ratio of the theoretical horsepower to the horsepower imparted to the air or gas actually delivered by the compressor. The power imparted to the air or gas is brake horsepower minus mechanical losses.

Compressor Efficiency (Adiabatic) is the ratio of the theoretical horsepower to the shaft horsepower. It is equal to the product, compression efficiency times mechanical efficiency.

Degree of Intercooling is the difference in air or gas temperatures between the inlet of the compressor and the outlet of the intercooler.

Discharge Pressure is the absolute total pressure at the discharge flange of a compressor. It is commonly stated in terms of gage pressure; unless the associated barometric pressure is included, this is an incomplete statement of discharge pressure.

Discharge Temperature is the total temperature at the discharge flange of the compressor.

Displacement of a compressor is the volume displaced per unit of time and is usually expressed in cubic feet per minute. In a reciprocating compressor it equals the net area of the compressor piston multiplied by the length of stroke and by the number of compression strokes per minute. The displacement rating of a multi-stage compressor is the displacement of the low pressure cylinder only.

Electrical Input is measured at the motor terminals. For synchronous motors with separately driven exciter, the excitation input as measured at the slip rings is added to the input to the stator. For synchronous motors with direct connected exciters, the exciter losses are deducted from the measured stator input.

Free Air is defined as air at atmospheric conditions at any specific location. Because the altitude, barometer, and temperature may vary at different localities and at different times, it follows that this term does not mean air under identical or standard conditions. Free air as a measure of volume may be applied either to displacement or capacity and in no way distinguishes between these two terms.

Gas Specific Weight is the weight of air or gas per unit volume. Unless otherwise specified, it refers to the weight per unit volume at conditions of total pressure, total temperature and composition prevailing at the inlet of the compressor.

Inlet Pressure is the absolute total pressure at the inlet flange of a compressor.

Inlet Temperature is the total temperature at the intake flange of the compressor.

Intercooling is the removal of heat from the air or gas between stages or stage groups.

Isothermal Compression is effected when interchange of heat between the air or gas and surrounding bodies occurs at a rate precisely sufficient to maintain the air or gas at constant temperature during compression. It may be considered as a special case of polytropic compression. The characteristic equation for isothermal compression is $pv=C$.

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k Value is the value of the exponent defined by the equation of Adiabatic Compression for any particular gas.

Load Factor is the ratio of the average compressor load during a given period of time to the maximum rated load of the compressor.

Mechanical Efficiency is the ratio of the horsepower imparted to the air or gas to the brake horsepower. In the case of a displacement type compressor it is the ratio of the air or gas indicated horsepower to the indicated horsepower of the power cylinders for a steam engine or internal combustion engine driven compressor or to the brake horsepower delivered to the shaft in the case of a power driven compressor.

n Value is the value of the exponent as defined by the equation of Polytropic Compression for any particular gas.

Perfect Intercooling prevails when the air temperature leaving the intercoolers is equal to the temperature of the air at the compressor intake.

Polytropic Compression is effected when heat is transferred to or from the gas, during the compression process, at the precise rate such that the relation between the pressure and volume can be expressed by the equation—

$$pv^n = C$$

in which n is constant. Where the actual compression path for a particular compressor is known, and where the heat transfer to or from the gas is at the proper rate, the value of n may be determined from the equation.

Pressure Ratio or Compression Ratio is the ratio of the absolute discharge pressure to the absolute inlet pressure.

Pressure Rise is the difference between the discharge pressure and the inlet pressure.

Specific Gravity is the ratio of the specific weight of air or gas to that of dry air at the same pressure and temperature.

Speed refers to the revolutions per minute of the compressor shaft.

Standard Air is defined as air at temperature of 68° F., a pressure of 14.70 pounds per square inch absolute, and a relative humidity of 36 percent (.0750 density). This agrees with the definitions adopted by the ASME, but in the gas industries the temperature of "standard air" is usually given as 60° F.

Static Pressure is the pressure measured in air or gas in such a manner that no effect on the measurement is produced by the velocity of the air or gas.

Static Temperature is the actual temperature of a moving gas stream. It is related to total temperature in the same manner that static pressure is related to total pressure. It is measured in such manner that no effect on the measurement is produced by the velocity of the air or gas.

Temperature Rise Efficiency is the ratio of the theoretical horsepower to the horsepower computed from the measured inlet temperature and the measured discharge temperature of the air or gas. Under certain conditions it may be used to determine the Compression Efficiency (Adiabatic). These conditions include constancy of specific heats of the air or gas, and determination of loss of heat from the compressor, and extreme accuracy of air temperature measurement to avoid error due to velocity and radiation. Temperature rise efficiency is useful principally to designers and is not satisfactory as the basis of a guarantee or commercial statement of performance.

Theoretical Horsepower is defined as the horsepower required to compress adiabatically the air or gas delivered by the compressor through the specified range of pressures.

Total Pressure is the pressure which would be produced by stopping a moving air or gas stream. It is the pressure by an impact tube. In a stationary body of air or gas, the static and total pressures are numerically equal.

Total Temperature is that temperature which would be measured at the stagnation point if a gas stream were stopped, with adiabatic compression from the flow condition to the stagnation pressure.

Velocity Pressure is the total pressure minus the static pressure in an air or gas stream. It is generally measured by a pitot tube. In displacement type compressor practice it is usually so small that it can be neglected.

Volumetric Efficiency is the ratio of the capacity of the compressor to the displacement of the compressor. The term does not apply to centrifugal compressors.

Note. Tables I, II, III, V, VI, VII, VIII, XII, and XIV, are reprinted from copyright material by permission of Compressed Air Institute. Table IV and Graph I are reprinted from copyright material by permission of Walworth Company.

Values for p, v, and c in Adiabatic Compression, Isothermal Compression, and Polytropic Compression have the following values:

p=Absolute Pressure.
v=Volume.
c=Constant.

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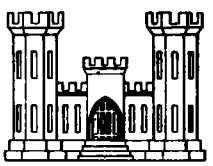

ARMY SERVICE FORCES
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

US Army

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APPENDIX

DEFINITIONS

PART V
MECHANICAL DESIGN

CHAPTER 4
PLUMBING

4-01 SCOPE: The following information and instructions cover the principal requirements in the design of plumbing. Good engineering practice consistent with the type of construction covered by these instructions should be followed in regard to special conditions, problems, and items not covered specifically by these instructions.

4-02 GENERAL: Rules and regulations governing design have been standardized in order to provide good and economical plumbing work. It has not been intended to incorporate all the information available but to compile only such parts thereof as are most likely to be of value to the designing engineer. The terms "Plumbing Installation" and "Plumbing System", as used herein, include the water service pipe and the building drain from their connections in the building to points five (5) feet outside of building, including all pipes, fixtures, vents, branches, devices, rain leaders and storm branches connected thereto. The plumbing installations should be such as to safeguard health, and should be of the most economical arrangement. Consideration should always be given in the field to location of buildings with reference to sewers and water mains, as these details govern the direction and runs for the branch piping.

4-03 DRAWINGS: The drawings should be accurate and to scale with fixtures, equipment and piping shown in proper location. Where there are congested places on the plans, large scale details should be made with dimensions locating all work relative to some structural feature of the building. Due consideration should be given to the following procedure in making plumbing layouts.

Each set of drawings should have a legend covering symbols and abbreviations as indicated on Figure 1. All equipment and fixtures, except the more common fixtures such as water closets, urinals and lavatories, should be identified on the plumbing plans. The legend, notes and tables should be grouped together and condensed; simplified titles should be outstanding, uniform and neat. Notes should include items that are pertinent to the plans to clarify or complete the layout. Where practicable, all notes, legends and schedules should be grouped at the right of the plan above the title block.

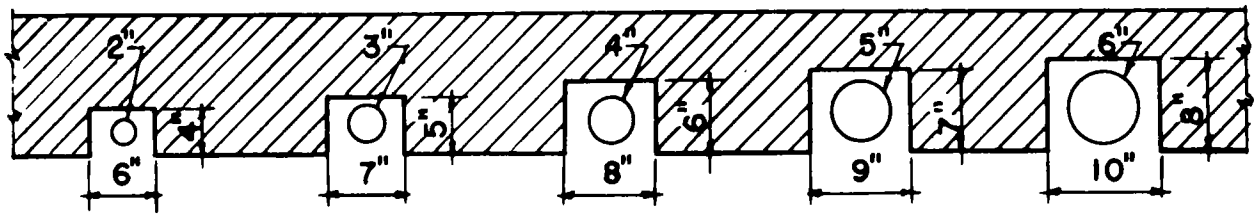
Each job should be accompanied by a project folder. Project folder should include plumbing calculations, architectural information, project data card, including capacities of equipment, and all correspondence.

Ample space should be provided for piping and particular care should be taken to avoid structural interferences and conflict between different branches of mechanical and electrical equipment. All piping should be shown as nearly as possible in the location at which it is to be actually installed. Pipesshould be concealed in chases, furring, or be run in pipe shafts or closets. Exposed vertical pipes above first floor should be kept to a minimum. Water and waste piping should not be located in exterior walls where there is danger of freezing. No water piping should be run in floor fill or in furred space above ornamental ceilings.

Plumbing sections of soil, waste, drain and vent stacks and water risers should be shown for all buildings three (3) stories and higher.

LEGEND

PURPOSE	PLAN	LINE	ABBREVIATION	BAND INITIAL	BAND COLOR
SOIL, WASTE, OR LEADER		———	S,W OR L.		
DRAIN	D	———	D	D	BLUE
SOIL STACK	S		SS	SS	"
WASTE STACK	W		WS	WS	"
VENT STACK	V	- - - - - - -	VS	VS	"
COLD WATER		——·——·——	CW	CW	WHITE
HOT WATER		——··——··	HW	HW	"
HOT WATER RETURN		——·--·——·--·	HWR	HWR	"
FIRE LINE		——F——F——	FL	FL	RED
GAS	G	——G——G——	G	G	BROWN
ACID OR CHEMICAL WASTE		——ACID——	AW	AW	GREEN
CHILLED DRINKING WATER		——DW—DW——	DW	DW	WHITE
CHILLED DRINK. WATER RETURN		—DWR-DWR—	DWR	DWR	BLACK
COMPRESSED AIR	A	——A——A——	A	A	GRAY
SUB-SOIL DRAIN		——▸——▸——	SSD	SSD	GREEN
INDIRECT WASTE		——›——›——	IND.W	IND.W	"
TEMPERED WATER	T	——T——T——	TW	TW	WHITE
OIL	O	——O——O——	O	O	BLACK
VACUUM	V	——V——V——	VAC	V	CREAM



PIPE CHASE DIMENSIONS

PLUMBING SYMBOLS FOR PIPING

FIGURE I

Pipe sleeves should be shown on the structural drawings for pipes passing through beams or footings. Sleeves for cast iron pipe should be large enough to pass the hubs of pipes or beads of fittings. The elevations of sleeves need not be given, except where passing through membrane waterproofing which requires a special sleeve with clamp.

Where the sewers are not sufficiently deep to drain basement fixtures by gravity, the main toilet rooms should be located on upper floors. If necessary to drain areas, etc., centrifugal sump pumps should be used when necessary to drain floors and areaways. Pumps should be single or duplex, depending on the probable amount of water to be handled and the necessity of continuous service. Where sanitary sewage is to be pumped, consideration should be given to the use of duplex pneumatic sewage ejectors set in a concrete pit.

The grades of all drain lines should be accurately figured and the center line elevations established. Attention is called to the fact that where open type backwater valves are used there is a difference in elevation between the inlet and outlet of approximately one and one half (1½) inches for the four (4) inch size (larger sizes are somewhat greater) for which an allowance should be made when figuring the grade of sewer piping.

Where sub-soil drain connects to building drain, a running trap and back-water valve should be indicated in the branch. Access to the running trap and back-water valve should be provided.

a. Tracing Notes: The following notes should be placed on one of the drawings, where applicable:

Pumps: Duplex Set Hot Water Circulating Pumps (2)
Capacity Each
_____Gallons Per Minute
Total Dynamic Head_____Feet
Non-Automatic Ejector Shall Have a
Capacity of_____Gallons Per Minute
And a Total Dynamic Head of_____Feet
Chilled Water Circulating Pumps
Capacity
_____Gallons Per Minute
Total Dynamic Head_____Feet

Water Heaters:
Capacity_____Gallons Per
Hour_____° F. Rise In Temperature

Hot Water Storage Tanks:
Dimensions_____" x_____"
Capacity_____Gallons

Hot Water Generators:
Dimensions_____" x_____"
Storage Capacity_____Gallons
_____Square Feet of Heating Surface

Water Coolers:
Cafeteria Type
Cooling Capacity G.P.H. _____Chilled_____°F to 50° F
Storage Capacity_____Gallons Minimum
Electric Drinking Water Coolers
Type ( ), Size ( )
Cooling Capacity_____G.P.H. Minimum

Condensing Units:

Capacity of Each Condensing Unit

_____Btu Per Hour Minimum

Condensing Medium; Water___°F., or Air___°F.

Grease Interceptors:

_____Pounds Fat Capacity

Flow Rating_____Gallons Per Hour

4-04 FIXTURES, MATERIALS AND EQUIPMENT. Fixtures, materials and equipment used in any plumbing system or any part thereof should meet accepted standards and be free from defects. Plumbing fixtures should be sanitary, ample in number and suitably located. All fixtures, materials and equipment should be located in a manner to afford access for cleaning.

a. Types of Fixtures. Plumbing fixtures should be made of smooth nonabsorbent material and should be free from fouling surfaces. Wherever practicable, supply and waste piping should be run to the wall. Plumbing fixtures so far as practicable should comply with the latest issue of Federal Specifications for Plumbing Fixtures and Standard Corps of Engineer Specifications. Variations from the fixtures covered in the Federal Specification should be permitted only in cases where fixtures covered by that specification are not adaptable to the project. In such cases the quality of the earthenware fittings and trimmings should be as required in Federal Specifications.

b. Fixture Requirements. The number of plumbing fixtures to be installed should be based on the number of contemplated personnel that will be assigned to the various floors or sections. The maximum number of persons for theaters and chapels should be based on the seating capacity; for industrial buildings, shops, hangars, warehouses and similar types of buildings on the number of employees; and for hospitals on the number of patients and the personnel required in addition to the patients. The number of service sinks required in any building should be determined by the janitor requirements and the location of the plumbing. The number of fixtures required in a building should be as prescribed under Table 1.

TABLE I

PERMISSIBLE NUMBER OF PERSONS PER FIXTURE

	Water Closets	Lava-tories	Urinals	Showers	Bath Tubs	Drinking Fountains.
Barracks for E.M.	10-12	8-9	16-18	16-18	-	75
Barracks for Women's Army Corps *	6-8	6-7	-	10-14	25-30	50-75
Quarters for Telephone Operators	6-8	6-7	-	10-14	25-30	50-75
Quarters for Civilian Women	6-8	6-7	-	10-14	25-30	50-75
Quarters for Nurses**	2	2	-	2	2	50-75
Quarters for Officers	2	2	-	2	-	50-75
Quarters for Cadet Officers	4	2	8	4	-	50-75
Industrial Buildings: Shops, Hangars, Warehouses, etc.						
Male	20	15	40	-	-	50-100
Female	15	15	-	-	-	50-100
Theaters, Assembly Halls, etc.						
Male	300	200	300	-	-	400
Female	150	150	-	-	-	400
Schools Male	25	15	25	-	-	100
Female	15	15	-	-	-	100
Chapels Male	300	150	300	-	-	400
Female	150	150	-	-	-	400
Hospital,						
Patients	8-10	5-7	18-20	18-20	25	100
Employees-Male	20	15	40	***	-	100
Female	75	15	-	***	-	100
Administration & Other Buildings for Similar Purposes ****						
Up to 10 Employees	5	5	10	-	-	10
11 " 16 "	8	8	16	-	-	16
17 " 25 "	9	9	25	-	-	25
26 " 100 "	15	15	30	-	-	50
Over 100 "	15	15	40	-	-	75
Mess Halls, Kitchen Personnel						
Hospitals Male	20	10	40	***	-	-
Female	10	10	-	***	-	-
Troops Enlisted Men	20	10	40	-	-	-
Women's Army Corps	10	10	-	-	-	-
Civilian Mess: Male	20	10	40	-	-	-
Female	10	10	-	-	-	-
Mess Hall Patrons						
Male	200	200	300	-	-	-
Female	150	150	-	-	-	-
Swimming Pool						
Toilet Room Male	40	40	40	30	-	-
Female	20	40	-	30	-	-

TABLE I CONT'D

* Twenty persons for each single-compartment laundry tray.
** Minimum of one bath tub and one shower in each toilet room.
*** Shower for each toilet room, hospital messes only.
**** The proportion of fixtures for women's toilets will be the same as required for men with the addition of one (1) water closet for each urinal omitted.

Each toilet room in enlisted men's barracks should be equipped with one 2-compartment laundry tray and one service sink.

c. Frost-proof Closets: Frost-proof closets should be provided only in compartments which have no direct access to a building used for human habitation or occupancy. The soil pipe between the hopper and the trap should not be less than three inch diameter and should be of lead, or cast iron enameled on the inside. The waste tube from the valve should not be connected to the soil pipe or sewer.

d. Swimming Pools: Standards for design, equipment and operation of swimming pools are included in many state department of health regulations. These for the most part are based on the report by The American Public Health Association dated 1942 and the latest requirements established by the Surgeon General's Office concerning Army swimming pools and swimming areas. In the design of any swimming pool, the standards above referred to should be followed. A summary of those sections applying to piping systems follows:

Under no circumstances should piping systems be so designed and constructed to permit pool water to enter a potable-water-supply system nor waste water or sewage to enter the pool through backflow connections or interconnections.

Cross-connections or interconnections in the pool piping system whereby pool water may under some conditions enter a potable-water-supply system should be avoided by providing for the admission of make-up water above the overflow elevation of the pool or by pumping from a pump suction well; and where filters are installed and filter washing with the recirculation pump is not feasible, a washwater pump of proper capacity should be installed and a suction well or small elevated tank used to supply water to the pump, the discharge to the suction well or tank being above the flow line. In no case should valved cross-connections be permitted, whereby water from a potable-water supply may be admitted directly to the recirculation system for the purpose of filter washing.

Pool drains or drains from filters, where the recirculating system is used, should not be connected to sanitary sewers. Such drains should discharge to the nearest storm sewer or open water course. Where such connections are not possible, pumping of pool and filter-wash drainage may be necessary.

e. Miscellaneous Fixtures: Baptistries, ornamental and lily ponds, aquaria, ornamental fountain basins, and similar constructions having water supply connections, should have the water supply thereto protected from backflow.

f. Ventilation: No plumbing fixtures should be located in any room not provided with proper ventilation. Ventilating pipes from toilet rooms should form an independent system.

g. Selection of Piping Materials and Storage Tanks: Water that that has been classified into "Categories" according to Calcium content is considered satisfactory for the purpose of selecting piping materials and storage tanks for installation in plumbing systems. The selection of pipe, valves, fittings and storage tanks should be made by referring to the General Category of Waters as follows:

Category 1: Calcium content, 0 to 25 ppm, expressed as calcium, very soft water, low pH and corrosive: the pipe, valves and fittings should be non-ferrous. Storage tanks should be constructed of non-ferrous metals or tanks should be cement lined.

Category 1A: Calcium content, 26 to 50 ppm, expressed as calcium, soft water, low pH and corrosive: the pipe, valves and fittings should be non-ferrous. Storage tanks should be constructed non-ferrous metals or tanks should be cement lined.

Category 2: Calcium content over 50 ppm, expressed as calcium; Langelier's index changes from negative at 20 degrees to positive at 90 degrees F.; the pipe, valves and fittings on cold water may be ferrous. All pipe, valves and fittings for use with hot water should be non-ferrous and tanks should be non-ferrous or cement lined.

Category 2A: Calcium content over 50 ppm, expressed as calcium; Langelier's index always positive; the pipe, valves, fittings and tanks should be as stated for Category 2 waters.

Category 3: Waters not included in Categories 1 to 2A inclusive; the pipe, valves, fittings and tanks should be as stated for Category 2 waters.

4-05 JOINTS AND CONNECTIONS: Joints and connections should be made gas tight and watertight.

a. Vitrified Clay and Concrete Pipe: Joints in vitrified clay and concrete pipe, or between such pipe and metals, should be hot-poured or cemented joints.

Hot-poured jointing compounds should liquify and flow freely at the pouring temperature, should adhere to the pipe, and should be sufficiently elastic when cold to permit slight movement without injury to joints. The compound should be of a composition that will not deteriorate in water or sewage at temperatures up to one hundred fifty (150) degrees Fahrenheit.

The mortar for cement joints should be freshly mixed, and of one part portland cement and two parts sand by weight. A layer of mortar should be placed in the bottom of the bell and the packing calked into it. The remainder of the joint should then be completely filled with the mortar and the outer face of the joint beveled.

b. Bell and Spigot Cast Iron Pipe: Calked joints should be firmly packed with approved packing, secured with well calked lead not less than one (1) inch deep, and no paint, varnish or putty should be permitted until after the joint is tested.

c. Screw Jointed Pipe: Screw joints should be made with a lubricant applied to the male thread. All burrs and cuttings should be removed before threading. All threads should be cut to make a tight joint and they should conform with the requirements for American National taper pipe threads.

d. Wiped and Welded Joints: Joints in lead pipe, or between lead pipe and brass or copper pipes, ferrules, soldering nipples, or traps should be wiped or welded.

e. Sweat Joints: Copper tubing installed inside of buildings should be the sweat joint type. The joints in thin-wall copper tubing are most generally made with soft solders using gasoline or air-acetylene torches.

Zinc chloride or mixture of zinc and ammonia chlorides are used almost exclusively as fluxes for soft soldered joints. These fluxes are acid in reaction, but unless needlessly excessive amounts have been used, no damage to the joint by corrosion is to be feared. Apparently the most satisfactory form in which to use flux for making sleeve-type joints in tubing is to have the fluxing material incorporated with mineral grease into a paste.

With the hard solders, a flux that is not decomposed at the soldering temperature should be used. Borax or mixture of borax and boric acid are satisfactory.

f. Slip Joints and Unions: Slip joints, other than expansion joints, should be used only in the trap seal or on the inlet side of the trap. Unions on the sewer side of a trap should be ground faced and should not be concealed or enclosed.

4-06 TRAPS AND CLEANOUTS:

a. Types and Sizes of Traps: Every trap should be self-cleaning and should be of the same nominal size as the drain to which it is connected. The size of trap and fixture drain for a given fixture should be the same as the size of the branch. The size of branches required for various types of fixtures is indicated under Table IV.

b. Traps Required: Each fixture should be separately trapped by an approved trap placed as near to the fixture as possible or integral therewith, except that a set of not more than three (3) fixtures, such as lavatories, sinks or laundry trays, or a set of two (2) laundry trays and one (1) sink, may connect with a single trap.

c. Prohibited Traps: No form of trap which depends for its seal upon the action of movable parts or partitions that cannot be exposed for inspection, except in a trap integral with the fixture, should be used for fixtures. No fixture should be double-trapped. The provision relative to "partitions" in traps applies only to traps constructed separately from and attached to fixtures in the process of installation. The purpose of the provision is to prevent the use of traps with inner partitions not accessible for inspection through which, if defective, the water seal of the trap might be lost without giving any indication that it had been lost. The provision regarding double-trapping is not to be construed as preventing the installation of a grease interceptor, sand interceptor, or oil interceptor in addition to a fixture trap or traps, provided a vent intervenes between such interceptor and fixture traps.

d. Trap Levels and Protection: All traps should be set true with respect to their water seals, and protected from frost.

e. Pipe Cleanouts Required: Accessible cleanouts should be provided at or near the foot of each vertical waste or soil stack and each inside leader that connects to the building drain, and at each change in direction of the building drain greater than forty-five (45) degrees. The distance between cleanouts in horizontal soil lines should not exceed fifty (50) feet. Cleanouts should be of the same nominal size as the pipes.

f. Accessibility of Traps and Cleanouts: Underground traps and cleanouts should be made accessible by the construction of manholes with proper cover, except where cleanouts are flush with the floor.

g. Grease Interceptors: Grease interceptors should be provided on the waste pipe from grease disposing sinks. Each interceptor should be indicated in a location that will permit proper and complete removal of the grease. Grease interceptors are not required on the wastes from dishwashing machines when pre-wash sinks are employed.

h. Sand interceptors: Sand interceptors, when installed, should be so designed and placed as to be readily accessible for cleaning.

i. Back-water Valves: Back-water valves should have all bearing parts of corrosion-resisting metal, and be so constructed that the valve seat be equal to the cross-sectional area of the pipe connection. When street sewers are combined, a back-water valve should be provided on the building drain. Where the invert of the sanitary sewer receiving discharge from a building is less than four (4) feet below the lowest floor, special study should be made to determine the need for a backwater valve. A gate valve should be installed on the sewer side of each back-water valve, both installed in a manhole. Fixtures on upper floors should be connected to building drain between the sewer and the gate valve protecting the low fixtures.

4-07 PUMPS AND EJECTORS: Detailed requirements for pumps and ejectors should be in accordance with the opinions and recommendations of Hydraulic Institute, a trade association comprising the principal manufacturers of displacement and centrifugal pumps.

a. Sewage Ejectors: Where the sewers are not of sufficient depth to drain the lower floor fixtures by gravity, the main toilet rooms should be located on higher floors wherever possible. When the sewage must be pumped, a duplex pneumatic sewage ejector should be provided in a concrete pit below the lowest floor. The pit should be protected by a pipe rail. The capacity of each ejector should be determined by Table II.

TABLE II

Number of Water Closets to be Handled by Ejector	Capacity in Gallons per Minute Each Pump
1 or 2	75
3 or 4	100
5 or 6	125
7 to 10	150
11 to 14	200
15 to 20	250
21 to 25	300

b. Sewage Pumps: Duplex sewage pumps should be installed in a pump house when the sewage from a group of buildings must be pumped and sewage injector installation in the buildings is impossible. The motors of these pumps should be so installed that they will not become submerged in case of interruption to the electric service and shut-down of the pumps.

c. Sump Pumps: Sump pumps should be installed in a pit below the basement or lowest floor. If a subsoil drain is provided, the drain from the subsoil basin may discharge into this sump. The depth of the pit below the finished floor should be in even feet (3, 4, 5, 6, etc.) to conform to standard lengths of the pump shafts of submerged pumps. Pumps required with discharge capacities in excess of twenty-five (25) gallons per minute, based on a total head of twenty (20) feet, should be duplex pattern.

d. Booster Pumps: Booster pumps should be installed when the water pressure to the building is inadequate. The pumps should be provided with automatic pressure controls actuated by the pressure on the suction side of each pump so that it will operate only when necessary to maintain an ample pressure in the supply piping. Pumps required for pneumatic and gravity tank water supply system should be approximately as indicated under Table III.

TABLE III

Number of Fixtures	G.P.M. Per Fixture	Minimum Capacity Of Pumps G.P.M.	Maximum Capacity Of Pumps G.P.M.
Up to 50'	1.0	25	50
51 to 100	0.75	45	75
101 to 200	0.6	80	120
201 to 400	0.5	150	200
401 & Over	0.4	170	-

e. Circulating Pumps: Where domestic hot and chilled water systems have long runs of pipe with numerous elbows, the water should be circulated at a rate that will maintain desired temperatures where the water is used.

Hot water circulating pumps should have a capacity of one (1) gallon per minute for each group of twenty (20) fixtures. The friction in a domestic hot water system should rarely exceed a head of twenty (20) feet.

Chilled water circulating pumps should have a capacity of 0.2 gallons per hour per person. The velocity of chilled water through the piping should not exceed ten (10) feet per second and the rise in temperature of the water should not exceed five (5) degrees Fahrenheit, based on the use of cork covering.

4-08 PNEUMATIC TANKS. A pneumatic water supply system should be installed if the normal water pressure is not sufficient to supply the building in congested areas or when storage requirements are 6000 gallons or less. Tanks should be designed in accordance with the current rules for the Construction of Unfired Pressure Vessels, Section VIII of the American Society of Mechanical Engineers, Boiler Construction Code. Consideration should be given to supplying fixtures located on the lower floors, directly from the street main to reduce the demand on the tank system. A surge tank on the pump suction should be installed when required by local conditions. A surge tank when installed should be the closed type, properly vented to the atmosphere and with three (3) valve by-pass. The capacity of the pneumatic tank should be approximately twenty-five (25) times the capacity of the booster pumps in gallons per minute.

4-09 GRAVITY TANKS: Gravity tanks with tight covers should be installed if the normal water pressure is not sufficient to supply the building with water for plumbing fixtures and for fire protection purposes. Construction and support of tanks should be in accordance with the standards of the National Board of Fire Underwriters' Pamphlet No. 22, as recommended by the National Fire Protection Association. For pumps having a capacity in excess of one hundred (100) gallons per minute, provide a gravity tank of thirty (30) times gallons per minute capacity of the pump. Tank capacity should have a reserve of not less than five thousand (5,000) gallons for fire protection except that for standpipes for small hose, a domestic gravity tank may be accepted with a minimum of three thousand (3,000) gallons reserved for fire protection.

4-10 STANDPIPES AND HOSE SYSTEMS FOR FIRE PROTECTION SYSTEMS: Standpipe and hose systems should be designed in accordance with the requirements of the National Board of Fire Underwriters' Pamphlet No. 14, as recommended by the National Fire Protection Association.

4-11 FIXTURE UNITS AND BRANCH CONNECTIONS TO FIXTURES: Fixture unit valves designating the relative load weights of different kinds of fixtures

and the sizes of branch water and waste connection to fixture should be as indicated on Table IV. A fixture unit is a factor so chosen that the load-producing values of the different plumbing fixtures can be expressed approximately as multiples of that factor. Fixture units should be used in determining water supply and drainage system requirements.

TABLE IV
FIXTURE UNITS AND BRANCH CONNECTIONS TO FIXTURES

Fixture	Fixture Units	Pipe Size in Inches		
		Cold Water	Hot Water	Waste
Bain Marie	2	1/2	-	1-1/2
Bath Tub - Hospital	3	1/2	1/2	2
Bath Tub - Private	2	1/2	1/2	1-1/2
Bath Tub - Public	4	1/2	1/2	2
Bath - Baby	1	1/2	1/2	1-1/2
Bath - Sitz	2	1/2	1/2	1-1/2
Bath - Arm	3	1/2	1/2	2
Bath - Leg	3	1/2	1/2	2
Bed Pan Washer (2 Inch Atmospheric Vent)	10	1	-	3
Dental Unit	1	1/2	-	1-1/2
Dishwasher	3	3/4	3/4	2
Drinking Fountain or Electric Water Cooler	1	1/2	-	1-1/4
Eye, Ear, Nose and Throat Unit	1	1/2	-	1-1/2
Floor Drain - 3 Inch	1	-	-	3
*Laundry Tray (One Fixture Unit for Each Compartment)	-	1/2	1/2	1-1/2
Lavatory - Private	1	1/2	1/2	1-1/4
Lavatory - Public	2	1/2	1/2	1-1/4
Lawn Faucet	-	1/2	-	-
Potato Peeler	3	1/2	-	2
Sink - Clinic, Service	10	1	1/2	3
Sink - Kitchen - Private	2	1/2	1/2	1-1/2
Sink - Kitchen	4	1/2	1/2	1-1/2
Sink - Laboratory, Surgeon or Medicine	2	1/2	1/2	1-1/2
Sink - Scullery	6	3/4	3/4	2
Sink - Service	3	1/2	1/2	3
Sink and Laundry Tray Combination	2	1/2	1/2	1-1/2
Sink and Pack Tray	3	1/2	1/2	1-1/2
Sink - Washup	2	1/2	1/2	1-1/2
Shower Stall	2	1/2	1/2	2
Shower - Hydrotherapeutic (1-1/4 Inch and 1 Inch Temperate Water	4	-	-	3
Table - Autopsy	3	1/2	1/2	3
Table - Massage, Shampoo, Pack		1-2	1/2	1-1/2

TABLE IV (CONTINUED)
FIXTURE UNITS AND BRANCH CONNECTIONS TO FIXTURES

Fixture	Fixture Units	Pipe Size in Inches		
		Cold Water	Hot Water	Waste
Table - Steam	-	1/2	-	1-1/2
Urinal - (Wall or Stall)	5	3/4	-	2
Urinal - Pedestal	10	1	-	4
Urinal - Prophylactic	5	1	1/2	3
Wash Fountain (54 Inch Diameter)	4	1/2	1/2	2
Water Closet - Flush Valve (Private)	6	1	-	4
Water Closet - Flush Valve (Public)	10	1	-	4
Water Closet - Flush Tank (Private) - (Water)	3	1/2	-	-
(Drainage)	6	-	-	4
Water Closet - Flush Tank (Public or Office) (Water)	5	1/2	-	-
(Drainage)	10	-	-	4
Water Closet - With Bed Pan Lugs	10	1	1/2	4

* These fixtures may be omitted in determining the total fixture units for a complete plumbing system but they shall be applied for determining the size of branches to groups of these fixtures.

For supply outlets likely to impose a continuous demand when other fixtures are in extensive use, add the estimated continuous demand to the total demand for fixtures. For example, five (5) gallons per minute for a sill cock or hose connection is a liberal but not excessive allowance.

Fixtures not listed in the table, if installed in relatively small numbers compared to the rated fixtures, may usually be ignored in estimating for the building main and large distributing branches. If installed in sufficiently large numbers to justify their consideration, they may be assigned fixture unit ratings on the basis of a comparison with a rated fixture that uses water in similar quantities and at similar rates. For example, if wash sinks or wash troughs with multiple supply outlets are to be installed, each supply outlet may be considered as comparable in demand to that of a lavatory in public service.

The fixture unit ratings given in Table IV are for the total hot and cold water demand. The engineer will need to exercise judgment in estimating separately for hot and cold water demands, depending to a large extent on conditions. The following is considered as ample allowance under favorable conditions. For main hot water branches allow three quarters (3/4) of the total fixture units as given by the table for all fixture units separately for fixtures that are and are not supplied with hot water and add three-quarters (3/4) of the total for fixtures that are supplied with hot water to the total for fixtures that are supplied with cold water only.

4-12 WATER SUPPLY AND DISTRIBUTION:

a. Quality of Water: The quality of the water supply should meet accepted standards of purity for potable water as established by the United States Public Health Service or by state or local authority. A water supply not conforming to accepted standards of purity for potable water, when used in an entirely separate system and when such use is specifically approved by proper administrative authority, may be used for flushing water closets and urinals and for other approved purposes where a potable water is not required. Water not meeting accepted standards should not be readily accessible for drinking.

b. Protection of Water Supply: Water supply should be protected as follows:

Water pumps, wells, hydrants, filters, appliances and devices should be protected from surface water and outside contamination by approved covers, walls, copings or casings.

All non-pressure potable water supply tanks should be tightly covered to prevent entrance of foreign material into the water supply. Soil or waste lines should not be permitted to pass directly over such tanks except on special approval by competent authority.

Potable and non-potable water supplies should be distributed through systems entirely independent of each other.

Water pipes, storage tanks, cisterns and appliances, when subject to freezing temperatures, should be protected. Water pipes underground should be installed below the recognized frost line or should otherwise be insulated to protect them from freezing. Interior piping should be insulated when necessary for protection.

Sterilization may be accomplished by introducing into the well, cistern, spring and piping systems one of the chlorine compounds in amounts sufficient to give a chlorine dosage of fifty (50) parts per million in the water. The chlorinated water should be circulated throughout the entire system and allowed to remain in the system eight (8) to ten (10) hours, after which the system should be flushed with water from the well or spring. No samples of water for bacteriological examination should be taken until after sterilization of supply and equipment and the removal of all traces of chlorine from the water. Directions regarding sterilization may be obtained from any of the health agencies.

Every supply outlet or connection to a fixture or appliance should be protected from backflow by means of an approved air gap or backflow preventer between the control valve of the outlet and the fixture or appliance. Requirements for air gaps should be in accordance with the American Standard "Air Gaps and Backflow Preventers in Plumbing Systems, A 40.6-1943".

c. Drinking Water Consumption: Drinking water consumption is subject to extreme variation depending upon the location and the class of building involved. Capacity of water cooling equipment should be based on the consumption for various conditions as listed under Table V.

TABLE V

	Gallons Per Hour Per Person	
	North	South
General	.08	.125
Mess Halls (Table Service)	.08	.125
Mess Halls (Cafeteria	.06	.10
Industrial Heavy Service	.20	.25
Industrial Light Service	.08	.17
Theaters	1.0 G.P.H Per 100 Seats	
Hospitals (Per Bed)	.15	.20
The line of demarcation between the North and South is generally defined as forty (40) degrees north latitude.		

d. Water Service: The water service pipe should be of sufficient size to furnish an adequate flow of water to meet the requirements of the building at peak demand. The size of the water piping should be based on velocities limited to a maximum of ten (10) feet per second and with a pressure loss such that there will be a minimum pressure of fifteen (15) pounds per square inch at the highest fixture for all fixtures except blowout pattern water closets and urinals which require a minimum pressure of twenty-five (25) pounds per square inch.

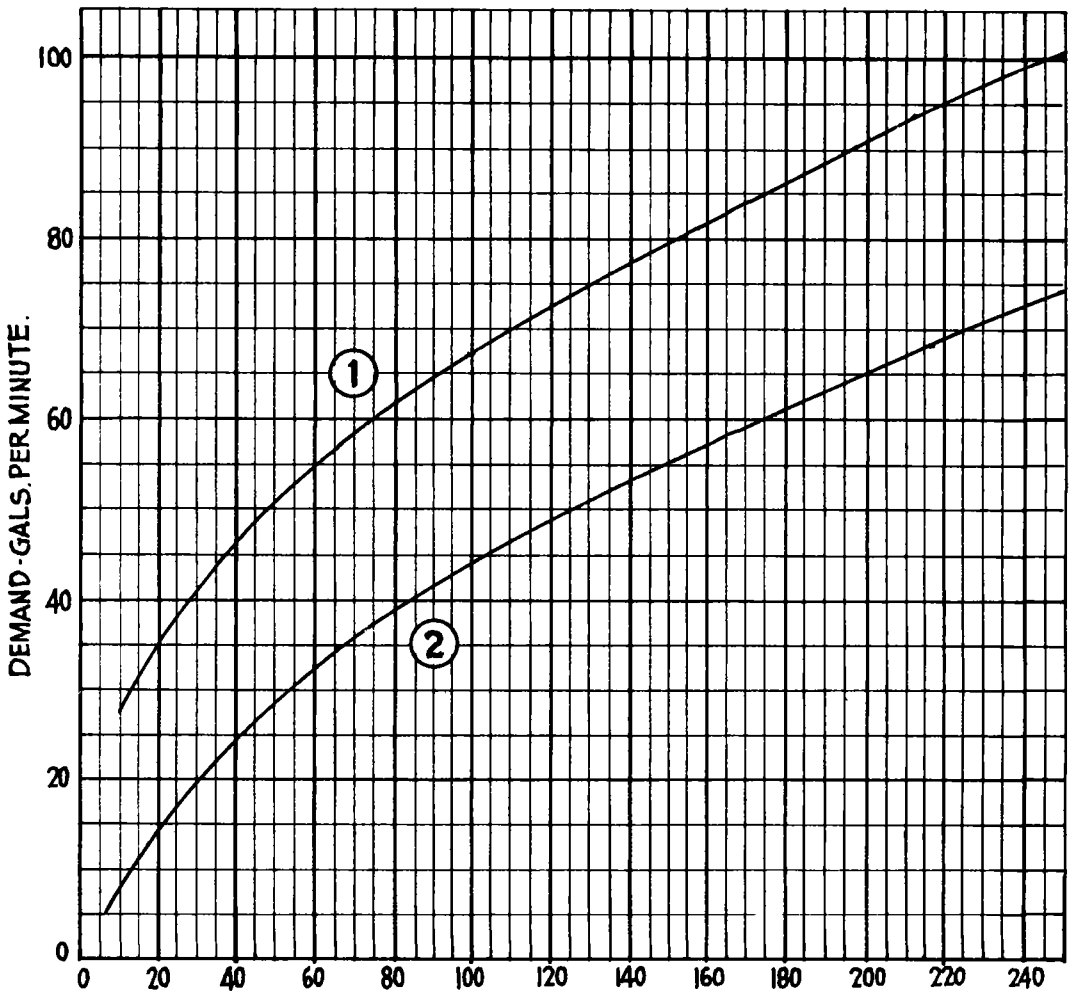
e. Application of Flow Charts - Figures 4 to 7: In many cases it is necessary to make a satisfactory selection of serviceable pipe sizes without making specific estimates of the probable change in diameter. For example, if the amount of corrosion or caking to be expected is small, it will be in most instances sufficient to refer to Figure 6. Likewise, it will be sufficient in many cases to refer to Figure 7 without specific corrections for bad conditions in respect to corrosion and deposit. If there is a wide margin of capacity over the estimated demand, ordinarily it will be safe to select the size indicated by the applicable chart. If the indicated size is on the border line, the next larger size than that indicated should be used. In all cases the engineer should bear in mind that small distributing pipes, especially hot water pipes are to be completely closed after a few years.

Chart, Figure 4, applies to smooth new copper tubing with recessed sweat or brazed joints and to the actual sizes of the types indicated on the diagram.

Chart, Figure 5, applies to actual diameters of standard weight, fairly smooth pipe such as brass, copper, lead, tin or glass. Centrifugally applied cement lining and bituminous enamel applied centrifugally on iron or steel pipe is satisfactory providing the probable change in diameter is considered in preparing the estimate.

Chart, Figure 6, applies to actual diameter of standard weight, fairly rough pipe such as welded and seamless steel pipe, wrought iron pipe, cast iron and tar coated cast iron.

Chart, Figure 7, applies to very rough pipe and actual diameter. If the character of the water is such as to produce a material change in diameter by reason of corrosion or caking or both, it will be safe to assume that the pipe falls in the category of very rough pipe.

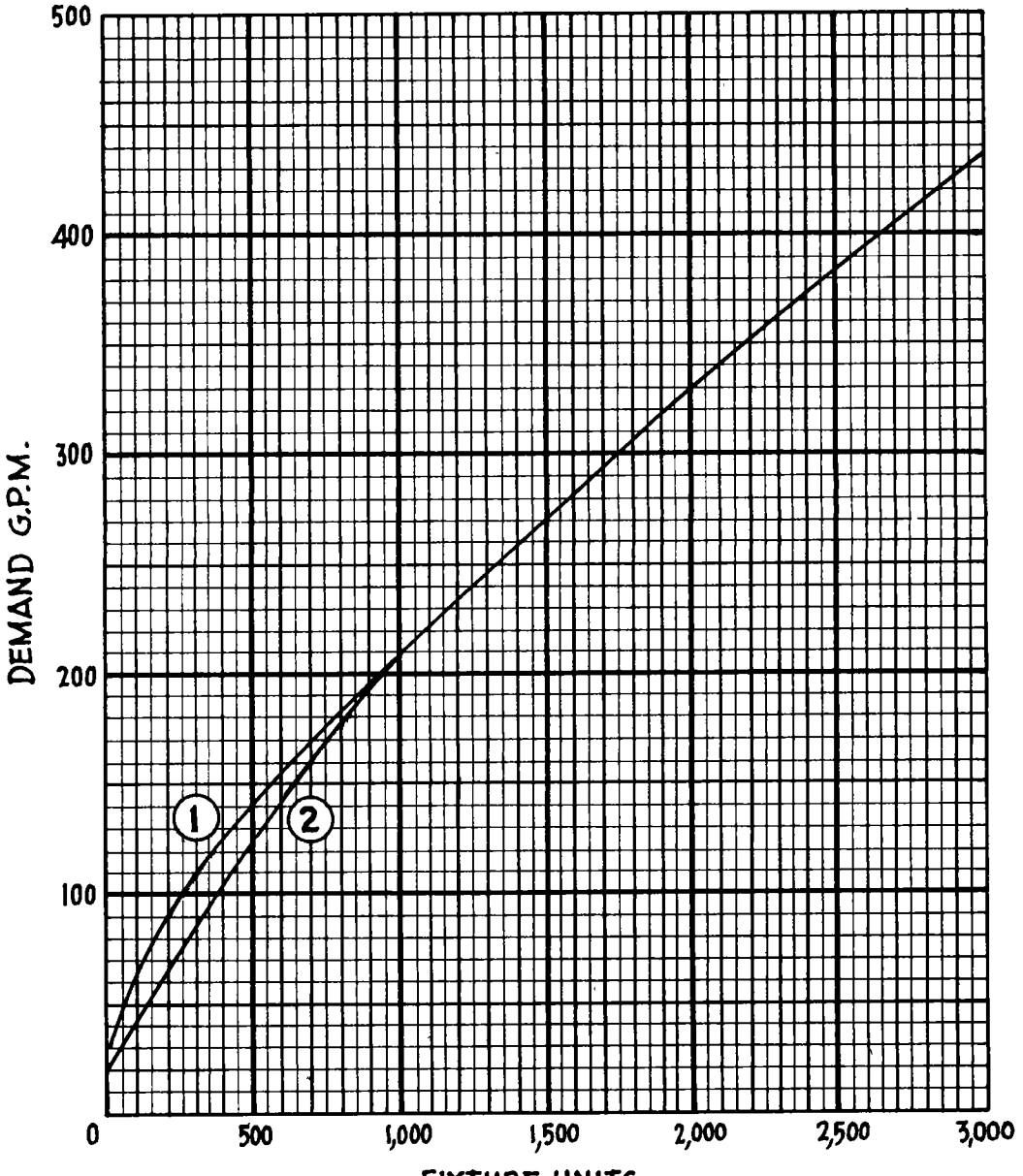


CURVE NO. 1 FOR SYSTEM WITH FLUSH VALVES.
CURVE NO. 2 FOR SYSTEM WITH FLUSH TANKS.

SUPPLY DEMAND CURVE

FOR USE WITH 240 AND LESS FIXTURE UNITS

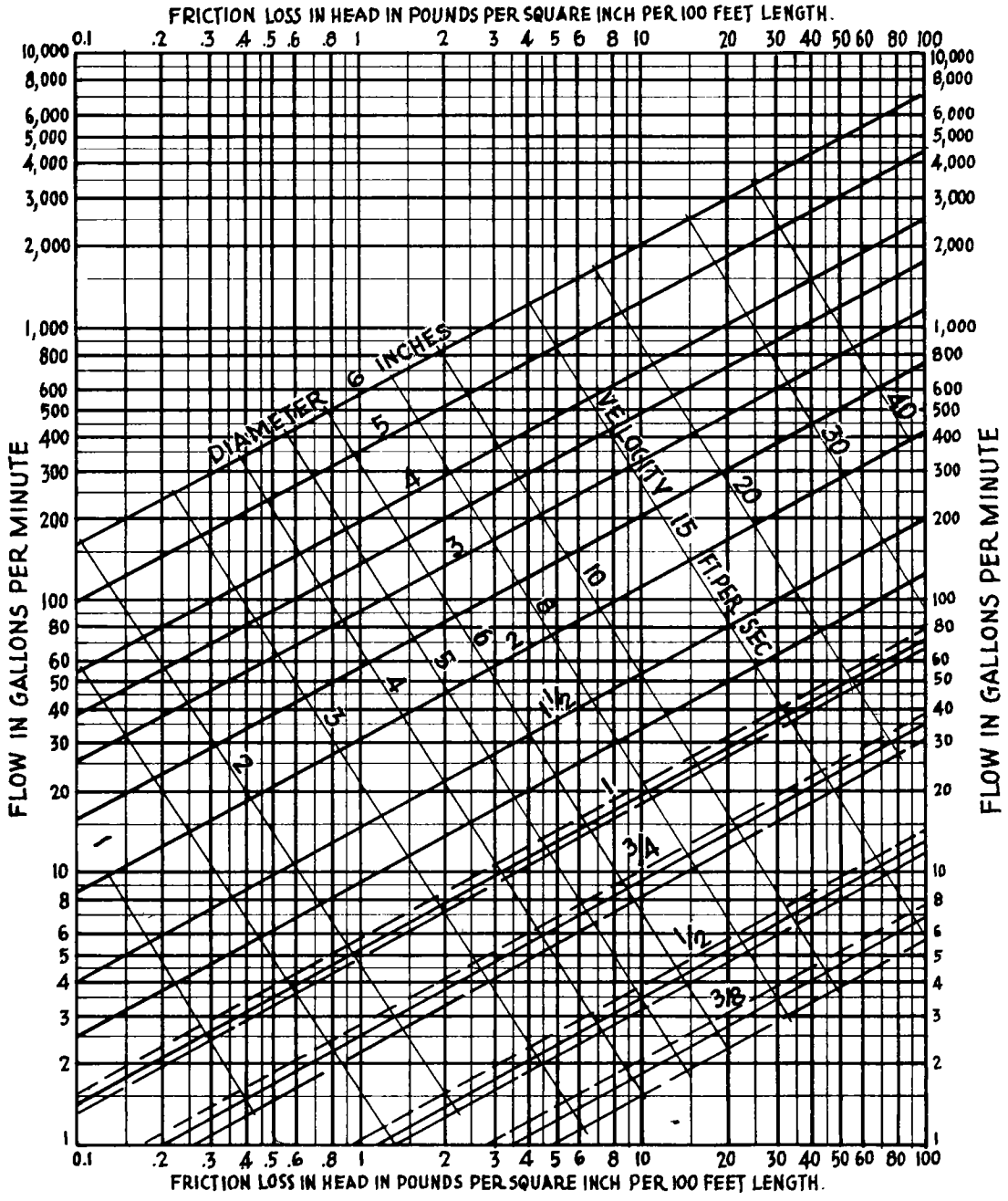
FIGURE 2



CURVE NO. 1 FOR SYSTEM WITH FLUSH VALVES.
CURVE NO. 2 FOR SYSTEM WITH FLUSH TANKS.

SUPPLY DEMAND CURVE
FOR USE WHEN FIXTURE UNITS ARE IN EXCESS OF 240.

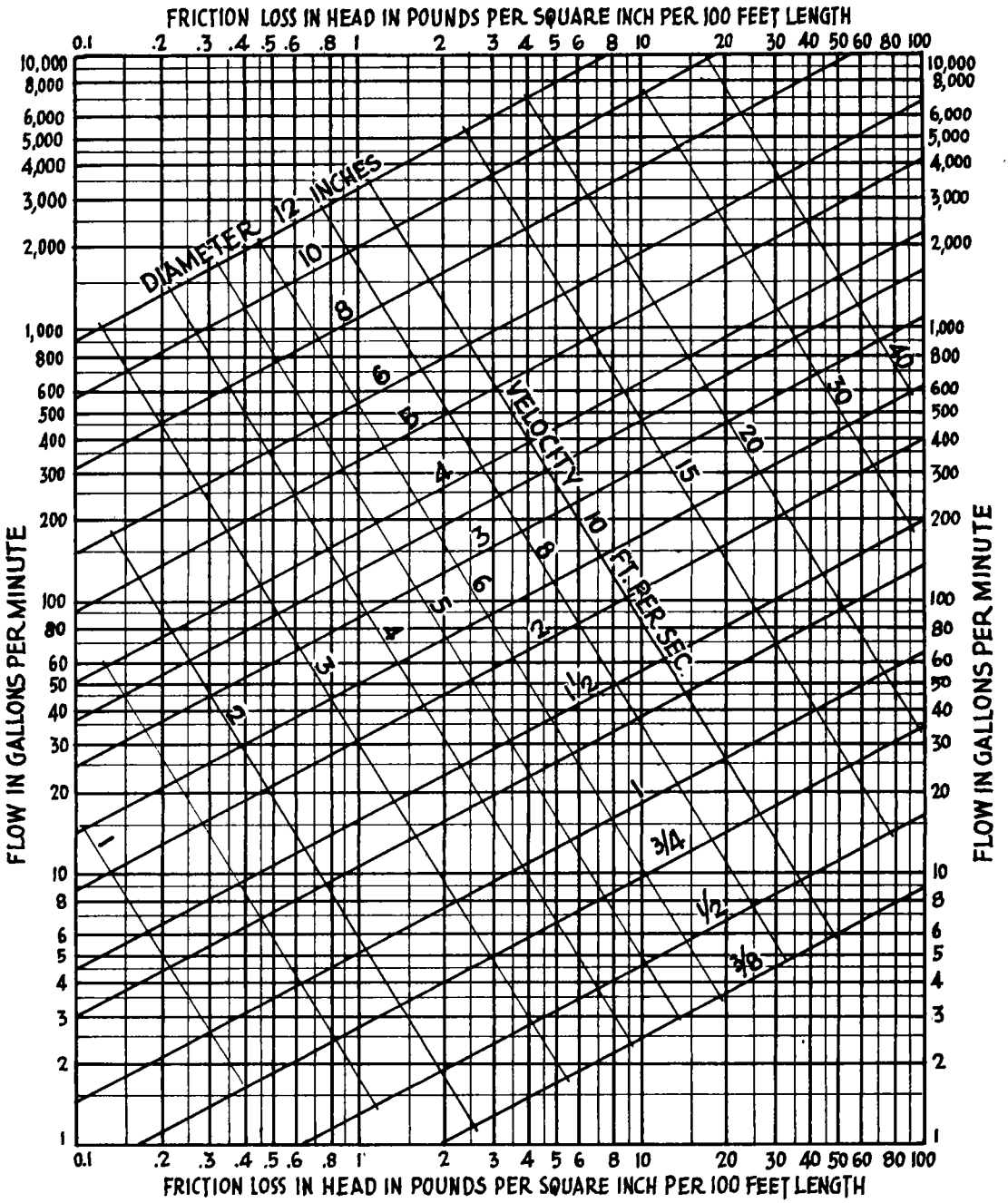
FIGURE 3



FLOW CHART FOR COPPER TUBING

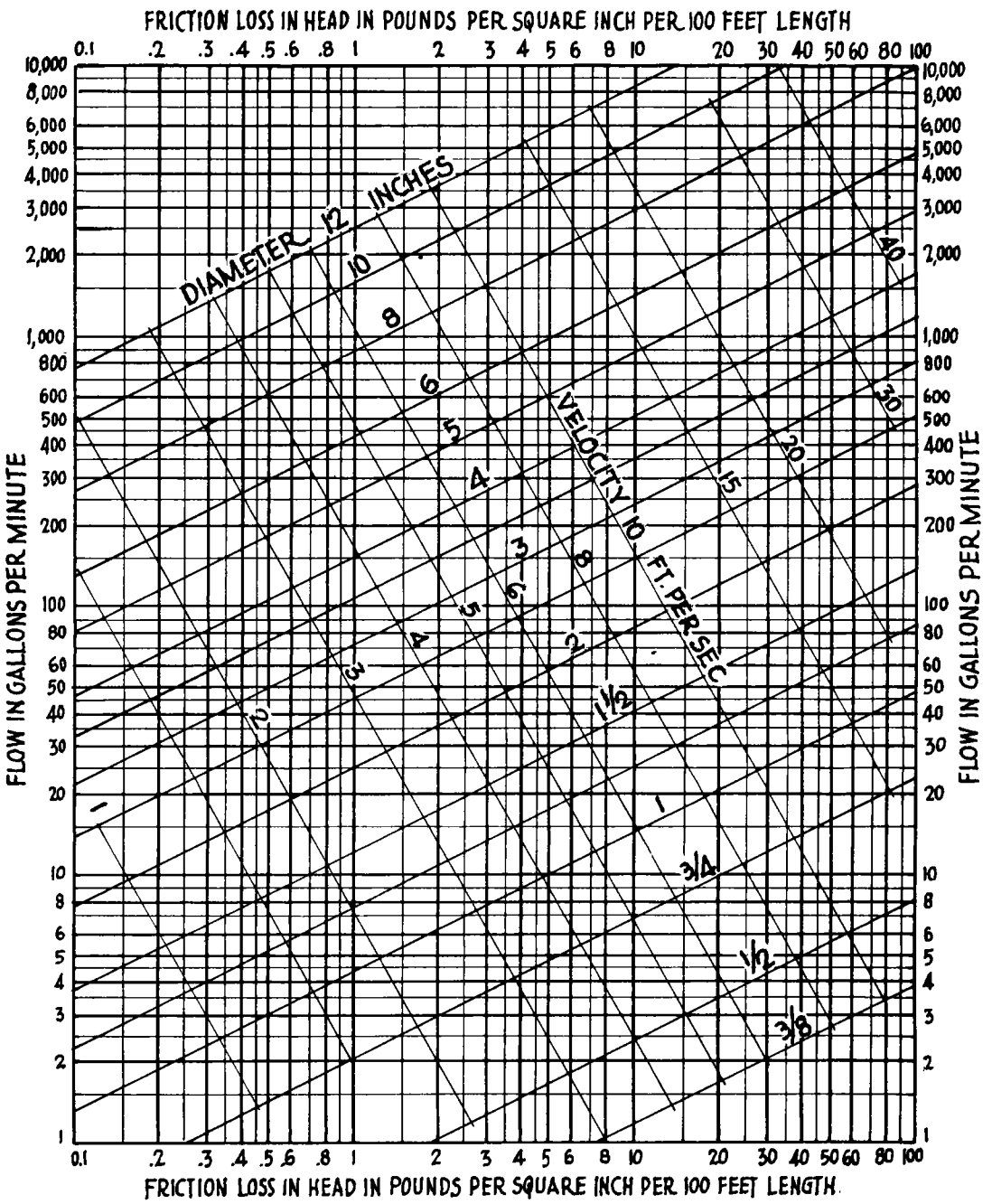
TYPE M — — — — —
TYPE L ————————
TYPE K —— ———— —

FIGURE 4



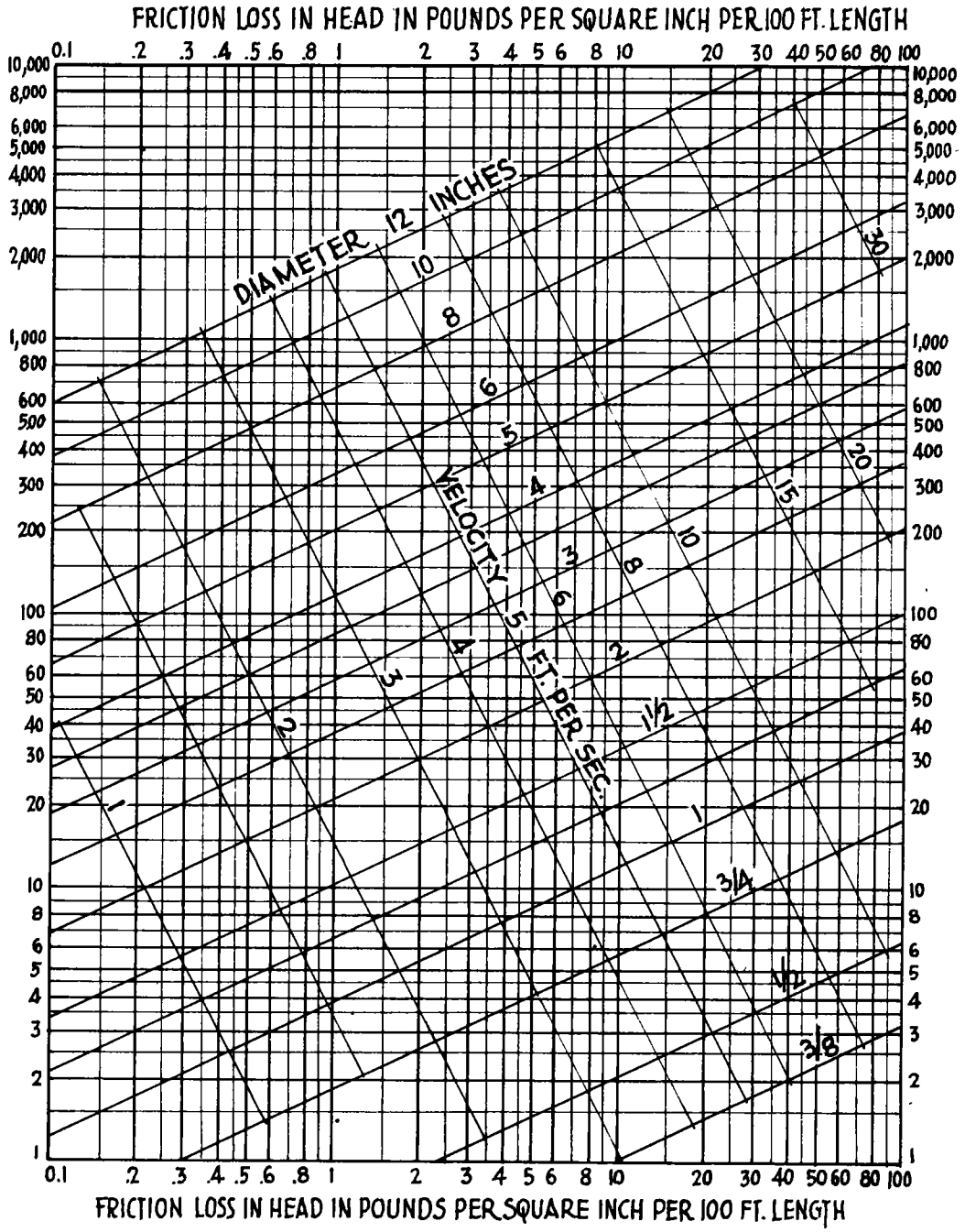
FLOW CHART FOR FAIRLY SMOOTH PIPE

FIGURE 5



FLOW CHART FOR FAIRLY ROUGH PIPE

FIGURE 6



FLOW CHART FOR ROUGH PIPE

FIGURE 7

f. Estimating Water Demand and Determination of Pipe Sizes: The following rules of procedure should be employed in determining the water requirements and the sizes of water supply pipes:

Tabulate the maximum and minimum water working pressures in street main and elevation of main at building site.

Obtain chemical characteristics of water.

Determine the kind of pipe to be used and refer to appropriate flow chart (Figures 4, 5, 6 or 7).

Estimate supply demands from fixture units (Table IV) and then by reading the corresponding ordinate from applicable curve, figures 2 or 3. Curves, Figure 2, should be employed for fixture units above two hundred forty (240) for estimating the expected demand in gallons per minute for various loads and total loads in fixture units.

Estimate supply demands from fixture units (Table IV) and then by reading the corresponding ordinate from applicable curve, figures 2 or 3. Curves, Figure 2, should be employed for fixture units less than two hundred forty (240) and Figure 3 for fixture units above two hundred forty (240) for estimating the expected demand in gallons per minute for various loads and total loads in fixture units.

Total the water supply requirements of equipment using water in building and include that for lawn sprinklers, air conditioning equipment, etc.

Establish the minimum water pressure that should be maintained at the highest fixture.

Determine the elevation of branches from risers above the street main. Multiply the elevations in feet by 0.434 to determine the static loss of pressure in pounds per square inch. (A column of water one foot in height produces a pressure of 0.434 pounds per square inch.)

Sketch the water supply from street main to and including all risers and determine the greatest developed length of pipe from street main.

Pipe sizes should be determined by flow charts (Figures 4 to 7); velocities should not exceed ten (10) feet per second.

Allowances in equivalent length of pipe for friction loss in valves and threaded fittings should be determined by Table VI.

TABLE VI
ALLOWANCE IN EQUIVALENT LENGTH OF PIPE FOR FRICTION LOSS IN VALVES AND THREADED FITTING

Diameter of Fittings	Equivalent Length of Pipe for Various Fittings						
	90° Ell	45° Ell	90° Tee	Coupling	Gate Valve	Globe Valve	Angle Valve
Inches	Feet	Feet	Feet	Feet	Feet	Feet	Feet
3/8	1	0.6	1.5	0.3	0.2	8	4
1/2	2	1.2	3	0.6	0.4	15	8
3/4	2.5	1.5	4	0.8	0.5	20	12
1	3	1.8	5	0,9	0.6	25	15
1-1/4	4	2.4	6	1.2	0.8	35	18
1-1/2	5	3	7	1.5	1.0	45	22
2	7	4	10	2	1.3	55	28
2-1/2	8	5	12	2.5	1.6	65	34
3	10	6	15	3	2.0	80	40
3-1/2	12	7	18	3.6	2.4	100	50
4	14	8	21	4.0	2.7	125	55
5	17	10	25	5	3.3	140	70
6	20	12	30	6	4.0	165	80

Actual diameters corresponding to nominal diameters of different kinds of pipe are listed under Table VII.

TABLE VII
ACTUAL DIAMETERS CORRESPONDING TO NOMINAL DIAMETERS OF DIFFERENT KINDS OF PIPE

	Actual Inside Diameters						
	Types of Copper Tubing			Steel		Brass (I.P.S.)	
Diameters	K	L	M	Stand-ard	Extra Strong	Stand-ard	Extra Strong
Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches
3/8	0.40	0.43	0.45	0.49	0.42	0.49	0.42
1/2	.53	.55	.57	.62	.55	.63	.54
3/4	.75	.79	.81	.82	.74	.82	.74
1	1.00	1.03	1.06	1.05	.96	1.06	.95
1-1/4	1.25	1.27	1.29	1.38	1.28	1.37	1.27
1-1/2	1.48	1.51	1.53	1.61	1.50	1.60	1.49
2	1.96	1.99	2.01	2.07	1.94	2.06	1.93
2-1/2	2.44	2.47	2.50	2.47	2.32	2.50	2.32
3	2.91	2.95	2.98	3.07	2.90	3.06	2.89
3-1/2	3.39	3.43	3.47	3.53	3.36	3.50	3.36
4	3.86	3.91	3.94	4.03	3.83	4.00	3.82
5	4.81	4.88	4.91	5.05	4.81	5.06	4.81
6	5.74	5.85	5.88	6.07	5.76	6.13	5.75

Plumbing Data Form P-1 is recommended for use in tabulating calculations when determining the size of water service main and for determining the available friction loss in pounds per square inch per hundred (100) feet of pipe.

Plumbing Data Form P-2 is recommended for use in tabulating calculations for determining the size of risers.

Example: Assume a hospital building of six stories and basement, water pressure at sit seventy (70) pounds per square inch, an elevation of seventy-two (72) feet at the highest fixture above the street main and a developed length of pipe from street main to the most distant fixture of two hundred thirty (230) feet. Allow fifteen (15) pounds per square inch at the highest fixture. The water is corrosive: therefore, red brass pipe should be installed for hot and cold water service. The fixture units are as follows:

Riser No.	Hot Water	Cold Water
R 1	60	200
R 2	48	160
R 3	50	170
R 4	72	252

Typical riser No. R 4 has forty-two (42) fixture units on cold water branches and twelve (12) fixture units on the hot water branches at each floor. Tabulate the data on Data Forms P-1 and P-2 and prepare sketches as indicated on Figures 8 and 9.

Plumbing Data
Form P-1

WATER SERVICE MAIN

Sheet 1 of 2
Date Dec. 1 1945
(Mo) (Day) (Year)
Engr. E.F.J.
Checked by A.R.G.

E. M. PART V
CHAPTER 4
MARCH 1946

POST Ft. Myer PROJECT Hospital

Minimum Service Pressure (Street) p.s.i.,(lbs./sq.in.) 70

Pressure loss, p.s.i., due to elevation of fixtures (Height of highest outlet above street main in feet x 0.434) 0.434x72 = 31

Pressure required for operation of highest fixture, p.s.i. 15

Deduct total pressure required for elevation and operation, p.s.i. 46

Pressure available for friction loss, p.s.i. 24

(AFL/100 Ft. - Allowable friction loss, p.s.i., per 100 Ft. of pipe) 10.4

AFL/100 Ft. - Pressure, p.s.i. available for friction loss x 100 / Developed length pipe, ft., from street main to most distant fixture.

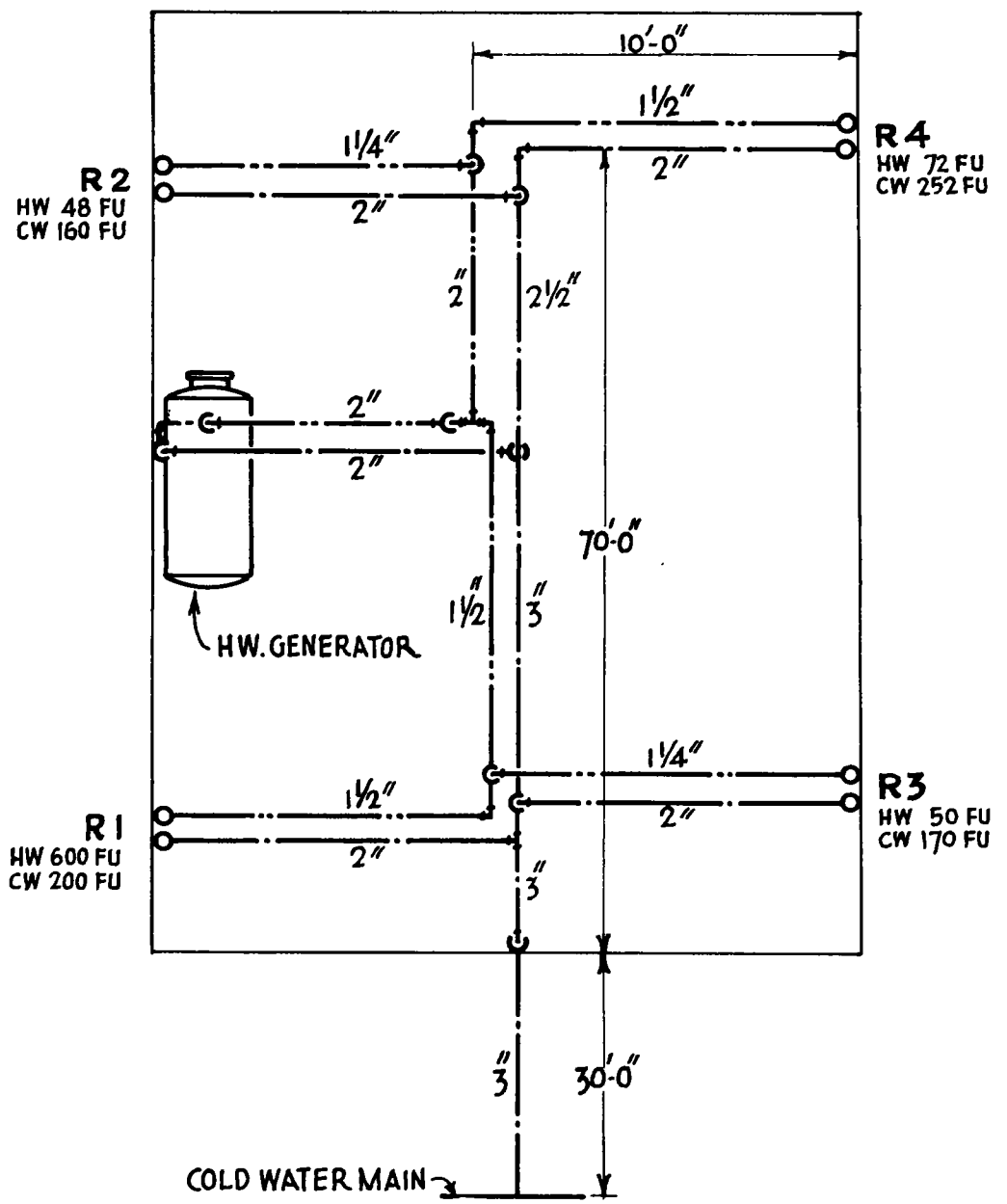
Building Service Main: Fixture Units 678 G.P.M. 170

Hot Water Service : Fixture Units 230 G.P.M. 70

Pipe Material - Brass - Figure 4

Cold or Hot Water	Branch Riser No.	FU Draw-off (Each Branch)	GPM Draw-off (Each Branch)	Branch Size inches	Main FU	Main GPM	Main Size inches
CW.	4	252	100	2			
	2	160	82	2			
					412	105	2½
	H.W.	230	70	2	642	160	3
	3	170	85	2	812	195	3
	1	200	90	2	1012	215	3
HW	4	72	37	1½			
	2	48	25	1¼			
					120	50	2
	1	60	32	1½			
	3	50	25	1¼			
					57	30	1½
Main	1012 x 0.67 =				678	170	3

Fixtures using HW take 3/4 FU for HW, 3/4 FU for CW.
Multiply total fixture units for hot and cold water x 0.67 for the water service main.



BASEMENT PLAN

FIGURE 8

Plumbing Data
Form P-2

WATER RISERS
Sheet 2 of 2
Date Dec. 1 1945.
(Mo) (Day) (Year)
Engr. E. F. J.
Checked By ARG.

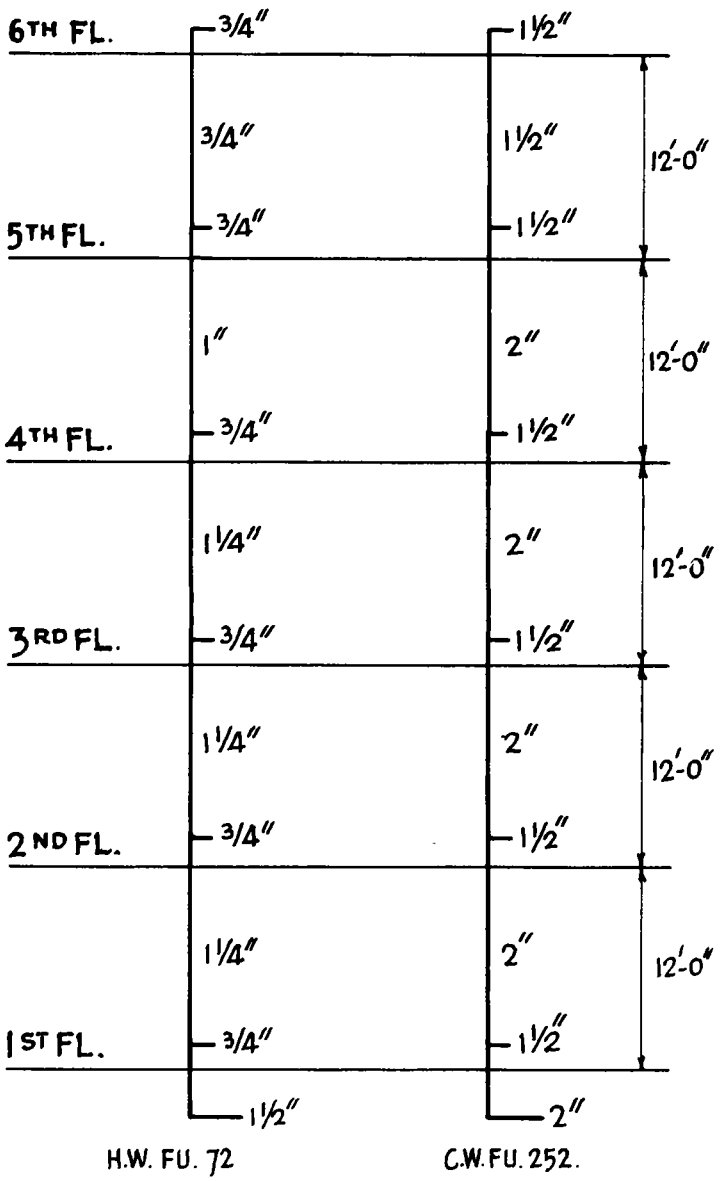
E. M. PART V
CHAPTER 4
MARCH 1946

POST Fort Myer PROJECT Hospital

Allowable Friction loss, in lbs. per sq. inch per 100 ft. of pipe 10.4

Cold or Hot Water	Riser No.	Floor	FU Draw-off	GPM Draw-off.	Branch Size inches	Riser GPM	Riser, FU	Riser Size inches
C.W.	4	6	42	47	1 1/2	42	47	1 1/2
		5	42	47	1 1/2	84	62	2
		4	42	47	1 1/2	126	75	2
		3	42	47	1 1/2	168	85	2
		2	42	47	1 1/2	210	92	2
		1	42	47	1 1/2	252	100	2
H.W.	4	6	12	10	3/4	12	10	3/4
		5	12	10	3/4	24	18	1
		4	12	10	3/4	36	22	1 1/4
		3	12	10	3/4	48	28	1 1/4
		2	12	10	3/4	60	32	1 1/4
		1	12	10	3/4	72	37	1 1/2

Fixtures using HW take 3/4 FU for HW, 3/4 FU for CW.



R-4

HOT & COLD WATER
RISER DIAGRAM
RISERS R-4

FIGURE 9

g. Water Piping. In designing water piping layouts, consideration should be given to delivery of water, accessibility of service valves, metering, drains, piping system, cross connections, lawn faucets or hydrants and hot water piping. Large buildings should be provided with two or more services to insure constant delivery to all fixtures and equipment. Service lines should enter the building in an accessible location. If water is to be purchased, each service connection should be metered. Drains should be installed on the fixture side of all service stops. The water supply piping should be distributed throughout the building with mains generally run near the ceiling of the lowest story. Cross connections between water supply piping and waste, drain, vent or sewer piping should be strictly prohibited. Piping should be designed so that in case of a negative pressure in the water supply pipe and a stopped-up waste, drain, vent or sewer pipe, there will be no possibility of siphoning waste water into the water supply piping. Check valves are not considered adequate protection against backflow. Wall hydrants, lawn faucets or street washers should be located so that with one hundred (100) feet of garden hose the area can be watered without crossing the main entrance of public type buildings or barracks. Lawn faucets should be used on small buildings and quarters and the branch to the lawn faucets should be equipped with stop and wastes.

Hot water return circulating piping should be provided in all buildings two or more stories in height, except quarters. The main circulating line at tank should be provided with a gate and check valve. The hot, cold, and return circulating piping branches to each individual toilet room should be valved. No circulation piping is to be installed in the small one story type buildings except when the horizontal run exceeds one hundred (100) feet and then a loop return of at least one half (1/2) the size of the hot water main should be provided. Circulating mains should have a cross-sectional area equal to or greater than the sum of the cross-sectional areas of circulating risers collected by the mains. Either of the following methods of running this piping should be used, depending upon the design of the building. From each hot water riser for fixtures above the first floor, a half (1/2) inch diameter return circulating pipe should be taken off. The connection to riser should be made at a point just below the highest hot water connection thereto. The half (1/2) inch return circulating pipes are to be run down to the basement and be connected to main return which in turn should be connected to the hot water storage tank. Circulating pipes, in general, should run parallel to the hot water pipes. Care should be taken that the hot water pipes from the storage tank be run without traps or air pockets to the last hot water riser. The height of structural beams, piping, etc., should be checked to see that such building features do not interfere with the installation of the hot water supply and return pipe. The second method: the main hot water supply pipe should be run up to the attic and graded up until the first fixture supply connection is taken off, which should be taken from the top of the main. From this point the main should grade down with branches taken from the bottom. Each hot water drop supply, after the last fixture connection is taken off, should be continued to the basement, and connected to one line, which should be connected to the hot water storage tank. In cold climates this method should be avoided. Provide an automatic air eliminator at the high point of a down feet system.

h. Water Hammer: "Water Hammer" or "Water Surge" is caused by the non-compressible liquid rebounding with an impact in the supply lines. The rebounding repeats with lower variations until it is finally damped by friction. Large water hammer pressures may be created without the presence of excessive noise. Large pressures developed by water hammer pressure may break pipes, cause leaky joints and injure valves. As an example of this force in small pipe when water hammer occurs, the pressure is increased by about sixth (60) pounds per square inch above the flow pressure for each foot per second of sudden decrease of velocity of flow. This means that if a flow velocity of ten (10) feet per second is stopped instantly, a maximum water pressure rise of ten (10) times sixty (60) or six hundred (600) pounds per square inch may occur. This pressure is added to the normal static pressure at the point of impact. Mr. M.M. Warren (Penstock and Surge-Tank Problems) suggests the following formula for determining pressure increase in feet, which has been borne out by experiment:

$$h = \frac{Lv}{g\left(T - \frac{L}{S}\right)}$$

h = Pressure head increase in feet.
v = Velocity of the water in feet per second before closing.
L = Length of pipe in feet.
g = Acceleration due to gravity (32.2).
T = Time of closure in seconds.
S = Speed of the pressure wave in feet per second.

Relief from destructive water hammer may be accomplished by air chambers installed near the valve producing the water hammer. Experience indicates that the greater the volume of the chamber occupied by the air, the more effective will be the air chamber. In Table VIII, air chamber sizes recommended by Mr. F. M. Dawson and Mr. A. A. Kalinske, Iowa Institute of Hydraulic Research, are shown. Experimental data have indicated that roughly, the restriction should be one half (1/2) of the diameter of the pipe line served. The table gives the volume of the air chamber and from this value the height of the chamber can be determined after selecting the diameter of pipe to be used.

TABLE VIII
RECOMMENDED SIZES OF AIR CHAMBERS FOR REDUCING WATER HAMMER PRESSURE
(Air Chamber Sizes In Cubic Inches)

Length Of Pipe	1/2"		3/4"		1"		1-1/2"		2"	
	Water Velocity In Feet Per Second									
	5	10	5	10	5	10	5	10	5	10
1 For Flow Pressures Of 15 Pounds Per Square Inch										
25	2	5	3	10	4	13	7	28	13	50
50	3	10	5	17	7	25	14	56	25	100
100	5	20	10	35	13	50	28	112	50	200
200	10	40	18	68	25	100	56	225	100	400
500	25	100	42	170	62	250	140	562	250	1000
2 For Flow Pressure of 30 Pounds Per Square Inch										
25	3	8	4	14	5	20	12	45	20	80
50	4	16	7	27	10	40	24	90	40	160
100	8	32	14	54	20	80	45	180	80	320
200	16	62	27	108	40	160	90	360	160	640
500	40	154	58	270	100	400	225	900	400	1600
3 For Flow Pressure of 60 Pounds Per Square Inch										
25	4	15	7	26	10	38	22	85	38	150
50	8	30	13	50	19	75	42	170	75	300
100	15	60	26	100	38	150	85	340	150	600
200	30	105	50	200	75	300	170	675	300	1200
500	74	290	125	500	188	750	420	1690	750	3000

Surge suppressors are available on the market which may be attached to pipes in any number and operated automatically without maintenance.

4-13 HOT WATER SUPPLY: The scope of details that should be given consideration for hot water supply systems is the amount of water to be heated, the rate at which the water is to be heated, the range of temperature through which the water should be raised, the efficiency of heat transmission and the heating medium, such as hot water, coal, gas or steam. These details should be considered in order that the accessories, storage and heating facilities will be of sufficient size and capacity to meet peak requirements without excess equipment cost. The final temperature of the hot water should normally be one hundred forty (140) degrees Fahrenheit. Hot water at one hundred eighty (180) degrees Fahrenheit is required for sterilization of dishes. In cases where disturbed patients have access to the hot water supply, the temperature should not exceed one hundred ten (110) degrees Fahrenheit.

a. Methods of Heating Water: Water may be heated by direct heat transfer in the burning of fuel, indirect means such as steam or hot water, sun's rays or by electrically heated surfaces. The critical water temperature at which the solids collect on heating surfaces varies with the character and the proportion of the solids but as a rule such deposits are

not serious with water temperatures lower than one hundred forty (140) degrees Fahrenheit.

Coal-burning direct-fired water heaters may be constructed of cast iron or steel with metal thicknesses and cores designed to withstand water pressures of one hundred (100) pounds per square inch gage. The strength and qualities of materials should be in accordance with A.S.M.E. Standards. In small capacity water heaters, efficiency is not considered as important as low first cost and ability to maintain a fire at a low rate of combustion. Anthracite coal contains between twelve thousand five hundred (12,500) Btu and fourteen thousand (14,000) Btu per pound and bituminous coal between 11,500 Btu and 14,500 Btu per pound depending upon the source of supply. The output ratings of surface-fired tank heaters are dependent upon the grate area, firebox depth, heating surface, available draft and the size of fuel.

Oil burning water heaters operate at higher flame temperatures than coal-burning heaters but with greater efficiency. They have a tendency to lime up and the water passages should be large in cross-section and accessible for periodic cleaning. Oils available for water heating equipment may contain from one hundred thirty-six thousand (136,000) Btu to one hundred fifty-two thousand (152,000) Btu per gallon.

Electricity is not used for large volume water heating because of high cost of electrical equipment of sufficient size. The fuel equivalent of electricity is three thousand four hundred fifteen (3,415) Btu per kilowatt hour.

Gas-burning water heaters are available in many types, sizes and capacities. All gas-burning water heaters should conform to the approval requirements for gas water heaters as sponsored by the American Gas Association and approved by the American Standards Association. Gas for fuel should be considered in the following divisions:

Natural Gas	950 to 1200 Btu per cubic foot
Manufactured Gas	525 to 550 Btu per cubic foot
Propane	2572 Btu per cubic foot
Butane	3393 Btu per cubic foot
Isobutane	3364 Btu per cubic foot

In the indirect method of heating water, either steam or hot water is employed as a heating medium. In hot water generators, the heating medium is within the tubes that are immersed in a hot water storage tank and in the instantaneous water heaters and heaters installed below the water lines of steam boilers, the heating medium is outside of the coil.

Solar water heaters utilize the energy from the sun for heating water. When properly installed and proportioned, solar heaters provide satisfactory service when the outside temperatures are high and extremely hot water is not required. These heaters are most frequently used south of thirty (30) degrees north latitude which includes Florida and southern California. The heater consists of a hot box insulated on sides and bottom with glass cover installed in such a manner to make it air tight. The heating surface should be painted black to absorb the heat. The box need not be deeper than necessary to house the coil and protect it from the weather. The heaters should be installed on the south side of the house and at an angle perpendicular to the sun's rays on the shortest day of the year. When it is desirable to operate a

solar water heater on bright days during the winter, an indirect system can be employed using a non-freezing solution in the absorber circuit. Bulletin 602, University of California, indicates that solar heaters will provide from seven hundred (700) to twelve hundred (1200) Btu per day, per square foot of glass area on clear days.

b. Selection of Water Heating Equipment: The following information may be used as a guide in the selection of water heating equipment:

The capacity of coal or gas-fired water heaters, based on a one hundred (100) degree Fahrenheit rise in temperature, should be not less than fifteen (15) gallons per hour. Capacity for hot water storage tanks should be not less than thirty (30) gallons, except tanks in combination with the heater when the storage capacity should be not less than twenty (20) gallons.

Where water heaters are to be installed in locations where water contains a total of calcium and magnesium bicarbonates in an amount exceeding two hundred (200) parts per million (expressed as calcium carbonate), consideration should be given to the use of a type of water heater that will not burn out or be subject to rapidly decreasing efficiencies as a result of scale accumulation. Heaters similar to the immersion type water heater, having heating surface such as fire tubes which expel the scale by alternate expansion and contraction and deposit the scale in the cold portions of the tank, or indirect heaters or coil heaters designed for high velocities, are recommended. Heaters which utilize portions of the heater tanks as the primary heating surfaces, or contain coils which will become clogged with scale deposits, are not recommended. Experience indicates that some scaling of heaters may be encountered when the calcium and magnesium bicarbonates expressed as calcium carbonate are less than two hundred (200) parts per million; however, in these cases central treatment of the water supply to correct scale-forming conditions is desirable. Actual operating experience has demonstrated that satisfactory results can be expected in the control of scale formation by central water treatment.

c. Estimating Hot Water Demand: Methods prescribed for calculating water heater and hot water storage capacities for buildings are by the number and type of plumbing fixtures and by the per capita method. The temperature rise should be based on the temperature of the local distribution system and the required delivery temperature. The temperature rise is generally assumed to be one hundred (100) degrees Fahrenheit when the water is heated from forty (40) degrees Fahrenheit to one hundred forty (140) degrees Fahrenheit. The recovery capacity is defined as the hourly heating capacity in gallons raised to the required temperature in degrees Fahrenheit. The per capita method of determining hot water requirements is recommended when the number of persons assigned to a building can be determined. In buildings having an assigned population of less than fifty (50) persons, the per fixture method may be appropriate because the number of fixtures may be in excess of the recommended ratios of plumbing fixtures.

The water heating and storage capacities may be determined by the per fixture method from the data in Table IX.

TABLE IX
CAPACITY OF WATER HEATING EQUIPMENT FOR VARIOUS TYPES OF BUILDINGS

	Gallons Per Hour (Maximum)							
	Barracks	Hospital	Administrative	Industrial	Apartments	Quarters	Gym	Club
Lavatories (Private)	3	3	3	3	3	3	-	3
Lavatories (Public)	10	10	8	12	5	5	10	10
Bath Tub	15	15	-	-	15	30	30	15
Kitchen Sink	20	20	-	-	10	20	-	20
Scullery Sink	45	45	-	-	-	45	-	45
Service Sink	30	20	30	20	20	20	-	30
Shower	150	100	-	250	100	150	250	200
Laundry Tub	35	35	-	-	25	35	-	25
Conversion Factors								
Heating	.185	.20	.20	.20	.15	.10	.30	.15
Storage	.25	.25	.35	.25	.20	.15	.35	.20

Example: Assume a barracks building has the following fixtures, determine the water heating and storage requirements.

20 Lavatories	x 3	=	60	Gallons Per Hour
12 Showers	x 150	=	1800	Gallons Per Hour
2 Service Sinks	x 30	=	60	Gallons Per Hour
2 Laundry Tubs	x 35	=	70	Gallons Per Hour
4 Scullery Sinks	x 45	=	180	Gallons Per Hour
Maximum			2170	Gallons Per Hour
Hourly Heating Capacity	2170 x 0.185	=	401	Gallons, Minimum
Storage Capacity	2170 x 0.25	=	543	Gallons, Minimum

The gallons of water to be heated per day, per capita, the number of hours assumed for the duration of the average heating load and the number of hours assumed to determine peak hourly requirements should conform with local conditions. The water heating and storage requirements may be determined on the per capita per day basis by the following equations:

A = Average Hourly Heating Capacity (Gallons) $\frac{G \times N}{B}$

P = Peak Hourly Requirements (Gallons $\frac{G \times N}{D}$

Storage Capacity (Gallons) $\frac{P - A}{0.75}$

Where G = The gallons of hot water required per day per person.
N = Number of persons assigned to building.
B = Duration of average heating period in hours per day.
D = Duration of peak load in hours per day.
0.75 = 75% of hot water available from storage tank. (Remainder of water in storage tank is assumed to be too cool for satisfactory use).

Factors are tabulated under Table X for determining minimum requirements for water heating and hot water storage by the Per Capita method.

TABLE X

FACTORS FOR DETERMINING MINIMUM REQUIREMENTS FORWWATER HEATING AND HOT WATER STORAGE "PER CAPITA PER DAY METHOD"

Types of Buildings	Gallons of Hot Water Per Person Per Day	Duration of Average Heating Period in Hours Per Day	Duration of Peak Load In Hours Per Day
Quarters and Apartments	40	8	4
Hotels	30	15	5
Barracks and Mess Halls	40	14	7
Barracks without Mess Halls	30	14	6
Administration Office Buildings, etc.	2	5	3
Industrial Type Buildings	5	4	2
Mess Halls: Machine Washing	10	10	5
Hand Washing (less than 100 persons)	10	8	3
Hand Washing (over 100 persons)	10	10	5

Example: Assume a Barracks with Mess Hall will house 200 soldiers. By reference to the equation and data under Table X the capacity of the water heating equipment and hot water storage tank may be determined as follows:

$$A = \text{Heating Capacity } \frac{40 \times 200}{14} = 571$$

$$P = \text{Peak Hourly Requirements } \frac{40 \times 200}{7} = 1143$$

$$\text{Storage Capacity } \frac{1143 - 571}{0.75} = 762$$

If the designer should select a hot water tank having a storage capacity of 950 gallons then the heating capacity could be revised as follows:

$$\text{Revised heating capacity} = \text{Peak} - (\text{Capacity of Tank} \times 0.75)$$

$$\text{or} \quad 1143 - (950 \times 0.75)$$

$$= 431 \text{ gallons per hour.}$$

If the designer snould select a water heater having a capacity of 350 gallons per hour in lieu of the capacity indicated in the example then the storage capacity should be revised as follows:

$$\text{Revised storage capacity} = \frac{\text{Peak} - \text{Selected heater capacity}}{0.75}$$

$$\text{or} \quad \frac{1143 - 350}{0.75}$$

$$= 1057 \text{ gallons.}$$

Hot water requirements for laundries should be computed by the following equations:

Demand based on the number and capacity of washers in pounds of dry clothes.

Total average requirements in gallons per hour = $R \times 5 \times .60$

Peak demand in gallons of water per minute = $\frac{R \times 5 \times .60}{3 \times F \times C}$

R = Total rated capacity of washers in pounds of dry clothes.
C = Number of fill cycles per hour.
3 = Number of machines that may be filled simultaneously.
F = Number of minutes required to fill each machine with water.
60 = 60% of total water to be heated.
5 = Gallons per pound of dry clothes.

Demand based on the number of men to be served by the laundry.

Total average in gallons per hour = $\frac{(N \quad 15\%) \times P \times 5}{H}$

Peak demand in gallons per minute = $\frac{(N \quad 15\%) \times P \times 5 \times .60}{H \times 3 \times F \times C}$

P = Pounds of dry clothes per person or hospital bed.
(10 Pounds per person and 35 pounds per hospital bed.)
5 = Gallons per pound of dry clothes.
.60 = 60% of total water to be heated.
3 = Number of machines that may be filled simultaneously.
C = Number of fill cycles per hour.
N = Number of persons or hospital beds.
H = Number of work hours per week.
F = Number of minutes to fill each machine with water.

Example 1: The capacity of the washing machines is six hundred (600) pounds of dry clothes. Find the average hot water requirements in gallons per hour and peak hot water demand in gallons per minute with five (5) operations per hour assuming that it will require two (2) minutes to fill the washers.

Total average requirements in gallons per hour = $600 \times 5 \times 0.60 = 1800$

Peak demand in gallons of water per minute = $\frac{600 \times 5 \times 0.60}{3 \times 2 \times 5} = 60$

Example 2: A laundry will process laundry for five hundred (500) men per forty (40) hour week assuming that it will require two (2) minutes to fill each washer. Determine the total average requirements in gallons of hot water per hour and peak demand in gallons of hot water per minute.

Total average in gallons per hour = $\frac{575 \times 10 \times 5 \times .60}{40} = 431$

Peak demand in gallons of water per minute = $\frac{575 \times 10 \times 5 \times .60}{40 \times 3 \times 2 \times 5} = 14$

d. Heating Surface of Coils for Hot Water Generators and Instantaneous Water Heaters. The surface area of a heating coil should be computed by the rate of heat transfer which may be determined from (1) the overall conductance of the intervening barrier of metals, films and deposits; (2) the exposed area available for the transfer of heat; and (3) the difference in temperature between the hot and cold bodies.

The formula for calculating the inside area is:

$$A = \frac{Q \times 8.33 \times (t_2 - t_1)}{U \times \Delta T} \qquad (1)$$

Where: A = Surface are of coil, square feet.
Q = Quantity of water to be heated in gallons per hour.
t_2 = Hot water outlet temperature, degrees Fahrenheit.
t_1 = Cold Water inlet temperature, degrees Fahrenheit.
U = The overall conductance of the intervening barrier of metal, films and deposits in Btu per hour, per square foot, per degree Fahrenheit: Copper Coil U = 230.
ΔT = Mean effective temperature difference between the hot and cold fluids.

Computing the value of U -

$$U = \frac{1}{\frac{x}{k} + \frac{1}{h_1} + \frac{1}{h_2} + \frac{1}{h_3} + \frac{1}{h_4}} \qquad (2)$$

Where: K = Conductivity of the metal, Btu per hour, per square foot.
X = Thickness of metallic wall, inch
h_1, h_2, h_3, h_4 = Conductances of the surface film and corrosion scales or deposits. Where any one or more of these factors are non-existent, then the conductance of that factor becomes infinite, and the expression $\frac{1}{h_1}$ for example becomes zero.

The computation to determine the value of U is based on the following conditions:

X = Copper tubing, thickness 0.058 inch.
K = Copper = 2680
h_1 = 1000 for condensing steam.
h_2 = 300 for water being heated.

Substitute the values in equation (2).

$$U = \frac{1}{\frac{0.058}{2680} + \frac{1}{1000} + \frac{1}{300} + 0 + 0} = 230$$

Computing the values for ΔT or the M.T.D.; mean temperature difference is as follows:

The arithmetic M.T.D. is computed by -

$$\Delta T_A = t_s - \left[\frac{(t_2 - t_1)}{2}\right] \qquad (3)$$

Where t_s = Temperature of heating medium, degrees Fahrenheit.

The logarithmic M.T.D. is computed by -

$$\Delta T_L = \frac{\Delta T_1 - \Delta T_2}{\log_e \frac{\Delta T_1}{\Delta T_2}} \qquad (4)$$

Where ΔT_1 = Greater temperature difference between hot and cold fluids.
ΔT_2 = Lesser temperature difference between hot and cold fluids.

Example 1: Determine the amount of heating surface required in a hot water generator to heat 200 gallons of water per hour from 50 to 150 degrees Fahrenheit with steam at 25 pounds pressure per square inch, using copper coil fabricated with tubing.

Substitute values in equations 3 and 4 for the mean temperature difference.

$$\text{Arithmetic M.T.D.} = \left[267 - \frac{(150 - 50)}{2}\right] = 167^{\circ}$$

$$\text{Logarithmic M.T.D.} = \frac{217 - 117}{\log_e 217/117} = \frac{100}{.6152} = 162^{\circ}\ \text{F.}$$

Substitute values in equation 1 for determination of the area inside of heating coil.

by Arithmetic Means -

$$A = \frac{200 \times 8.33 \times 100}{230 \times 167} = 4.34$$

by Logarithmic Means -

$$A = \frac{200 \times 8.33 \times 100}{230 \times 162} = 4.47$$

Factors for determining the square feet of heating surface for hot water generators with various steam pressures and various water temperatures and temperature rise are given under Table XI.

TABLE XI
CONVERSION FACTORS
(For Determining the Square Feet of Heating Surface for Hot Water Generators)

Water Temperature Degrees Fahrenheit		Steam Pressure (Pounds Per Square Inch Gage)								
From	To	0	5	10	15	25	40	50	75	100
50	100	.0135	.0119	.0114	.0103	.0106	.0087	.0081	.0075	.0069
	125	.0224	.0198	.0181	.017	.0154	.0137	.0129	.0117	.0109
	135	.0269	.0235	.0215	.020	.0179	.0161	.0152	.0137	.0127
	150	.0347	.0298	.0270	.0251	.0222	.0198	.0188	.0168	.0154
	160	.0411	.0348	.0312	.0288	.0256	.0226	.0212	.0190	.0174
	180	.0586	.0474	.0416	.0378	.033	.0286	.0268	.0237	.0216
60	100	.0111	.0098	.0092	.0086	.0078	.0069	.0066	.00600	.0057
	125	.0202	.0177	.016	.0151	.0137	.0122	.0117	.0103	.0098
	135	.0245	.0214	.0194	.0181	.0163	.0144	.0137	.0124	.0114
	150	.0324	.0276	.025	.0232	.0206	.0183	.0172	.0154	.0142
	160	.0388	.0327	.0293	.027	.0238	.021	.0198	.0174	.0161
	180	.0563	.0453	.0397	.0360	.0312	.0271	.0254	.0224	.0204
80	100	.0060	.0054	.0048	.0044	.0041	.0038	.0035	.0031	.0028
	125	.0151	.0132	.0119	.0111	.01	.0089	.0084	.0075	.0069
	135	.0194	.0168	.0151	.0142	.0127	.0111	.0106	.0095	.0087
	150	.0273	.0232	.0208	.0192	.017	.0149	.0139	.0124	.0114
	160	.0337	.0281	.025	.0229	.0202	.0177	.0165	.0147	.0134
	180	.0512	.0406	.0353	.0321	.0277	.0238	0222	.0194	.0177

Example: Determine the amount of heating surface required to heat 500 gallons of water per hour from 60 degrees to 180 degrees Fahrenheit with steam at 25 pounds pressure per square inch gage.

500 x .0312 15.6 square feet of heating surface.

e. Control of Hot Water Temperatures: It is considered advisable to describe the functions of controls for water heating equipment which are more or less inter-related. Figures 10 and 11 indicate the recommended location of controls.

The automatic damper regulator is a device for operating the dampers on water and steam boilers to increase or decrease the draft proportionately to the decrease or increase of the temperature on water heaters or pressure on steam boilers. Levers, weights, chains and pulleys generally comprise the assembly of equipment needed in addition to the main regulator, all of which should be properly adjusted to obtain best results to maintain the water in the hot water storage tank at a predetermined temperature. The regulator is generally actuated by a tube containing a volatile liquid, or an expanding tube containing a non-expanding member or both, the expansion and contraction of which will operate the valve direct or cause a metal diaphragm or metal bellows to expand and contract.

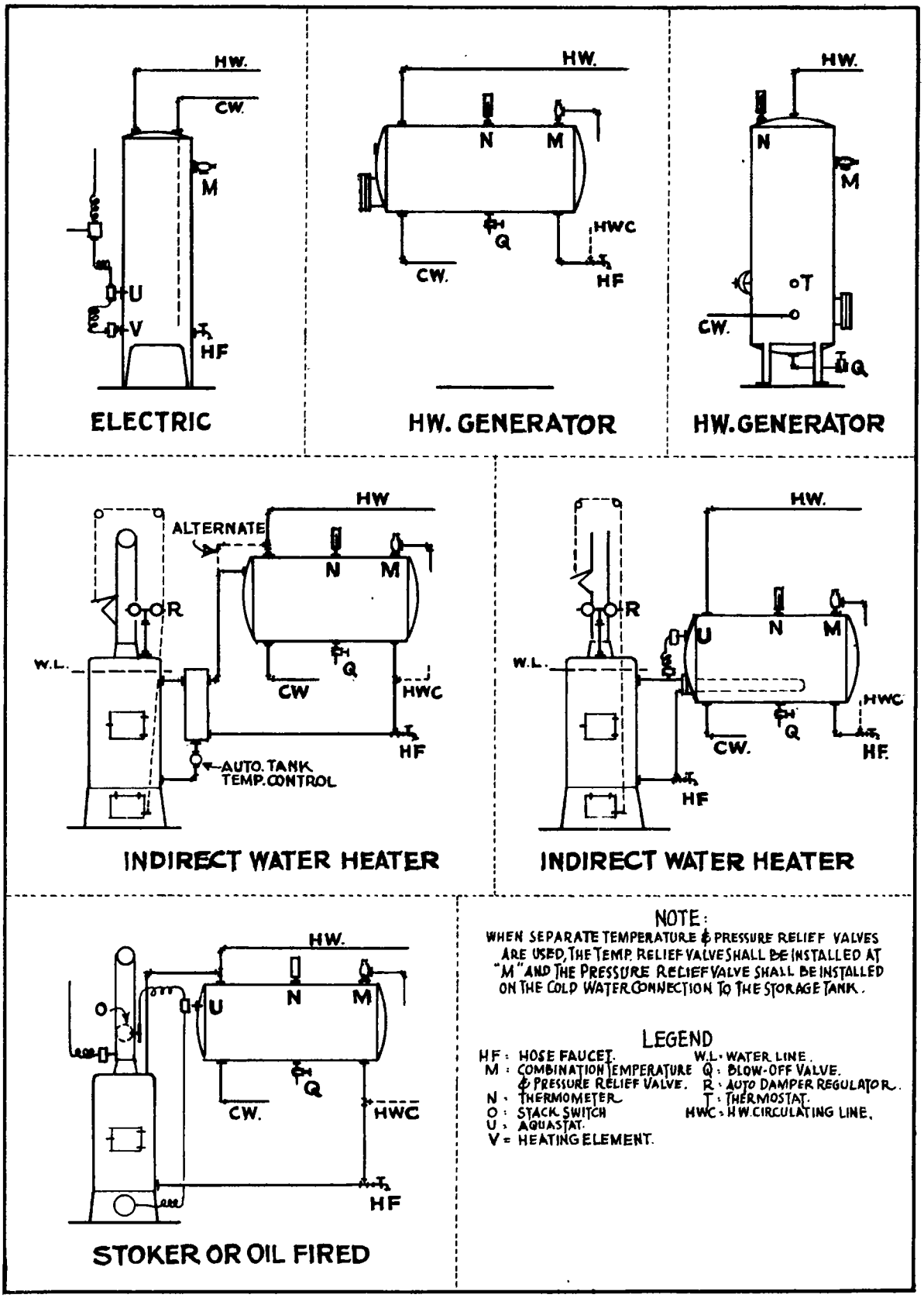
The aquastat is a device employed for controlling the supply of heat (either through operation of a burner or of a valve) to the water in the storage tank. When the temperature of the water drops below the lower setting, heat will be supplied and when the temperature of the water rises above the higher setting, the heat supply will be shut off. Aquastats are available as immersion or surface units and they most generally have low voltage rating.

The stack switch is a safety device consisting generally of the required electrical auxiliaries, such as relays, transformer for reduction of voltage, and a metallic spiral for inserting across the flue gas stream in the stack. The spiral insert is metal of a total developed length and satisfactory expansion coefficient to provide the necessary mechanical movement for operation of the switch. While the fuel is actually ignited and the flue gas is therefore up to at least its normal operating temperature, the expansion of the metallic spiral will through its electrical auxiliaries permit the continued feeding of fuel; but if the fuel being fed is not ignited, the flue gas temperature will be sufficiently lowered to contract the metallic spiral and switch off the current to stop operating the burner motor.

The thermostat is a device consisting of an element immersed in the storage tank that expands or contracts dependent upon whether the water in the tank is at the upper or lower range of temperature. The motion of the expanding or contracting element is transferred ultimately to cause the opening or closing of the supply of fuel used for heating the water.

Minimum standards for relief valves including the performance, safe operation and substantial construction requirements should be included in specifications.

Listing requirements for relief and automatic gas shutoff valves for use on water heating systems has been sponsored by the American Gas Association and approved by the American Standards Association. There are two kinds of relief devices known as pressure relief valves and temperature relief valves. They may be made as separate devices or made up in one body.


HW.
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AUTO. TANK
TEMP. CONTROL
INDIRECT WATER HEATER
HW.
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INDIRECT WATER HEATER
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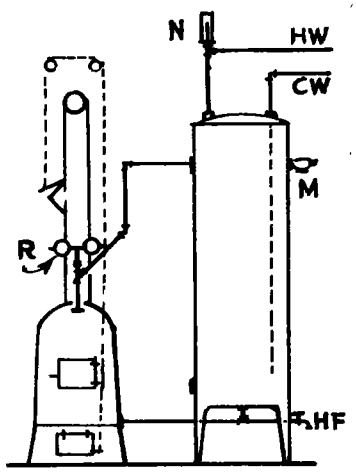
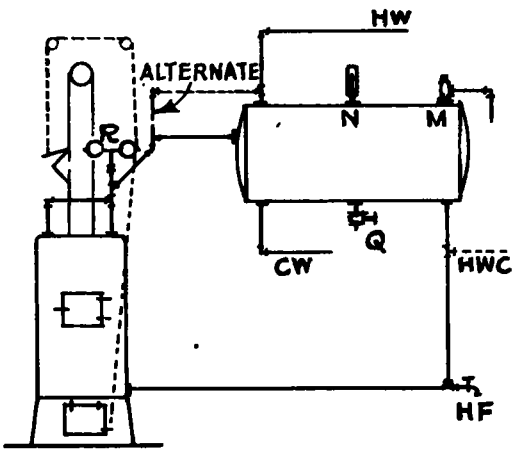
CW.
HWC
HF
STOKER OR OIL FIRED
NOTE:
WHEN SEPARATE TEMPERATURE & PRESSURE RELIEF VALVES ARE USED, THE TEMP. RELIEF VALVE SHALL BE INSTALLED AT "M" AND THE PRESSURE RELIEF VALVE SHALL BE INSTALLED ON THE COLD WATER CONNECTION TO THE STORAGE TANK.
LEGEND
HF = HOSE FAUCET.
M = COMBINATION TEMPERATURE & PRESSURE RELIEF VALVE.
N = THERMOMETER.
O = STACK SWITCH
U = AQUASTAT.
V = HEATING ELEMENT.
W.L. = WATER LINE.
Q = BLOW-OFF VALVE.
R = AUTO DAMPER REGULATOR.
T = THERMOSTAT.
HWC = H.W. CIRCULATING LINE.

FIGURE 10.



COAL FIRED



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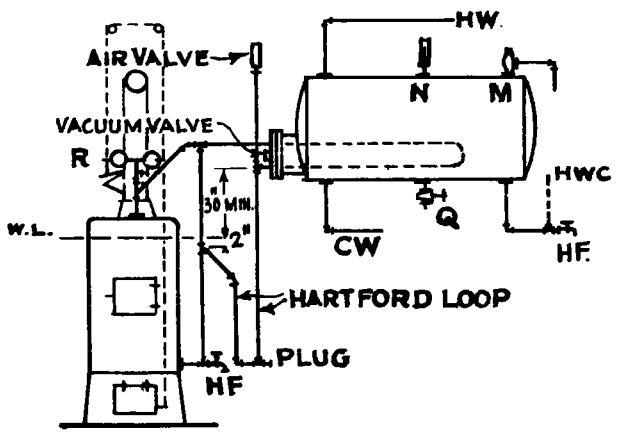
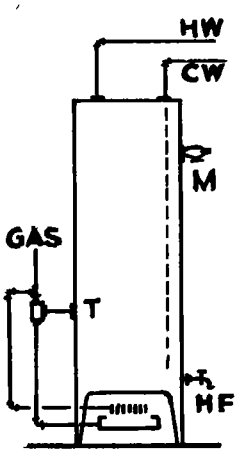
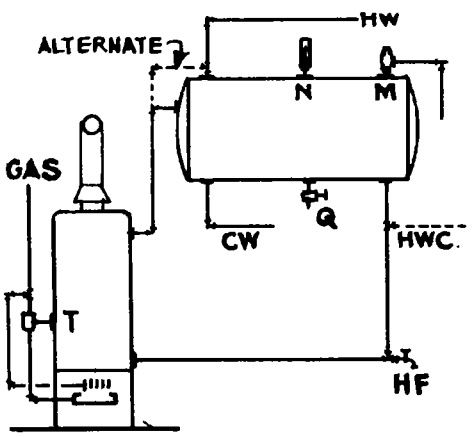


STEAM BOILER & GENERATOR



GAS FIRED



GAS FIRED

NOTE

WHEN SEPARATE TEMPERATURE & PRESSURE RELIEF VALVES ARE USED, THE TEMP. RELIEF VALVE SHALL BE INSTALLED AT "M" AND THE PRESSURE RELIEF VALVE SHALL BE INSTALLED ON THE COLD WATER CONNECTION TO THE STORAGE TANK.

LEGEND.

HF = HOSE FAUCET.
M = COMBINATION TEMPERATURE & PRESSURE RELIEF VALVE.
N = THERMOMETER.
O = STACK SWITCH.
U = AQUASTAT.
W.L. = WATER LINE
Q = BLOW-OFF VALVE.
R = AUTO DAMPER REGULATOR.
T = THERMOSTAT.
HWC = H.W. CIRCULATING LINE.

FIGURE 11.

If there is only one valve and seat in the body and it is actuated by either the pressure or the temperature, it may be termed a "combination pressure and temperature" device. Locations of relief valves are shown on Figures 10 and 11.

4-14 DESIGN OF SANITARY DRAINAGE SYSTEM: The design of sanitary drainage piping should be governed by figures 12, 13 and 14, including the following text. Fixture unit values, designating the relative load weights of different kinds of fixtures are listed in Table IV. These fixture units should be employed in estimating the capacities of soil and waste stacks, horizontal branches and drains from more than one (1) branch interval by reference to Table XII.

a. Stacks: Soil and waste stacks should extend in a vertical line from the highest to the lowest branch, except that a forty-five (45) degree offset may be employed provided that the total number of fixture units on such stack does not exceed one-half (1/2) of the limit. No soil or waste stack should be smaller than the largest horizontal branch connected thereto.

b. Horizontal Piping. Sloping fixture drains and horizontal branches of three (3) inches in diameter and less should be installed with a minimum grade of one-quarter (1/4) inch per foot. Horizontal drainage piping larger than three (3) inches in diameter should be installed with a fall of not less than one-eighth (1/8) inch per foot. Changes in direction in drainage piping should be made by the appropriate use of forty-five (45) degree wyes, half wyes, long sweep quarter bends, sixth, eighth or sixteenth bends, or by combination of these fittings or by the use of equivalent fittings or their combinations, except that sanitary tees may be used in vertical sections of stacks and short quarter bends may be used in the drainage lines where the change in direction of flow is from the horizontal to the vertical.

TABLE XII
CAPACITIES OF SOIL AND WASTE STACKS, HORIZONTAL BRANCHES AND DRAINS FROM MORE THAN ONE BRANCH INTERVAL

Pipe Size Inches	Maximum Fixture Units That May Be Connected				
	Vertical Soil and Waste Stack	A Horizontal Branch Or At One Branch Interval On Stack	Building Drains and Sewers or Other Drains Receiving Discharge From More Than One Branch Interval		
			1/8 Inch Fall Per Foot	1/4 Inch Fall Per Foot	1/2 Inch Fall Per Foot
1-1/4	2	1	-	2	2
1-1/2	4	3	-	3	4
2	10	6	-	6	10
3	48+	32 +	36 *	42 *	48 *
4	240	160	180	216	240
5	540	360	400	480	540
6	960	600	660	790	920
8	2240	1200	1600	1920	2240
10	3780	1800	2700	3240	3780
12	6000	2800	4200	5000	6000

* Not over one water closet
Not over two water closets

No change in direction greater than ninety (90°) degrees in a single turn should be made in the drainage pipes.

c. Cross Connections: No fixture, device or construction should be installed which will provide a backflow connection between a distributing system of water for drinking and domestic purposes and a drainage system, soil or waste pipe and which would permit or make possible the backflow of sewage or waste into the water supply system. No interconnection or cross-connection should be made between a water supply system carrying water meeting accepted standards of purity and any other water supply system.

d. Protection of Pipes: Pipes passing under or through walls should be protected from breakage. Pipes passing through or under cinder, concrete or any other corrosive material should be protected against corrosion. No soil or waste should be installed or permitted outside of a building or in an exterior wall unless adequate provision is made to protect it from freezing.

e. Protection of Electrical Machinery: Water or drainage piping should not be located over electrical machinery or equipment unless adequate protection is provided against drip caused by condensation on the piping.

4-15 VENTS AND VENTING: The seal of every fixture trap in a plumbing system should be adequately protected by a properly installed vent or system of venting. A stack vent, back vent, relief vent, dual vent, circuit vent or loop vent, or a combination of two (2) or more of these forms, should be installed in a manner and within the limitations considered as adequate protection of trap seals.

a. Stack Vents: Every soil or waste stack should be extended vertically as a stack vent to at least six (6) inches above the highest horizontal branch and then to the open air above the roof; or the stack vent and vent stack may be connected together within the building at least six (6) inches above the flood level of the highest fixture, with a single extension from the connection to the open air.

b. Vent Stacks: A vent stack or main vent should be installed with a soil or waste stack whenever relief vents, back vents, or other branch vents are required in two (2) or more branch intervals. The vent stack should terminate independently in the open air outside the building or may be connected with the stack vent and should connect with the soil or waste stack through, at or below the lowest horizontal branch or with the primary branch of the building drain.

c. Frost Closure: In cold climates adequate provision should be made to guard against frost closure of vents by increasing the pipe diameter at least one (1) pipe size before passing through the roof.

d. Location of Vent Terminals: No vent terminals from the sanitary drainage system should be within twelve (12) feet of any door, window or ventilating opening of the same or an adjacent building unless it is at least three (3) feet higher than the top of such opening. Extensions of vent pipes through a roof should terminate at least one (1) foot above it and should be properly fastered. Vent terminals extending through walls should not terminate within twelve (12) feet horizontally of any adjacent building, should be turned to provide a horizontal opening downward, should be effectively screened, and should be properly flashed, calked or otherwise sealed.

e. Distance of Trap from Vent: Except for water closets, pedestal urinals, trap standard service sinks, and other fixtures which depend on

siphon action for the proper functioning of the fixture, each fixture trap should have a protecting vent located so that the total fall in the fixture drain from the trap weir to the vent fitting is not more than one (1) pipe diameter and the developed length of drain from trap weir to vent fitting is not less than two (2) pipe diameters nor more than forty-eight (48) pipe diameters. If the fixture drain slopes continuously from the trap weir, assuming a fall of one quarter (1/4) inch per foot, limits the permissible length of drain between trap and vent to: 5 feet for a 1-1/4 inch drain; 6 feet for a 1-1/2 inch drain; 8 feet for a 2 inch drain; and 12 feet for a 3 inch drain. A back vent or relief vent, preferably in the form of a continuous waste and vent, should be installed within these limits as may be necessary for compliance with this requirement.

f. Continuous Vents. A continuous vent may be employed with no additional vents: (1) when both fixture drains connect with a vertical drain or stack at the same level; (2) in a bathroom where the traps for the lavatory and bathtub or shower may be served by the continuous vent for the lavatory waste only, provided that none of the piping is less than one and one-half (1-1/2) inch size.

g. Circuit and Loop Vents. A branch soil or waste pipe to which two, and not more than eight (8) water closets, pedestal urinals, trap standard service sinks, shower stalls, or floor drains are connected in series, may be vented by a circuit or loop vent which shall be taken off in front of the last fixture connection. When other fixtures discharge above such branch, each branch shall be provided with a relief vent taken off in front of the first fixture connection.

Two circuit-vented horizontal branches in the same branch interval may have a dual relief vent.

h. Stack Venting: A fixture located at the top level within five (5) feet of the soil or waste stack should be considered as individually vented. A water closet should be considered as individually vented if there are not in excess of four (4) fixture units connected to the stack above the water closet connection.

i. Tank Vents: All tanks used for receiving sewage or other wastes should be provided with a vent. Pneumatic ejectors should be separately vented to the open air.

j. Venting Stack Offsets: Offsets in soil or waste stacks at an angle greater than forty-five (45) degrees from the vertical, serving fixtures below and on two (2) or more floors above the offset, should be vented with a yoke equal in diameter to the vent or soil stack or vented as two (2) separate soil or waste stacks. The lower end of the yoke vent should connect to the soil or waste stack through a wye below the lowest horizontal branch above the offset, and the upper end should connect to the vent stack through a wye not less than three (3) feet above the floor. When vented as two (2) separate soil or waste stacks, the stack section below the offset and the stack section above the offset should be vented.

k. Vent Headers: Stack vents and vent stacks may be connected into a common vent header at the top of the stacks and extended to the

open air at one point. This header should be sized by reference to Table XIII, the number of fixture units being the sum of all fixture units on all stacks connected thereto and the developed length being the longest vent length from the intersection at the base of the most distant stack to the vent header terminal in the open air.

l. Vent Pipe Grades and Connections. All vent and branch vent pipes should be free of traps and be so graded and connected as to drip back to the soil or waste pipe or vent stack by gravity. When vent pipes connect to a horizontal soil or waste pipe, the vent should be taken off above the center line of the soil pipe and the vent pipe should rise vertically, or at an angle of forty-five (45) degrees to the vertical. The vent should be continued to a point six (6) inches above the flood level of the fixture it is venting except, when construction will not permit. When construction does not permit, it should be run off horizontally, provided the bottom of the section of the vent pipe is above the top of the waste pipe before offsetting horizontally or connecting to the branch soil or waste vent.

m. Size and Length of Vents. The length of a vent stack or main vent should be its developed length from the lowest connection of the vent system to the vent stack terminal in open air or the connection to the stack vent. A vent stack should have a diameter of at least one-half (1/2) of the diameter of the accompanying soil or waste stack.

The length of a branch vent should be the developed length from its connection to the vent stack or stack vent to the fixture drain or horizontal soil or waste branch served by the vent.

The length of a stack vent should be the developed length from the highest horizontal or fixture branch connected to the stack to the terminal of the stack vent in the open air. Stack vents should be not less than the diameter of the soil or waste stack.

Back vent should be not less than one and one-quarter (1-1/4) inch in diameter not less than one-half (1/2) the diameter of the drain to which it is connected.

Relief vent should be at least equal in diameter to that of the vent stack or to that of the largest horizontal soil or waste branch, whichever is the smaller.

Circuit or loop-vent should be at least equal to the diameter of the horizontal soil or waste branch or the diameter of the vent stack whichever is the smaller.

n. Vents not Required. Vents are not required for a leader trap, a back water trap, area drain or sub-soil catch basin trap.

TABLE XIII

SIZE AND LENGTH OF MAIN VENTS

Diameter of soil or waste stack (inches)	Number of fixture units on soil or waste stack	Diameter of Vent, Inches								
		1¼	1½	2	2½	3	4	5	6	8
		Length of Vent, Feet								
1¼	2	75								
1½	4	70	150							
2	4	100	200	300						
2	10	50	150	200						
2½	11	50	100	300	400					
2½	18	20	75	200	300					
3	19		100	300	500	800				
3	34		60	200	400	600				
3	48		30	100	250	500				
4	50		50	150	350	600				
4	100		30	90	200	450				
4	150		20	50	150	400				
4	240		15	40	120	300				
5	100			50	125	400	700			
5	200			40	80	250	500			
5	350			20	50	150	400			
5	540			10	25	100	300			
6	175				40	150	450	800		
6	350				30	90	250	500		
6	750				20	70	200	400		
6	960				10	50	150	300		
8	150						75	150	350	1000
8	350						40	100	200	800
8	750						25	75	150	500
8	2000							40	100	400
8	2240							20	50	300

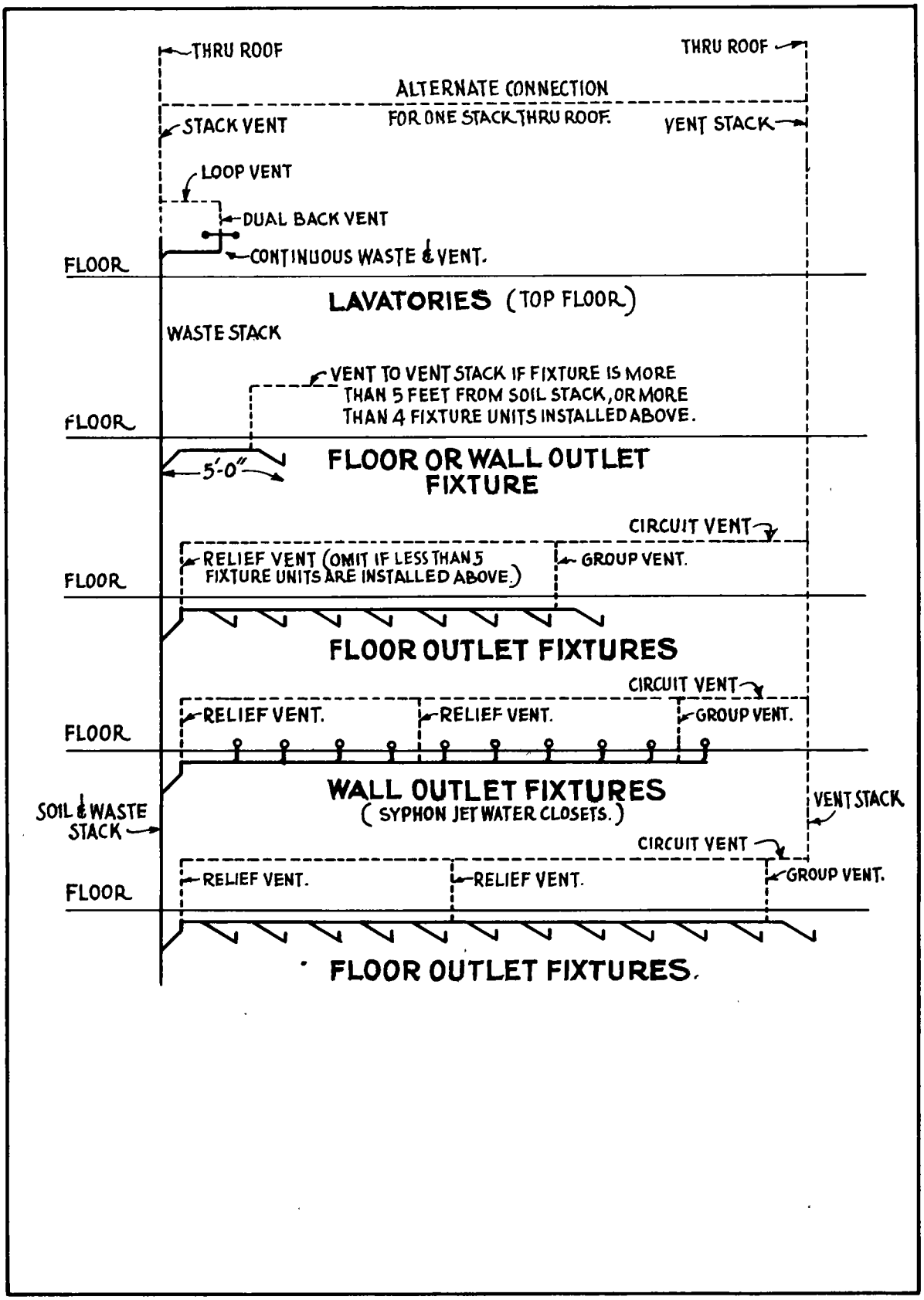

THRU ROOF
THRU ROOF
ALTERNATE CONNECTION
FOR ONE STACK THRU ROOF.
STACK VENT
VENT STACK
LOOP VENT
DUAL BACK VENT
CONTINUOUS WASTE & VENT.
FLOOR
LAVATORIES (TOP FLOOR)
WASTE STACK
VENT TO VENT STACK IF FIXTURE IS MORE THAN 5 FEET FROM SOIL STACK, OR MORE THAN 4 FIXTURE UNITS INSTALLED ABOVE.
FLOOR
5'-0"
FLOOR OR WALL OUTLET FIXTURE
CIRCUIT VENT
RELIEF VENT (OMIT IF LESS THAN 5 FIXTURE UNITS ARE INSTALLED ABOVE.)
GROUP VENT.
FLOOR
FLOOR OUTLET FIXTURES
CIRCUIT VENT
RELIEF VENT.
RELIEF VENT.
GROUP VENT.
FLOOR
WALL OUTLET FIXTURES
(SYPHON JET WATER CLOSETS.)
SOIL & WASTE STACK
VENT STACK
CIRCUIT VENT
RELIEF VENT.
RELIEF VENT.
GROUP VENT.
FLOOR
FLOOR OUTLET FIXTURES.

FIGURE 12

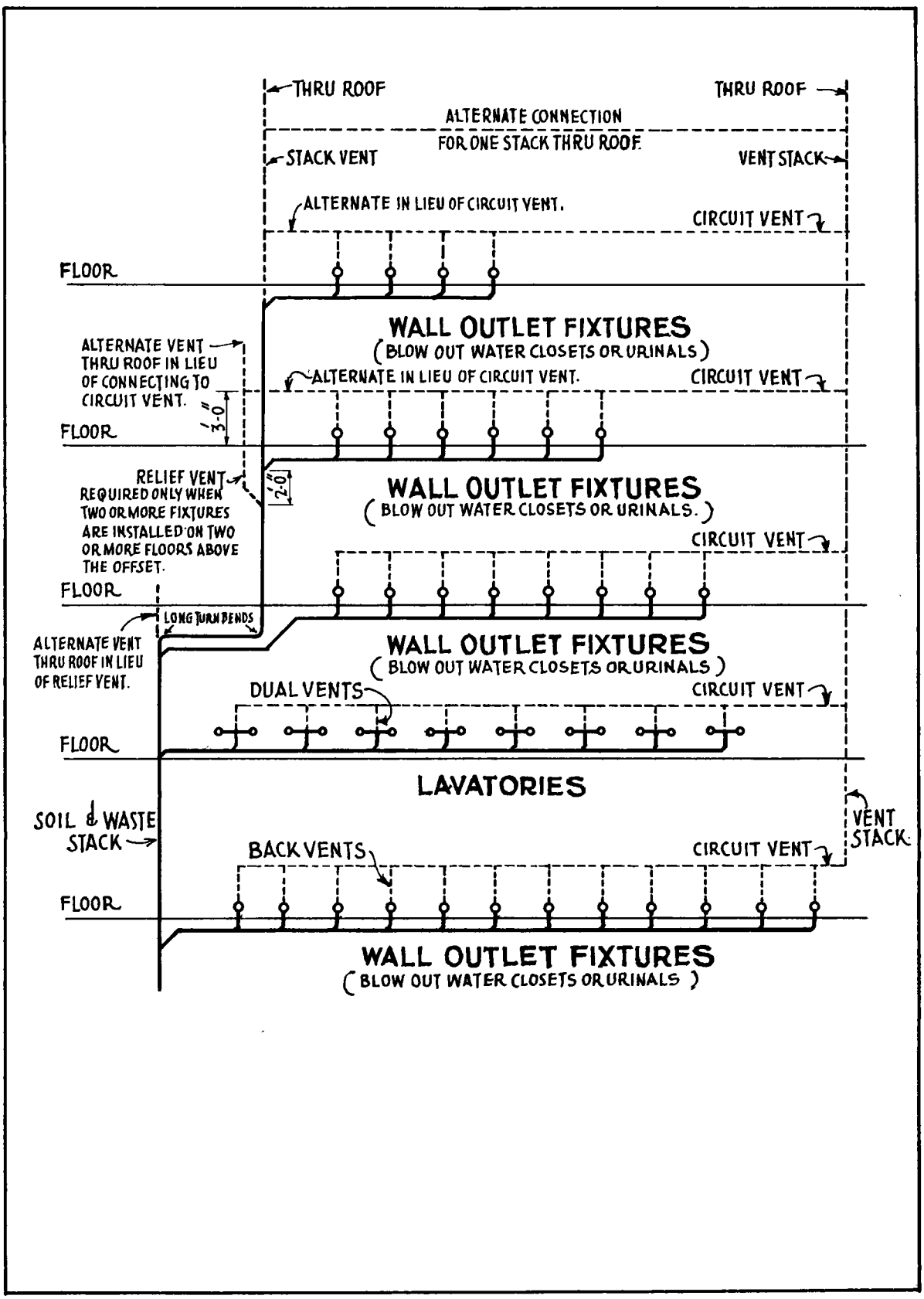
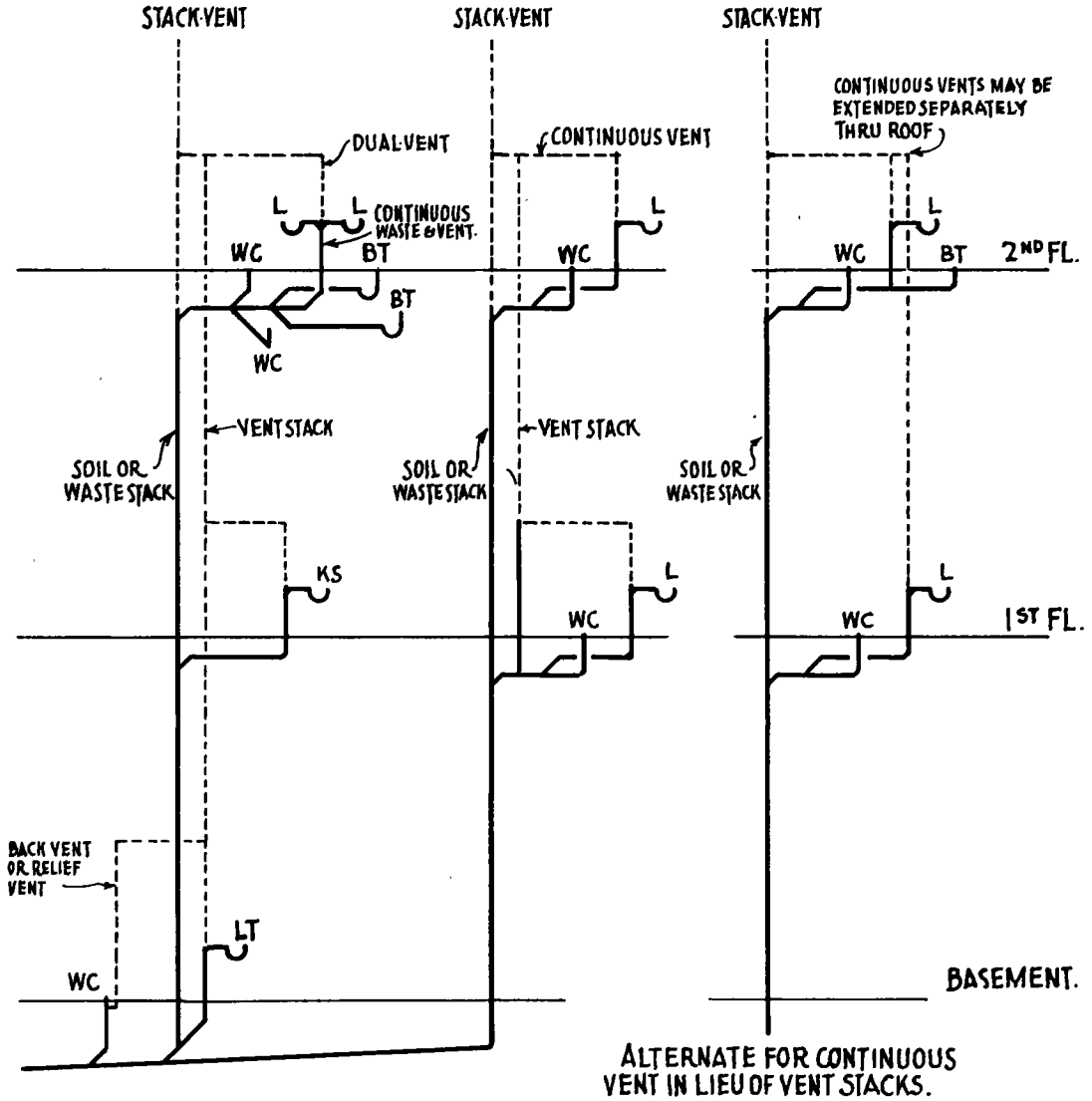

THRU ROOF
THRU ROOF
ALTERNATE CONNECTION
FOR ONE STACK THRU ROOF
STACK VENT
VENT STACK
ALTERNATE IN LIEU OF CIRCUIT VENT.
CIRCUIT VENT
FLOOR
WALL OUTLET FIXTURES
(BLOW OUT WATER CLOSETS OR URINALS)
ALTERNATE VENT THRU ROOF IN LIEU OF CONNECTING TO CIRCUIT VENT.
3'-0"
ALTERNATE IN LIEU OF CIRCUIT VENT.
CIRCUIT VENT
FLOOR
RELIEF VENT
REQUIRED ONLY WHEN TWO OR MORE FIXTURES ARE INSTALLED ON TWO OR MORE FLOORS ABOVE THE OFFSET.
2'-0"
WALL OUTLET FIXTURES
(BLOW OUT WATER CLOSETS OR URINALS.)
CIRCUIT VENT
FLOOR
LONG TURN BENDS
ALTERNATE VENT THRU ROOF IN LIEU OF RELIEF VENT.
WALL OUTLET FIXTURES
(BLOW OUT WATER CLOSETS OR URINALS)
DUAL VENTS
CIRCUIT VENT
FLOOR
LAVATORIES
SOIL & WASTE STACK
VENT STACK
BACK VENTS
CIRCUIT VENT
FLOOR
WALL OUTLET FIXTURES
(BLOW OUT WATER CLOSETS OR URINALS)

FIGURE 13



LEGEND

LAVATORY	L.
WATER CLOSET	WC.
BATH TUB	BT.
KITCHEN SINK	KS.
LAUNDRY TRAY	LT

SOIL, WASTE & VENT DIAGRAMS

FIGURE 14

4-16 STORM SEWERS.

a. General.

Roof and paved areas, yards, courts, and courtyards should be drained into a storm-sewer system or a combined sewer system. Storm water should not be drained into sewers intended for sanitary sewage only. Leaders and storm drains, when connected to a combined sewer should be effectively trapped. When the sanitary or storm drains are combined within the building, one trap on the main storm drain of the building may serve. Expansion joints or sleeves should be provided when warranted by temperature variations.

Tables XIV; XV; and XVI are based upon a maximum rate of rainfall of four (4) inches per hour. If the maximum rate of rainfall is more or less than four (4) inches per hour, then the figures in the tables should be adjusted proportionately by multiplying the figures by four (4) and dividing by the maximum rate of rainfall in inches per hour.

b. Size of Leaders, Downspouts, and Drains. The size of a vertical leader inside of a building should be determined by the maximum roof area as listed in Table XIV. Sheet metal downspout sizes should be determined by reference to Table XVI. Sizes of downspouts for roof areas listed in Table XIV are based on four (4) inches of rainfall per hour. When the weather records indicate maximum rates and frequency of rates higher than four (4) inches per hour, the tables can be utilized by multiplying the allowable roof areas by 4/X where X is the rate of rainfall to be provided for.

TABLE XIV
SIZES OF VERTICAL LEADERS
(inside of building)

Diameter of Leader or Pipe (inches)	Maximum Roof Area (square feet)
2	500
2-1/2	960
3	1500
4	3100
5	5400
6	8400
8	17400

Allowance for projecting walls should be added to the roof areas. For one (1) wall add fifty (50) percent of wall area and for two (2) adjacent walls add thirty-five (35) percent of the sum of wall areas.

Building storm sewer, main storm sewer or any of its branches having a slope of one-half (1/2) inch or less fall per foot should be sized by the maximum roof area in Table XV.

TABLE XV

MAXIMUM ROOF AREA FOR BUILDING STORM SEWERS OR DRAINS

Diameter of Pipe (inches)	Maximum Roof Area for Drains of Various Slopes in Sq. Ft.		
	1/8-inch Fall per Foot	1/4-inch Fall per Foot	1/2-inch Fall per Foot
2	-	350	500
3	750	1050	1500
4	1550	2150	3100
5	2700	3600	5400
6	4200	6000	8400
8	8700	11900	17400
10	15200	19600	30400
12	24700	31800	49400

c. Roof Gutters and Downspouts. Roof Gutters and sheet metal downspouts should be sized by referring to Table XVI.

TABLE XVI

MAXIMUM ROOF AREA FOR GUTTERS AND SHEET METAL DOWNSPOUTS

Gutters, Semi-circular (1/16 inch fall per foot)				Downspouts			
Diameter of Gutter (inches	Maximum Roof Area (sq. ft.)	Standard Sizes nominal	actual	Types	Size	Area	Maximum Roof Area in square feet
3	170	2	1-3/4x2-1/4		3	7	1200
4	360	3	2-3/8x5-1/4	Plain Round	4	12.5	2500
5	625	4	2-3/4x4-1/4		5	19.5	4500
6	960	5	3-3/4x5		6	28	8000
7	1380				3	6	900
8	1990			Corru-	4	11	1800
10	3600			gated	5	17.7	3350
12	6800			Round	6	26	6000
					2	4	600
				Plain	3	7.7	1200
				Rectang-	4	11.7	1800
				ular	5	18.7	4000
				Corru-	2	3.8	500
				gated &	3	7.7	1200
				Rectang-	4	11.7	2500
				ular	5	18.7	4000
Capacities of gutters are based on a fall of 1/16 inch per foot or less and a rainfall of four (4) inches per foot.							

The capacities of gutters in Table XVI are based on the flow without slope, one outlet and a rate of rainfall of four (4) inches per hour. If the fall is greater than one sixteenth (1/16) inch per foot or if the gutter has two or more outlets (leaders), the permissible roof area may be increased by multiplying it by one or both of the following factors as they apply: (1) by $\sqrt{\frac{s}{1/16}}$ where "s" is the actual fall in inches per foot; and (2) by N, the number of outlets, provided the roof area drained into any one leader does not exceed the values in Table XVI. For example, assume that a three (3) inch semi-circular roof gutter is pitched with a fall of one-eighth (1/8) inch per foot so as to divide the roof area equally between two (2) leaders. The permissible roof area on the three (3) inch gutter becomes $170\sqrt{\frac{1/8}{1/16}} \times 2 = 479$ square feet.

4-17 COMBINED SANITARY AND STORM DRAINS AND SEWERS. The sanitary and storm drainage system of a building should be entirely separate, except that when a combined sanitary and storm street sewer is available, the sanitary and storm drains of the building may be connected to a combined sanitary and storm building drain or sewer downstream and preferably at least ten (10) feet from any stack connection. The size of combined sanitary and storm drains up to the point of combining into one system should be as required for separate storm and sanitary systems. The size of the combined drains or sewers shall be computed by Table XVII.

TABLE XVII

REQUIRED DIAMETERS FOR COMBINED BUILDING DRAINS AND SEWERS ACCORDING TO NUMBER OF FIXTURE UNITS

For Drains and Sewers Having 1/8 Inch Fall Per Foot

Fixture units / Roof area	0	225	425	450	675	850	1350	1400	2450	2800	4000	4900	8000
sq. ft	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
0		4	4	4	5	5	6	8	8	8	10	10	12
775	4	4	5	5	6	6	8	8	8	10	10	10	12
1,350	4	5	5	6	6	6	8	8	10	10	10	10	12
1,550	4	5	6	6	6	8	8	8	10	10	10	12	12
2,100	5	6	6	6	6	8	8	8	10	10	10	12	12
2,700	5	6	6	6	8	8	8	8	10	10	12	12	12
4,200	6	8	8	8	8	8	8	8	10	10	12	12	12
4,350	8	8	8	8	8	8	8	8	10	10	12	12	15
7,600	8	8	10	10	10	10	10	10	10	12	12	12	15
8,700	8	8	10	10	10	10	10	10	12	12	12	12	15
12,400	10	10	10	10	10	10	12	12	12	12	12	15	15
15,200	10	12	12	12	12	12	12	12	12	15	15	15	15
24,800	12	12	12	12	12	12	12	12	15	15	15	15	15

For Drains and Sewers Having 1/4 Inch Fall Per Foot

Fixture units / Roof area	0	315	595	630	950	1190	1900	1950	3400	3900	5650	6800	11300
sq. ft.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
0		4	4	4	5	5	6	8	8	8	10	10	12
1,075	4	4	5	5	6	6	8	8	8	10	10	12	12
1,800	4	5	5	6	6	6	8	8	10	10	10	12	12
2,150	4	5	6	6	6	8	8	8	10	10	10	12	12
3,000	5	6	6	6	6	8	8	8	10	10	10	12	12
3,600	5	6	6	6	8	8	8	8	10	10	12	12	15
5,950	6	6	8	8	8	8	8	8	10	10	12	12	15
6,000	6	8	8	8	8	8	8	10	10	10	12	12	15
9,800	8	8	8	8	10	10	10	10	10	12	12	12	15
11,900	8	10	10	10	10	10	10	10	12	12	12	12	15
15,900	10	10	10	10	10	10	12	12	12	12	12	15	15
19,600	10	10	12	12	12	12	12	12	12	12	15	15	15
31,800	12	12	12	12	12	15	15	15	15	15	15	15	15

TABLE XVII CONT'D

For Drains and Sewers Having 1/2 Inch Fall Per Foot

Fixture units / Roof area	0	450	850	900	1350	1700	2700	2800	4900	5600	7500	9800	15000
sq. ft	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
0		4	4	4	5	5	6	8	8	8	10	10	12
1,550	4	4	5	5	6	6	8	8	8	8	10	10	12
2,700	4	5	5	6	6	8	8	8	10	10	10	10	12
3,100	4	5	6	6	6	8	8	8	10	10	10	12	12
4,200	5	6	6	6	6	8	8	8	10	10	10	12	12
5,400	5	6	6	6	8	8	8	8	10	10	10	12	15
8,400	6	8	8	8	8	8	8	8	10	10	12	12	15
8,700	8	8	8	8	8	8	8	8	10	10	12	12	15
15,200	8	8	10	10	10	10	10	10	10	12	12	12	15
17,400	8	10	10	10	10	10	10	10	12	12	12	15	15
24,700	10	10	10	10	10	10	12	12	12	12	12	15	15
30,400	10	10	10	12	12	12	12	12	12	12	15	15	15
49,400	12	12	12	12	12	15	15	15	15	15	15	15	15

APPENDIX

DEFINITIONS: Certain terms used in this mannual are defined which might be subject to variations in meaning. No attempt is made to define ordinary words which are used in accordance with their established dictionary meaning, except when the word has been loosely used and it is necessary to define its meaning as used in this manual to avoid misunderstanding. The primary purpose is to define terms rather than words, the definitions are arranged alphabetically according to the first word rather than the noun.

Air Gap. The air gap in a water supply system is the unobstructed vertical distance through the free atmosphere between the supply fitting outlet (spout) and the highest possible water level in the receptor when flooded. If the plane of the end of the spout is at an angle to the surface of the water, the main gap is the basis for measurement.

Area Drain. The area drain is a drain installed to collect surface rain water from an open area.

Backflow. Backflow means the flow of water or other liquids into the distributing pipes of a potable supply of water from any source or sources other than its intended source. Back-siphonage is one type of backflow.

Backflow Connection. A backflow connection or condition is any arrangement whereby backflow can occur. (It is recognized that other terms have been used, including cross-connection, interconnection, back-siphonage, and gravity flow, but the term backflow connection is the one used in this manual for the condition as defined).

Backflow Preventer. A backflow preventer (sometimes called vacuum breaker is device for installation in a water supply pipe to prevent backflow of water into the water supply system from the connections on its outlet end.

Back Vent. See Individual Vent.

Branch. A branch of a drainage system is any part of a piping system other than a main. A branch of a water supply system is a portion of the piping leading from the runout to the individual fixture.

Branch Interval. A branch interval is a length of soil or waste stack corresponding in general to a story height, but in no case less than eight (8) feet, within which the horizontal branches from one floor or story of the building are connected to the stack.

Branch Vent. A branch vent is a vent connecting one or more individual vents with a vent stack or a stack vent.

Building Drain. The building (house) drain is that part of the lowest horizontal piping of a building drainage system which receives the discharge from soil, waste and other drainage pipes inside the walls of the building and conveys it to the building (house) sewer beginning five (5) feet outside of the building wall.

Building Main. The building main is the water supply pipe, including fittings and accessories, from the water (street) main or other source of supply to the first branch of the water distributing system.

Building Sewer. The building (house) sewer is that part of the horizontal piping of a building drainage system extending from the building main five (5) feet outside of the building wall to the street sewer or other place of disposal (a cesspool, septic tank or other type of sewage treatment device or devices) and conveying the drainage of but one (1) building site.

Building Storm Drain. A building storm drain is a building drain used for conveying rain water, ground water, subsurface water, condensate cooling

water, or other similar discharge to a building storm sewer or a combined building drain and building storm sewer.

Building Storm Sewer. A building storm sewer is the extension from the building storm drain to the public storm sewer, combined sewer, or other place of disposal.

Building Subdrain. A building subdrain is that portion of a drainage system which cannot drain by gravity into the building sewer.

Circuit Vent. A circuit vent is a group vent extending from in front of the last fixture connection of a horizontal branch to the vent stack.

Combination Fixture. Combination fixture is a trade term designating an integral combination of one sink and one or two laundry trays in one fixture.

Combined Sewer. A sewer which receives both storm water and sewage.

Continuous Waste. Continuous waste is a waste from two (2) or more fixtures connected to a single trap.

Cross Connection. A physical connection through which a supply of potable water could be contaminated, polluted or infected.

Developed Length. The developed length of a pipe is its length along the center line of the pipe and fittings.

Diameter. Unless specifically stated, the term diameter means the nominal diameter as designated commercially.

Distance. The distance or difference in elevation between two (2) sloping pipes is the distance between the intersection of their center lines with the center line of the pipe to which both are connected.

Drainage System. A drainage system, or drainage piping shall mean and include all the piping within public or private premises, which conveys sewage, rainwater, or other liquid wastes, to a legal point of disposal, but shall not include the mains of a sewer system.

Drain. A drain or drain pipe is any pipe which carries water or water borne wastes in a building drainage system.

Dry Vent. A dry vent is any vent that does not carry water or water borne wastes.

Dual Vent. A dual vent is a vent connecting at the junction of two fixture drains and serving as an individual vent for both fixtures.

Fixture Branch. A fixture branch is the supply pipe between the fixture and the water distributing pipe.

Fixture Drain. A fixture drain is the drain from the trap of a fixture to the junction of the drain with any other drain pipe.

Fixture Unit. A fixture unit is a factor so chosen that the load-producing values of the different plumbing fixtures can be expressed approximately as multiples of that factor.

Grade. The grade of a line of pipe is its slope in reference to a horizontal plane. In plumbing it is usually expressed as the fall in inches per foot length of pipe.

Grease Interceptor. A grease interceptor is a receptacle designed to collect and retain grease and fatty substances normally found in kitchen or similar wastes and is installed in the drainage systems between the kitchen or other point of production of the waste and the building sewer.

Group Vent. A group vent is a branch vent that performs its functions for two (2) or more traps.

Horizontal Branch. A horizontal branch is a branch drain extending laterally from a soil or waste stack or building drain, with or without vertical sections or branches, which receives the discharge from one (1) or more fixture drains and conducts it to the soil or waste stack or to the building (house) drain.

Indirect Waste Pipe. An indirect waste pipe is a waste pipe which does not connect directly with the building drainage system, but discharges into it through a properly trapped fixture or receptacle.

Individual Vent. An individual vent (back vent) is a pipe installed to vent a trap, soil or waste pipe underneath or back of the fixture it serves and connected to a point above the fixture to the general vent system.

Interconnection. An interconnection, as the term is used in the manual, is any physical connection or arrangement of pipes between two (2) otherwise separate building water supply systems whereby water may flow from one system to the other, the direction of flow depending upon the pressure differential between the two (2) systems.

Interceptor. An interceptor is a receptacle designed and constructed to intercept or separate and prevent the passage of oil, grease, sand or similar materials into the drainage system to which it is directly or indirectly connected.

Leader. A leader or downspout is the water conductor from the roof to the storm drain or other means of disposal.

Loop Vent. A loop vent is the same as a circuit vent except that it loops back and connects with a soil or waste-stack-vent instead of the vent stack.

Main. The main of any system of continuous piping is the principal artery of the system to which branches may be connected.

Offset. An offset in a line of piping is a combination of elbows or bends which brings one section of the pipe out of line with, but into a line parallel with, another section.

Plumbing. Plumbing is the installing within buildings of the pipes, fixtures and other apparatus for bringing in the water supply and removing liquid and water-borne wastes. The term is also used to denote the installed fixtures and piping of a building.

Plumbing Fixtures. Plumbing fixtures are receptacles which receive water, liquid, or water-borne wastes and discharge them into a drainage system.

Plumbing System. The plumbing system of a building includes the water supply distributing pipes; the fixtures and fixture traps; the soil, waste, and vent pipes; the building (house) drain and building (house) sewer; and the storm drainage pipes, with their devices, appurtenances and connections all within or adjacent to the building.

Relief Vent. A relief vent is a branch from the vent stack, connected to a horizontal branch between the first fixture branch and the soil or waste stack, whose primary function is to provide for circulation of air between the vent stack and the soil or waste stack.

Riser. A riser is a water supply pipe which extends vertically for at least one (1) full story or more to convey water to horizontal runouts to branches.

Runout. A runout is a horizontal section of piping leading from a riser and conveys water to one or branches to fixtures.

Sand Interceptor (Sand Trap). A sand interceptor (sand trap) is a watertight receptacle designed and constructed to intercept and prevent the passage of sand or other solids into a drainage system to which it is directly or indirectly connected.

Sanitary Sewer. A sanitary sewer is a sewer designed or used only for conveying liquid or water-borne waste from plumbing fixtures.

Sewage. Sewage is any liquid waste continuing animal or vegetable matter in suspension or solution, and may include liquids from laboratories or industrial institutions, containing chemicals in solution.

Size of Pipe and Tubing. The size of pipe or tubing, unless otherwise stated, is the nominal size by which the pipe or tubing is commercially designated. Actual dimensions of the different kinds of pipe and tubing are given in the applicable specifications.

Soil Pipe. A soil pipe is any pipe which conveys the discharge of water closets or fixtures having similar functions, with or without the discharges from other fixtures.

Stack. Stack is a general term for the vertical main of a system of soil, waste or vent piping.

Stack Vent. A stack vent is the extension of a soil or waste stack above the highest horizontal or fixture branch connected to the stack.

Subsoil Drain. A subsoil drain is a drain installed for collecting subsurface or seepage water and conveying it to a place of disposal.

Trap. A trap is a fitting or device so designed and constructed as to provide a liquid trap seal which will prevent the back passage of air without materially affecting the flow of sewage or waste through it.

Trap Seal. The trap seal is the vertical distance between the crown weir and the dip of the trap.

Vent. A vent is a pipe installed to provide a flow of air to or from a drainage system or to provide a circulation of air within such system to protect trap seals from siphonage and backpressure.

Vent Stack. A vent stack, sometimes called a main vent, is a vertical vent pipe installed primarily for the purpose of providing circulation of air to or from any part of the building drainage system.

Waste Pipe. A waste pipe is any pipe which receives the discharge of any fixture, except water-closets or similar fixtures, and conveys the same to the house drain, soil or waste stack. When such pipe does not connect directly with a building drain or soil pipe it is termed an indirect waste pipe.

Water Distributing Pipe. A water distributing pipe in a building is one which conveys water from the water service pipe to the plumbing fixtures and other outlets.

Wet Vent. A wet vent is a soil or waste pipe that serves also as a vent.

Yoke Vent. A yoke vent is a pipe connecting upward from a soil or waste stack to a vent stack for the purpose of preventing pressure changes in the stacks.

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ENGINEERING MANUAL
MILITARY CONSTRUCTION

PART V
CHAP. 5
JUNE '48

Housing and Home Finance Agency
Office of the Administrator
LIBRARY

MECHANICAL DESIGN

GAS FITTING

DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

CHAPTER 5

GAS FITTING

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PART V
MECHANICAL DESIGN

CHAPTER 5
GAS FITTING

5–01. SCOPE

The following information and instructions cover the principal requirements in the mechanical design of gas piping for interior of buildings to points 5 feet outside of building walls. Good engineering practice consistent with the type of structure should be followed in regard to special conditions and to items not covered specifically by these instructions.

5–02. DRAWINGS

The drawings should show the sizes and arrangement of all piping, the location of valves and the gas pressure regulator. The piping, in general, should be shown parallel with the lines of the building. Where gas-burning units are located adjacent to each other, a manifold should be provided for the battery and each end of the manifold connected to the gas distribution system in order to maintain uniform gas pressure at each piece of equipment. On military projects meters will not be required at the buildings when master meters are installed for the measurement of purchased gas except for temporary installations for test purposes, exchange buildings, or to private interests and business activities on the post in accordance with the provisions of AR 100–90. On civil works projects meters will be installed as required by Civilian Personnel Regulations 125.

5–03. FLOW OF GAS IN PIPES

The size of gas pipe required depends on the equivalent length of pipe, maximum gas consumption to be provided for, allowable loss in pressure from service pipe to appliance, specific gravity of the gas, and the diversity factor for ranges and refrigerators in quarters. The selection of the proper size gas piping should be made by reference to table I or graph I which shows the amount of gas in cubic feet which will flow per hour in pipes of various diameters and lengths based on 0.3 inch water column pressure drop and 0.6 specific gravity. In deciding upon the maximum gas consumption (in cubic feet per hour) to be provided for, adequate allowance will be made for any probable change in the specific gravity or heating value of the gas supply. The pressure of gas is measured in inches of water, and the gas capacities for the various pipe sizes are given for a 3/10-inch pressure drop. By adopting a 3/10-inch pressure drop, due allowance for the effect of an ordinary number of fittings was made.

TABLE I.—*Cubic Feet of Gas Per Hour, 0.3-inch Pressure Drop and 0.6 Specific Gravity*

Length of pipe, feet	Diameter of pipe, inches								
	½	¾	1	1¼	1½	2	3	4	6
15	76	172	345	750	1, 220	2, 480	6, 500	13, 880	38, 700
30	52	120	241	535	850	1, 780	4, 700	9, 700	27, 370
45	43	99	199	435	700	1, 475	3, 900	7, 900	23, 350
60	38	86	173	380	610	1, 290	3, 450	6, 800	19, 330
75		77	155	345	545	1, 120	3, 000	6, 000	17, 310
90		70	141	310	490	1, 000	2, 700	5, 500	15, 800
105		65	131	285	450	920	2, 450	5, 100	14, 620
120			120	270	420	860	2, 300	4, 800	13, 680
150			109	242	380	780	2, 090	4, 350	12, 240
180			100	225	350	720	1, 950	4, 000	11, 160
210			92	205	320	660	1, 780	3, 700	10, 330
240				190	300	620	1, 680	3, 490	9, 600
270				178	285	580	1, 580	3, 250	9, 000
300				170	270	545	1, 490	3, 000	8, 500
450				140	226	450	1, 230	2, 500	7, 000
600				119	192	390	1, 030	2, 130	6, 000

a. **Flow Formula.** The flow of gas in pipes as listed in table I and graph I is computed by the use of the Spitzglass formulas 1 and 2, as adopted by the American Gas Association.

Formula 1 for gas pressures not exceeding 1-pound gage:

$$Q=3550\ K\sqrt{\frac{h}{SL}}$$

Formula 2 for gas pressures exceeding 1-pound gage:

$$Q=4830\ K\sqrt{\frac{Pa}{SL}}$$

$$K=\sqrt{\frac{D^5}{1+\frac{3.6}{D}+0.03\ D}}$$

Where Q=Standard cubic feet of gas per hour.
D=Inside diameter of pipe, inches.
h=Pressure drop, inches water column.
S=Specific gravity of gas referred to air as 1.0.
L=Length of pipe, feet.
P=Pressure drop, lb. per square inch.
a=Average pressure in pipe, pounds per square inch absolute.
K=Constant for a given size of pipe.

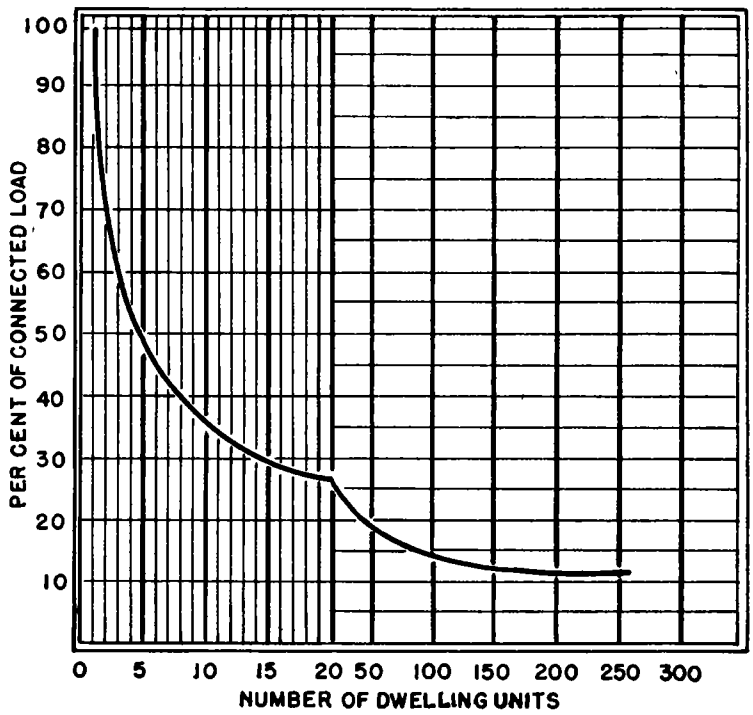
TABLE II.—*Values of K and D for Different Pipe Sizes*

Nominal pipe size, inches	Inside diameter, inches D	Constant K
1½	1. 61	1. 81
2	2. 067	3. 67
3	3. 068	10. 95
4	4. 026	22. 91
6	6. 065	67. 97

See Example 1.

b. **Connected Load.** The most important factor in determining correct pipe size is the percentage of the total connected load in use at any one time. This percentage depends upon the characteristics of the project and the number and kind of gas appliances being installed. The gas company can suggest the proper factor based on their previous years of experience. On projects of 100 or more families, the maximum hourly flow of gas through the meter may be as little as 15 percent of the connected load, although the flow at the most distant riser would be a greater percentage of the load which that riser serves. The diversity of use for quarters is shown in graph II.

GRAPH II
PER CENT OF CONNECTED LOAD



c. **Compensation for Pressure Variations.** To select the minimum practical pipe size for a single installation, make a simple computation for each branch, beginning at the most distant point of the system, using table I. This table automatically compensates for pressure loss through valves and fittings. Pressure rise varies inversely with the specific gravity of the gas and the elevation of the site above sea level. Gas piping should be large enough to supply the maximum rate for low-pressure distribution with comparatively small differences between the initial and final pressures. Pressure drop is usually expressed in inches of water; if given in ounces per square inch, multiply by 1.73 to convert to inches.

TABLE III.—*Pressure Drop Multiplier*

Drop in pressure, inches of water	Multiplier
0. 3	1. 00
. 4	1. 15
. 5	1. 29
. 6	1. 41
. 7	1. 53
. 8	1. 63
. 9	1. 73
1. 0	1. 82

The multipliers may be applied to the flow figures as given in table I.

d. **Pipe Size Selections.** In summarizing the criteria for piping lay-outs, a number of conditions should be kept in mind. Horizontal gas pipes under floors should be kept at a minimum. Piping from a riser to appliances should be proportional to the size of the appliance manifolds, when short runs are anticipated. A half-inch outlet for a gas refrigerator should be provided at an appropriate location in quarters. Risers serving ranges, or ranges and refrigerators in quarters, should be of a size based on the percentage of connected load in use at one time. Values for this percentage are shown on graph II. Risers serving appliances and equipment other than ranges and refrigerators in quarters should be of a size based on the connected load. To estimate the size of basement piping which supplies the risers, the percent of connected load in use at each riser take-off should be taken into account. This percentage is based on the number of quarters served from that point.

See example 2.

5–04. EQUIVALENT LENGTH OF PIPE

Allowances in equivalent length of pipe for friction in valves and fittings are indicated in table IV and they should be added to the actual pipe length for determining the pipe size. The values represent the friction loss in valves and fittings of a size in relation to that of straight pipe of the same diameter.

TABLE IV.—*Equivalent Length of Pipe in Lineal Feet for Valves and Fittings*

Fittings	Size of pipe, inches									
	¾	1	1¼	1½	2	2½	3	4	5	6
90° elbow	1	2	2. 5	3	4	5. 5	6. 5	9	12	15
Tee (run)	. 5	. 75	1	1. 5	2	3	3. 5	4. 5	6	7. 5
Tee (branch)	2. 5	3. 5	4. 5	6	8	11	13	18	24	30
Gate valve	. 5	. 6	. 8	1	1. 5	2	2. 5	3. 5	5	6
Globe valve	4	5	7. 5	9	12	17	20	28	37	46

5–05. SPECIFIC GRAVITY

The specific gravity of most gases varies between 0.4 and 0.8. The capacity of pipe is affected by this factor inversely as the square root. Table I is based on a specific gravity of 0.6. To convert the figures in this table to other values for a different gravity, multiply by $\sqrt{\frac{0.6}{\text{specific gravity}}}$ where specific gravity is the gravity of the gas for the particular condition. The Edwards balance and the Schilling apparatus are simple and convenient devices for determining specific gravity.

TABLE V.—*Specific Gravity of Common Gases*

Name of gas	Specific gravity
Commericlal propane	1. 52
Commercial butane	1. 95
Natural gases	. 60–0. 75
Manufactured coke oven	. 42– . 45
Manufactured carburetted water	. 55– . 70
Sewage gas	. 80

TABLE VI.—*Multipliers to Convert Gas Flow at 0.6 Specific Gravity to Flow at Other Specific Gravity*

Specific gravity	Multiplier
1. 2	0. 707
1. 1	. 740
1. 0	. 775
. 9	. 817
. 8	. 866
. 7	. 926
. 6	1. 000
. 5	1. 095
. 4	1. 225

TABLE VII.—*Equivalent Flow Factors for Converting Cubic Feet of Gas from Any Condition of Specific Gravity and Pressure Drop to 0.6 Specific Gravity and 0.3-inch Pressure Drop*

Pressure drop, inches water	Specific gravity								
	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80
0.1	1. 41	1. 50	1. 58	1. 66	1. 73	1. 80	1. 86	1. 93	1. 99
0.2	1. 01	1. 06	1. 12	1. 18	1. 23	1. 28	1. 32	1. 37	1. 42
0.3	. 82	. 87	. 91	. 96	1. 00	1. 04	1. 08	1. 12	1. 15
0.4	. 71	. 75	. 79	. 83	. 87	. 90	. 93	. 97	1. 00
0.5	. 63	. 67	. 71	. 74	. 78	. 81	. 84	. 87	. 90
0.6	. 58	. 61	. 65	. 68	. 71	. 74	. 76	. 79	. 82
0.7	. 53	. 57	. 60	. 63	. 66	. 68	. 71	. 73	. 76
0.8	. 50	. 53	. 56	. 59	. 61	. 64	. 66	. 69	. 71
0.9	. 47	. 50	. 53	. 55	. 58	. 60	. 62	. 65	. 67
1.0	. 45	. 48	. 50	. 53	. 55	. 57	. 59	. 61	. 63

See example 3.

TABLE VIII.—*Maximum Gas Demand for Common Gas Appliances*

Appliance	Type, size or capacity	B. t. u. per hour
Broiler	Small	30, 000
	Large	60, 000
Broiler and roaster	Combination	66, 000
Broiler, toaster and griddle	Combination	30, 000
Coffee maker, glass	3 burner	12, 000
	4 burner	16, 000
Dishwashers	50 racks/hr	20, 000
	180 racks/hr	22, 500
	300 racks/hr	35, 000
Deep fat fryers	28 lb	30, 000
	58 lb	45, 000
Doughnut fryers	200-lb. fat	72, 000
Heaters, circulating	Water	25, 000
Hot plate, domestic	Per burner	12, 500
Kettles, jacketed	25 gal	47, 500
	40 gal	80, 000
	60 gal	150, 000
	100 gal	180, 000
Logs, gas	Small	12, 000
	Large	25, 000
Lighting fixture	Per outlet	5, 000
Ovens, roasting	1 section	58, 000
	2 sections	116, 000
	3 sections	174, 000
revolving	140 lb	150, 000
	210 lb	225, 000
traveling tray	400 loaves	660, 000
	640 loaves	825, 000
	720 loaves	900, 000
	800 loaves	975, 000
	880 loaves	1, 050, 000
bake	Cabinet type	100, 000

TABLE VIII.—*Maximum Gas Demand for Common Gas Appliances*—Continued

Appliance	Type, size or capacity	B. t. u. per hour
Ranges, domestic	4 burner	62, 500
heavy duty	Hot top with oven	129, 000
	Hot top without oven	69, 000
	Open top with oven	121, 500
	Open top without oven	78, 500
	Fry top with oven	109, 000
	Fry top without oven	66, 000
Refrigerator	Gas	3, 000
Steam radiator, gas	Per section	2, 000
Stove, bakers	3 rings	40, 000
	4 rings	94, 100
Steamers, vegetable	2½ to 4 bu	50, 000
Urns, coffee	6/17 gals	18, 000
	8/21 gals	18, 000
	3/22/3 gals	18, 000
	6/34/6 gals	36, 000
	8/45/8 gals	48, 000
	15/36/15 gals	54, 000
	20/46/20 gals	54, 000
Urns, stands and cup warmer		5, 000
Water heaters, instantaneous	Automatic:	
	4 gal. per min	150, 000
	6 gal. per min	225, 000
	8 gal. per min	300, 000

For accuracy, the input ratings in B. t. u. per hour should be determined by referring to the American Gas Association Testing Laboratories Directory of Approved Gas Appliances.

5–06. HEATING VALUE OF GAS

When the exact calorific value of the gas is not known, assume that manufactured gas has 530 B. t. u. per cubic foot, mixed gas has 800 B. t. u. per cubic foot, and natural gas has 1,000 B. t. u. per cubic foot. Gas contracts are generally written with specific rates per 1,000 cubic feet, based on the average B. t. u. content per cubic foot of gas.

5–07. GAS CONSUMPTION FOR APPLIANCES

Allowance should be made for any probable change in the specific gravity and heating value of the gas supply when determining the maximum gas consumption in cubic feet per hour. The gas requirements in B. t. u. per hour for some of the common gas appliances are listed in table VIII. The maximum requirements or connected load in cubic feet of gas per hour should be determined in accordance with the following standards.

a. **Space Heating.** The cubic feet of gas required per hour for space heating should be determined by the formula—

$$\text{Cubic feet of gas per hour, } Q=\frac{\text{B. t. u.}}{E\times CV}$$

Where B. t. u.=Boiler B. t. u. capacity requirement in output per hour.
E=Efficiency (75 percent is a conservative figure for the efficiency of gas-fired space-heating equipment).
CV=Calorific value of gas in B. t. u. per cubic foot.

See example 4.

b. **Domestic Water Heating.** The cubic feet of gas required per hour for domestic water heating should be determined by the formula—

$$\text{Cubic feet of gas per hour, } Q=\frac{8.3\times T\times G}{E\times CV}$$

Where G=Quantity of U. S. gallons of water to be heated per hour.
T=Temperature rise in degrees Fahrenheit.
E=Efficiency (75 percent is a conservative figure for the efficiency of gas-fired water heating equipment).
CV=Calorific value of gas in B. t. u. per cubic foot.

See example 5.

c. **Kitchen and Bakery Equipment.** The cubic feet of gas required per hour for kitchen and bakery equipment should be determined by the formula—

$$\text{Cubic feet of gas per hour, } Q=\frac{\text{B. t. u.}}{CV}$$

Where B. t. u.=B. t. u. per hour requirements of the appliances.
CV=Calorific value of gas in B. t. u. per cubic foot.

See example 6.

5–08. FLUE CONNECTIONS

The minimum requirements established by the American Gas Association include the following recommended practice in regard to the installation of flues.

a. **Classes of Appliances.** Every gas appliance should be connected to an effective flue if it is included in any of the following classifications:

Any appliance used for domestic purposes having a demand in excess of 50,000 B. t. u. per hour.

Automatically controlled appliances which use more than 5,000 B. t. u. per hour. Automatically controlled appliances, which use less than this amount, should be flue-connected, unless equipped with an effective cut-off device which, in the event the constantly burning flame or pilot flame is extinguished, will automatically shut off the gas supply to the main burner or burners.

Appliances installed in the same room which have a total demand at normal rating of 30 B. t. u. per hour per cubic foot of room content.

Water heaters installed in bath rooms, bedrooms, or any occupied rooms normally kept closed.

Note.—Domestic gas ranges are exempt from this provision because of their intermittent use. Automatically controlled appliances should not include such appliances equipped with devices or controls governing the gas supply to the main burner or burners which cannot automatically reduce the supply below 30 percent of the maximum demand.

b. **Draft Hood.** Every flue-connected appliance (except an incinerator) should be equipped with an effective draft hood. Large industrial or power boilers, industrial heating equipment such as ovens, heat treating furnaces, etc., require no draft hood. Commercial cooking equipment, which is located under a general kitchen ventilating hood and is not directly connected to exhaust ducts, require no draft hood.

c. **Vent Size.** The vent pipe or connection should not be smaller than the size indicated by the vent collar of the appliance. Where the appliance has more than one vent, the vent pipe should equal the combined area of the vents for which it acts as a common connection to the flue.

d. **Dampers.** No damper should be placed in any flue connection between the appliance and the draft hood. Except for fixed baffles, it is best to avoid installing dampers between a draft hood and a chimney. Dampers for all open fireplaces should be specified and shown on the plans. These dampers conserve room heat when the fireplace is not in use.

5–09. SATISFACTORY FLUE REQUIREMENTS

Flue pipes, also called vent pipes, should be constructed and connected so that the best possible draft may be obtained and that the draft may be reasonably uniform. The draft will generally be sufficient if the following conditions are considered:

a. **Length of Flue.** The flue should not be unduly long. The length for a satisfactory flue pipe depends upon the nature of the appliance, the quantity and temperature of the flue products, and the probable available draft. The disadvantage of a long horizontal flue are undue cooling of the products of combustion and friction for the passage of flue gases. The horizontal run of flue pipe should be limited to 20 feet.

b. **Bends.** Friction in the flow of gaseous products can be kept at a minimum by elimination of unnecessary bends. Bends should be 45° pattern instead of 90° wherever possible. Long-radius bends should be considered rather than short-radius bends.

c. **Chimney Connection and Pitch.** No chimney connection should enter the flue closer than 1 foot from the bottom, nor should the connection protrude within the flue, obstructing the flow of gas in the chimney. A gas-appliance vent pipe and a smoke pipe from an appliance burning another fuel may be connected into the same flue through separate openings on different levels, or may be connected through a single opening by a wye-shaped fitting located as close as practicable to the chimney. All vents should be connected to a chimney by a slip-joint with the thimble cemented to the chimney wall but not extending beyond the lining. When a vent connection passes through a wall, partition, or floor made of combustible material, an approved ventilated or insulated sleeve should be installed. The vent pipe should maintain an upward pitch or rise of at least one-quarter inch per foot from the appliance to the flue or chimney. For runs longer than 15 feet, the pitch should be at least one-half inch per foot. A vent connection should be securely supported at intervals of not less than 6 feet.

d. **Types of Flues.** *Type "A" constructed chimney* is built of brick, stone, solid block masonry, or concrete. Such chimneys, intended for gas appliances, should be lined with a terra cotta or fire clay flue, set in acid- and moisture-resistant mortar. Type "A" chimneys are designed to withstand the high temperatures produced by coal or oil fires, and to resist disintegration by ordinary flue products. Offsets retard the draft and offer a place for debris to accumulate, decreasing the efficiency of the chimney. When the direction of the chimney and flue must change, it should not depart by more than 30 degrees from the vertical. The ends of the flue linings forming offsets should be carefully cut, fitted, and set. Each length of flue should be placed in position and the brick should be laid around it. A tightly fitting door should be placed near the bottom of the chimney to provide means to clean out the chimney and inspect the flue.

Type "B" flues save money and construction space. They are simple to install and are therefore particularly useful for the new all-gas home. Since gas appliances produce lower flue temperatures than appliances using other fuels, they do not require the construction of expensive flues. The National Board of Fire Underwriters has authorized a class of flue known as Type "B", which may be used with all gas appliances, except gas incinerators. These flues are not suitable for use with liquid or solid fuel appliances. They should be permanently and plainly labeled:

"THIS FLUE IS FOR THE USE OF GAS BURNING APPLIANCES ONLY"

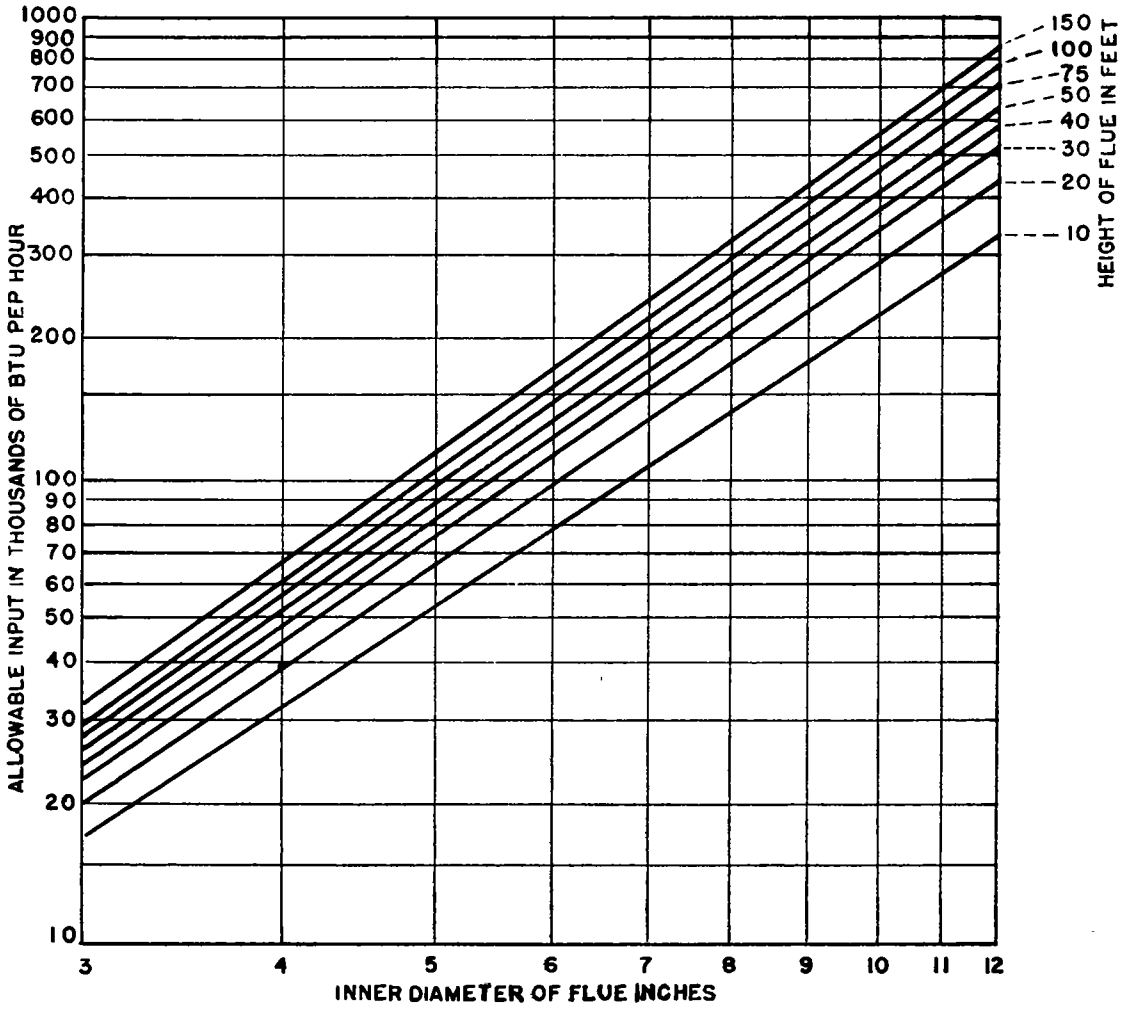
The label should be attached in plain sight at a point near the junction of the vent pipe and the vertical flue. Flue material used in type "B" construction should bear the approval of the Underwriters Laboratory. Complete information on type "B" flues will be found in section 1105 of the National Board of Fire Underwriters' Building Code. Joints in Type "B" flues should be made up gastight. Type "B" flues should have a clearance of not less than 1 inch from plastered or unplastered combustible material. Vents from floor furnaces, water heaters, and space heaters should have a clearance of not less than 3 inches for a distance of not less than 3 feet from the outlet of the draft hood measured along the center line of the vent pipe. Suitable provision should be made to prevent mechanical injury to type "B" flues where they extend through walls, floors, or roofs. The pitch of the flue through an attic should not be less than 45° from the horizontal. The flue should run continuously through the roof. This applies particularly to appliances installed in the attic. Because of the relatively small size of many type "B" flues, 4 to 6 inches, the vent cap should have a wire screen to prevent birds from building nests in the opening during the summer when the appliance is not in use. To avoid making several holes through the roof, it is common and satisfactory practice to tie several flues together by means of a wye fitting in the attic. If more than one floor furnace is to be vented by a single flue, the connections may be made under the floor of the house, provided that the vent connections are straight, without elbows, and can be pitched at the rate of one-half inch per foot of horizontal distance. Horizontal distances should not exceed 20 feet, and preferably should be kept down to 15 feet or less. Where a single flue is used for a gas water heater and several other appliances, provision should be made for a 4-inch tee opening to take the water heater flue. This permits the use of practically any size water heater. A 3-inch tee limits the size of appliances which may be used.

e. **Size of Flues.** The size of flues required with gas-burning appliances is given in the following graphs. Graph III supplies data to establish the proper size flue, either type "A" or type "B," to which a vent pipe should be connected. A flue should not be installed a size smaller than specified in this graph nor one smaller than the size provided by the vent collar on the appliance. Capacities in this graph should be decreased 4 percent for each 1,000 feet the building site is above sea level. Where several appliances are connected to the same flue, the flue should be large enough to take care of the entire load.

See example 7.

GRAPH III

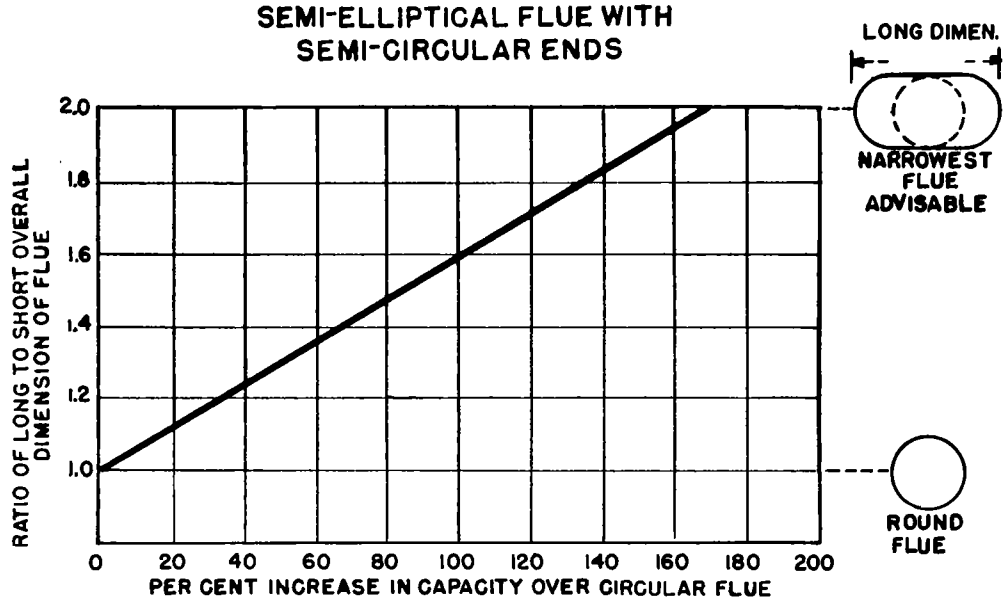
CIRCULAR FLUES FOR DOMESTIC GAS APPLIANCES WITH DRAFT HOODS FOR TYPE A AND B CONSTRUCTION



For each elbow over two, reduce the allowable horizontal run by a length in feet equal to the diameter of the elbow in inches.

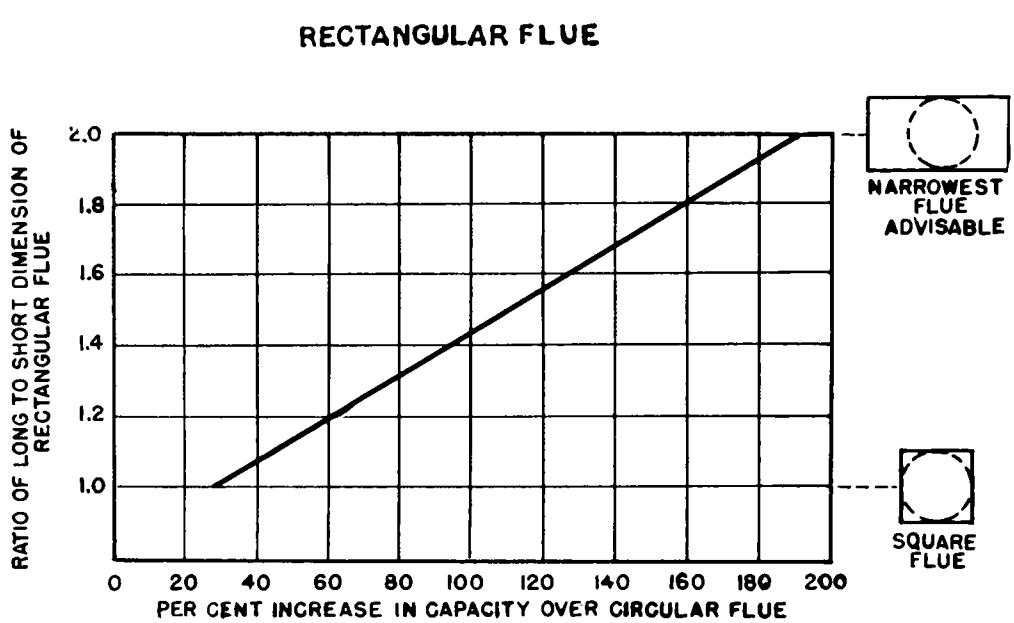
A comparison between circular and rectangular and or elliptical size flues is illustrated.

GRAPH IV



Capacity of a semi-elliptical flue with semi-circular ends, having its minimum width equal to the diameter of a circular flue, compared with the capacity of the circular flue.

GRAPH V



Capacity of a rectangular flue, having its minimum width equal to the diameter of a circular flue, compared with the capacity of the circular flue.

5–10. GAS PRESSURE REGULATORS

Regardless of the pressure of gas in the transmission mains, it is customary to reduce it for use in buildings to pressures from 3½ inches to 6 inches of water column for manufactured gas and from 5 inches to 15 inches for natural gas. The outlet pressure should not vary more than one-half inch of water column from the setting point at the connected load capacity of the regulator. Regulators should be equipped with vent pipes leading to the outside of the building. The requirements of a good pressure regulator are summarized as follows:

Maintain a uniform operating pressure at all appliances independent of the number of appliances in use.

Prevent the possibility of dangerous over-pressure on the house piping and appliances.

Maintain a low pressure for metering where meters are required and still give satisfactory pressure at appliances.

Be able to respond to quick changes in rate of flow occasioned by thermostatic valves, instantaneous water heaters, etc.

Maintain these characteristics over a long period of time in spite of changing inlet pressure and other variables.

5–11. EXAMPLES

The examples illustrate the method used in selecting pipe sizes. Gas companies are always glad to assist or advise in piping matters to assure that all local requirements will be properly met.

Example 1

Determine the quantity of gas in cubic feet per hour that will flow through a 2-inch pipe 300 feet in length, with gas based on a specific gravity of 0.6 and a pressure drop of 0.3 inches of water column.

Substitute in the Spitzglass formula $Q=3{,}550\ K\sqrt{\frac{h}{SL}}$

The quantity of gas, $Q=3{,}550\times 3.67\sqrt{\frac{0.3}{0.6\times 300}}$

$=532$ cubic feet per hour.

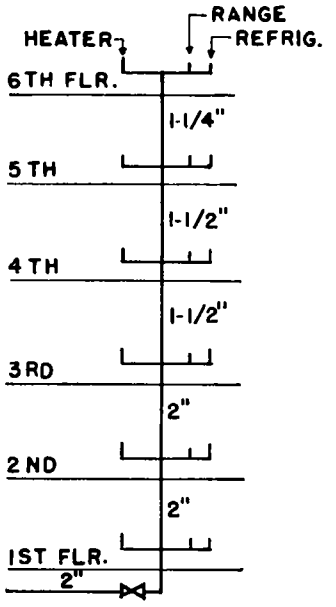
Table I shows 545 cubic feet of gas is required. The difference of 13 cubic feet of gas compensates for pressure drop in the fittings.

Example 2

Figure the pipe sizes for an apartment building consisting of 48 apartments, 8 apartments on each of 6 floors with shut-off valve in the basement (see fig. 1). It is assumed that this apartment house is in a city supplied with manufactured gas. The pipe sizes are selected from table I, cubic feet of gas per hour and graph II, percent of connected load. Each riser serves 6 apartments. The basement piping leading from the valve to the risers will be as shown (see fig. 2).

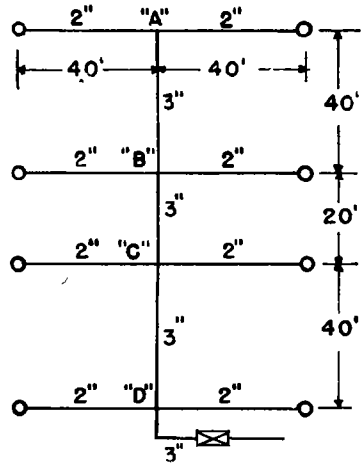
In this system, the pipe must increase in size going from the distant points toward the regulator valve. The pressure drop to each of the ends of the risers is assumed to be 0.3 inch. It is assumed that all risers and run-outs will be of the size determined for the riser and run-out most distant in the piping system from the regulator valve. The apartment most distant from the gas pressure regulator requires 205 feet of piping. A flow of 120 cubic feet per hour is needed for the range,

6 cubic feet per hour for the refrigerator, and 40 cubic feet per hour for the space heater. The hourly flow required is 166 cubic feet per apartment. Table I for 210 feet shows that a 1¼-inch pipe will deliver 205 cubic feet per hour.



RISER ELEVATION

FIGURE 1



BASEMENT PLAN

FIGURE 2

Number of quarters×(cu. ft./range+cu. ft./refrigerator)×connected load diversity factor+(Number of quarters×cu. ft./space heater)=cu. ft./hour.

At the sixth floor, the cubic feet of gas per hour is 166 cubic feet and requires 1¼-inch pipe.

$$1\times(120+6)\times\frac{100}{100}+40=166 \text{ cubic feet per hour}$$

At the fifth floor, the connected load doubles to 332 cubic feet per hour, but according to graph II, the 70 percent of connected load in use applies only to the range and refrigerator loads. One hundred percent of the connected space heating load should be provided as 2 times 40, or 80 cubic feet per hour, must be added for this purpose.

$$2\times(120+6)\times\frac{70}{100}+(2\times40)=256 \text{ cubic feet per hour}$$

The pipe should be able to furnish an estimated flow of 256 cubic feet per hour. The 1½-inch pipe is adequate at the fifth floor.

At the fourth floor, the required flow is 347 cubic feet per hour, requiring 1½-inch pipe.

$$3\times(120+6)\times\frac{60}{100}+(3\times40)=347 \text{ cubic feet per hour.}$$

At the third floor, the flow increases to 432 cubic feet per hour, requiring 2-inch pipe.

$$4\times(120+6)\times\frac{54}{100}+(4\times40)=432 \text{ cubic feet per hour.}$$

At the second floor, the flow increases to 509 cubic feet per hour, requiring 2-inch pipe.

$$5\times(120+6)\times\frac{49}{100}+(5\times40)=509 \text{ cubic feet per hour.}$$

At the first floor, the flow increases to 580 cubic feet per hour, requiring 2-inch pipe.

$$6\times(120+6)\times\frac{45}{100}+(6\times40)=580 \text{ cubic feet per hour.}$$

In the basement, the load increases several times because additional risers enter the basement main. At the first junction "A," where the branches to the right and left wings of the building meet, the required flow will be 979 cubic feet per hour. Table I for 110 feet shows the size of pipe "A to B" for 979 cubic feet is 3 inches.

$$12\times(120+6)\times\frac{33}{100}+(12\times40)=979 \text{ cubic feet per hour.}$$

At junction "B," the flow will be 1,656 cubic feet per hour. Table I for 70 feet shows the size pipe "B to C" for 1,656 cubic feet is 3 inches.

$$24\times(120+6)\times\frac{23}{100}+(24\times40)=1{,}656 \text{ cubic feet per hour.}$$

At junction "C," the flow will be 2,347 cubic feet per hour. Table I for 50 feet shows the size of pipe "C to D" for 2,347 cubic feet is 3 inches.

$$36\times(120+6)\times\frac{20}{100}+(36\times40)=2{,}347 \text{ cubic feet per hour.}$$

At junction "D", the flow will be 3,009 cubic feet per hour. Assume the main "D to Regulator Valve" is 10 feet, then table I for 3,009 cubic feet shows the size of pipe is 3 inches.

$$48\times(120+6)\times\frac{18}{100}+(48\times40)=3{,}009 \text{ cubic feet per hour.}$$

Example 3

Determine the proper size pipe to carry 2,000 cubic feet of gas per hour a distance of 200 feet, with a pressure drop of 0.5 inch, and a specific gravity of 0.4.

Refer to table VII and read the factor 0.63 at 0.5-inch pressure drop and 0.4 specific gravity. Multiply these numbers:

$$2{,}000\times0.63=1{,}260 \text{ cubic feet of gas.}$$

Now use table I or graph I for 1,260 cubic feet of gas and for 200 feet length of pipe and find that a 3-inch diameter pipe will be required to carry the equivalent flow of gas per hour.

Example 4

Space heating requirements for an area are 2,200 square feet steam radiation. Determine the cubic feet of natural gas per hour that will be required at the boiler.

$$Q=\frac{2200\times240}{0.75\times1000}=705 \text{ cubic feet of gas per hour.}$$

Example 5

Determine the cubic feet of manufactured gas required to heat 100 gallons of water per hour through a temperature rise of 100° F.

$$Q=\frac{8.3\times100\times100}{0.75\times530}=209 \text{ cubic feet of gas per hour.}$$

Example 6

Determine the cubic feet of natural gas per hour for a mess hall kitchen. The B. t. u. per hour requirements for appliances are taken from table VIII.

	B. t. u. per hour
1 Range, hot top with oven	129, 000
1 Range, open top without oven	78, 500
1 Range, fry top without oven	66, 000
1 Coffee urn 8/45/8	48, 000
1 Urn stand and cup warmer	5, 000
1 Roasting oven (3 sections)	174, 000

The total requirements for the mess hall kitchen are 500,500 B. t. u. per hour.

$$Q=\frac{500,500}{1,000}=500 \text{ cubic feet of gas per hour}$$

Example 7

Given an input of 100,000 B. t. u. per hour for a domestic appliance and a flue height of 20 feet, the horizontal run may be circular but the flue is limited to a 4-inch width to fit within a wall. What will be the dimensions of the run and of the flue?

From graph III, a circular flue and run of 6-inch diameter is sufficient. This fixes the dimension of the run. Graph III also shows that a 4-inch circular flue and run would have a capacity of 38,000 B. t. u. per hour for a flue height of 20 feet. The flue cross-section must be elongated to give an additional 62,000 B. t. u. per hour capacity.

$$\frac{62,000}{38,000}\times100 \text{ percent}=163 \text{ percent, or}$$

the increase needed beyond the capacity of the 4-inch circular flue. If a semi-elliptical flue is used, graph IV shows that a flue with a ratio of 2 between its long and short dimension is satisfactory. The flue will be 4 x 8 inches. If a rectangular flue is used, graph V shows that the flue will have dimensions of 4 x 7.3 inches. The next largest conventional size should be used.

5–12. DESIGN ANALYSIS

Design analysis in accordance with paragraph 4106.13 of Orders and Regulations should be submitted with plans and specifications. The following data are taken from examples given in the text for the purpose of illustrating an acceptable method for submitting design data.

Gas Data
Form G–1

GAS SERVICE

Date _____ Sheet _____ of _____
Engineer _____ Checked by _____
Post _____ Project _____

Minimum service pressure at building _____ per square inch.
Pressure loss in main 0.3 inch water column.
Length of pipe from main to most distant outlet 300 feet.

Risers

Floors	1	2	3	4	5	6
Height, feet	5	15	25	35	45	55
Pipe size, inches	2	2	2	1½	1½	1¼

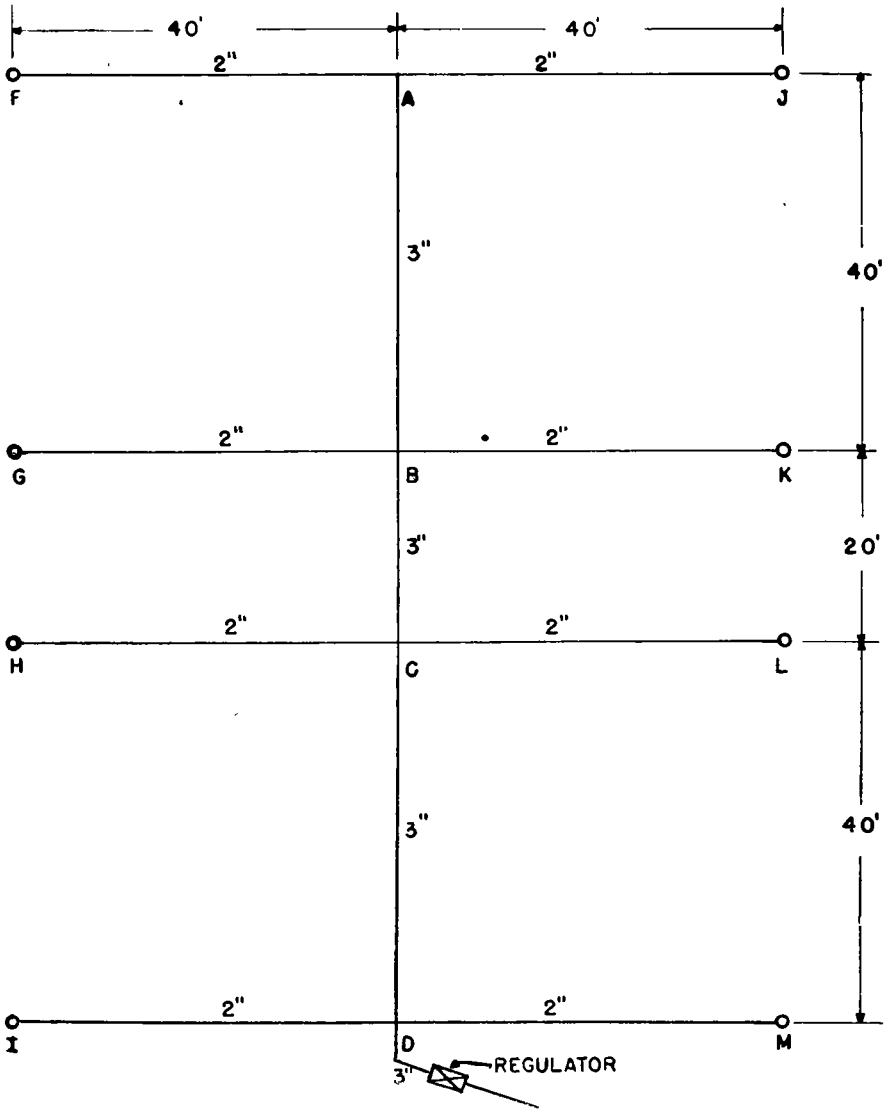
Gas consumption, cubic feet

Ranges and refrigerators	756	630	504	378	252	126
Range and refrigerator:						
Connected load	340	309	272	227	176	126
Space heating	240	200	160	120	80	40
Total load	580	509	432	347	256	166

Connected load, cubic feet:

Main	A–B	B–C	C–D	D–Regulator
No. ranges and refrigerators	12	24	36	48
Range and refrigerator:				
Connected load	499	696	907	1,089
Space heating	480	960	1,440	1,920
Total load	979	1,656	2,347	3,009
Length of pipe, feet	110	70	50	10
Pipe size, inches	3	3	3	3

Note. Sketch of gas piping lay-out shown on attached sheet.



GAS PIPING LAYOUT

FIGURE 3

APPENDIX

Definitions. Gas fitting terms in common use are defined as follows:

Air:

Primary.—The air introduced into the burner which mixes with the gas before it reaches the port or ports.

Secondary.—The air externally supplied to the flame at the point of combustion.

Air mixer.—That portion of a Bunsen burner into which the primary air is introduced.

Air shutter.—An adjustable device for varying the size of the primary air inlet or inlets.

Appliance.—A gas appliance is any device which utilizes gas fuel to produce light, heat, power, or refrigeration.

Appliances—automatically controlled.—Appliances equipped with an automatic device which accomplishes turn-on or shut-off of gas to the main burner or burners, or graduates the gas supply to the burner or burners, but does not effect complete shut-off of the gas.

Automatic pilot.—Consists of an automatic pilot device and pilot burner securely assembled in fixed relationship.

Bracket riser (or drop).—The vertical pipe from a "branch line" up (or down) to the bracket "outlets."

B. t. u.—Abbreviation for British Thermal Unit which is the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit.

Bunsen burner.—A type of burner that draws in primary air which is mixed with the gas prior to burning. It usually consists of a mixer head, throat, mixer tube, and burner head.

Burner.—A device for the final conveyance of the gas, or a mixture of gas and air, to the combustion zone.

Ceiling drop.—The pipe which comes through the ceiling to supply a fixture.

Chimney.—That part of a building which contains one or more flues for transmitting the products of combustion from a fireplace or appliance to the outer air.

Closed water piping system.—A system of water piping where a check valve or other device prevents the free return of water or steam to the water main.

Combustion.—Combustion, as used herein, refers to the rapid oxidation of flue gases accompanied by the production of heat, or heat and light. Complete combustion of a fuel is possible only in the presence of an ample supply of oxygen.

Condensate.—The liquid which separates from a gas (including flue gases) due to a reduction in temperature.

Control cock.—A cock used in piping to control the gas supply to any section of a system of piping or to an appliance.

Cubic foot (cu. ft.) of gas.—The amount of gas which would occupy one cubic foot when at a temperature of 60° F. saturated with water vapor and under a pressure equivalent to that of 30 inches of mercury.

Damper.—A valve or plate for regulating draft.

Demand.—The maximum amount of gas required per unit of time, usually expressed in cubic feet per hour, or B. t. u. per hour, required for the operation of the appliance or appliances supplied.

Diversity factor.—Ratio of the maximum probable demand to the maximum possible demand.

Draft hood.—A device placed in and made a part of the flue pipe from an appliance, or in the appliance itself, which is designed to insure the ready escape of the products of combustion in the

event of no draft, back draft, or stoppage beyond the draft hood; to prevent a back draft from entering the appliance; and to neutralize the effect of stack action of the chimney flue upon the operation of the appliance.

Drip.—The container placed at a low point in a system of piping to collect liquid condensate and from which it may be removed.

Drop.—Any vertical pipe or nipple which conducts the gas down.

Excess air.—Air which passes through the combustion chamber and the appliance flues in excess of that which is required for complete combustion.

Flames.—The flame produced by burning gas without any premixing of air with the gas is yellow, luminous, or nonbunsen. The bunsen flame is produced by premixing some of the air required for combustion with the gas before it reaches the burner ports or point of ignition.

Flue.—The general term for the passages and conduits through which flue gases pass from the combustion chamber to the outer air.

Flue collar.—A projection or recess provided to accommodate the flue pipe.

Gas pressure.—The pressure in piping or appliances which is imparted from the source of gas supply, usually by the gas company from outside of the building. This is usually stated in inches of water and measured with a "U" tube gage.

Heating surface.—All surfaces which transmit heat from flames or flue gases to the medium to be treated.

House piping.—The gas piping from the point where the service pipe connects 5 feet beyond the outer wall of the building.

Manifold.—The conduit of an appliance which supplies gas to the individual burners.

Orifice.—The opening in an orifice cap, orifice spud, or other device whereby the flow of gas is limited and through which the gas is distributed.

Pilot.—A small flame which is utilized to ignite the gas at the main burner or burners.

Regulator.—A device for controlling and maintaining a uniform gas supply pressure.

Spring type.—A regulator in which the regulating force acting upon the atmospheric side of the diaphragm is derived from a compressed spring.

Dead weight type.—A regulator in which the regulating force acting upon the atmospheric side of the diaphragm is derived from a weight or combination of weights.

Relief device.—A safety device designed to forestall the development of a dangerous condition in the medium being heated, by relieving either pressure, temperature, or vacuum built up in the appliance, or by permanently shutting off the main gas supply.

Riser.—Any vertical pipe which conducts the gas up.

Space heater.—A self-contained gas-burning appliance installed in and for heating rooms. This definition includes neither unit heaters, central heating gas appliances, nor garage heaters.

Specific gravity.—Specific gravity is the ratio of the weight of a given volume of gas to that of the same volume of air, both measured under the same conditions.

Thermostat.—An automatic device actuated by temperature changes, designed to control the gas supply to a burner, or burners, in order to maintain temperatures between predetermined limits.

Trap.—A section of piping in a horizontal line which is below the general level and from which condensate cannot naturally be removed by grading.

Vent.—The vent opening provided in an appliance for the escape of the gaseous products of combustion.

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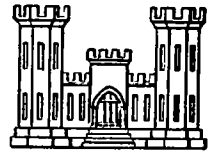
ELECTRICAL DESIGN

ELECTRIC POWER SUPPLY AND DISTRIBUTION



WAR DEPARTMENT
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

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1–04 INSTALLATION.

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Part VI

ELECTRICAL DESIGN

Chapter 1

ELECTRIC POWER SUPPLY AND DISTRIBUTION

GENERAL

1–01 SCOPE. The following instructions and information are intended to serve as a guide in determining the major requirements for electric power supply, substations, electrical distribution systems, and lighting systems. Where special conditions and problems are encountered, which are not covered specifically by these instructions, good engineering practice should be followed.

1–02 STANDARDS. The current regulations of the National Electrical Code, the American Institute of Electrical Engineers, The National Electrical Manufacturers Association, The Edison Electric Institute, the American Standards Association, and the National Electrical Safety Code (Bureau of Standards) will apply to equipment and construction where applicable. Departures therefrom will be permitted only when necessary to conform to the standard voltage, frequency, equipment, and construction methods used by the power company serving the project, providing the latter are considered acceptable.

1–03 DESIGN PROCEDURE. Investigations relating to electric power supply for a project should be made simultaneously with the development of the site plan. Power companies serving the area should be contacted at an early date in order to determine the availability of an adequate supply of electricity for the project and lowest applicable rates. Assistance of the power company's engineers should be solicited in the preparation of preliminary power studies and in the final design of the electrical system in order that the equipment will, as far as practicable, be similar to that used in the vicinity. This procedure will permit the utilization of the power company's personnel familiar with the equipment in cases of emergency.

1–04 INSTALLATION. The criteria contained in this chapter pertain to the design of electric power supply and distribution systems. For details covering materials, equipment, and installation, reference should be made to the following specifications:

CE 303.3 Electrical Unit Substations.
CE 303.4 Electrical Conventional Substation.
CE 303.5 Electrical Switching Station.
CE 303.6 Underground Electrical Distribution and Street Lighting System.
CE 303.7 Aerial Electrical Distribution and Street Lighting System.
CE 303.8 Protective Lighting System.

ELECTRIC POWER REQUIREMENTS

1–05 GENERAL. In order to select a suitable power supply, to specify the proper equipment, and to compute the cost of electricity for the project, it is necessary to determine the maximum demand in kilowatts and the average consumption of energy in kilowatt hours.

1–06 MAXIMUM DEMAND. The most accurate means of estimating the maximum demand is to determine the connected load and apply suitable demand and diversity factors. These factors are based on experience with projects similar in character and size to that under consideration. A break-down of large projects and classification of the types of service required may be

helpful in estimating the total maximum demand and in applying the data obtained from other projects containing facilities of similar nature but not necessarily of the same size and composition. In view of the fact that information relative to the ultimate connected load is not always available to the engineer designing the project, the total connected load of the proposed facilities, together with any other pertinent information available to the engineer, should be submitted to the office of the Chief of Engineers for determination of demand factors. In general, the maximum 30-minute demand for the entire electrical system at posts, camps, and airfields will be approximately 30 percent of the total connected load and at storage depots will be approximately 200 kilowatts per million square feet of warehouse area. For ordnance plants, chemical plants, air force assembly plants and other industrial developments, the maximum demand should be determined from data contained in the directive or obtained from the Office of the Chief of Engineers.

1–07 CONSUMPTION. The average monthly consumption should be computed by multiplying the maximum demand by a suitable load factor and by the number of hours during which the facility is in operation during the month. The load factor will usually be between 30 and 45 percent of the maximum demand at Army posts, camps, airfields, and storage depots. For instance, at an Army post having a total connected light and power load of 1,000 kilowatts, the estimated maximum demand would be $1{,}000 \times 0.30 = 300$ kilowatts. Using a load factor of 45 percent, the estimated average monthly consumption would be $300 \times 0.45 \times 720 = 97{,}200$ kilowatt-hours.

ELECTRIC POWER SUPPLY

1–08 GENERAL. For the purpose of this manual, the electric power supply is defined as the transmission lines, main substation or switching station, and other devices and equipment necessary to deliver energy to the distribution lines at the project.

1–09 SELECTION OF POWER SUPPLY. The following factors should be considered in selecting a power supply:

a. Adequacy. The first consideration should be the capability of the power company's system to furnish power having proper characteristics in the required amount.

b. Reliability. The supply should have a degree of reliability which the project warrants. Except for small posts and camps having a population of less than one thousand, duplicate supply lines should be installed wherever this type of service can be made available without excessive construction cost. To be of any value in insuring an uninterrupted supply of electricity to the project, the two supply lines should be fed from different sources, over different routes.

c. Rates. All electric service rate schedules applicable to the project should be carefully reviewed and checked with the estimated demand and consumption to insure the supply of electricity at the lowest available rate. Care should be taken to see that the schedule selected compares favorably with those of any other power companies serving the area and that the rates are no higher than those paid by other customers for similar service. Where a connection charge is made by the power company, an agreement should be worked out whereby the amount paid by the Government for such connection charge will be recovered by the Government over a period of 5 years or less, by deducting a certain percentage each month for the total bill or by a fixed annual or monthly refund.

1–10 RIGHTS-OF-WAY FOR SUPPLY LINES. The power company will procure all rights-of-way outside the limits of the Government reservation. The Government will grant the necessary rights-of-way and license for the installation and maintenance of power company's facilities within the reservation. Power company's facilities within the reservation should be located to avoid any interference with the activities of the project.

1–11 SUBSTATION. Where the supply voltage is 13,800 volts or less, this voltage should be used for the distribution system throughout the project. Where the supply voltage is in excess of 13,800 volts, a substation should be provided to reduce the supply voltage to 13,800 volts for the distribution system. Substation having a secondary voltage of less than 13,000 volts will not be provided unless specifically authorized by the Office of the Chief of Engineers.

a. Ownership. Substation should be installed and maintained by the government only when rate schedules or primary discounts indicate that the cost of the station will be amortized in 20 years or less by reason of the purchase of electricity at the substation primary voltage in lieu of the substation secondary voltage. Otherwise, the substation should be owned and operated by the power company.

b. Types. The type of substation should be selected in accordance with the requirements of the project, due consideration being given to future expansion. In general, a conventional type substation should be installed where the estimated maximum demand is not expected to exceed 1,000 kilovolt-amperes. Figures 1 and 2 show typical arrangements of conventional substations, using three single-phase transformers and two three-phase transformers, respectively. Where the estimated maximum demand is expected to exceed 1,000 kilovolt-amperes, the substation should be either of the conventional type or of the unit substation type, depending upon the results of cost comparison and local requirements. Figures 3 and 4 show typical arrangement of unit substations for aerial and underground systems respectively. In no case should a substation comprise only one three-phase transformer, as a failure of this transformer would result in a complete outage of the distribution system.

c. Capacity. The total combined capacity of all transformers in the substation should be approximately 150 percent of the estimated maximum demand. This capacity will permit normal growth of the distribution system and will insure a supply of electricity to at least one-half of the load in the event of the failure of one transformer. In view of the recent improvement in transformer design and construction, the installation of sufficient transformer capacity to carry the entire load with one transformer out of service is not considered necessary.

d. Transformers. Substation transformers should be of the outdoor type and of applicable self-cooled rating selected from table I. Where required sizes are not listed in the table, the next larger size should be installed unless the next smaller size will provide at least 90 percent of the required rating. For instance, transformers for an Army camp, airfield, storage depot, or other facility, having an estimated maximum demand of 300 kilowatts and an estimated power factor of 80 percent would be selected as follows:

Example. Estimated maximum demand (300 kilowatts), divided by the estimated power factor (0.80), multiplied by the capacity factor given in 1–11 *c* above, (1.5), gives a total of 562.5 kilovolt-amperes as the most desirable rating of the transformer bank. Referring to table I it is noted that the next smaller standard rating comprises three 150 kilovolt-amperes single-phase or two 200 kilovolt-amperes three-phase transformers. Neither of these banks would provide 90 percent of the required rating. It would, therefore, be necessary to select the next larger rating (three 200 kilovolt-amperes single-phase or two 300 kilovolt-amperes three-phase).

TABLE I.—*Transformer kilovolt-ampere ratings*

Single-phase			
1½	75	833	6, 667
3	100	1, 000	8, 333
5	150	1, 250	10, 000
7½	200	1, 667	12, 500
10	250	2, 000	16, 667
15	333	2, 500	20, 000
25	500	3, 333	25, 000
37½	667	4, 000	33, 333
50		5, 000	

TABLE I.—*Transformer kilovolt-ampere ratings*—Continued

		Three-phase	
10	200	2, 500	12, 000
15	300	3, 000	15, 000
25	500	3, 750	20, 000
37½	750	5, 000	25, 000
50	1, 000	6, 000	30, 000
75	1, 200	7, 500	37, 500
100	1, 500	10, 000	50, 000
150	2, 000		

e. High voltage switchgear. Switchgear for use on lines having a voltage rating in excess of 15,000 volts should consist of horn gap switches and high tension fuses, provided the system interrupting requirements can be met. The system interrupting requirements are determined by the capacity of generators and ratings of motors connected to the power company's lines and the total reactance in the circuits to the point of application of the switchgear, and should be obtained from the power company serving the project. In general, fuses should be installed where the system interrupting requirements do not exceed the values given in table II. Where the system interrupting requirements exceed the values given in table II, circuit breakers, having the required interrupting capacity, should be installed.

TABLE II.—*System interrupting requirements*

Line voltage (kilovolt):	Interrupting requirement (kv.-a.)
16 to 23	150, 000
24 to 34	250, 000
35 to 46	500, 000
47 to 138	1, 000, 000

f. Low voltage switchgear. Switchgear for use on lines having a voltage rating of 1,000 to 15,000 volts should consist of cubicle-mounted circuit breakers for conventional substations and metal-clad switchgear for unit substations.

g. Voltage regulators. Voltage regulation in unit substations is accomplished by tap-changing-under-load on transformers and should be included in all substations of this type. Voltage regulators should be installed in conventional substations when the voltage regulation of the incoming power supply exceeds plus or minus 5 percent. These regulators should be of the three-phase, step type, and should be installed for the purpose of regulating the bus voltage, rather than the voltage of individual feeders. Bypass disconnecting switches should be installed in the regulator circuit in order to permit inspection and repairs without prolonged interruption of electric service to the distribution system. Figure 5 shows a typical installation of voltage regulator. The kilovolt-ampere rating of voltage regulator should be 20 percent of the estimated maximum kilowatt demand, or the next larger standard size listed in table III, unless the next smaller standard size will provide at least 90 percent of the required rating. For instance, the rating of regulator for an Army camp, airfield, storage depot, or other facility having an estimated maximum demand of 800 kilowatts and a distribution voltage of 13,800 volts would be selected as follows:

Example: Twenty percent of the estimated maximum demand (800 kilowatts is 160. Referring to table III under 13,800 volts it is noted that the next smaller size (120 kilovolt-amperes) is less than 90 percent of the required rating; it would therefore be necessary to select the next larger standard size (179 kilovolt-amperes).

TABLE III.—*Voltage regulators*

System voltage					
2, 400	4, 160	4, 800	7, 200	12, 000	13, 800
Standard ratings (kilovolt-amperes)					
125	144	83. 2	62. 4	104	120
150	180	125	125	156	179
200	216	166	200	208	239
250	250	250	250	250	300
300	300	300	300	300	375
375	375	375	375	375	500
500	500	500	500	500	600
600	600	600	600	600	750
750	750	750	750	750	

h. Power company's meters. Provision should be made in the substation for power company's meters and metering transformers, in accordance with the power company's recommendations.

i. Protective provisions. Electrical protection to equipment and operators should be provided by the use of lightning arresters and by an adequate grounding system. Protection against intrusion should be provided by fencing. Gates should be equipped with padlocks to prevent the entrance of unauthorized persons. Arrester application is determined by the circuit voltage rating and requires consideration of the minimum and maximum arrester voltage rating. Station type arresters should be installed at all substations as this type of arrester has a larger discharge capacity than the distribution or line types. Arresters should be selected so that the circuit voltage is within the voltage range given in table IV. If the circuit voltage is below the minimum voltage rating of the arresters, the protection will not be as good as can be obtained. If the circuit voltage is above the maximum voltage rating of the arresters, the arresters will likely be damaged. The maximum rating of arresters given in table IV is expressed in terms of the maximum sustained voltage which may exist for any period on the system, including high voltages caused by transformer taps above normal voltage, voltage regulators, or light load operation. It is imperative that the arresters be so selected that the maximum permissible line to ground voltage will never be exceeded for any condition or period of operation. Arresters should be installed as close to the transformers as wiring arrangements will permit. Figures 1 and 2 show typical locations of lightning arresters.

TABLE IV.—*Lightning Arresters*

(Altitude 0 to 6,000 feet)

Ungrounded neutral circuits		Solidly grounded neutral circuits	
Nominal system voltage class, (kilovolts)	Arrester rating, maximum permissible line to ground voltage (kilovolts)	Nominal system voltage class, (kilovolts)	Arrester rating, maximum permissible line to ground voltage (kilovolts)
2. 4	3	4. 16	3
4. 16	6	4. 8	6
4. 8	6	6. 9	6
6. 9	9	11. 5	9
11. 5	12	13. 8	12
13. 8	15	18. 0	15
18. 0	20	23. 0	20
23. 0	25	28. 5	25
28. 5	30	34. 5	30
34. 5	37	46. 0	40
46. 0	50	57. 5	50
57. 5	60	69. 0	60
69. 0	73	92. 0	79
92. 0	97	115. 0	97
115. 0	121	126. 5	109
126. 0	133	138. 0	121
138. 0	145	161. 0	145
161. 0	169	230. 0	195
230. 0	242		

The grounding system should consist of a lightning arrester ground and a station ground. The lightning arrester ground should be independent of all other grounds. At least one ground rod should be installed for each lightning arrester. Ground rods should be at least 3 feet apart and should be connected to each other about 1 foot below the finished grade. The grounding conductors should have a current capacity sufficient to insure continuity and continued effectiveness of the ground connections under conditions of excess current caused by, or following discharge of the arrester. No individual grounding conductor should have less conductance than No. 6 copper wire. Station ground should consist of at least six ground rods. These rods should be connected to each other and to all equipment tanks or cases, metal structures, operating levers, neutral conductors, and metallic fence in such a manner that the path to ground will not be broken by the manual or automatic operation of any equipment. The grounding conductor should have a current-carrying capacity not less than one-fifth of that of the largest conductor to which it is attached and in no case less than that of No. 8 copper wire.

Substation equipment should be entirely inclosed by a fence, preferably of the chain link type with three strands of barbed wire at the top. Unless the fence is of the removable panel type, at least one double gate, of sufficient width to permit the entrance of a truck, should be provided.

1–12 SWITCHING STATION. Where the supply voltage is 13,800 volts or less, a switching station should be provided, unless a single distribution circuit will meet the requirements of the facility being served. Switching station should conform to the requirements of paragraph 1–11 covering substations, except for the omission of transformers. As in the case of substations, provision should be made for the installation of power company's meters and metering transformers in accordance with the company's recommendations. Figures 6 and 7 show typical arrangement of switching stations for aerial and underground systems, respectively.

1–13 EMERGENCY POWER SUPPLY. In addition to the normal supply system, emergency or standby supply of electric power should be provided as required for maintenance of communications, emergency lighting of critical locations and where serious fire, explosion, freezing, or other damage to equipment or loss of life might result from temporary power interruptions. The installation of emergency power supply will not be made for any other purpose without prior approval of the Office of the Chief of Engineers. Emergency circuits operating at a voltage of less than 30 volts should be supplied with emergency service by means of storage batteries. Emergency circuits operating at 30 volts or more should be supplied with emergency service by means of internal combustion engine-driven generators. Generators installed for the purpose of supplying emergency service to hospitals should start automatically upon failure of normal supply and should be of sufficient capacity to carry the entire load of operating suites, night lights, and other key lights in disturbed section of neuropsychiatric wards, corridor lights located at key points, stair and exit lights. Where elevators are installed in hospitals, the generator should have sufficient additional capacity to permit the operation of one elevator.

GENERATING PLANTS

1–14 GENERAL. Where commercial electric service of the required capacity and reliability is not available or cannot economically be made available, generating plants should be provided. Generating plants for the normal supply of electricity shall not be provided within the continental United States, however, without prior approval of the Office of the Chief of Engineers.

1–15 TYPE. Unless steam-turbine generators can economically be operated in conjunction with a heating plant, the following types of generating equipment should be utilized:

a. Generating plants comprising generators of less than 20 kilowatts should consist of gasoline-engine-driven generators, unless some other type of fuel is more readily available and will result in a saving in the cost of electricity.

b. Generating plants comprising generators of 20 to 50 kilowatts should consist of gasoline-engine-driven or diesel-engine-driven generators, as determined by availability of engines and fuel and comparative cost of operation.

c. Generating plants comprising generators having a capacity in excess of 50 kilowatts and having a total capacity of less than 5,000 kilowatts should be of the diesel-engine-driven generator type.

d. Generating plants having a total capacity of 5,000 to 10,000 kilowatts should be of the diesel-engine-driven or steam-turbine-driven generator type, as determined by availability of engines and fuel and comparative cost of operation.

e. Generating plants having a total capacity in excess of 10,000 kilowatts should consist of steam-turbine-driven generators, with fuel selected in accordance with availability and minimum cost of operation.

1-16 CAPACITY. The total combined capacity of all generators in the plant should be approximately 150 percent of the estimated maximum demand, except that where one generator is installed for a specific load, such as floodlight banks, the capacity of the plant should be approximately equal to the load. With the exception of small isolated plants comprising only one generator, the capacities of the individual generators should be selected so that the plant will carry the maximum demand with one of the largest generators out of service and so that periods of light load can be carried without the operation of excessive generating capacity. For instance, the generating plant for a project having an estimated maximum of 1,000 kilowatts should have a total capacity of 1,500 kilowatts. Three 500-kilowatt generators would be sufficiently flexible to carry the load with one generator out of service. If, however, the demand during light load periods can be carried by a 250-kilowatt generator, two 500- and two 250-kilowatt generators should be installed. In connection with the determination of maximum and light load period demands, consideration should be given to the possibility of fire pump loads coming on at any time of the day of night.

1-17 NUMBER OF GENERATORS. The number of generators in any plant should be the minimum required to provide adequate reliability and flexibility and should in no case exceed six. The number of different sized generators should be kept to a minimum and, in general, should not exceed two. Generating plants comprising only one generator should not be installed where electric service cannot frequently be cut off to permit inspection and maintenance of the equipment. Single generator plants should be limited to installations requiring intermittent service, such as floodlight banks which operate only at night or emergency plants which operate only upon failure of normal supply of electricity.

1-18 PARALLEL OPERATION. All main generators in the plant should be so connected that any or all of them can furnish power to the main bus at the same time.

1–19 VOLTAGE RATING. Voltage rating of generators should be determined by the size of the area to be served by the generating plant. In general, the generator voltage should be the lowest applicable standard voltage that can be carried over the distribution system without excessive voltage drop and without the use of excessively large conductors. Step-up transformers should be utilized only where their use will effect economy of operation and where required for proper operation of available equipment. Joint NEMA—NELA preferred voltage ratings should be used unless these ratings conflict with local conditions, such as interconnection with other systems or local procurement of equipment. Joint NEMA—NELA preferred voltage ratings are as follows:

120	2, 400
240	4, 160
480	6, 900
600	11, 500
	13, 800

1–20 FREQUENCY. Frequency should be 60 cycles wherever this frequency is applicable to the installation.

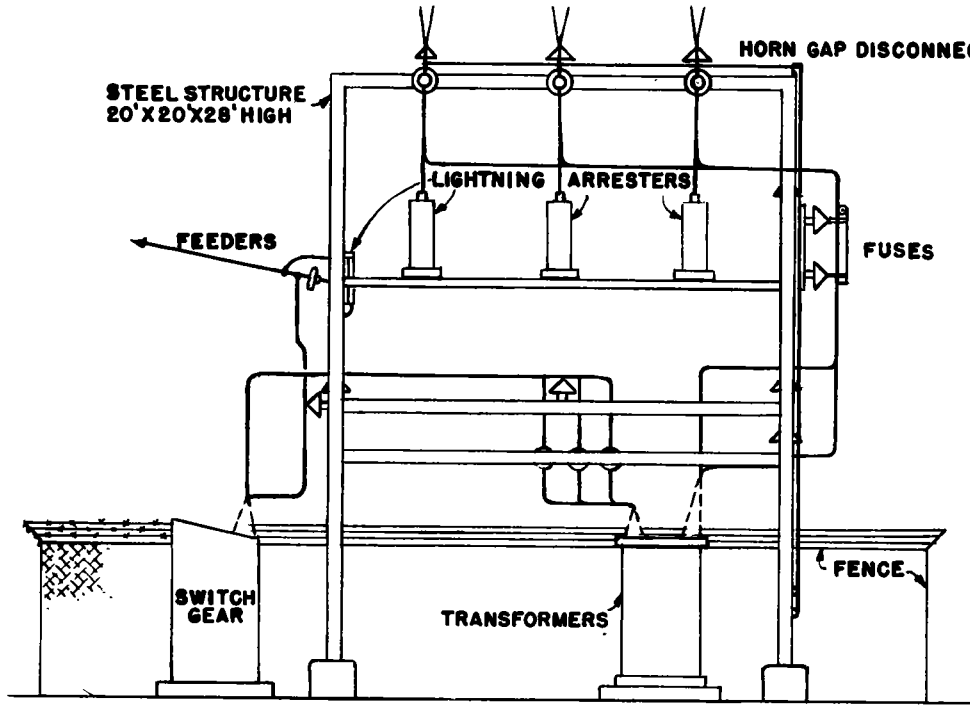
1–21 BUILDING. With the exception of cooling towers and other outdoor accessories, all generating equipment should be installed in buildings constructed essentially of noninflammable materials. Adequate natural light and natural ventilation should be provided to facilitate maintenance and efficiency of operation.

1–22 FOUNDATIONS. Concrete foundations should be provided for each piece of equipment having a weight in excess of the capacity of the floor of the building. The size and depth of the foundations should be determined from data furnished by the equipment manufacturer. Where manufacturer's data are not available, and opening should be left in the floor until the weight and dimensions can be obtained from the equipment to be installed. A one-half inch space should be provided between the engine and generator foundations and the floor of the building in order to reduce the effects of vibration. This space should be filled with vibration insulation material.

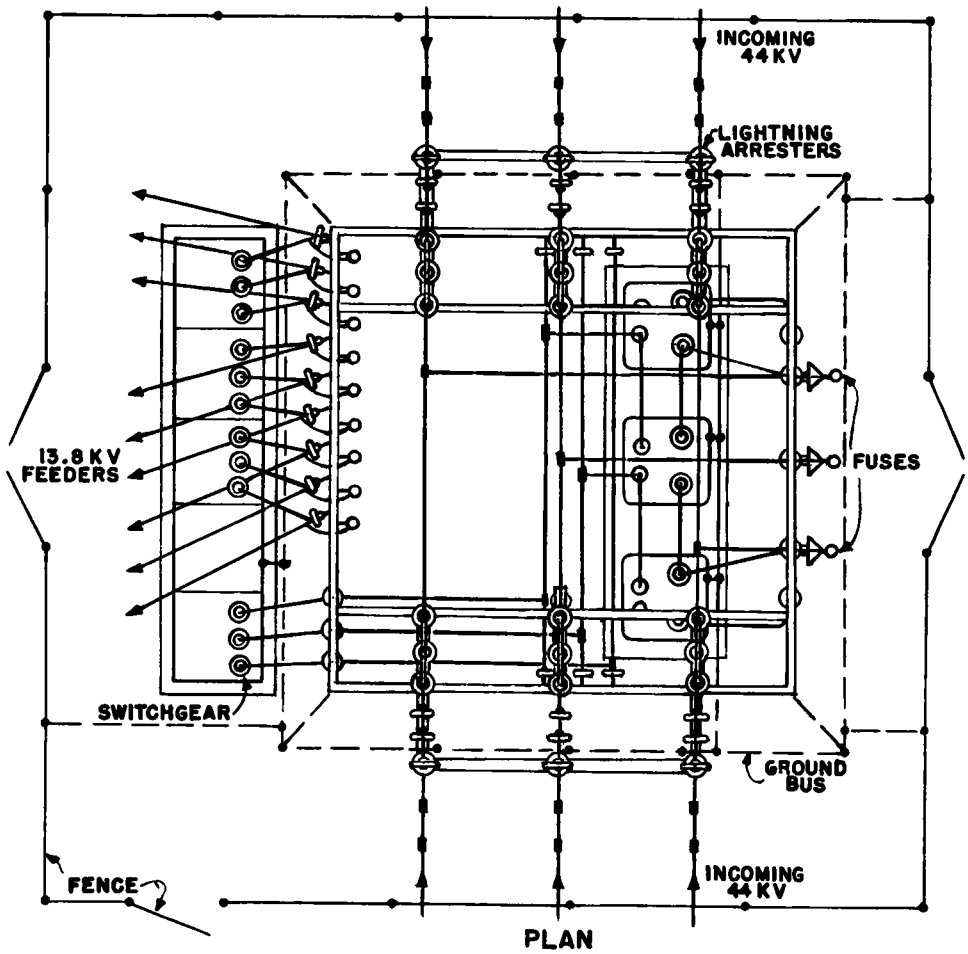
1–23 FUEL STORAGE. . In addition to the day tank usually furnished with gasoline-and diesel-engine-driven generators, an underground storage tank should be provided for all plants of these types, with the/exception of small portable plants which can conveniently be furnished with fuel often enough to preclude the necessity for a storage tank. The storage tank should be of sufficient capacity to operate the plant for at least 2 weeks during the months of largest average demand. This capacity should be increased as required when deliveries of fuel at 10-day intervals cannot be relied upon. Actual fuel consumption of the engines and estimated number of hours of operation should be used in determining the capacity of storage tank whenever this information is available. When actual fuel consumption is not available, an average of 4 kilowatt-hours per gallon of gasoline and 10 kilowatt-hours per gallon of diesel oil will be sufficiently accurate for this purpose.

AERIAL ELECTRICAL DISTRIBUTION AND STREET LIGHTING SYSTEMS

1–24 GENERAL. Aerial systems will be employed in areas where less than 25 percent of the buildings to be served by the system are of the permanent type of construction and in dispersed areas where the difference in cost between aerial and underground construction cannot be adequately justified, unless War Department safety regulations require the use of underground cable. No exceptions will be made to this requirement without prior approval of the Office of the Chief of Engineers.



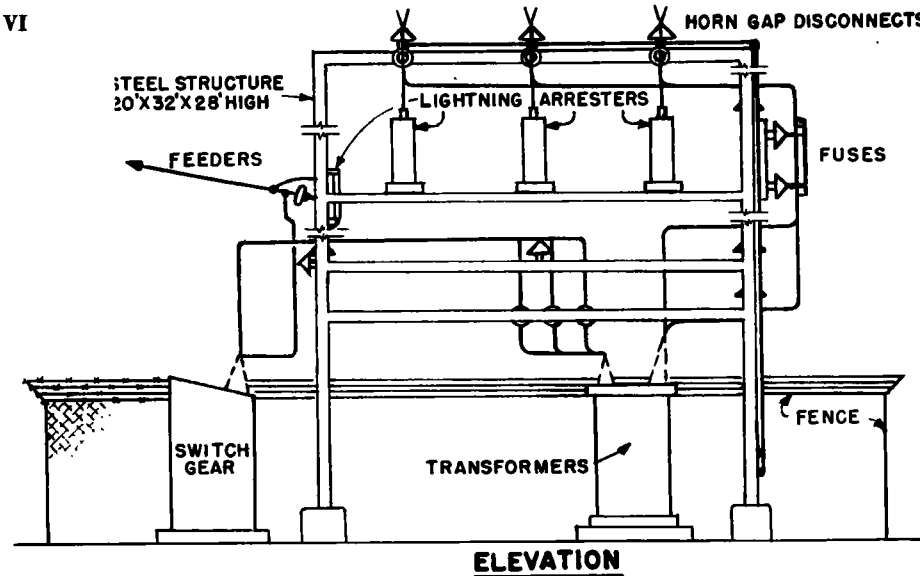
ELEVATION



PLAN

FIG. 1

750 KVA - 44/13.8 KV CONVENTIONAL SUBSTATION



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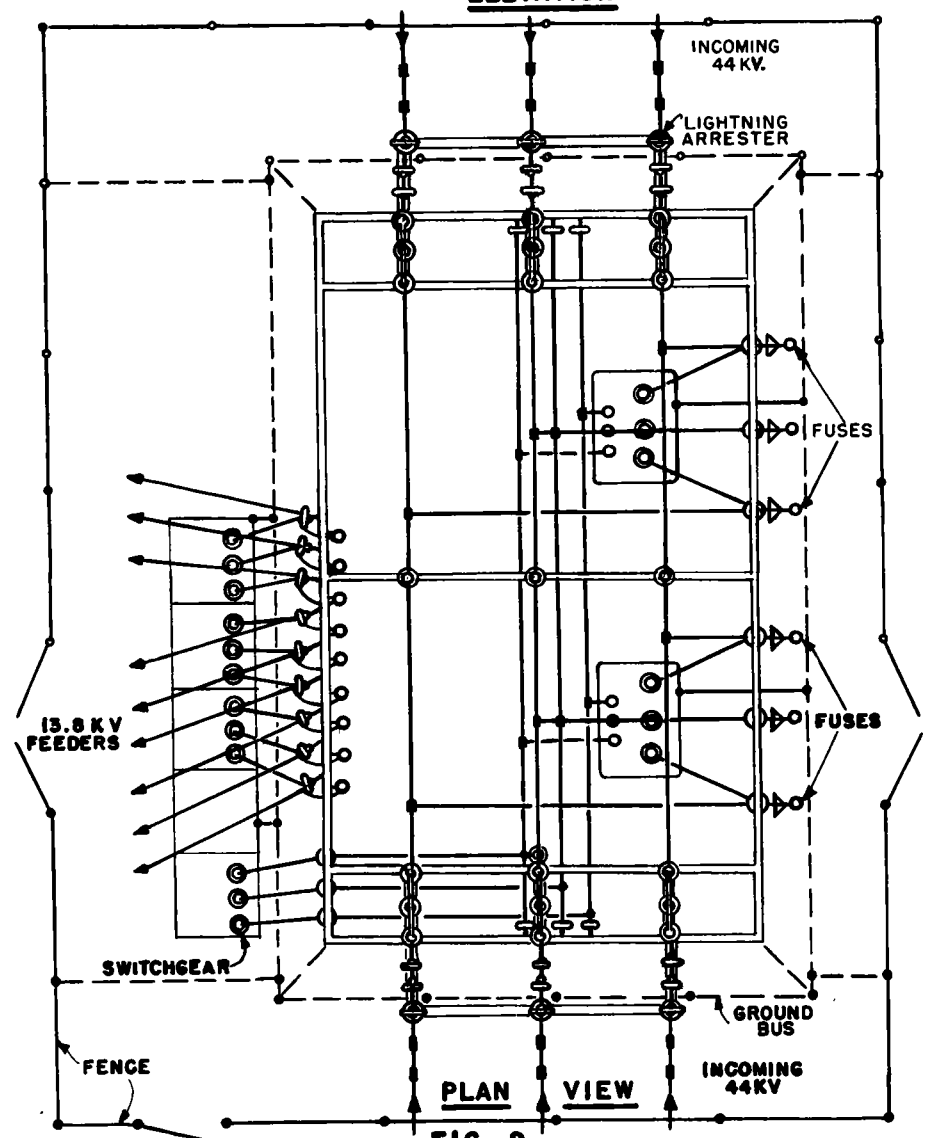
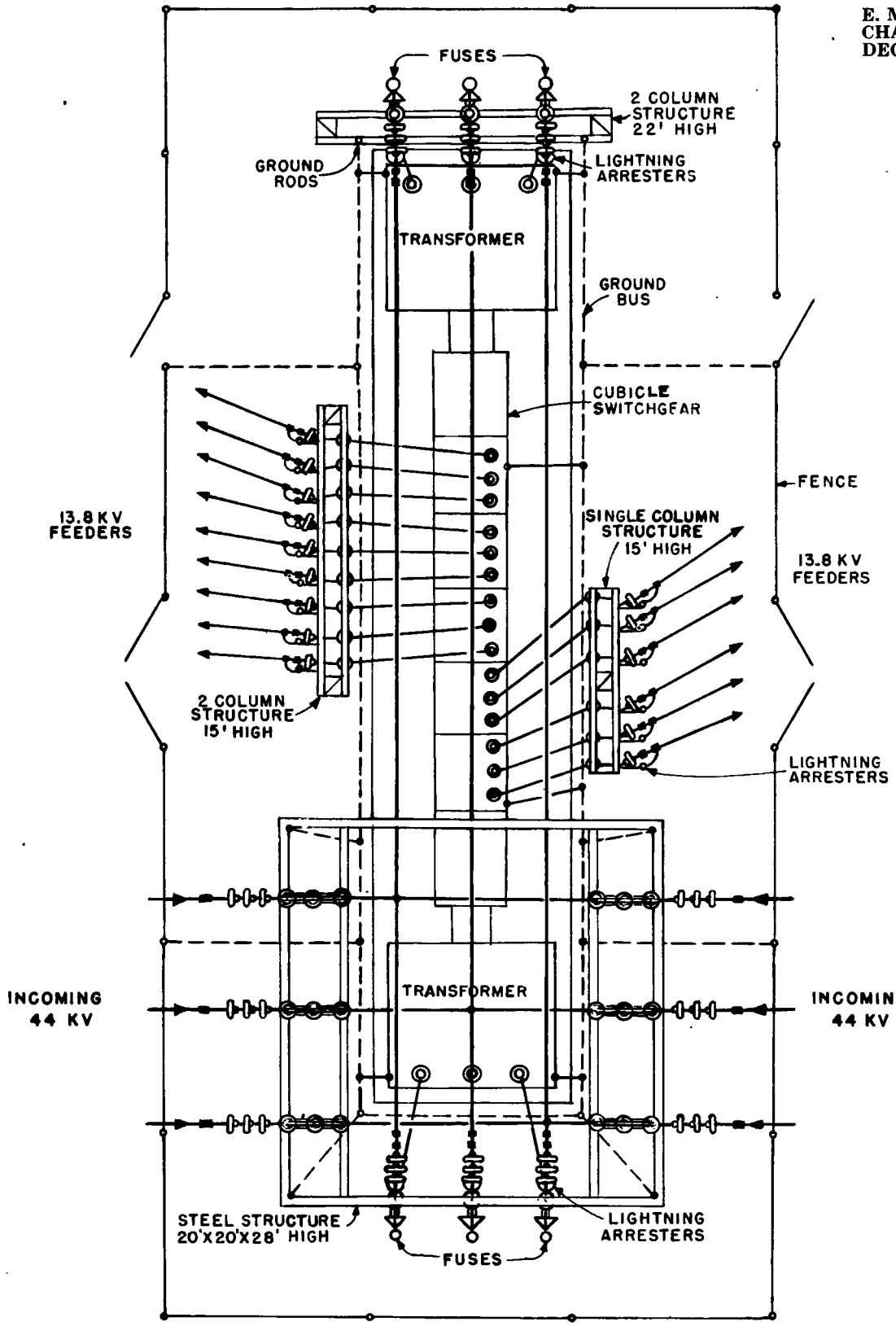


PLAN VIEW

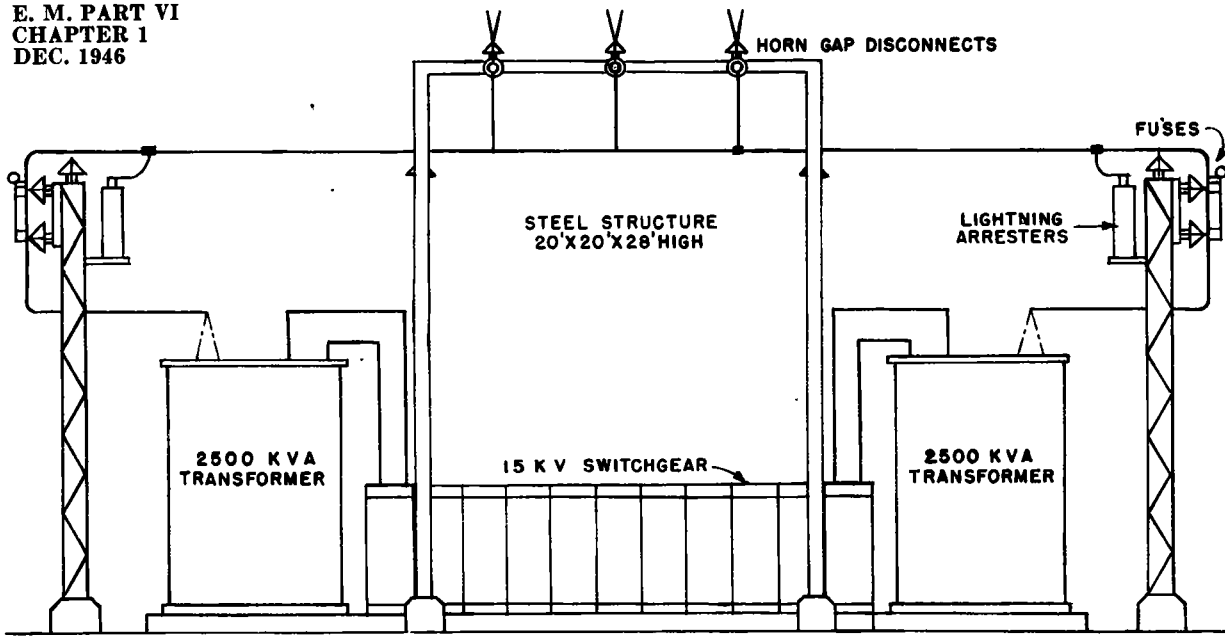
FIG. 2
1,000 KVA-44/13.8 KV CONVENTIONAL SUBSTATION



PLAN

FIG. 3

4,000 KVA - 44/13.8 KV UNIT SUBSTATION



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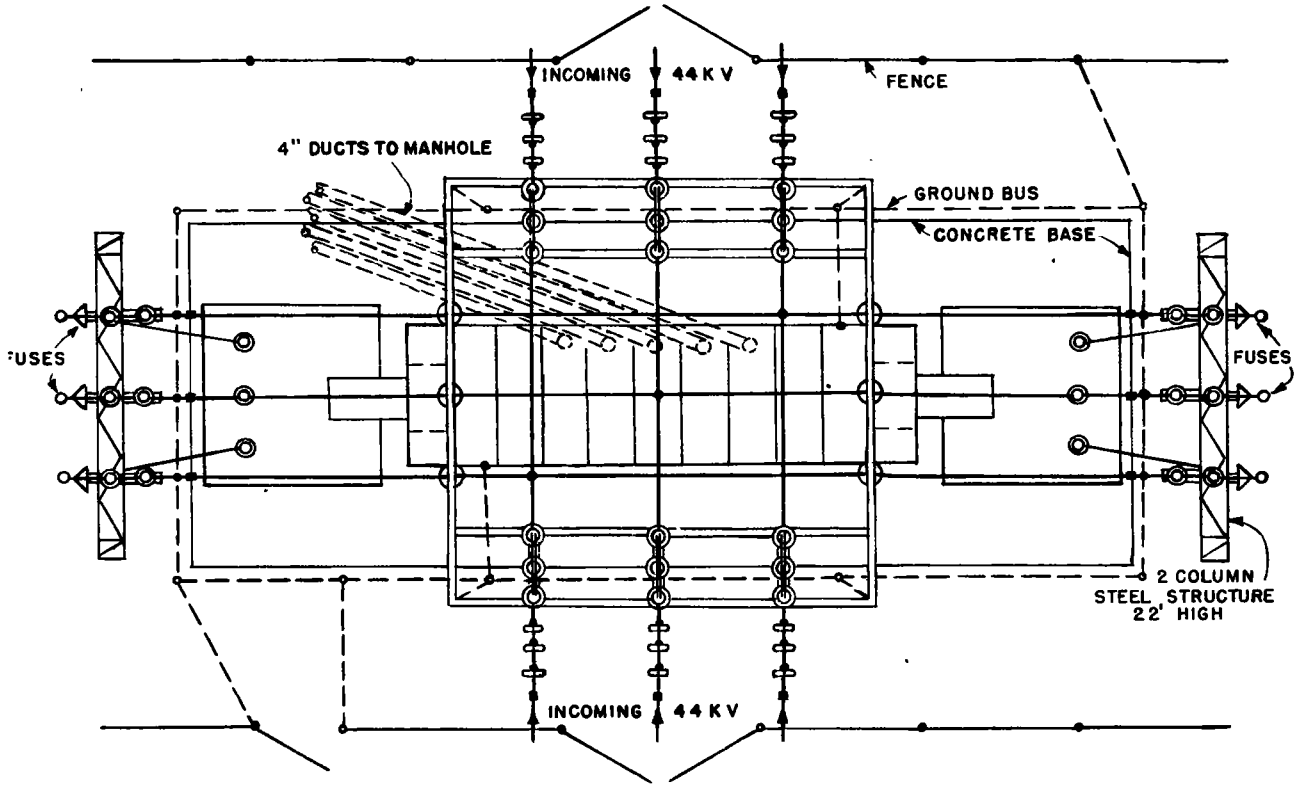
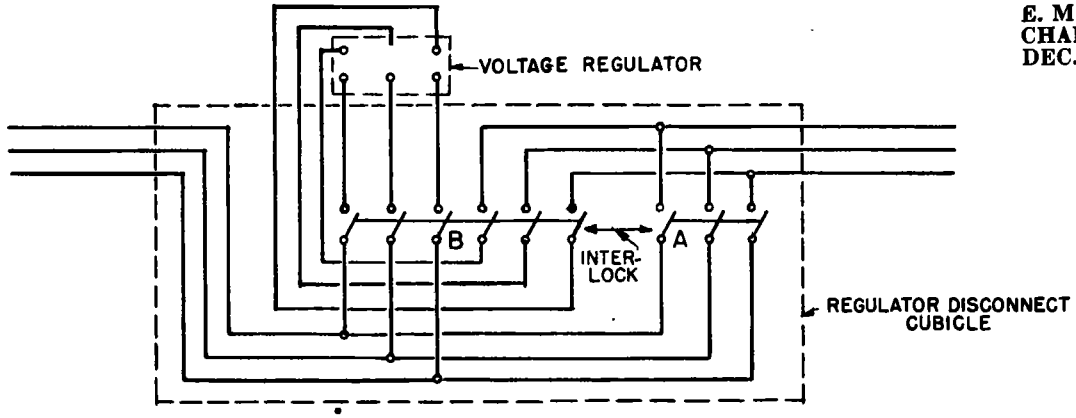


PLAN

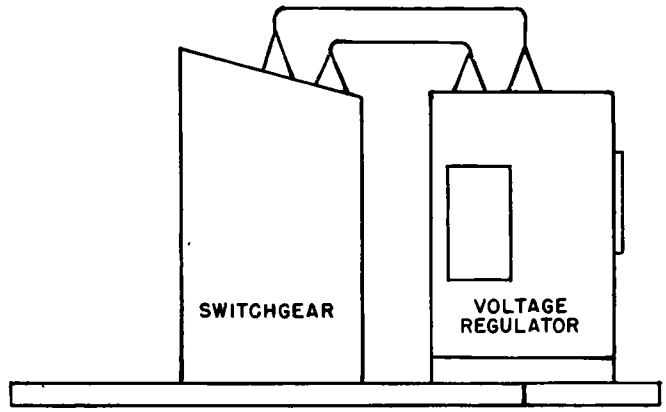
FIG.4

5,000 KVA - 44/13.8 KV UNIT SUBSTATION

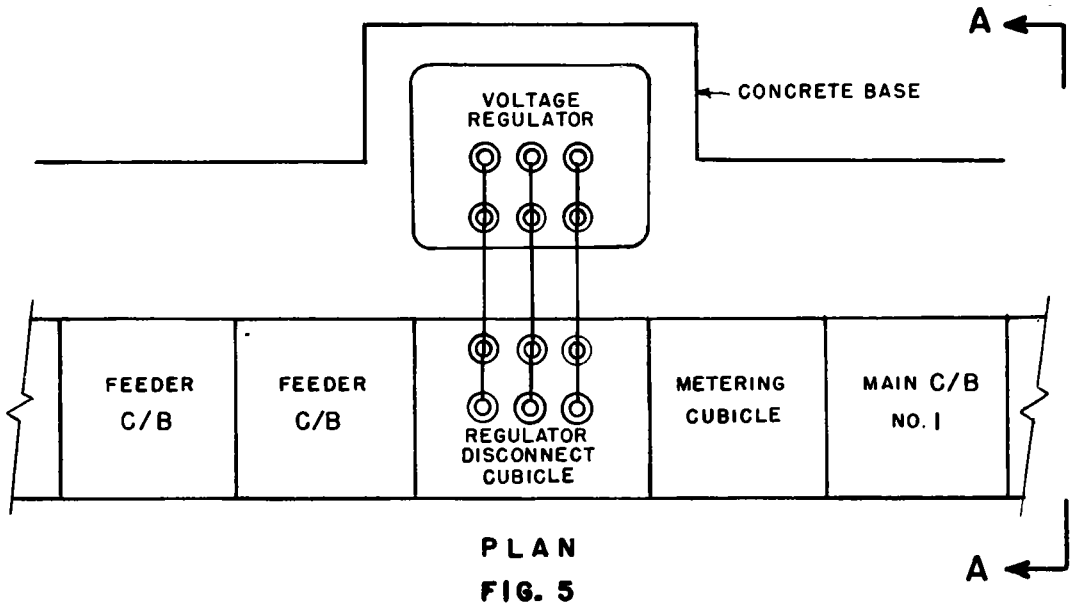


CONNECTION DIAGRAM

SWITCH "A" CAN NOT BE OPENED UNLESS
" "B" IS CLOSED.
" "B" CAN NOT BE OPENED UNLESS
" "A" IS CLOSED.



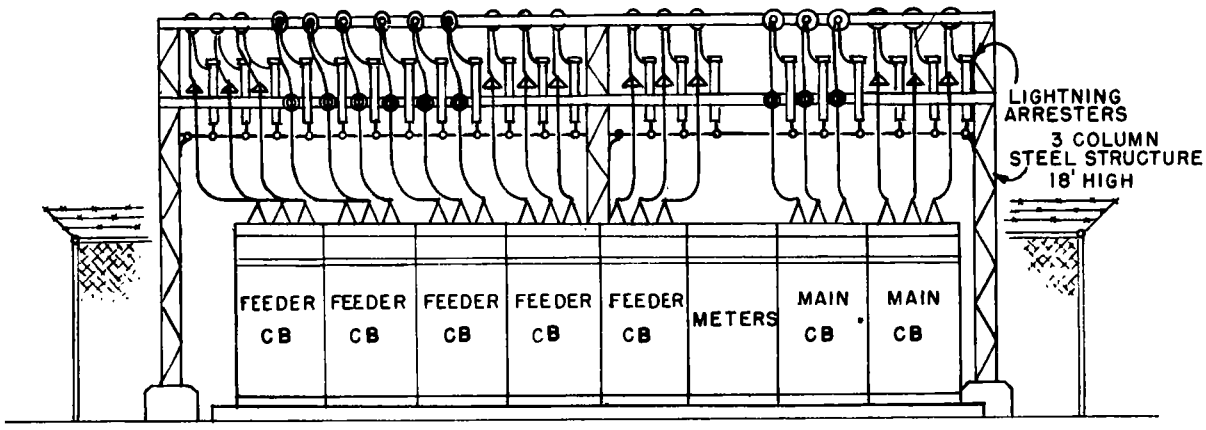
ELEVATION A - A



PLAN

FIG. 5

TYPICAL VOLTAGE REGULATOR INSTALLATION



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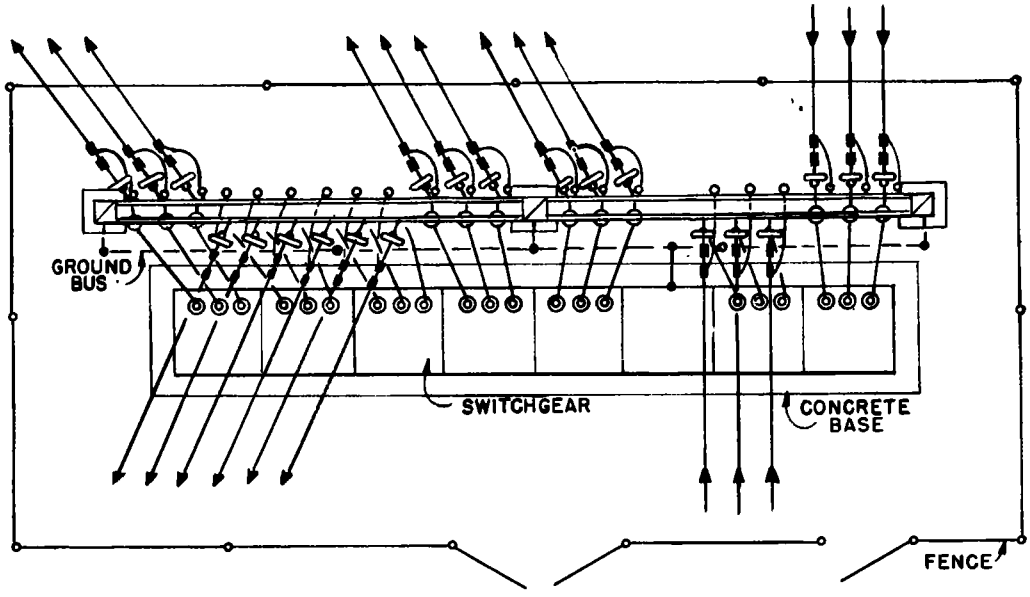
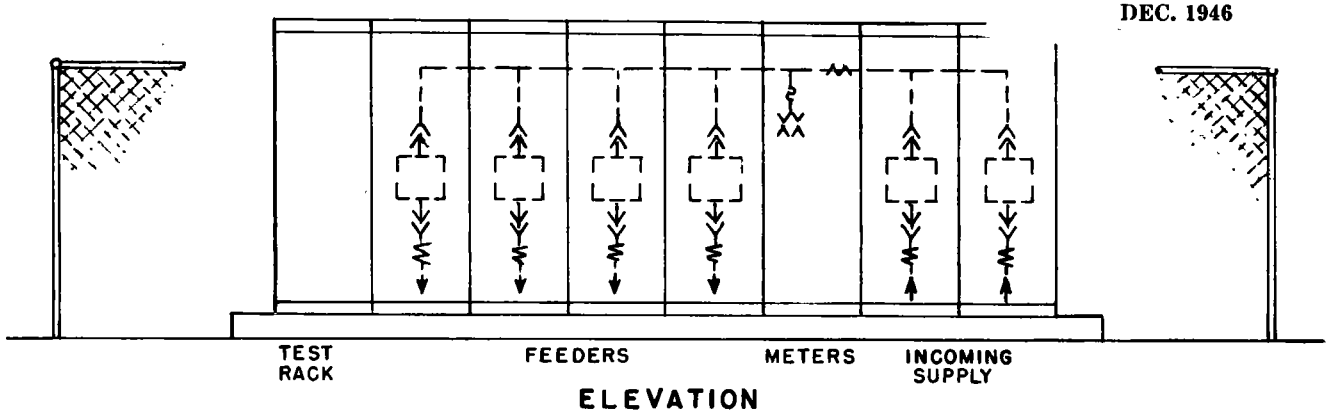


PLAN

FIG. 6

TYPICAL 13.8 KV SWITCHING STATION
FOR AERIAL SYSTEMS



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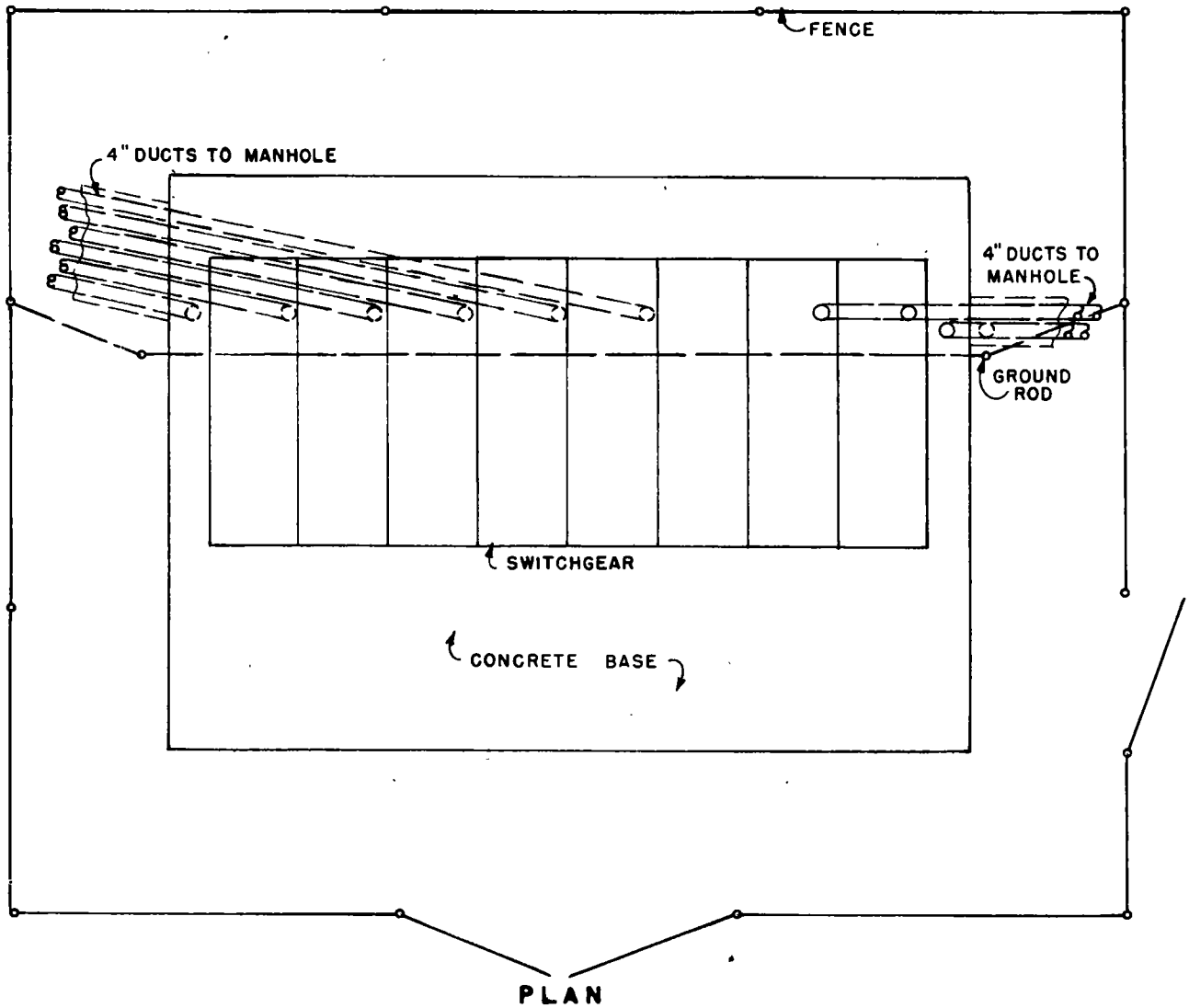


PLAN

FIG. 7

13.8 KV SWITCHING STATION

1-25 POLE LINES. Pole lines should be installed along streets or roads, wherever practicable, in order to avoid the use of separate poles for street lights. Figure 8 shows a typical lay-out of pole lines for an aerial electrical distribution and street lighting system. For uniformity, symbols shown on figure 9 should be used to indicate pole line construction on drawings. Poles, cross arms, loading, guying, clearances, spans, sags, and tensions should comply with the requirements of National Bureau of Standards Safety Rules for The Installation and Maintenance of Electric Supply and Communication Lines for grade "B" construction. In connection with the selection of pole lengths, allowance should be made for the installation of telephone lines on all distributor poles. These lines are usually installed by the Signal Corps or the local telephone company, but the designer of the distribution system is responsible for the additional space and strength requirements. Pole lengths specified should include the section below ground line. Table V indicates the average setting depth of poles in normal, firm ground. Class of pole should be selected on the basis of having the minimum breaking strength at the ground line listed in table VI. For grade "B" construction, the poles should have four times the strength required for supporting the actual vertical and transverse loading, except that when poles are guyed, the guy should support the entire load in the direction in which it acts, the pole simply acting as a strut.

TABLE V.—*Pole setting depth*

Pole length over-all, feet	Setting depth			
	Straight lines		Curves, corners, and points of extra strain	
	Feet	Inches	Feet	Inches
30	5	6	5	6
35	6	0	6	0
40	6	0	6	6
45	6	6	7	0
50	7	0	7	6
55	7	6	8	0
60	8	0	8	6
70	9	0	9	6

TABLE VI.—*Poles*

Class of pole:	*Minimum breaking strength (pounds)*
1	4, 500
2	3, 700
3	3, 000
4	2, 400
5	1, 900
6	1, 500
7	1, 200

1-26 PRIMARY CIRCUITS. The number of primary circuits should be established on the basis that each circuit will carry the kilovolt-ampere load listed in table VII for the distance indicated, without exceeding a 2-percent voltage drop. The kilovolt-ampere load should be determined by adding the kilovolt-ampere capacity of all transformers to be connected to the circuit, plus planned building expansion, plus 50 percent for normal growth of loads within the buildings served by the circuit. The use of wire larger than No. 0—AWG should be avoided wherever practicable, as the heavier conductors are difficult for small maintenance crews to handle. Not more than two primary circuits should be carried on one pole. Loop circuits, equipped with disconnecting switches on the poles adjacent to each important transformer bank, provide maximum flexibility and should be utilized whenever this type of system is suitable for the building lay-out. Where radial circuits are suitably located, disconnecting switches should be provided to permit the load from one circuit to be transferred to another in case of emergency. A loop circuit or at least two primary

circuits should be available for use at all hospital transformer banks, to insure a continuous supply of electricity during inspection and repair operations. At airfields, in order to avoid danger of contact between radio antennae and high voltage lines, the primary circuits should not be installed within a radius of 300 feet of any stage or traffic-control tower. All primary circuits should be installed on cross arms. Figures 10, 11, 12, and 13 show typical arrangements of primary circuits.

TABLE VII.—*Three-phase primary circuit loading*

Kilowatt capacity of wires and maximum distance in feet to load center for 2 percent voltage drop aerial systems

Wire size	2,400-volt				4,160-volt			
	Kilowatts	100 percent pf distance	Kilowatts	80 percent pf distance	Kilowatts	100 percent pf distance	Kilowatts	80 percent pf distance
8	295	670	236	670	511	1, 160	409	1, 160
6	407	720	326	720	705	1, 250	564	1, 250
4	541	860	433	780	936	1, 480	749	1, 330
2	733	1, 010	586	805	1, 267	1, 750	1, 011	1, 400
1	845	1, 090	676	805	1, 460	1, 880	1, 168	1, 400
1/0	985	1, 195	788	795	1, 710	2, 070	1, 369	1, 380
2/0	1, 140	1, 300	912	785	1, 970	2, 250	1, 572	1, 360
3/0	1, 320	1, 430	1, 058	770	2, 290	2, 480	1, 830	1, 330
4/0	1, 530	1, 540	1, 224	735	2, 650	2, 650	2, 120	1, 270
250	1, 700	1, 610	1, 360	710	2, 950	2, 790	2, 360	1, 230
300	1, 910	1, 630	1, 530	670	3, 310	2, 830	2, 640	1, 160
350	2, 110	1, 760	1, 690	646	3, 650	3, 050	2, 920	1, 120
400	2, 300	1, 920	1, 840	630	4, 000	3, 340	3, 200	1, 090
500	2, 610	2, 100	2, 090	550	4, 520	3, 650	3, 610	1, 040
	4,800-volt				7,200-volt			
8	590	1, 340	471	1, 340	884	2, 000	706	2, 000
6	814	1, 440	650	1, 440	1, 220	2, 160	975	2, 160
4	1, 080	1, 710	864	1, 550	1, 620	2, 570	1, 300	2, 330
2	1, 460	2, 030	1, 170	1, 610	2, 190	3, 040	1, 750	2, 410
1	1, 690	2, 170	1, 300	1, 610	2, 530	3, 260	2, 020	2, 410
1/0	1, 970	2, 390	1, 570	1, 590	2, 950	3, 590	2, 360	2, 390
2/0	2, 280	2, 590	1, 820	1, 570	3, 410	3, 900	2, 730	2, 360
3/0	2, 640	2, 850	2, 110	1, 530	3, 960	4, 280	3, 170	2, 300
4/0	3, 060	3, 080	2, 450	1, 470	4, 580	4, 620	3, 660	2, 200
250	3, 400	3, 200	2, 720	1, 420	5, 110	4, 830	4, 100	2, 130
300	3, 820	3, 260	3, 300	1, 340	5, 730	4, 900	4, 580	2, 000
350	4, 220	3, 520	3, 380	1, 290	6, 320	5, 280	5, 050	1, 940
400	4, 600	3, 840	3, 680	1, 260	6, 900	5, 780	5, 520	1, 890
500	5, 220	4, 210	4, 180	1, 200	7, 830	6, 320	6, 260	1, 800
	12,000-volt				13,800-volt			
8	1, 470	3, 340	1, 175	3, 340	1, 690	3, 840	1, 350	3, 840
6	2, 040	3, 600	1, 630	3, 600	2, 340	4, 130	1, 870	4, 130
4	2, 700	4, 280	2, 160	3, 900	3, 100	4, 930	2, 480	4, 470
2	3, 650	5, 060	2, 920	4, 020	4, 200	5, 820	3, 360	4, 630
1	4, 220	5, 430	3, 380	4, 020	4, 850	6, 250	3, 880	4, 630
1/0	4, 710	5, 980	3, 920	3, 980	5, 650	6, 880	4, 520	4, 580
2/0	5, 690	6, 500	4, 550	3, 930	6, 540	7, 460	5, 220	4, 510
3/0	6, 600	7, 150	5, 280	3, 840	7, 600	8, 220	6, 080	4, 410
4/0	7, 650	7, 690	6, 120	3, 680	8, 780	8, 850	7, 020	4, 230
250	8, 510	8, 050	6, 800	3, 550	9, 790	9, 260	7, 820	4, 080
300	9, 550	8, 160	7, 640	3, 350	10, 980	9, 400	8, 780	3, 850
350	10, 550	8, 800	8, 440	3, 230	12, 100	10, 100	9, 670	3, 720
400	11, 500	9, 640	9, 210	3, 150	13, 200	11, 100	10, 550	3, 620
500	13, 060	10, 500	10, 400	2, 990	15, 000	12, 100	12, 000	3, 440

Notes. 1. All voltages are line to line.
2. Wire capacities are for bare or weatherproof wires.
3. Wires run overhead with effective spacing of 18 inches.
4. To compute the maximum distance to a load center with 2 percent voltage drop for connected loads not listed above:
   a. Select from the table the desired wire size which will carry the load at the applicable voltage rating.
   b. Multiply the "kilowatts" given in the table by the "distance" given in the table, for the selected wire size.
   c. Divide this product by the actual load in kilowatts.
   d. If the computed distance is not adequate, select a larger wire size and repeat the calculation.

1–27 SECONDARY CIRCUITS. Secondary circuits should be installed on the poles carrying primary circuits where these poles are suitably located for the purpose. Secondary conductors should be supported below the primary lines on secondary racks, clevises, or wire holders, as applicable. Figures 14, 15, 16, 17, 18, and 19 show typical arrangements of secondary circuits. Conductors should be triple-braid, weatherproof. The following maximum wire loading is recommended, based on a 55° temperature rise, provided the voltage drop given in paragraph 1–28 is not exceeded.

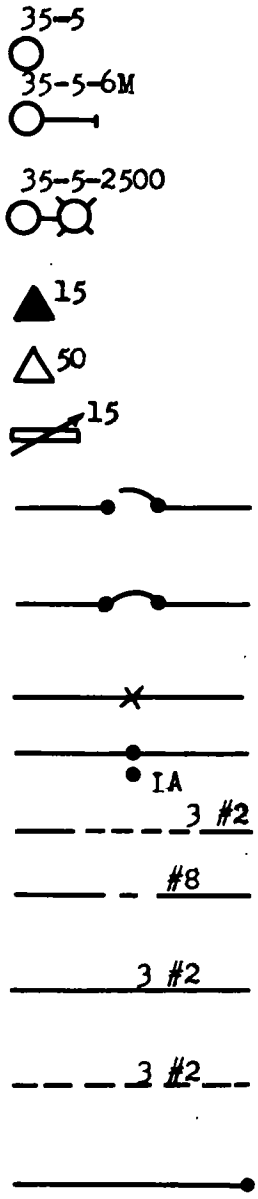
AWG size	*Amperes*	*AWG size*	*Amperes*
No. 8	85	No. 0	280
No. 6	105	No. 2/0	385
No. 4	145	No. 4/0	425
No. 2	200	500 MCM	750

1–28 VOLTAGE DROP. Voltage drop should not exceed 2 percent on the primary and secondary circuits, respectively. Assuming a drop of approximately 2 percent for transformers, the total voltage drop on the distribution system should not exceed 6 percent.

1–29 TRANSFORMERS. Transformers should be of the self-cooled type, with rating selected from table I. Where required size is not listed in the table, the next larger size should be installed. Transformers or transformer banks having a capacity in excess of 75 kilavolt-amperes should be installed on two-pole platforms or on concrete mats. Smaller transformers should be pole-mounted. Figures 20, 21, 22, and 23 show typical transformer installations. Capacities should be selected so that all transformers will be operating as nearly as practicable to the allowable temperature limits during periods of maximum demand. In general, the capacity of transformers should be equal to approximately 80 percent of the connected load, exclusive of electric ranges. The transformer capacity for each installation, however, will require special study and will vary from a demand factor of 50 percent for large hospital buildings to a demand factor of 100 percent for isolated power installations. Demand factors for electric ranges are approximately as follows:

Number of ranges	*Demand factor (percent)*	*Number of ranges*	*Demand factor (percent)*
1	80	16 to 20	28
2	65	21 to 25	26
3	55	26 to 30	24
4	50	31 to 40	22
5	45	41 to 50	20
6 to 10	40	51 to 60	18
10 to 15	32	61 and over	16

1–30 SERIES STREET LIGHTING SYSTEMS. Series systems may be either 6.6 or 20 amperes and should employ complete metallic loops. Series street lighting wires should be placed on the inside pins of the cross arms or, when poles are installed for series street lighting purposes only, wire may be installed on pole-top pin insulators and the cross arms omitted. Single circuits should be limited, if possible, to 30 kilowatts or less, using pole-type transformers. Where it is necessary to use constant current transformers larger than 30 kilowatts, they should be of the indoor type and should be installed in suitable fireproof vaults. Supplementary multiple lights may be used on 6.6 ampere systems only, in which case insulating transformers with multiple secondary windings should be employed. Control should be by means of a primary switch which should be operated by a time switch wherever a low voltage control circuit is available. Figure 24 shows a typical installation of street lighting regulator and control.



Pole - Length and class indicated.

Pole with down guy and anchor - Length and class of pole and strength of guy in pounds as indicated.

Pole with street light - length and class of pole and size of lamp in lumens or watts as indicated.

Single-phase transformer - Rating in kva as indicated.

Three-phase transformer - Rating in kva as indicated.

Street lighting regulator - Rating in kw as indicated.

Sectionalizing switch mounted on crossarm - Normally open.

Sectionalizing switch mounted on crossarm - Normally closed.

Pole top switch.

Lightning arrester in each phase wire.

Primary line - Number and size of wires as indicated.

Series street lighting circuit - Single conductor - Of size indicated.

Single phase secondary line - Number and size of wires as indicated.

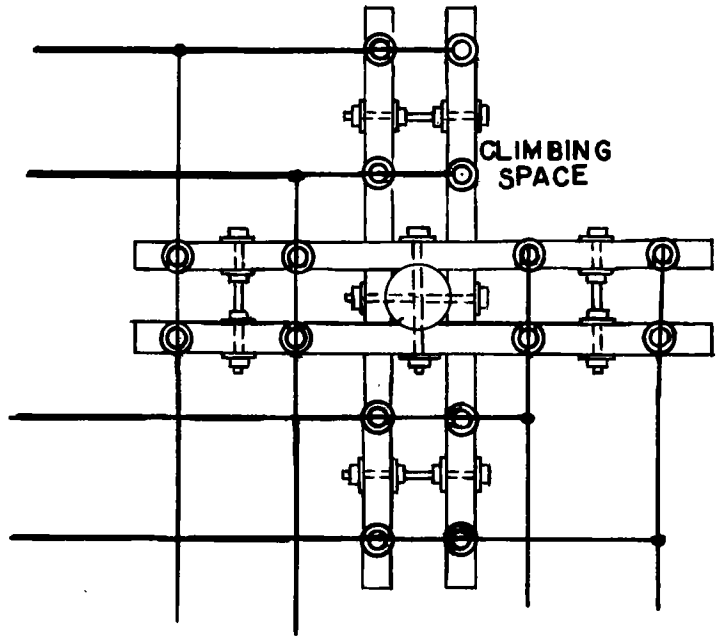
Three-phase secondary line - Number and size of wires as indicated.

Conductor deadend.

STANDARD SYMBOLS

AERIAL ELECTRICAL DISTRIBUTION CONSTRUCTION

Fig. 9



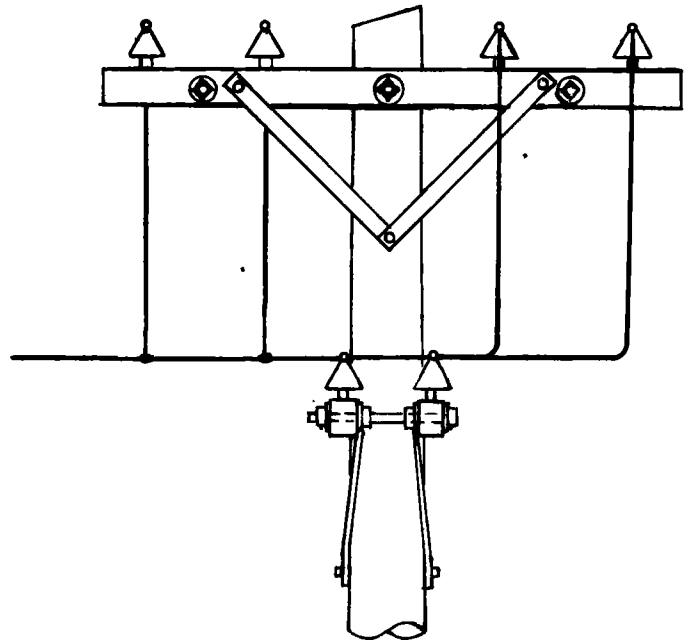


FIG. 10

L - CORNER -
(4 WIRE)

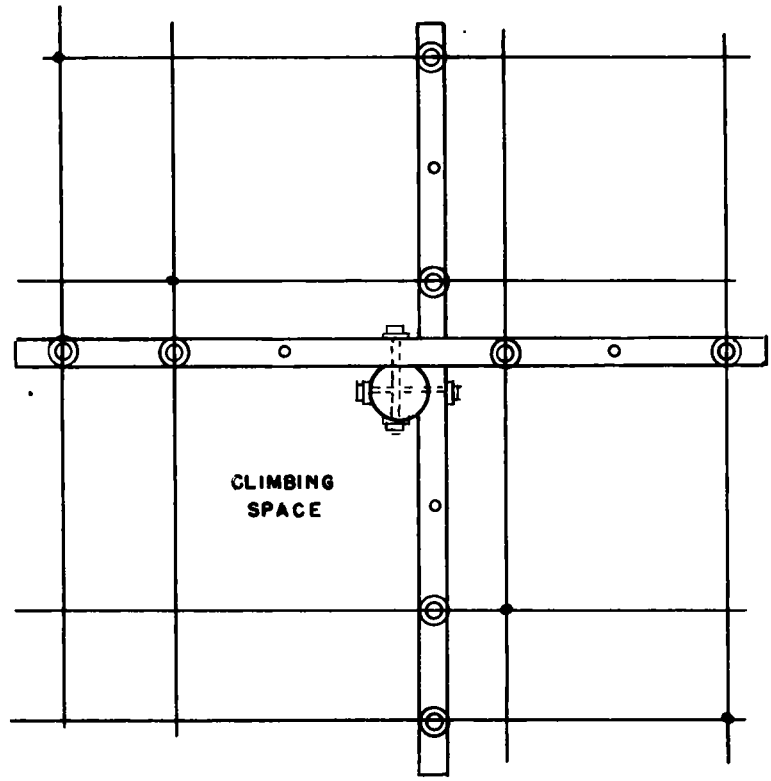


FIG. 11
X-CORNER
(4 WIRE)

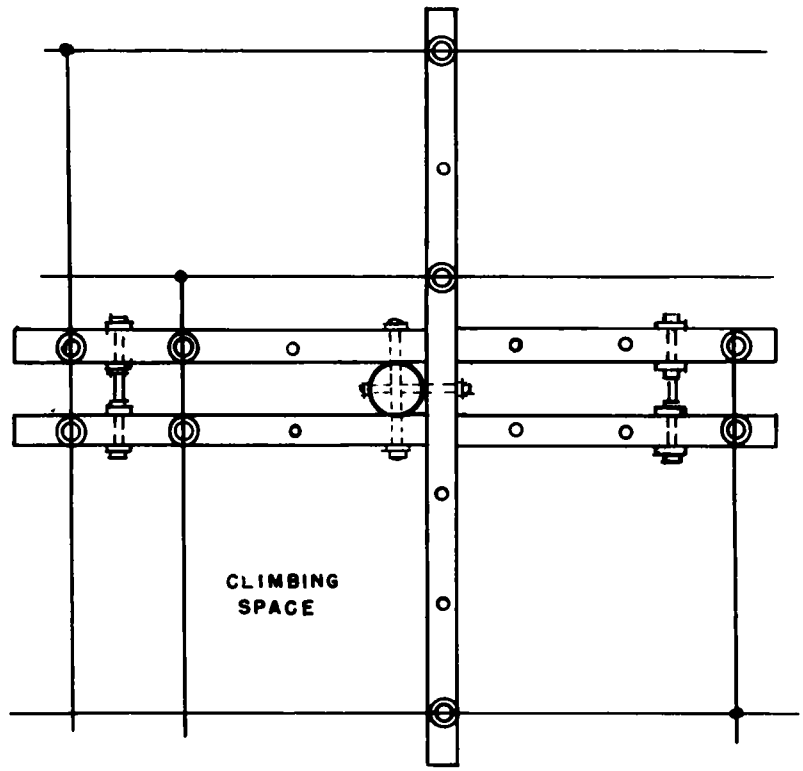


FIG. 12
T-CORNER
(3 WIRE)

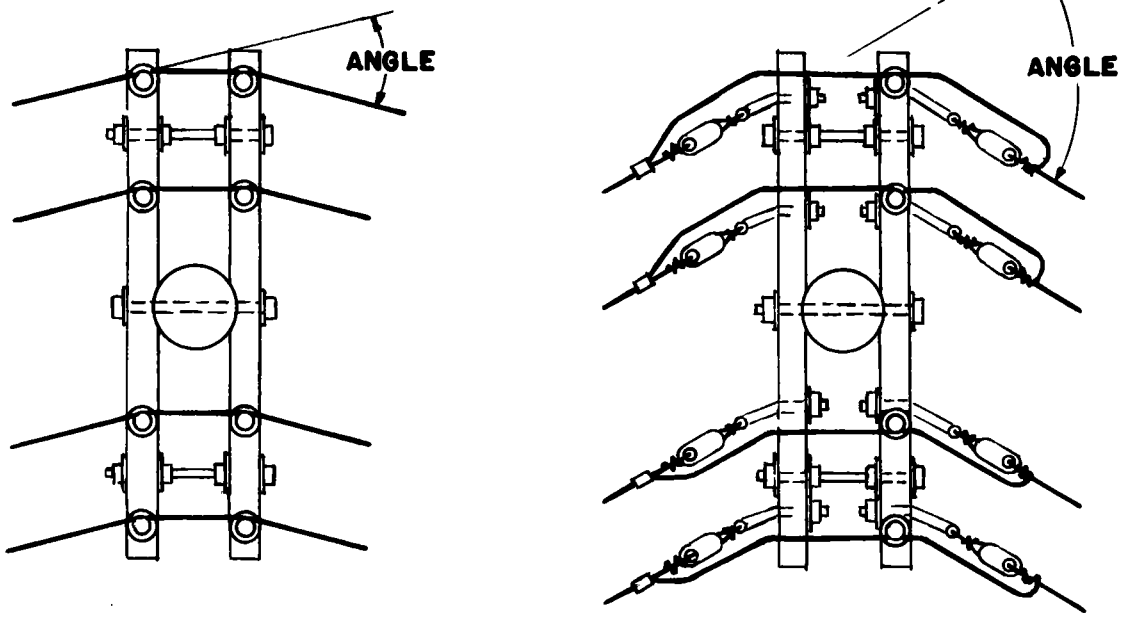


FIG. 13

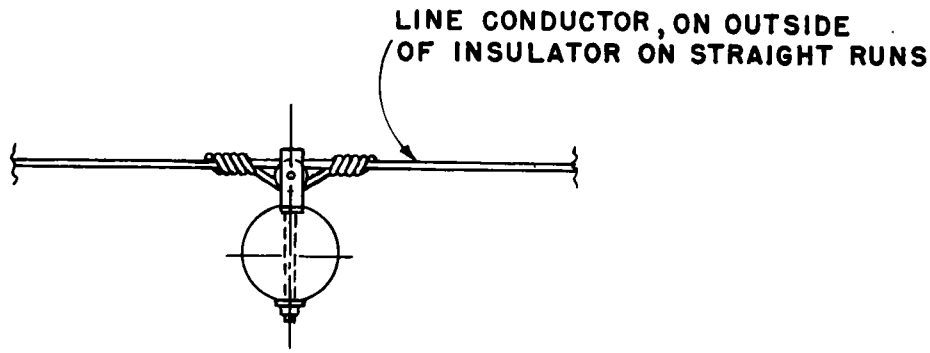
DOUBLE ARM

ANGLE	COND.
12-24°	6
6-12°	2
4- 8°	1/0
2- 4°	4/0

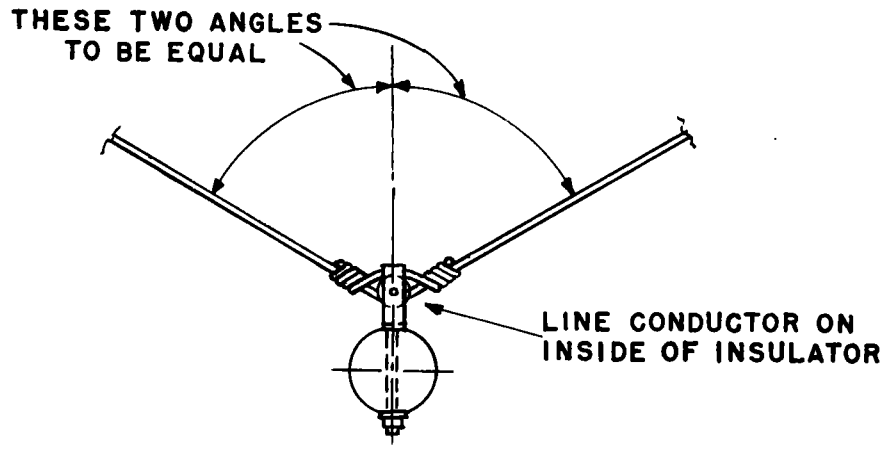
ANGLE	COND.
24-60°	6
12-60°	2
8-60°	1/0
4-60°	4/0

-NOTE-

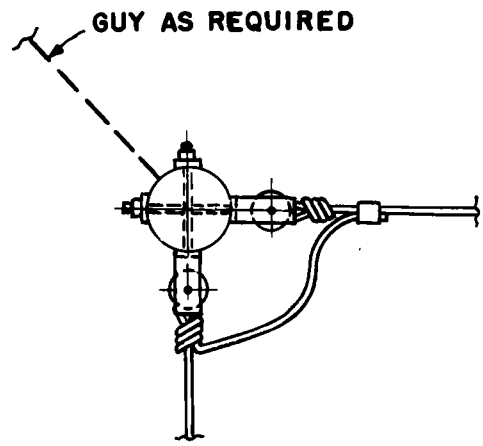
FOR ANGLES GREATER THAN 60° USE CORNER TYPE CONSTRUCTION.



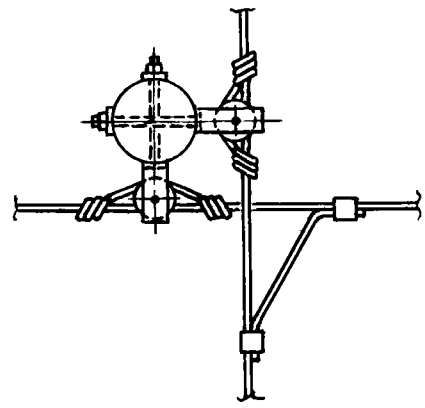
STRAIGHT - LINE INSTALLATION FIGURE 14



ANGLE INSTALLATION FIGURE 15



CORNER
INSTALLATION
FIG. 16



CROSS
FIG. 17

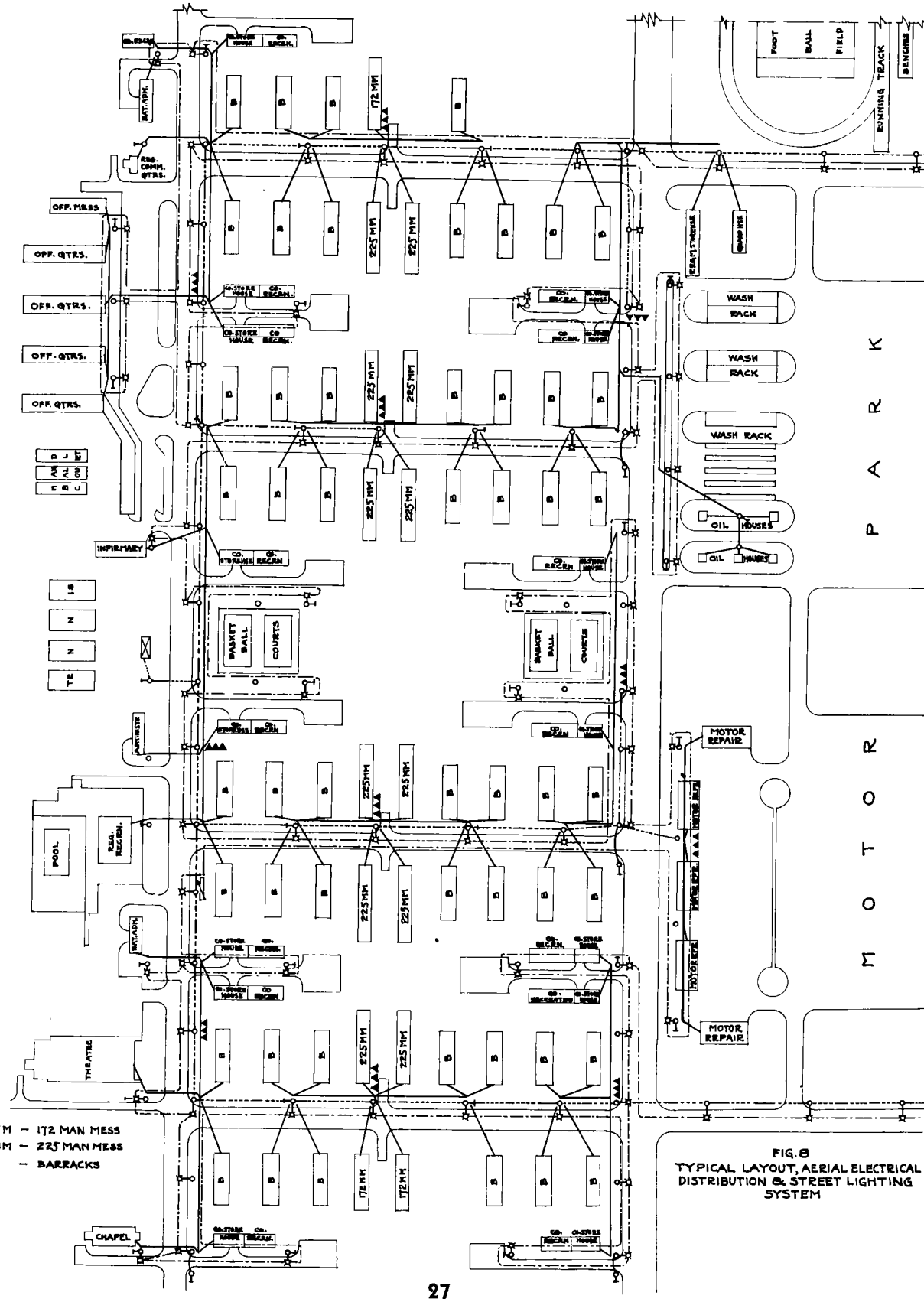
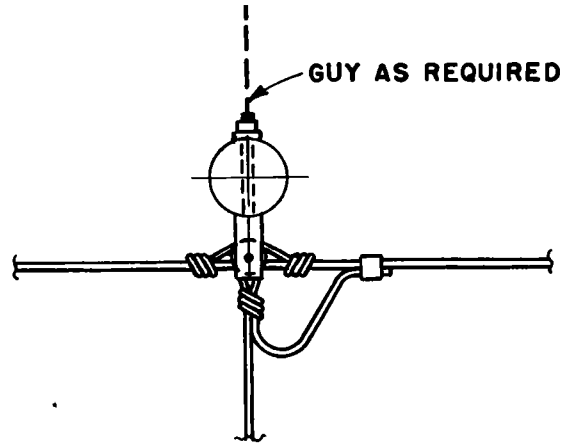
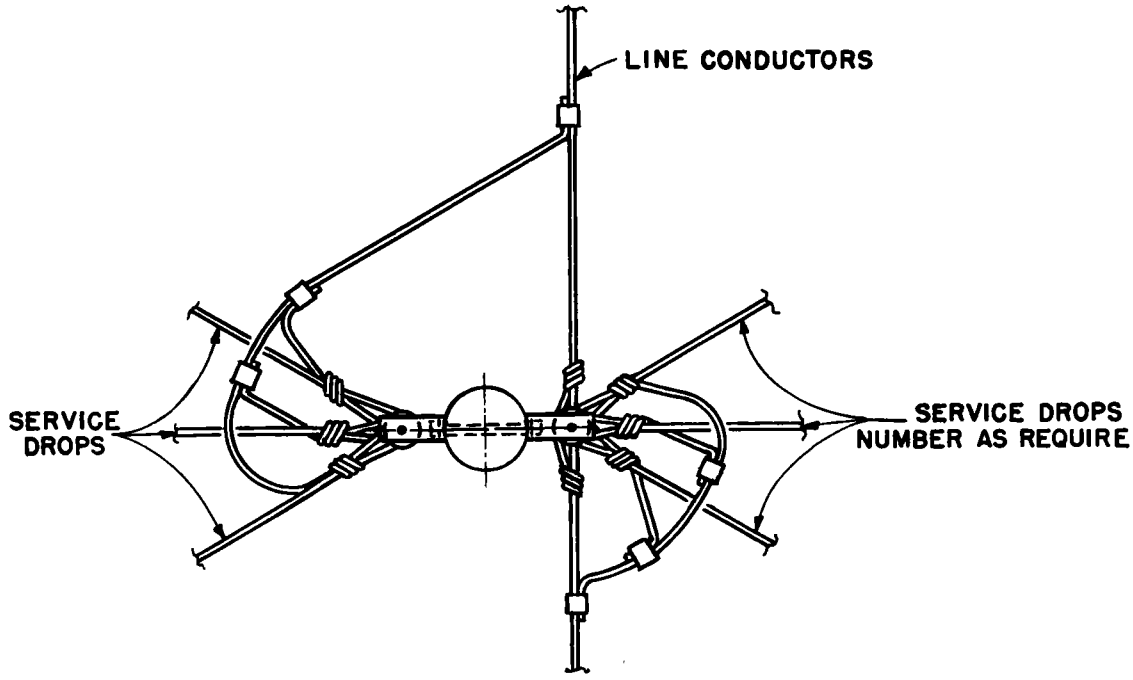


FIG. 8
TYPICAL LAYOUT, AERIAL ELECTRICAL DISTRIBUTION & STREET LIGHTING SYSTEM



TEE TAP
FIGURE 18



TYPICAL SERVICE CONNECTIONS
FIGURE 19

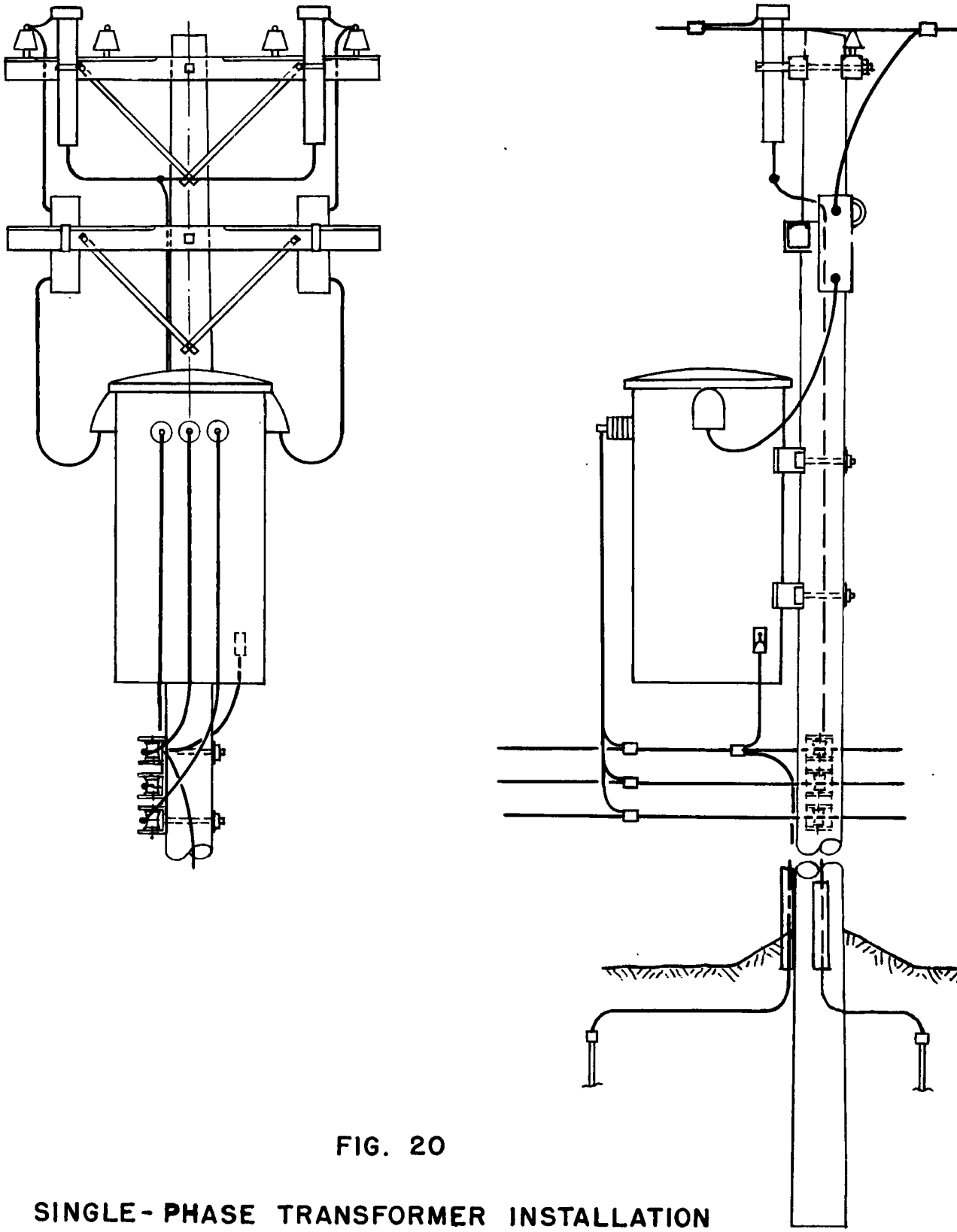


FIG. 20

SINGLE-PHASE TRANSFORMER INSTALLATION

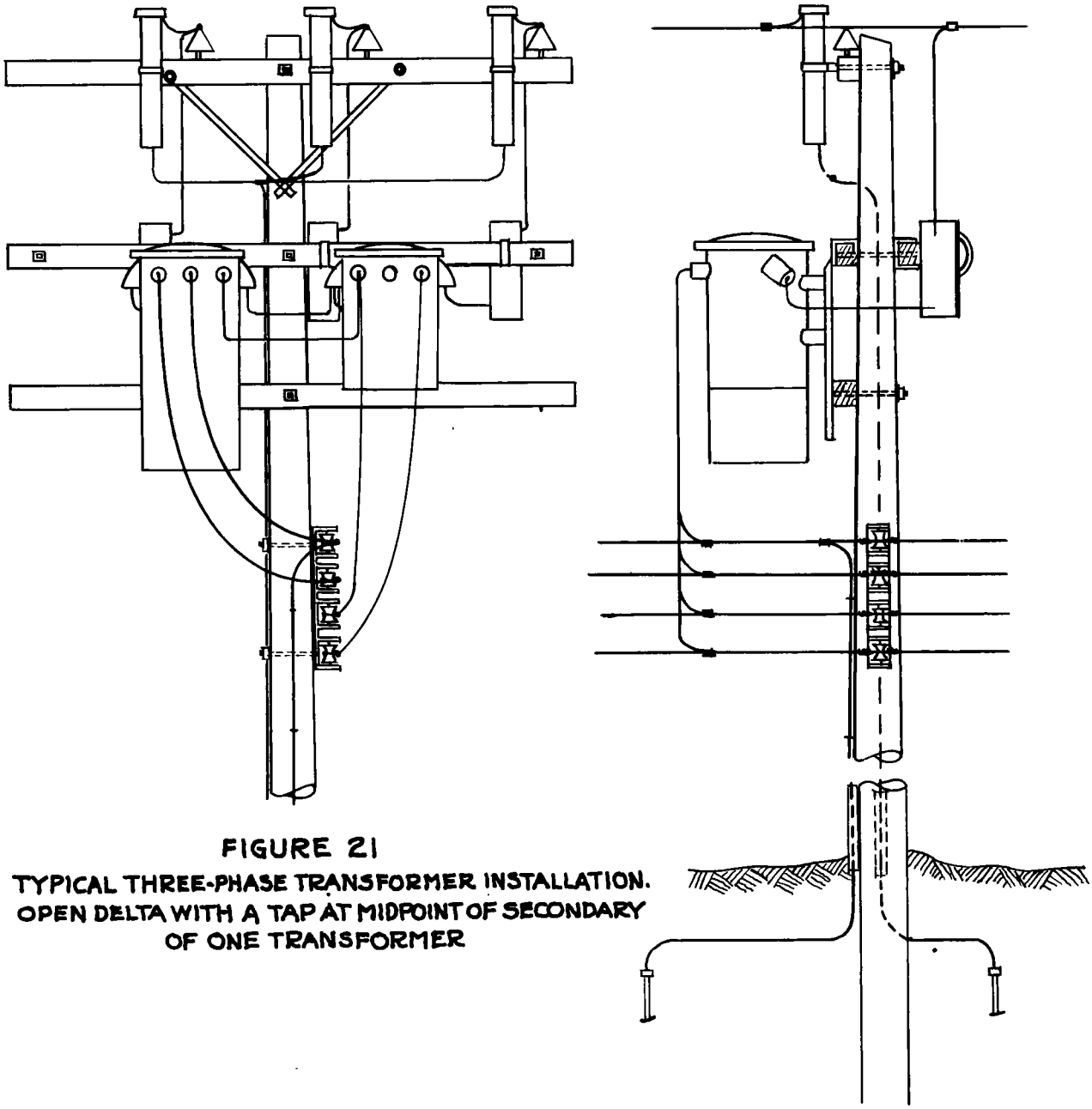


FIGURE 21

TYPICAL THREE-PHASE TRANSFORMER INSTALLATION. OPEN DELTA WITH A TAP AT MIDPOINT OF SECONDARY OF ONE TRANSFORMER

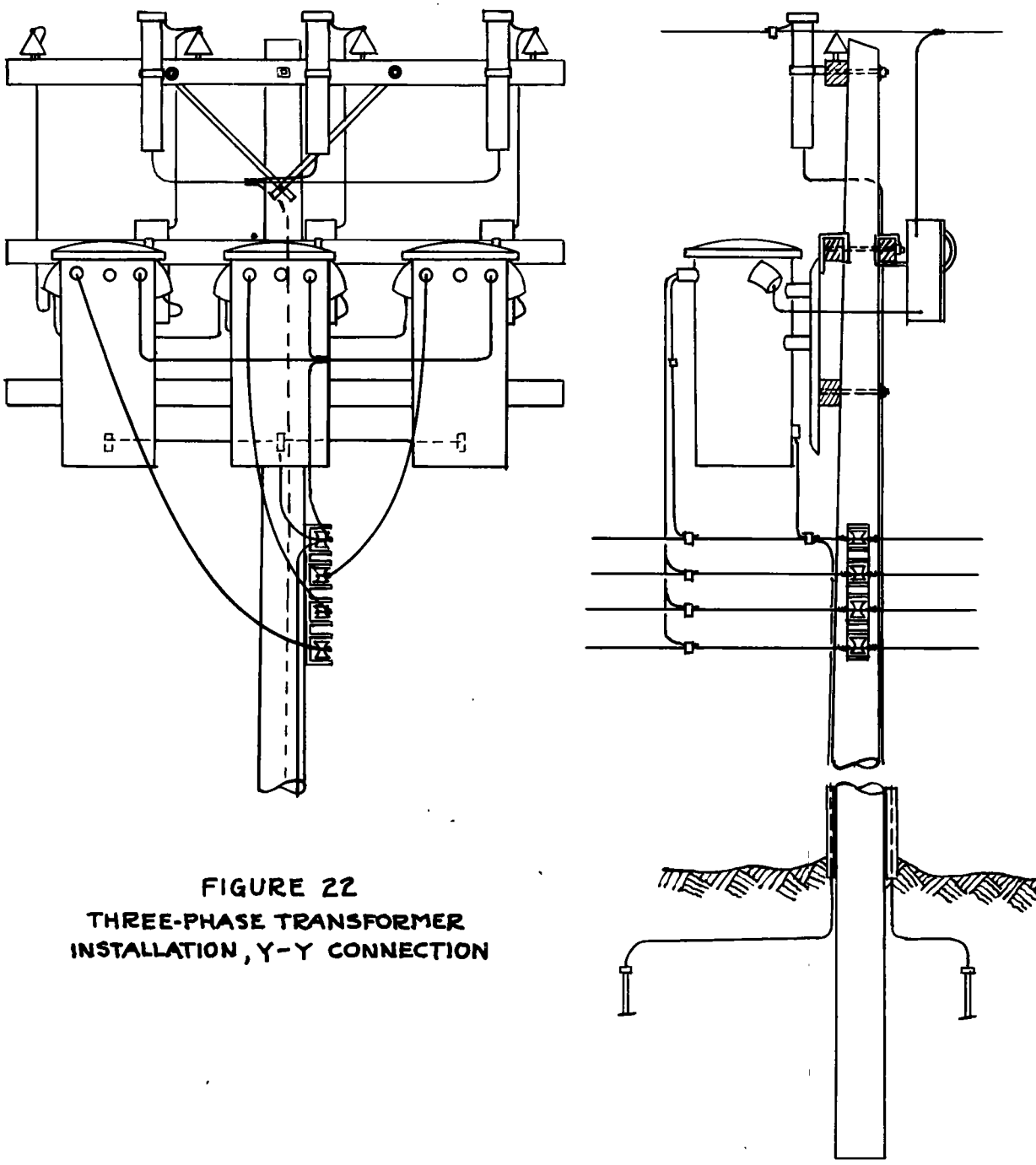


FIGURE 22
THREE-PHASE TRANSFORMER
INSTALLATION, Y-Y CONNECTION

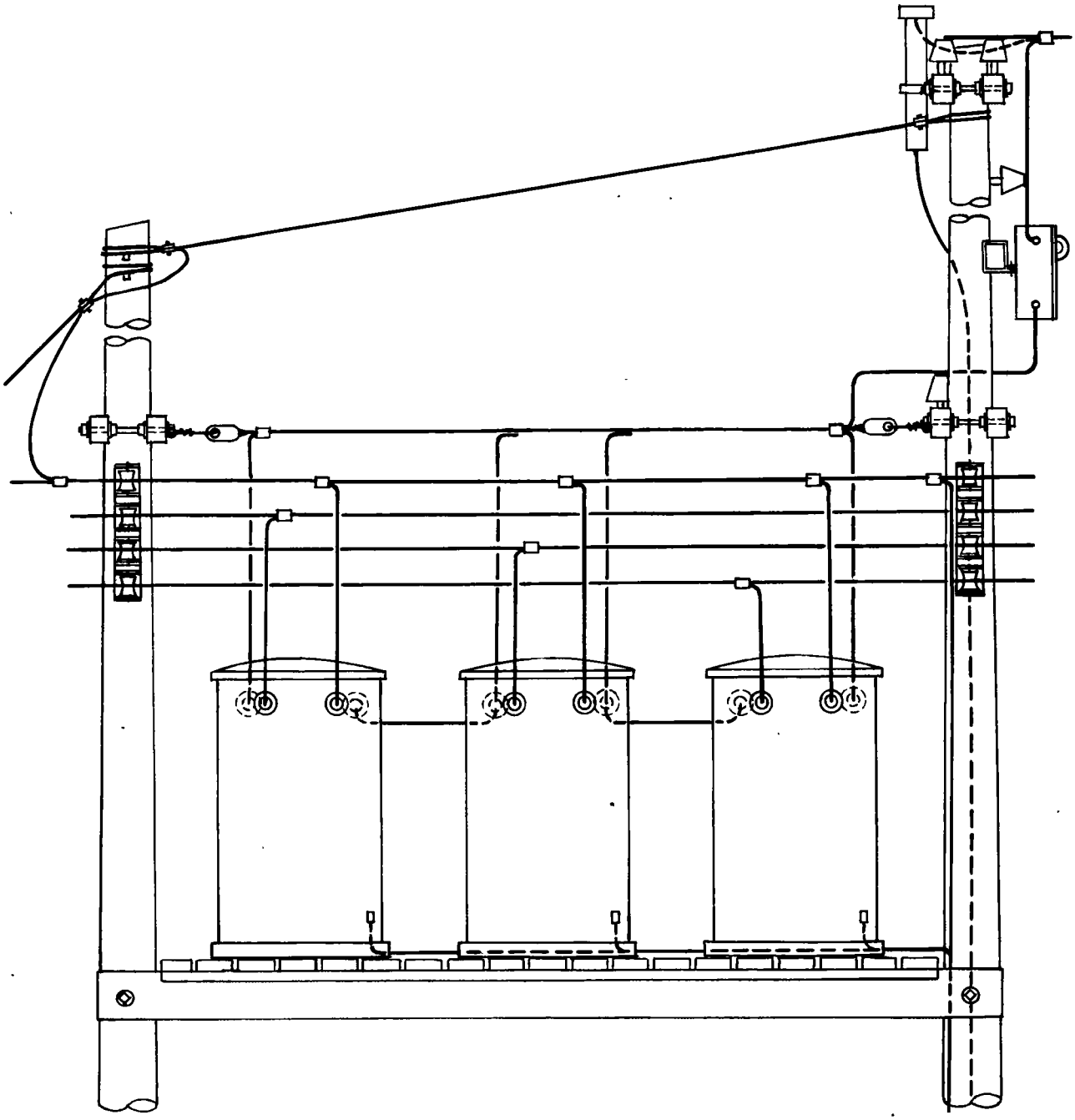


FIG. 23

TYPICAL 3-PHASE TRANSFORMER INSTALLATION
ON PLATFORM 3-37½ TO 3-100 KVA SIZE

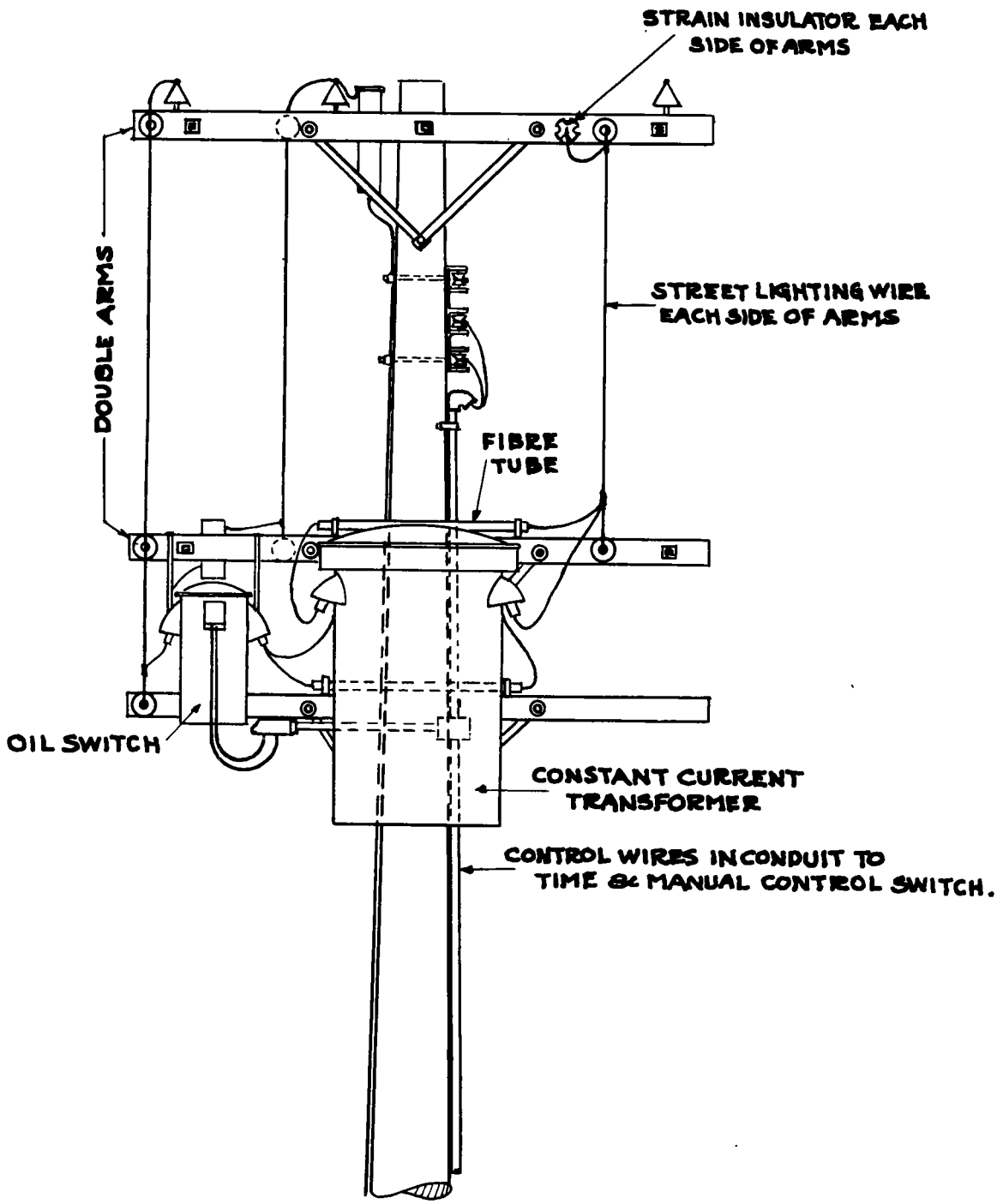


FIGURE 24
STREET LIGHTING REGULATOR
AND CONTROL

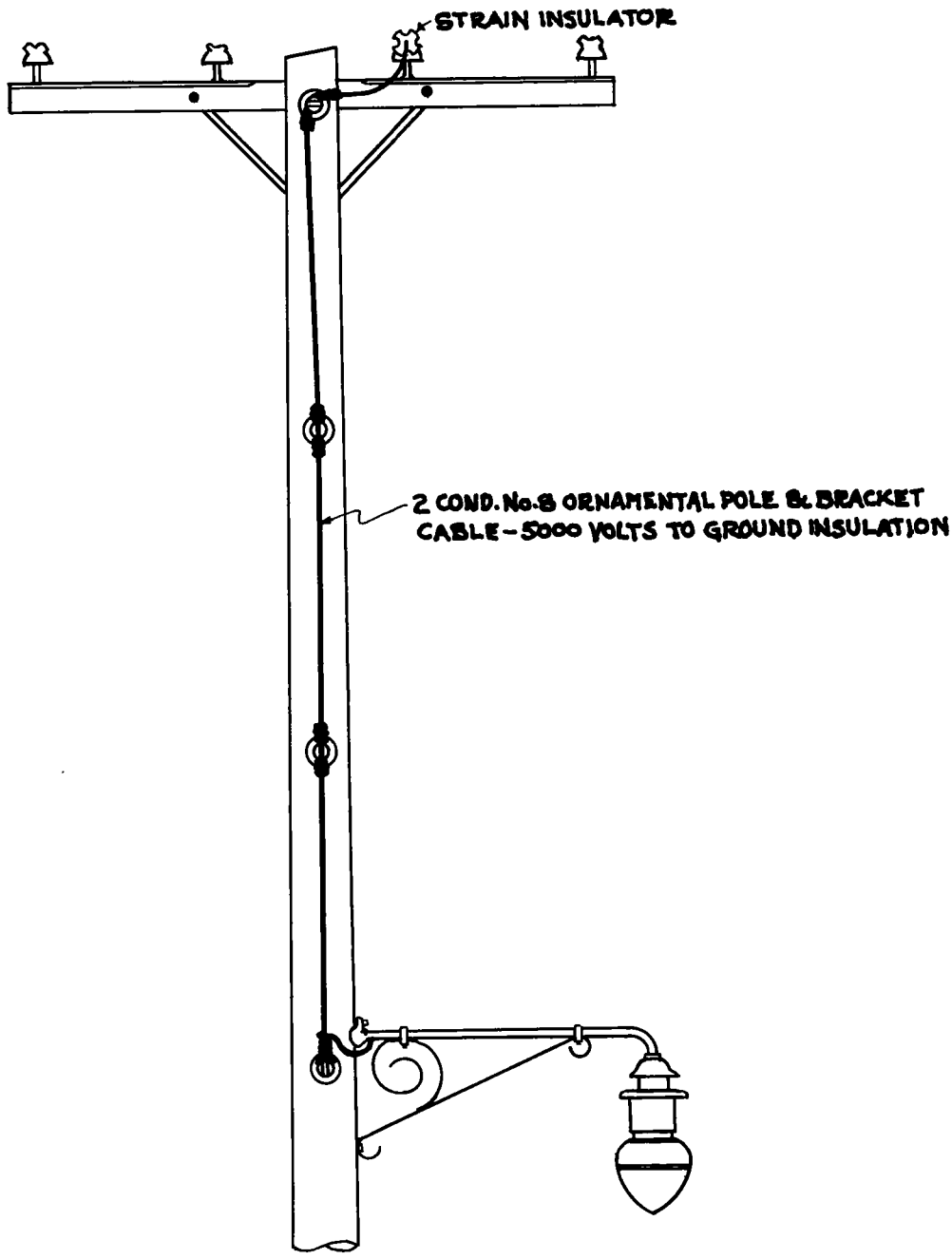


FIGURE 25
STREET LIGHTING UNIT

1-31 MULTIPLE STREET LIGHTING SYSTEMS. Multiple systems utilizing extension to the primary or secondary electrical distribution system should be employed where a small number of lamps are to be installed within a reasonably small area. Control should be by means of weatherproof safety switches located approximately 6 feet above the ground on a pole or other convenient place.

1-32 STREET LIGHTING UNITS. Street lighting units should consist of bowl refractor luminaires in administration, recreation, hospital, quarters, barracks, and industrial areas and 20-inch radial wave reflectors in warehouse, utility, and storage areas. Radial wave reflectors should also be installed along roads outside of the building areas, with the exception of extended main entrance roads. Lighting intensities should be based on the installation of 4,000-lumen series lamps or 200-watt multiple lamps spaced 150 feet apart in administration, hospital, recreation, and industrial areas and 2,500-lumen series lamps or 150-watt multiple lamps spaced 150 feet apart in all other areas. One lighting unit should be installed at each street intersection in the building areas. Units should be mounted on 4-foot pipe brackets attached to the poles and should be located approximately 20 feet above the ground. Figure 25 shows a typical installation of street lighting unit.

UNDERGROUND ELECTRICAL DISTRIBUTION AND STREET LIGHTING SYSTEMS

1-33 GENERAL. Underground systems should be installed in areas where 25 percent or more of the buildings to be served by the system are of the permanent type of construction and in other areas where War Department safety regulations require the use of underground cable. Otherwise, aerial systems should be employed as required in paragraph 1-24. Aerial systems should also be installed in dispersed areas where the difference in cost between aerial and underground construction cannot be adequately justified.

1-34 DUCT LINES. Duct lines should be installed adjacent to streets or roads wherever practicable, in order to avoid interference with future building foundations. Figure 26 shows a typical lay-out of duct lines for an underground electrical distribution system. For uniformity, symbols shown on figure 27 should be used to indicate underground construction on drawings. In order to encourage competitive bidding, the contractor should be given the option of furnishing either clay, fiber, or asbestos-cement duct, unless local conditions indicate that it would be more advantageous to the Government to specify a definite material. Duct lines for both primary and communication cables should be installed. The two systems should be completely isolated from each other throughout. The nominal diameter of ducts for primary cables should not be less than 4 inches. The nominal diameter of ducts for communication cables be not less than 3 inches.

Multiple duct is suitable for communication cables but should not be used for the primary system. Duct lines for primary and communication cables should be incased in concrete, with the exception of multiple duct. A concrete base and cover is sufficient for this type of duct. Concrete should be reinforced under railroad tracks and under streets carrying heavy truck traffic. Figure 28 shows typical cross sections of duct lines. Minimum coverage should be 2 feet to top of concrete. All duct lines should drain to manhole with an even grade to avoid water pockets. High point may be either at or between manholes, depending on the contour of finished grade. A sufficient number of spare ducts should be installed to provide for the future installation of a 50 percent increase in the initial number of cables. For grounded neutral systems or systems suitable for future change-over to grounded neutral systems a bare neutral cable should be installed in the bottom of duct line trench and should be extended through each manhole. A careful study should be made of all other underground utilities in order to insure a minimum of conflict between electrical, water, sewer, steam, and gas systems.

1–35 MANHOLES. Manholes should be of applicable type shown on figures 30, 31, or 32 and should be located to provide maximum flexibility for future expansion of the system. Stubs for future extensions should be provided wherever future extensions are considered probable. Manhole hardware should be similar to that shown on figure 29. Sufficient cable racks should be installed to support properly all cables on both sides of the cable splices. Pulling irons should be installed opposite each duct line entrance. Distance between manholes on straight runs should not exceed 500 feet and should not be less than 400 feet except as required for connections and corners and to avoid conflict with streets or other utilities. Distance between manholes on curved sections of duct lines should not exceed 300 feet. A copper or copper-clad steel ground rod should be installed near one corner in each manhole for grounding purposes. No electrical equipment should be installed in manholes, unless extension of cables to nearest transformer vault for sectionalizing or tapping, is impracticable. Metal ladders in manholes will not be required.

1–36 PRIMARY CIRCUITS. The number of primary circuits should be established on the basis that each circuit will carry the kilovolt-ampere load listed in table VIII for the distance indicated, without exceeding a 2 percent voltage drop. The kilovolt-ampere load should be determined by adding the kilovolt-ampere capacity of all transformers to be connected to the circuit, plus planned building expansion, plus 50 percent for normal growth of loads within the buildings served by the circuit. Where building lay-out is suitable, primary circuits should be installed in loops with sectionalizing switches provided at convenient points to insure the supply of electric service to all transformers with any one section of cable cut out. Where building lay-out is not suitable for loop circuits, radial circuits should be installed. Figures 33 and 34 show typical lay-outs of loop and radial primary systems, respectively. Either a loop or two radial feeders should be available for use at all hospital transformer banks, to insure a continuous supply of electricity during inspection and repair operations. Primary cable should be varnished cambric or paper insulated, and should be lead-covered. Cable having a voltage rating of 15,000 volts or more should be shielded. All primary cable should be installed in concrete-incased duct lines.

TABLE VIII.—*Three-phase primary circuit loading*

Kilowatt capacity of wires and maximum distance in feet to load center for two percent voltage drop underground systems

Wire size	2,400-volt				4,160-volt			
	Kilowatt	100 percent pf distance	Kilowatt	80 percent pf distance	Kilowatt	100 percent pf distance	Kilowatt	80 percent pf distance
8	208	1, 020	167	1, 020	360	1, 770	288	1, 770
6	282	1, 160	226	1, 160	490	2, 000	392	2, 000
4	366	1, 350	293	1, 350	634	2, 340	506	2, 340
2	490	1, 500	392	1, 500	850	2, 600	680	2, 600
1	575	1, 620	460	1, 550	995	2, 810	795	2, 700
1/0	652	1, 800	522	1, 660	1, 130	3, 130	905	2, 880
2/0	765	1, 930	613	1, 690	1, 320	3, 360	1, 060	2, 930
3/0	870	2, 170	695	1, 780	1, 500	3, 760	1, 200	3, 080
4/0	985	2, 400	789	1, 850	1, 710	4, 160	1, 370	3, 210
250	1, 130	2, 420	905	1, 820	1, 960	4, 200	1, 570	3, 170
300	1, 240	3, 510	992	1, 860	2, 150	4, 360	1, 720	3, 230
350	1, 350	2, 760	1, 080	1, 920	2, 340	4, 790	1, 870	3, 330
400	1, 500	2, 960	1, 200	1, 920	2, 600	5, 130	2, 080	3, 330
	4,800-volt				7,200-volt			
8	415	2, 040	332	2, 040	623	3, 060	498	3, 060
6	564	2, 310	450	2, 310	846	3, 470	676	3, 470
4	730	2, 700	584	2, 700	1, 090	4, 040	872	4, 040
2	980	3, 000	784	3, 000	1, 470	4, 520	1, 175	4, 500
1	1, 145	3, 240	915	3, 110	1, 720	4, 870	1, 375	4, 670
1/0	1, 300	3, 600	1, 040	3, 320	1, 960	5, 410	1, 570	4, 980
2/0	1, 530	3, 860	1, 222	3, 380	2, 290	5, 810	1, 830	5, 080
3/0	1, 735	4, 340	1, 385	3, 550	2, 600	6, 520	2, 040	5, 320
4/0	1, 970	4, 800	1, 572	3, 700	2, 950	7, 200	2, 360	5, 560
250	2, 260	4, 850	1, 810	3, 650	3, 390	7. 280	2, 710	5, 490
300	2, 480	5, 020	1, 980	3, 720	3, 720	7, 530	2, 980	5, 590
350	2, 700	5, 500	2, 160	3, 840	4, 050	8, 280	3. 240	5, 770
400	3, 000	5, 920	2, 400	3, 840	4, 500	8, 900	3, 600	5, 770
	12,000-volt				13,800-volt			
8	1, 040	5, 090	832	5, 090	1, 193	5, 860	955	5, 860
6	1, 410	5, 770	1, 130	5, 770	1, 622	6, 650	1, 300	6, 650
4	1, 830	6, 740	1, 460	6, 740	2, 100	7, 750	1, 680	7, 750
2	2, 450	7, 520	1, 960	7, 500	2, 820	8, 660	2, 250	8, 630
1	2, 870	8, 110	2, 300	7, 760	3, 290	9, 320	2, 630	8, 940
1/0	3, 260	9, 030	2, 610	8, 300	3, 750	10, 400	3, 000	9, 550
2/0	3, 820	9, 680	3, 060	8, 440	4, 400	11, 100	3, 520	9, 710
3/0	4, 350	10, 850	3, 480	8, 890	5, 000	12, 500	4, 000	10, 220
4/0	4, 930	12, 000	3, 940	9, 250	5, 650	13, 800	4, 520	10, 650
250	5, 650	12, 100	4, 520	9, 110	6, 500	13, 950	5, 200	10, 500
300	6, 210	12, 550	4, 960	9, 300	7, 150	14, 500	5, 710	10, 700
350	6, 750	13, 800	5, 400	9, 600	7, 760	15, 900	6, 200	11, 000
400	7, 500	14, 800	6, 000	9, 600	8, 620	17, 000	6, 900	11, 000

Notes. 1. All voltages are line to line.
2. Wire capacities are for V. C. wires induct.
3. To compute the maximum distance to a load center with 2 percent voltage drop for connected loads not listed above:
   a. Select from the table the desired wire size which will carry the load at the applicable voltage rating.
   b. Multiply the "kilowatts" given in the table by the "distance" given in the table, for the selected wire size.
   c. Divide this product by the actual load in kilowatts.
   d. If the computed distance is not adequate, select a larger wire size and repeat the calculation.

1–37 SECONDARY CIRCUITS. Secondary circuits should be installed in metal or nonmetallic conduit where subject to mechanical damage and under all paved areas. Where mechanical damage is considered unlikely, such as in single or double quarters areas, the cable not under paved areas should be buried directly in a trench. Metal conduit should be painted with heavy asphaltum or tar before being covered. Minimum coverage for both types of installation should be 2 feet. Splices and taps below ground should be kept to a minimum. Where one secondary feeder supplies service to more than one building, the necessary connections should be made in junction boxes mounted on the buildings as shown on figure 35 or in type "D" manholes as shown on figure 36, depending upon the size and number of cables involved. The following maximum wire loading is recommended for plastic or rubber-insulated cable, based on a 55° temperature rise above a 20° centigrade earth temperature, provided the voltage drop given in paragraph 1–38 is not exceeded.

AWG size	*Amperes*	*MCM size*	*Amperes*
8	68	250	357
6	95	300	397
4	120	359	436
2	160	400	476
1	185	500	541
1/0	214	600	605
2/0	243	700	658
3/0	282	750	682
4/0	322	800	707

For ambient earth temperatures other than 20° centigrade, the current carrying capacities listed above should be multiplied by the following factors:

Ambient temperature:	*Multiply by*
10° C	1. 09
30° C	0. 90
40° C	0. 79
50° C	0. 68

1–38 VOLTAGE DROP. Voltage drop should not exceed 2 percent on the primary and secondary circuits respectively. Assuming a drop of approximately 2 percent for transformers, the total voltage drop on the distribution system should not exceed 6 percent.

1–39 TRANSFORMERS. Conventional liquid- or air-cooled transformers should be utilized for installations of less than 100 kilovolt-amperes and for isolated power loads such as water pumps, sewage disposal plants, etc. All other transformers should consist of factory-assembled unit load centers comprising a high voltage section, transformer section, and low voltage section. These units should be located as close to the center of secondary load as practicable, and should preferably be located in buildings. Where the installation of transformer units in buildings is not practicable, such as in quarters areas, the transformer units should be installed on outdoor, fence-inclosed, concrete foundations. Careful consideration should be given to the location of outdoor installations in order that the equipment and inclosure will be as inconspicuous as possible and with the addition of shrubbery, will fit properly into the landscaping lay-out. All necessary switching of primary cables should be accomplished in the high voltage section of transformer unit. Figures 37 and 38 show typical liquid-cooled and air-cooled units, respectively. Transformers should be of the self-cooled type, with rating selected from table I. When the required size is not listed in the table,

the next larger size should be installed. Capacities should be selected so that all transformers will be operating as nearly as practicable to the allowable temperature limits during periods of maximum demand. In general, the capacity of transformers should be equal to approximately 80 percent of the connected load, exclusive of electric ranges. The transformer capacity for each installation, however, will require special study and will vary from a demand factor of 50 percent for large hospital buildings to a demand factor of 100 percent for isolated power installations. Demand factors for electric ranges are approximately as follows:

Number of ranges	*Demand factor percent*	*Number of ranges*	*Demand factor percent*
1	80	16 to 20	28
2	65	21 to 25	26
3	55	26 to 30	24
4	50	31 to 40	22
5	45	41 to 50	20
6 to 10	40	51 to 60	18
11 to 15	32	61 and over	16

1-40 STREET LIGHTING SYSTEM. Street lighting system should be 6.6- or 20-ampere and should employ complete metallic series loops. Transformers and control equipment should be located in load center vaults. Street lighting transformer should be connected to high voltage section of load centers when primary system voltage is 4.8 kilovolts or less and to low voltage section of load centers when primary system voltage is in excess of 4.8 kilovolts. Both automatic and manual control should be provided. Automatic control should be by means of time switch equipped with astronomical dial Manual control should be by means of push button station located on the outside of wall or fence inclosing the load center. Provision should be made to prevent the operation of push button station by unauthorized persons. Street lighting cable should be installed in nonmetallic conduit where subject to mechanical damage and under paved areas. Where mechanical damage is considered unlikely, the cable not under paved areas should be buried directly in a trench. Minimum coverage should be 2 feet. Typical lay-out of underground street lighting system is shown in figure 39.

1-41 STREET LIGHTING UNITS. Street lighting units should consist of concrete standards and glass luminaires similar to those shown on figures 40 and 41. The style of standard and luminaire should be selected to harmonize with the type of architecture of surrounding buildings. Preliminary selection should be submitted to the Office of Engineers for approcal. Lighting intensities should be based on the installation of 4,000-lumen lamps spaced 150 feet apart in administration, hospital, recreation, and industrial areas and 2,500-lumen lamps spaced 150 feet apart in all other areas. This spacing should be measured along the center line of streets designed for two or three lanes of traffic and along each side of streets designed for more than three lanes of traffic and streets having parkways along the center. One street lighting unit should be installed at each intersection designed for two or three lanes of traffic and at least two street lighting units at each intersection designed for more than three lanes of traffic and streets having parkways along the center.

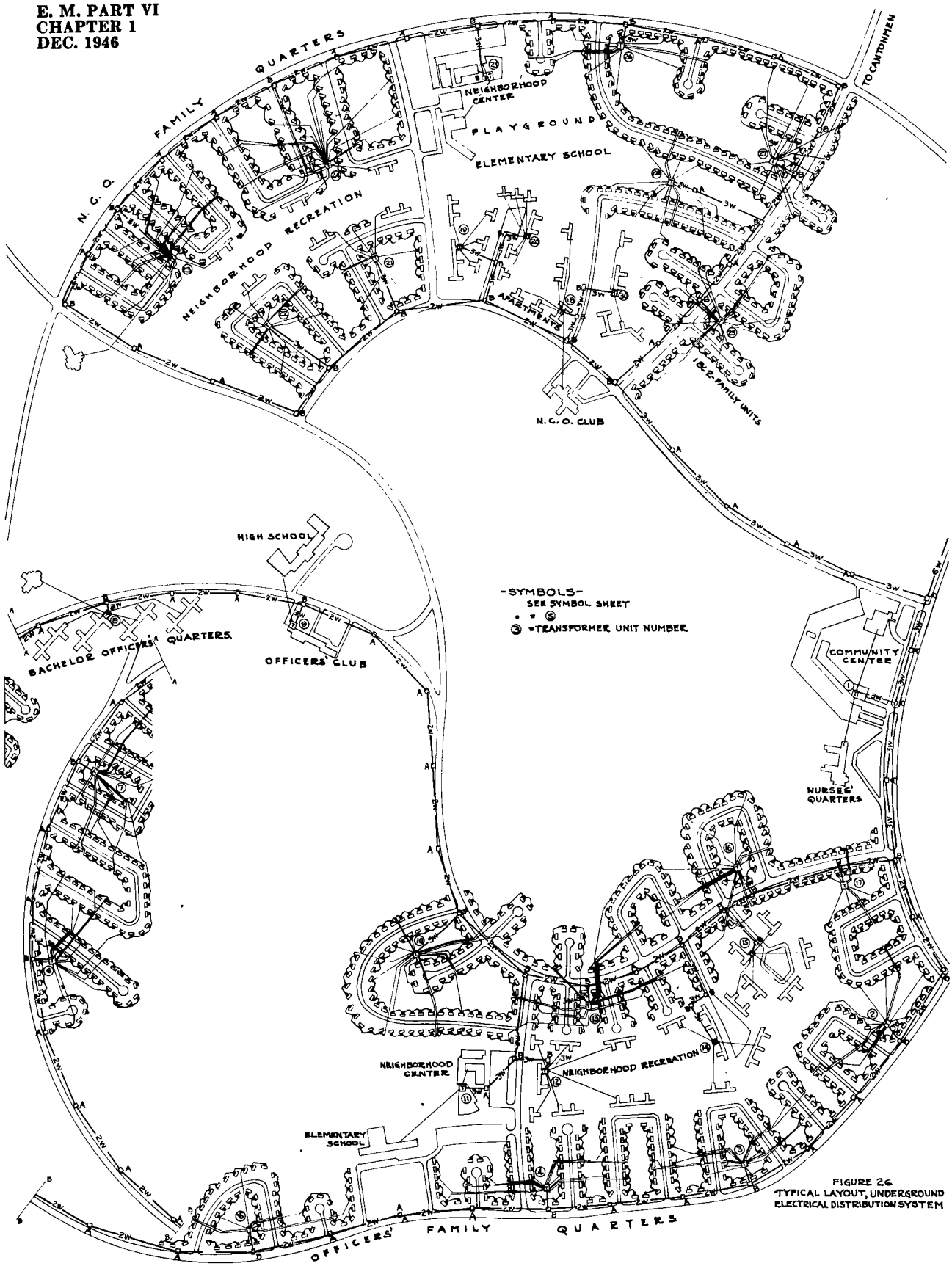
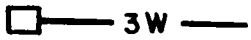


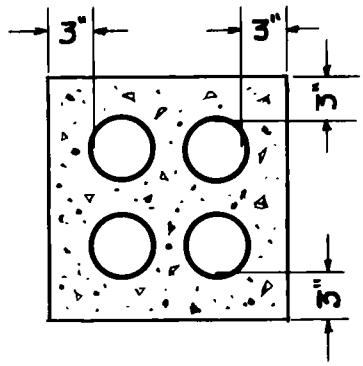
FIGURE 26
TYPICAL LAYOUT, UNDERGROUND
ELECTRICAL DISTRIBUTION SYSTEM

	Manhole - Type as indicated - See details.
	Transformer Vault.
	Street Lighting Standard.
	Cast iron weatherproof secondary junction box mounted 1'-0" above grade (12" x 12" x 6" unless otherwise indicated).
	Duct line - Number of ducts as indicated.
	Series street lighting cable buried in trench - Single conductor - Of size indicated.
	Single-phase secondary cable buried in trench - Number and size of conductors as indicated.
	Three-phase secondary cable buried in trench - Number and size of conductors as indicated.
	Single-phase secondary cable installed in conduit - Number and size of conductors and size of conduit as indicated.
	Three-phase secondary cable installed in conduit - Number and size of conductors and size of conduit as indicated.

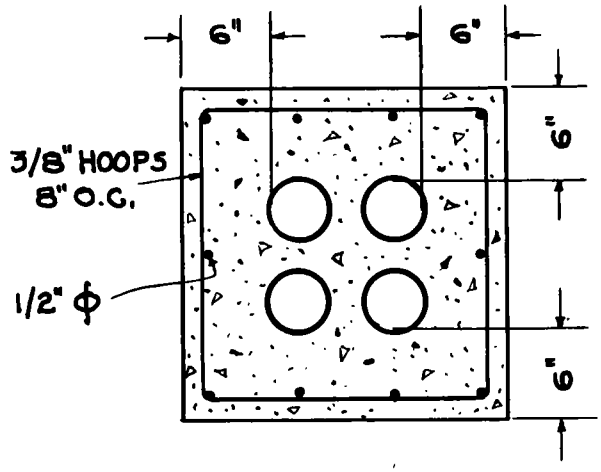
STANDARD SYMBOLS

UNDERGROUND ELECTRICAL DISTRIBUTION CONSTRUCTION

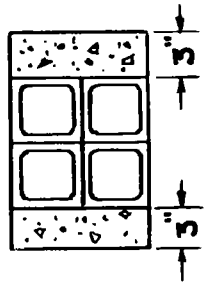
Fig. 27



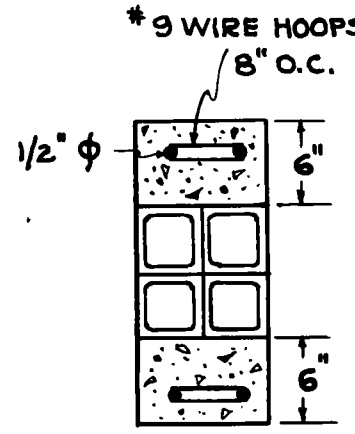
4 WAY DUCT LINE
UNREINFORCED
SINGLE DUCT



4 WAY DUCT LINE
REINFORCED
SINGLE DUCT



4 WAY DUCT LINE
UNREINFORCED
MULTIPLE DUCT



4 WAY DUCT LINE
REINFORCED
MULTIPLE DUCT

FIGURE 28
TYPICAL SECTIONS
OF DUCT LINES

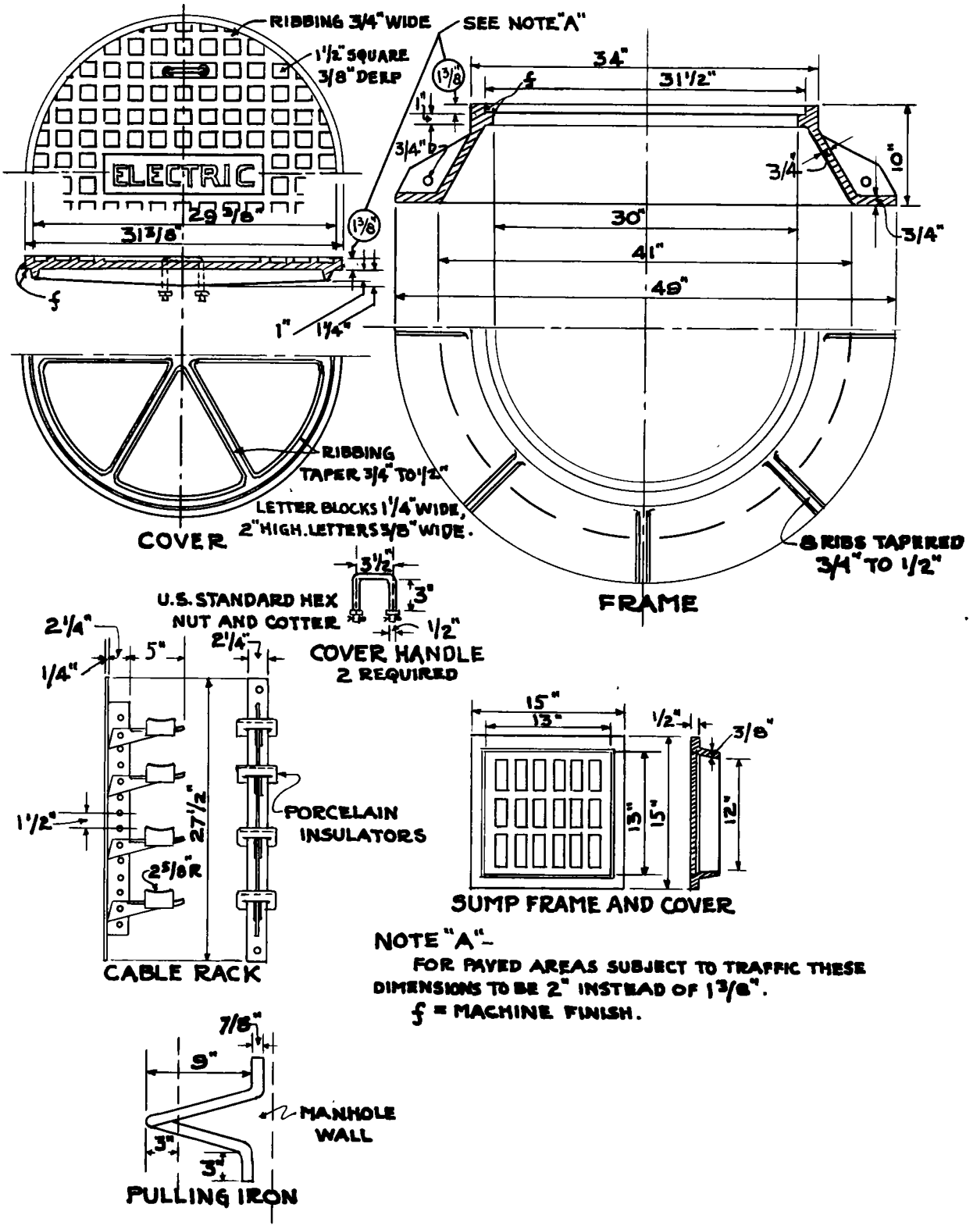


FIGURE 29
MANHOLE HARDWARE

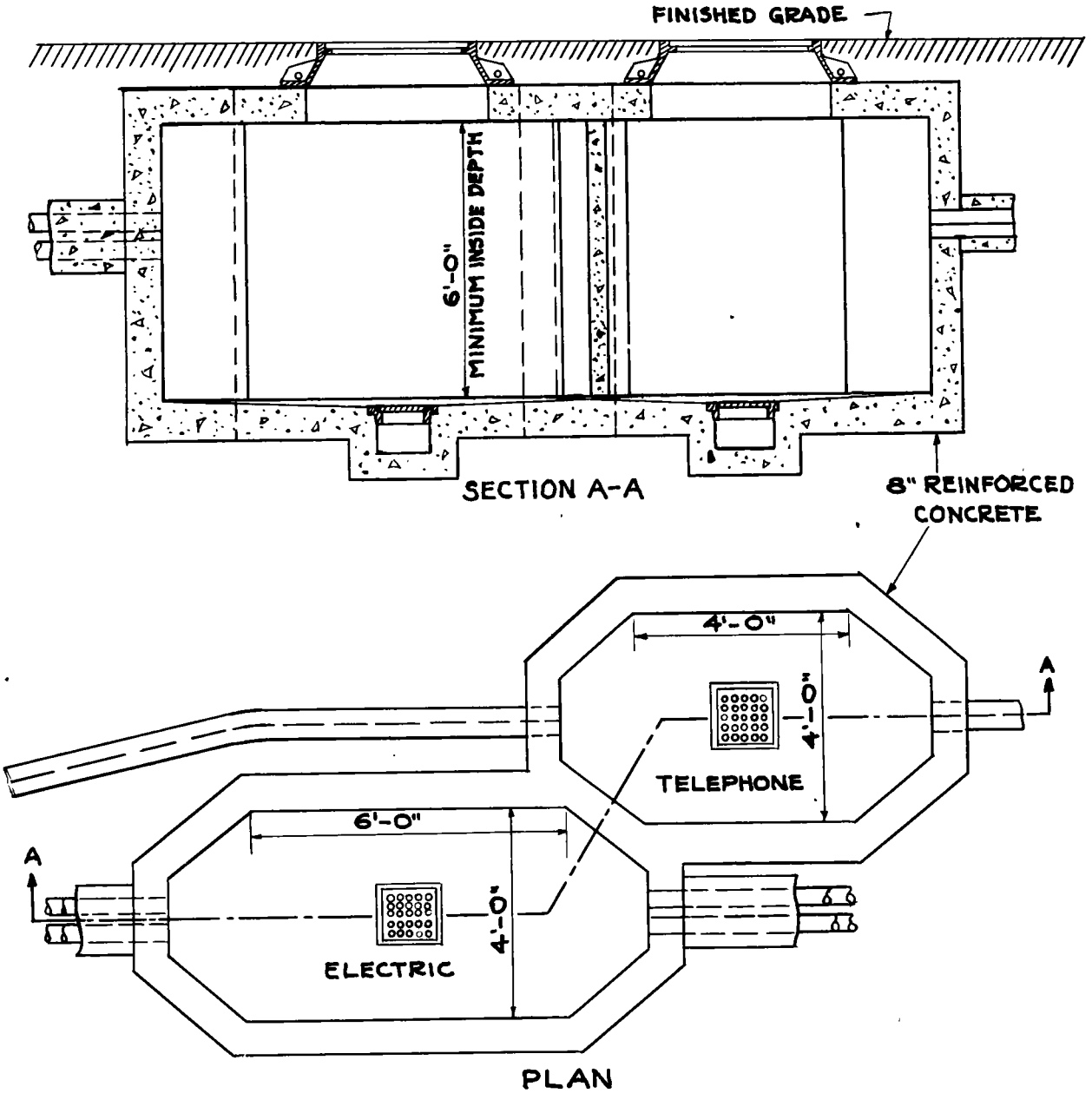


FIGURE 30
TYPE "A" MANHOLE

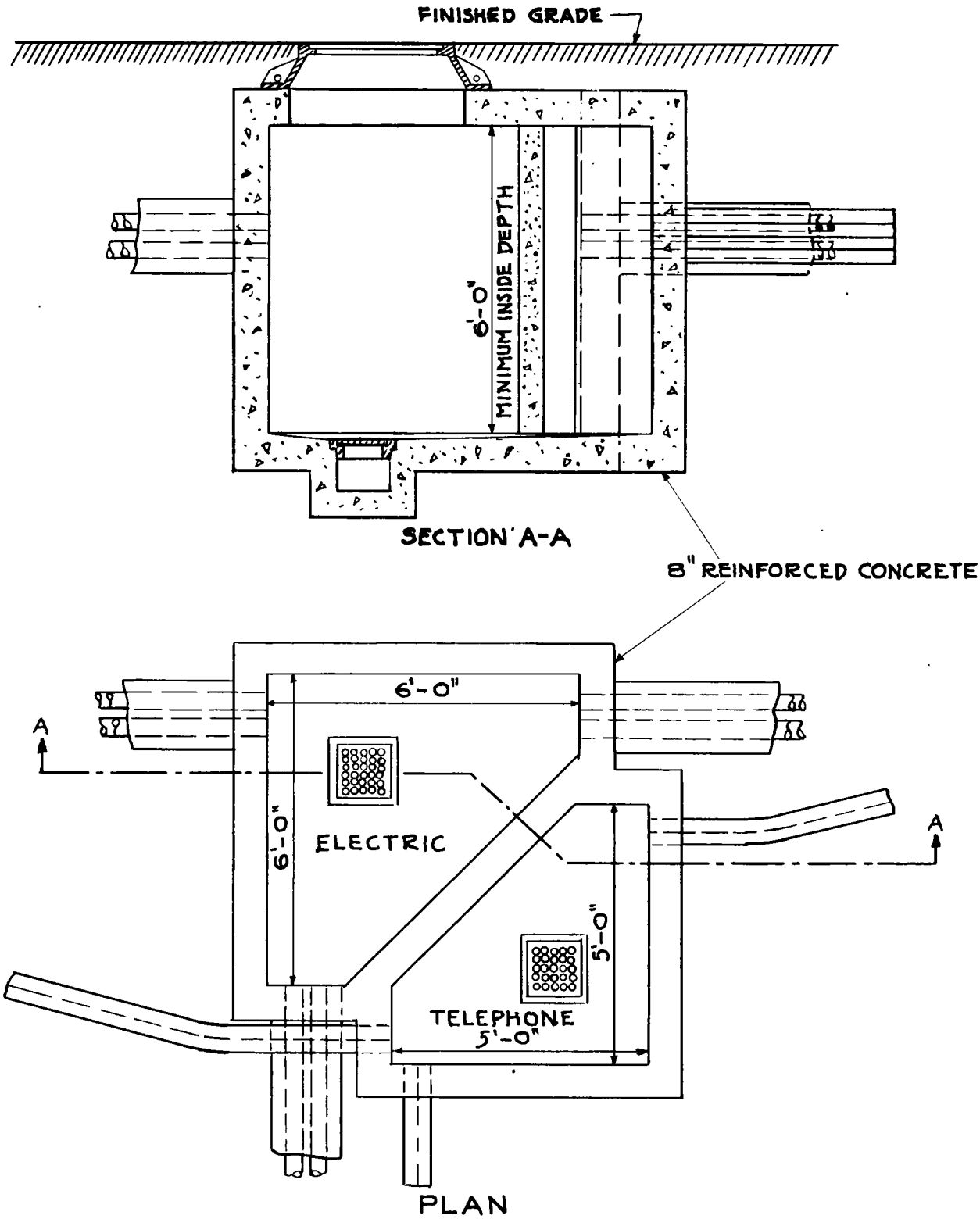


FIGURE 31
TYPE "B" MANHOLE

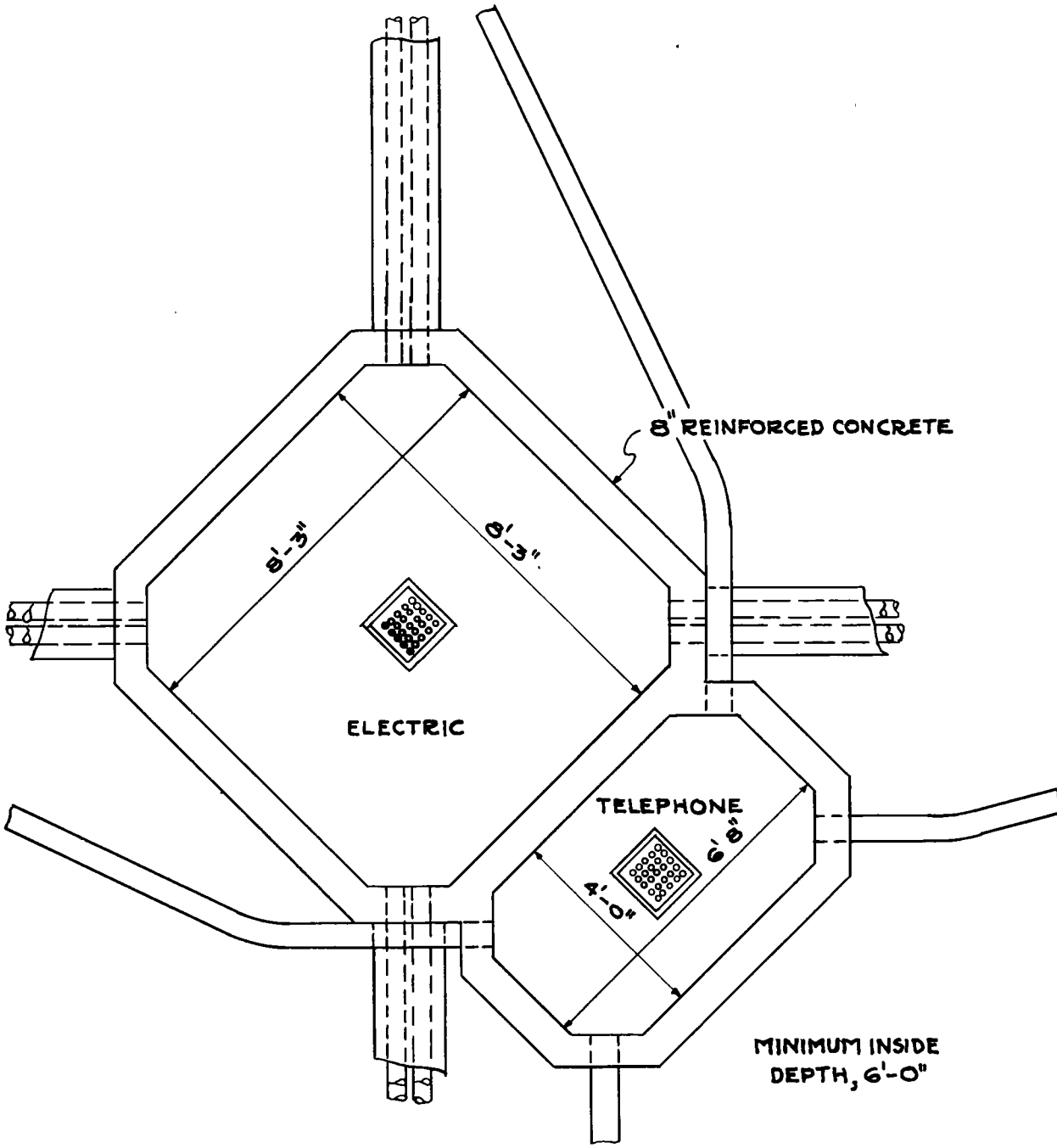


FIGURE 32
TYPE "C" MANHOLE

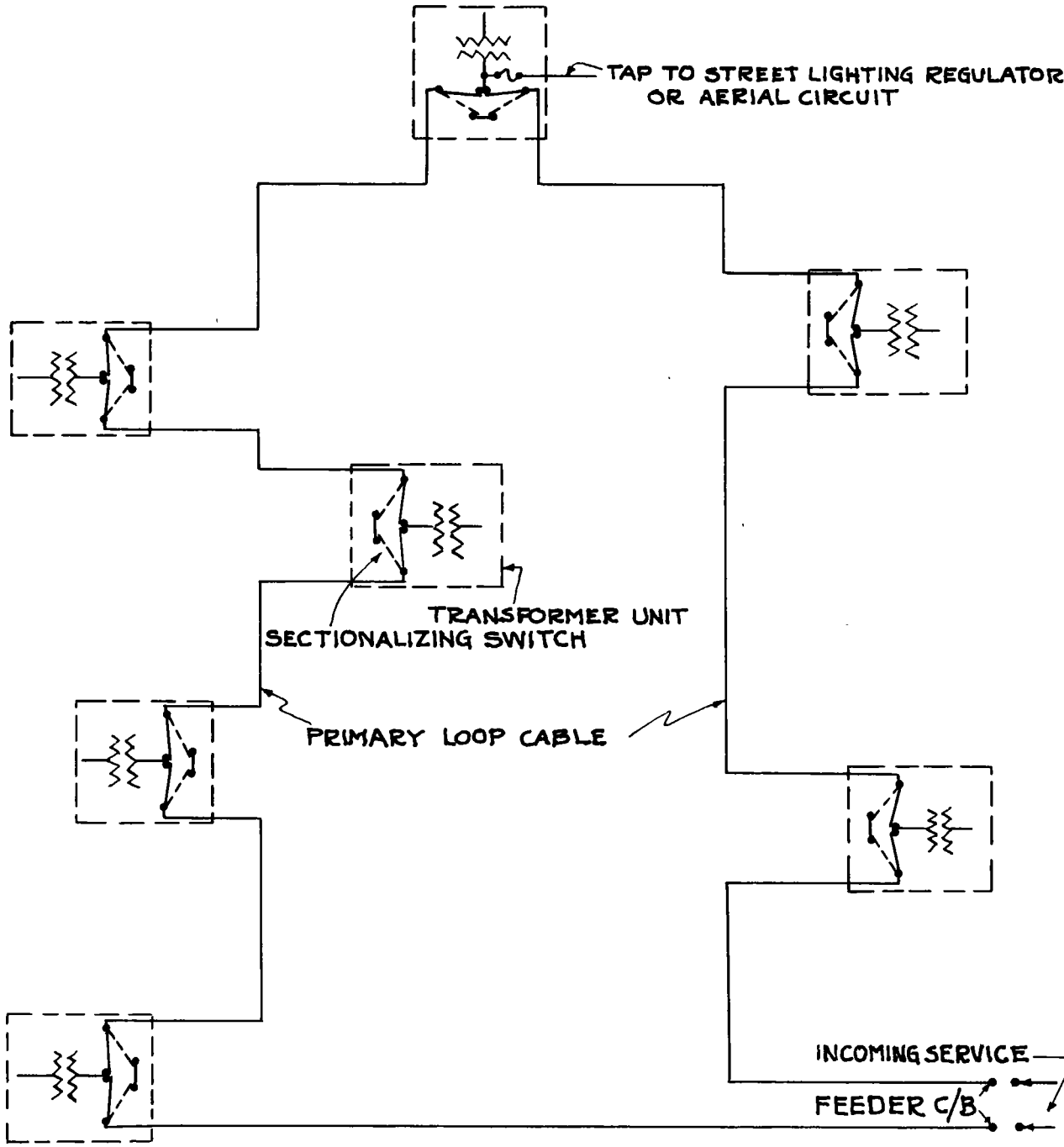


FIGURE 33
TYPICAL UNDERGROUND ELECTRICAL
LOOP SYSTEM

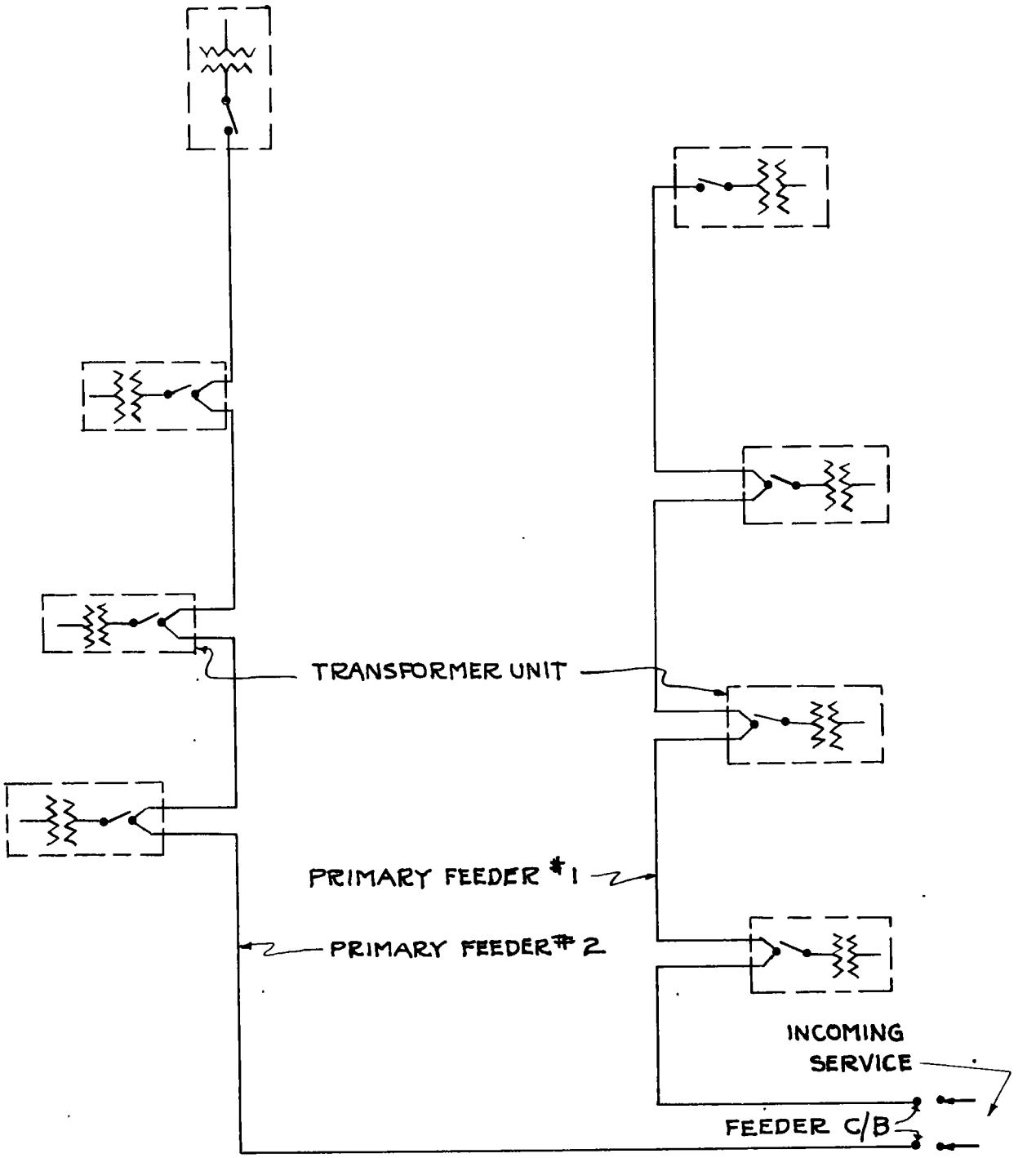
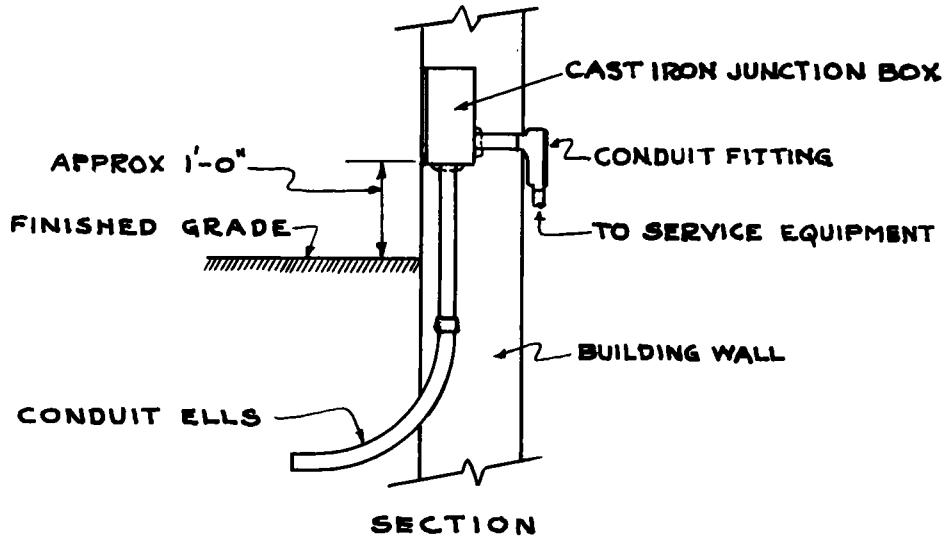


FIGURE 34
TYPICAL UNDERGROUND ELECTRICAL
RADIAL SYSTEM



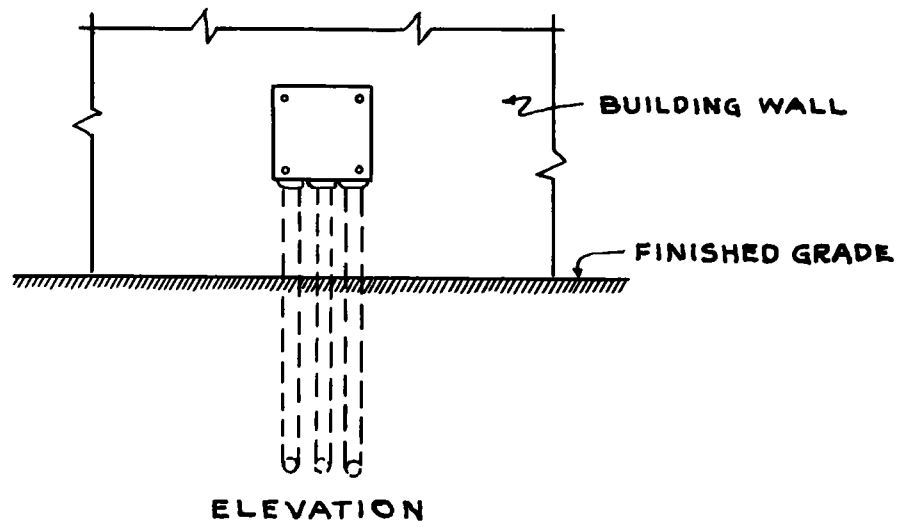


FIGURE 35

SECONDARY JUNCTION BOX

NOTE: JUNCTION BOX SHOULD BE SURFACE-MOUNTED ON EXISTING BUILDINGS

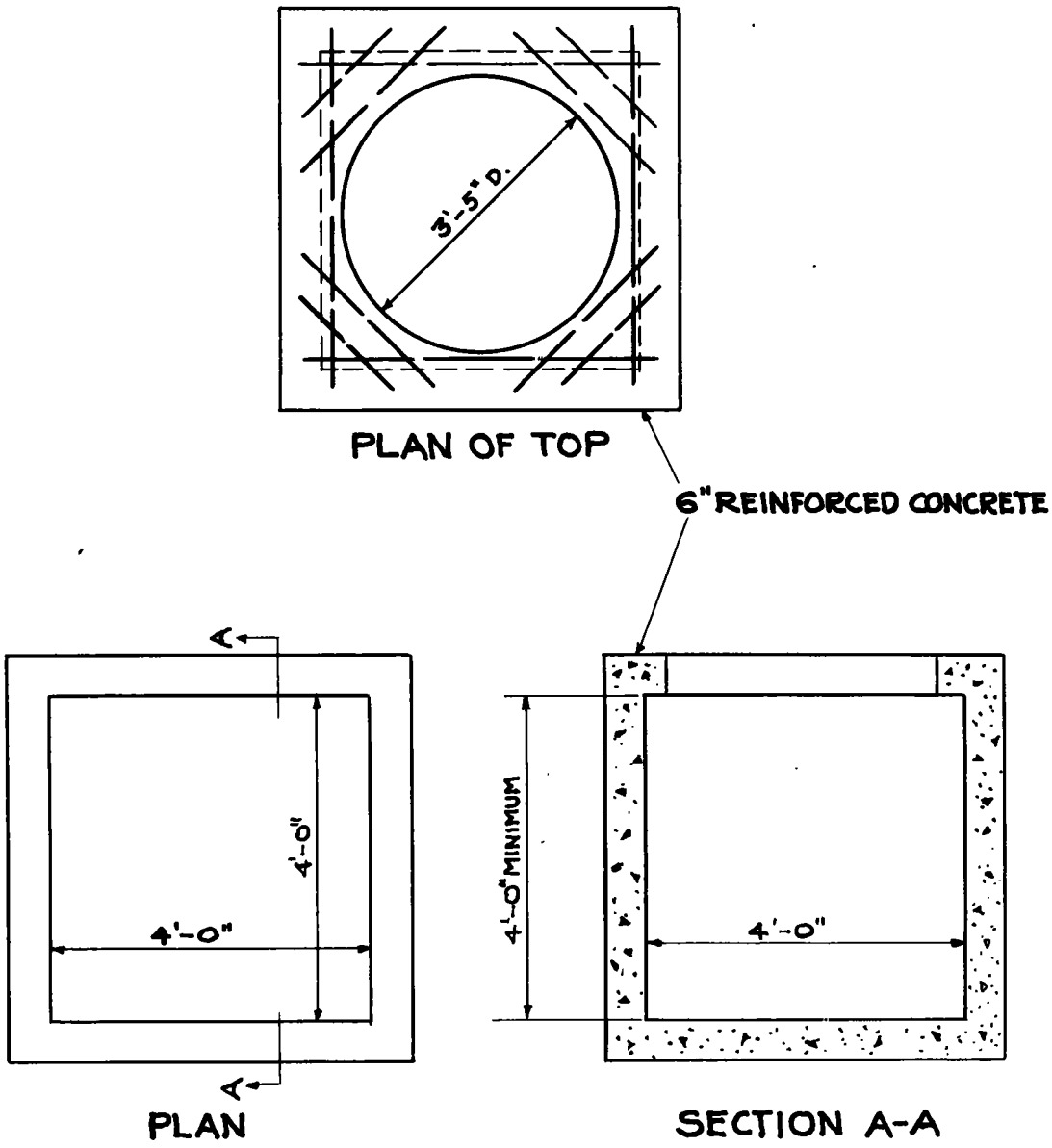


FIGURE 36
TYPE "D" MANHOLE

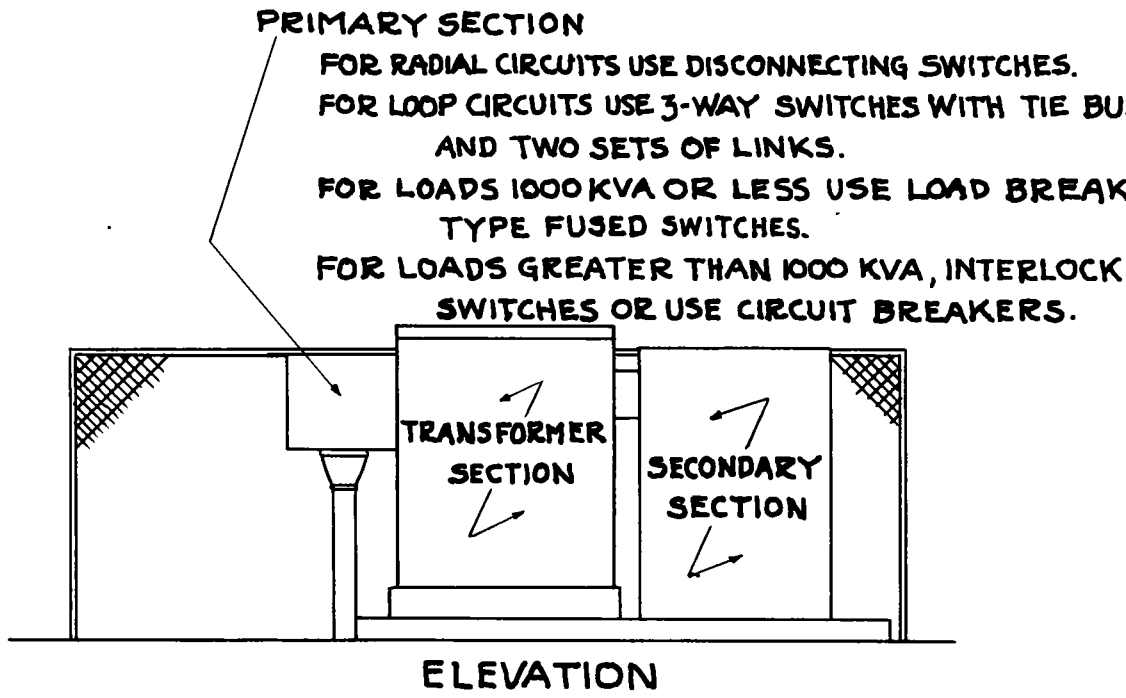


FIGURE 37
LIQUID-COOLED TRANSFORMER LOAD CENTER

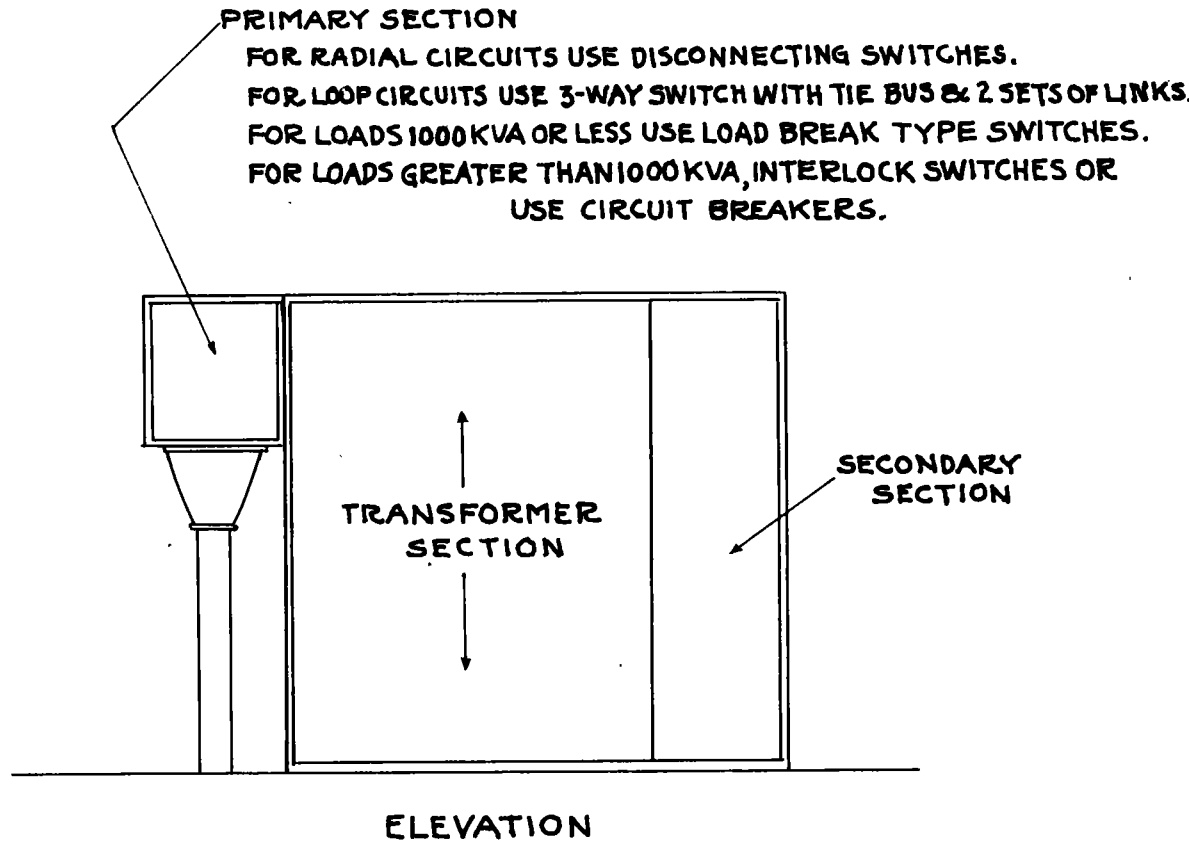


FIGURE 38
AIR-COOLED TRANSFORMER LOAD CENTER

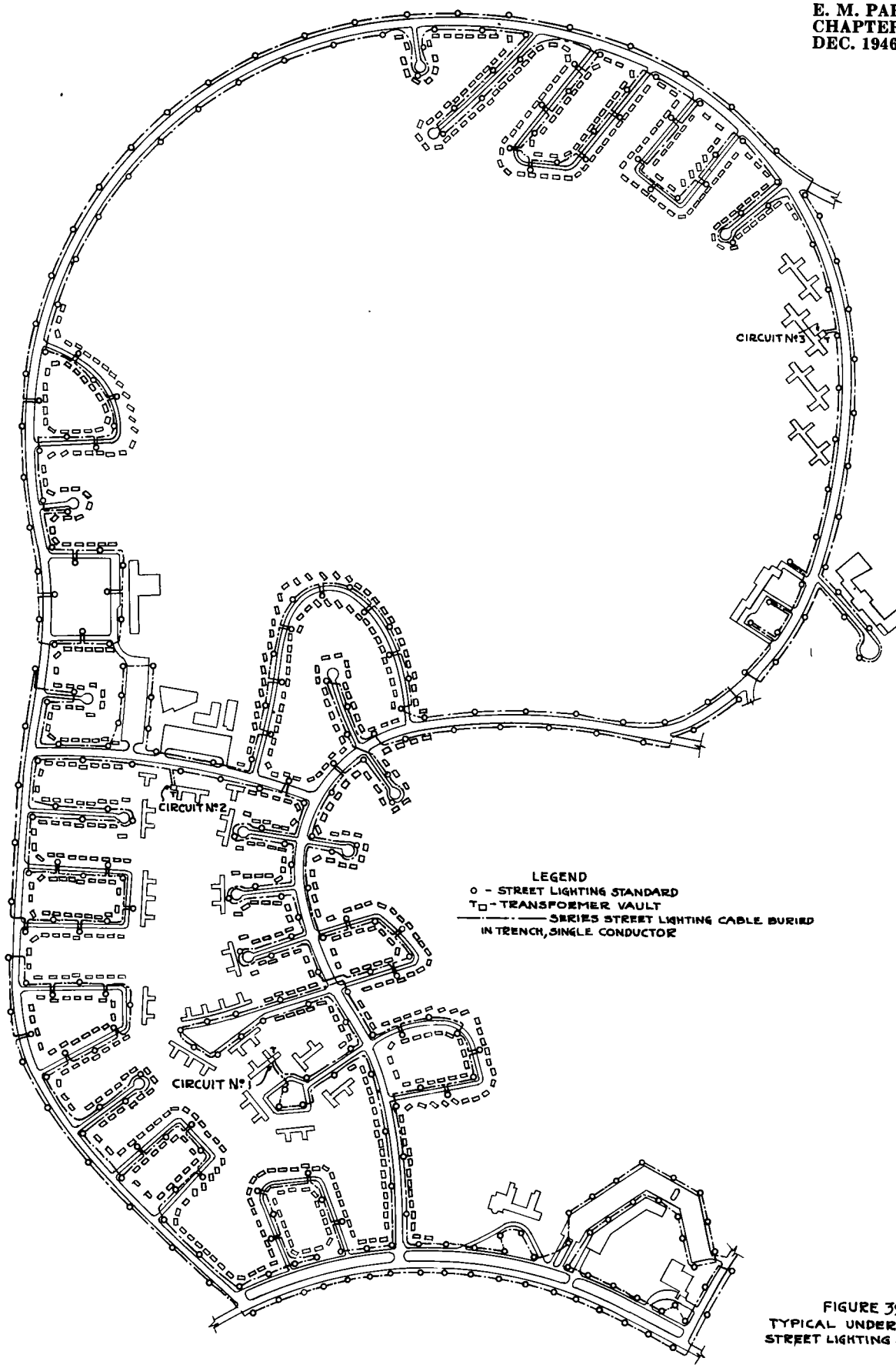


FIGURE 39
TYPICAL UNDERGROUND
STREET LIGHTING SYSTEM

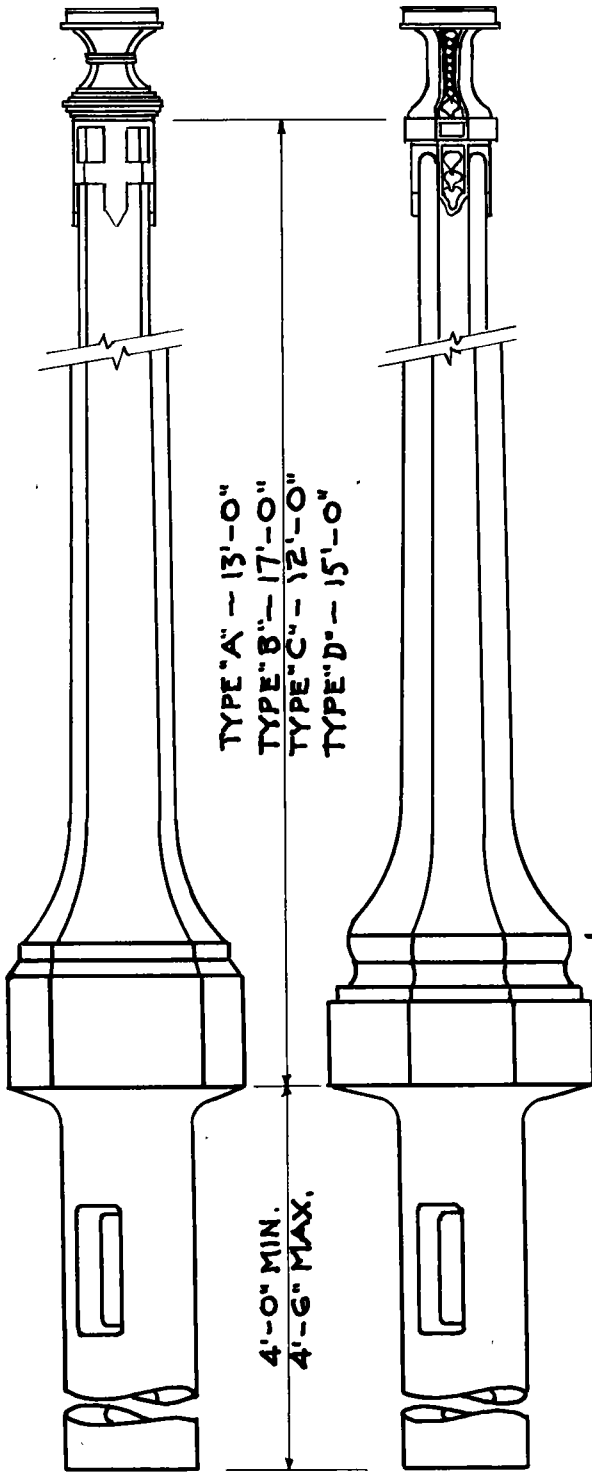


FIGURE 40
TYPES "A" & "B" STREET LIGHTING STANDARD

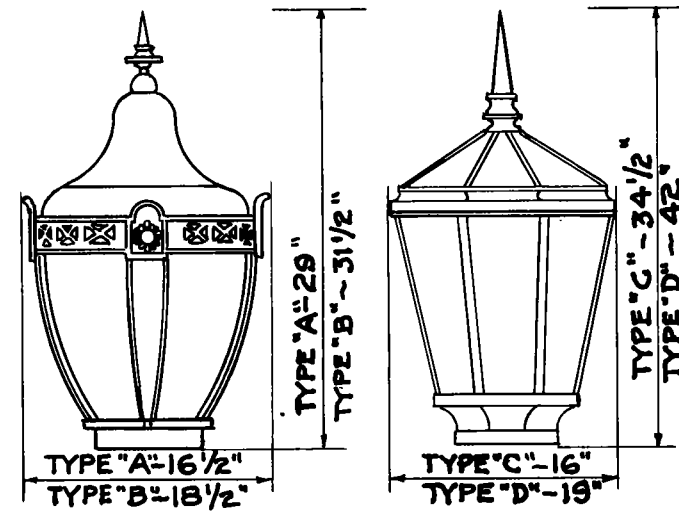


FIGURE 41
TYPES "C" & "D" STREET LIGHTING STANDARD

FLOODLIGHTING OF AREAS

1–42 GENERAL. Floodlights should be provided as required for the purpose of lighting open storage areas, swimming pools, service aprons at hangars, service areas at filling stations, loading platforms, parking areas at theaters, etc.

1–43 WIRING SYSTEMS. Multiple systems should be utilized for floodlighting. Where the number and size of floodlights will permit, the wiring should be connected to the interior system of an adjacent building or to an exterior secondary distribution circuit. Where a substantial quantity of power is involved, a primary distribution system circuit should be extended to the area and transformers provided at suitable locations. Control should be by means of low voltage switches or air circuit breakers. Switches should be of the fused type unless the wiring is connected to a fused circuit. All secondary wiring should be installed in conduit, to facilitate replacement in case of failure. Conduits installed underground should be of the nonmetallic type or, if of the metallic type, should be given a heavy coat of asphalt paint or otherwise protected from direct contact with the earth. Primary wiring should be of the same type as the primary system to which it is connected, unless material handling, flying hazards, or other local conditions indicate that a change in the type of system is necessary for efficient operation or is desirable to effect economy. Aerial and underground primary circuits should comply with the requirements of paragraphs 1–26 and 1–36, respectively.

1–44 LIGHTING UNITS. Lighting units should consist of inclosed adjustable type floodlights mounted on buildings, poles, or towers as required to provide a uniform distribution of light over the areas to be lighted. The floodlights should be mounted on buildings or distribution system poles wherever this method of mounting will serve the desired purpose. Poles provided for floodlights only should be made of concrete, cast iron, or steel. All towers should be made of steel and should be grounded at the base. The location and mounting height of each lighting unit should be carefully selected to avoid objectionable glare. The number, size, location, mounting height, and beam characteristics of floodlights should be such as to provide a uniform distribution of light over the entire area, with a minimum of waste light against buildings and in unused areas. Lighting installations complying with the following criteria will give satisfactory results for most applications. Departures therefrom shall be approved by the Office of the Chief of Engineers prior to award of contract.

a. Open storage areas. Open storage areas subject to night operation should be provided with approximately ½- to 1-foot candle of light at the working level.

b. Paved areas around swimming pools. Lighting level should approximate 3- to 5-foot candles for the pool and adjacent paved area. Floodlights should be spaced approximately 100 to 120 feet apart around the perimeter of paving.

c. Service aprons at hangars. Floodlight banks, each consisting of three 1,500-watt floodlights, spaced approximately 150 feet apart should be installed along the top of exterior wall of hangar and on steel towers located approximately 75 feet behind the back edge of apron where hangars do not occur.

d. Service areas at filling stations. Service areas at filling stations should be provided with approximately 7- to 10-foot candles of light on that portion of the area which is actually used for servicing cars at night.

e. Loading platforms. Loading platforms subject to night operations should be provided with approximately 5-foot candles of light at the working level.

f. Parking areas at theaters, etc. Parking areas at theaters and other similar buildings regularly used for night activities should be provided with 200-watt floodlights spaced approximately 100 feet apart adjacent to the parking area.

PROTECTIVE LIGHTING SYSTEMS

1–45 GENERAL. Protective lighting systems should be installed where the lighting of boundaries or areas for the purpose of deterring trespassers and making them visible to guards is established as necessary by the using service. Such systems should consist essentially of a series of bowl-refractor, luminaires of fresnel-lens luminaires on poles or buildings located in lines parallel with the boundary lines. Uniform spacing of units, were possible, should be maintained throughout the installation. Where required, supplementary lighting units should be used to light entrances and all vulnerable boundary points. Patrol roads and points of observation should be kept in darkness as much as possible.

a. At locations where lighting is used to discourage the entry of intruders, protective lighting systems should be located 5 to 15 feet from fence within the bounded area, between the patrol road and the boundary, arranged to direct the light toward the boundary or area from which the intruder would approach.

b. At locations where lighting is used to discourage the escape of prisoners, protective lighting systems should be located 10 to 20 feet from fence beyond the compound area boundary, between the patrol road and this boundary, and arranged to direct the light toward the compound area. Units should be arranged so that glare will not interfere with vision from the guard towers. Each guard tower should be equipped with at least one 12-volt searchlight to be used during emergency periods. At critical points, such as corner guard towers, an emergency storage battery and automatic throwover switch should be provided to insure an uninterrupted supply of electricity to the searchlight in the event of the failure of normal supply during an emergency. Batteries will not be required at intermediate guard towers, provided the distance between the corner towers does not exceed 2,000 feet and the vision of the guards from these points is not obstructed.

1–46 WIRING SYSTEMS. Wiring systems should be selected in accordance with the requirements of paragraph 1–24 or 1–33, as applicable.

1–47 PROTECTIVE LIGHTING UNITS. The lighting units commonly used for protective lighting are bowl refractor luminaires, fresnel-lens luminaires, flood lights, and searchlights. Bowl refractor and fresnel lens luminaires should be equipped with 4,000-lumen series lamps or 200-watt multiple lamps and should be spaced approximately 150 feet apart. Characteristics of the luminaires should be such that a uniform distribution of light is obtained along the boundary line. Mounting height should be 20 to 30 feet. Luminaires should be located to avoid objectional glare along roadways and railroads Floodlights should be used only for supplementary lighting where a higher intensity of illumination than that provided by luminaires may be required, or for protected area lighting. Searchlights should be used as a form of intermittent supplementary lighting where a manually-controlled beam is required, such as on guard towers. Spacing of searchlights should be governed by the coverage desired. A 1,000,000-beam candlepower searchlight has an effective range of approximately 1,000 feet.

DESIGN ANALYSES

1–48 GENERAL REQUIREMENT. Design analyses required by Orders and Regulations, Corps of Engineers, chapter VII, paragraph 740.09 will be prepared to accompany all plans and specifications for electric power supply, generating plants, electrical distribution systems, street lighting systems, floodlighting systems, and protective lighting systems.

1–49 SCOPE. Design analyses should include information relative to the adequacy, dependability, number, characteristics, and regulation of incoming supply lines, power company's recommendation relative to the interrupting capacity of main fuses or circuit breakers, total connected load, and estimated maximum demand. Design criteria should include computations for transformer capacities, voltage drop on primary and secondary feeders, size of emergency generator units and lighting intensities and fixture types for street, area, and protective lighting systems, as applicable.

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ELECTRICAL DESIGN

INTERIOR ELECTRICAL SYSTEM



WAR DEPARTMENT
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

Chapter 2

INTERIOR ELECTRICAL SYSTEMS

2–01 GENERAL.
2–02 STANDARDS.
2–03 INSTALLATIONS.
2–04 SERVICE CONNECTIONS.
2–05 MAIN SERVICE EQUIPMENT.
2–06 METERS.
2–07 WIRING SYSTEMS.
2–08 POWER AND CONVENIENCE OUTLETS.
2–09 UNDERFLOOR DUCT SYSTEMS.
2–10 PNEUMATIC TUBE SYSTEMS.
2–11 NURSES' SIGNALLING SYSTEM.
2–12 DOCTORS' PAGING SYSTEM.
2–13 CLOCK SYSTEM.
2–14 INTERCOMMUNICATION SYSTEMS.
2–15 RADIO OUTLETS AND SYSTEMS.
2–16 TELEPHONE SYSTEM.
2–17 OBSTRUCTION LIGHTING.
2–18 DRY CLOSET OUTLETS.
2–19 LIGHTING.
2–20 DESIGN ANALYSES.

739604—47——1

Part VI

ELECTRICAL DESIGN

Chapter 2

INTERIOR ELECTRICAL SYSTEMS

2–01 GENERAL. The following instructions and information are intended to serve as a guide in determining the major requirements for interior electrical systems. Where special conditions and problems are encountered which are not covered specifically by these instructions, good engineering practice should be followed.

2–02. STANDARDS. Wiring system should be installed in accordance with the requirements of the current regulations of the National Electrical Code and National Electrical Safety Code. Equipment should conform to the requirements of the applicable Federal, Joint Army-Navy or Army Specification or Standards of the American Institute of Electrical Engineers, American Standards Association, National Electrical Manufacturers Association, or Underwriters Laboratories, Inc. For uniformity, symbols shown on figure 1 should be used to indicate interior wiring systems on drawings.

2–03 INSTALLATION. The criteria contained in this chapter pertain to the design of interior electrical systems. For details covering materials, equipment, and installation, reference should be made to the following specifications:

CE 303.1 Interior Electrical Work
CE 303.2 Pneumatic Tube System
CE 303.10 Nurses Signalling System
CE 303.11 Doctors Paging System

STANDARD ELECTRICAL SYMBOLS

Sheet No. 1

Ceiling	Wall	
○	—○	Outlet.
(B)	—(B)	Blanked Outlet.
(C)	—(C)	Clock Outlet.
(D)		Drop Cord.
(F)	—(F)	Fan Outlet.
(H)	—(H)	Unit Heater or Cooler.
(J)	—(J)	Junction Box.
(L)	—(L)	Lamp Holder.
$(L)_{PS}$	—$(L)_{PS}$	Lamp Holder with Pull Switch.
(S)	—(S)	Pull Switch.
	—(T)	Thermostat.
[○]	—[○]	Outlet for Fluorescent Fixture.
(X)	—(X)	Exit Light Outlet.
◍	—◍	Night Light.
(G)		Generator.
(M)		Motor.
⊖		Duplex Convenience Outlet.
$⊖_{1,3}$		Convenience outlet other than Duplex. 1=Single, 3=Triplex.
$⊖_{WP}$		Weatherproof Convenience Outlet.
$⊖_{S}$		Switch and Convenience Outlet.
⊖(R)		Radio and Convenience Outlet.
$⊖_{R}$		Range Outlet.
⊘		20 A. 250 V. Receptacle and Plug, Polarized.
◑		30 A. 250 V. Receptacle and Plug, Polarized.
◭		Special Purpose Outlet.
⊙		Floor Outlet.
▬		Lighting Panel.
▨		Power Panel.
⊠		Motor Controller.
⊐		Disconnect Switch.
■		Service Switch or Breaker.

S	Single Pole Switch.
S_2	Double Pole Switch.
S_3	Three Way Switch.
S_4	Four Way Switch.
S_D	Automatic Door Switch.
S_E	Electrolier Switch.
S_K	Key Operated Switch.
S_P	Switch and Pilot Lamp.
S_{MC}	Momentary Contact Switch.
S_{RC}	Remote Control Switch.
S_{WP}	Weatherproof Switch.
———	Branch Circuit: Concealed in Ceiling or Wall.
— — —	Branch Circuit; Concealed in Floor.
-------	Branch Circuit; Exposed.
—.—.—	Auxiliary System Circuit.
▬▬▬	Feeders. Use Heavy Lines.
——►	Home Run to Panel Board. Number of arrows indicates number of circuits.

Note: Any circuit without further designation indicates a two-wire circuit. A greater number of wires is indicated as follows:

—//— (3 wires)
—//// (4 wires), etc.

Underfloor Duct and Junction Box. Triple System. Single and double Systems are indicated by one and two lines respectively.

FIGURE 1.

STANDARD ELECTRICAL SYMBOLS

Sheet No. 2



Push Button.
Buzzer.
Bell.
Fire Alarm Bell.
Fire Alarm Station.
Fire Alarm Central Station.
Automatic Fire Alarm Device.
Watchman's Station.
Watchman's Central Station.
Horn.
Radio Outlet.
Nurses' Calling Station.
Transformer, Signal.
Annunicator.
Telephone Outlet.
Intercommunication Outlet.
Loud Speaker Outlet.
Telephone or Signal Cabinet.
Single Nurses' Call Dome Light.
Nurses' Call Dome Light—Number indicates number of lights.
Single Combination Nurses' Call Station and Radio Outlet.
Double Combination Nurses' Call Station and Radio Outlet.
Control Station Doctors' Paging System.
Doctors' Paging Station—Ceiling.
Doctors' Paging Station—Wall.
Master Clock.
Single Face Clock—Ceiling.
Single Face Clock—Wall.
Double Face Clock—Ceiling.
Double Face Clock—Wall.

Heights to center wall outlets unless otherwise specified or noted.

Bracket Light	5′–8″
Bracket Light over Mirror	6′–3″
Switch	4′–0″
Thermostat	5′–0″
Receptacles	1′–0″
Radio	1′–0″
Telephone	1′–0″
Nurses' Calling Station	4′–6″
Combination Nurses' Call and Radio	4′–6″
Watchman's Station	4′–6″

FIGURE 1.

2–04 SERVICE CONNECTIONS. Connections between main service equipment and exterior electrical system should be as short and direct as practicable. The design of interior and exterior electrical systems should be coordinated to avoid the installation of excessive lengths of secondary service conductors. All permanent buildings should have provision for connection to an underground distribution system, even though the initial service connections may be aerial. Provision for underground service connections should consist of an empty conduit or conduits extending from the service equipment to a point approximately 2 feet outside of the buildings and 2 feet below finished grade. Buildings having small electrical loads, such as single or double officers' quarters, which are likely to be served by a secondary distribution cable common to several buildings, should be provided with junction boxes similar to that shown on figure 35, chapter 1. Buildings with large electrical loads, such as apartment houses, theaters, hangars, and hospitals should be provided with transformer vaults. Groups of buildings, other than single and double officers' quarters, should be connected to a centrally located transformer unit installed in one of the buildings. Transformer unit should be so located that the voltage drop in the secondary feeders to the buildings will not exceed 2 percent and the size of secondary feeder will not be excessive. Figure 26, chapter 1, shows typical service connections to buildings and typical method of grouping several buildings on one transformer unit.

2–05. MAIN SERVICE EQUIPMENT. Main service equipment should be located to facilitate inspection and maintenance. Where high voltage service is used, transformer vaults should be provided for the installation of transformers and switchgear. The vaults should be located to permit the entrance and removal of equipment without passing through any other room or up or down any interior stairways. Except for small isolated installations, the inside dimensions of transformer vaults should be not less than 12 feet wide and 15 feet long, with at least an 8-foot clear headroom. These dimensions should be increased as required to insure adequate circulation of air on all sides of the equipment and to provide sufficient space for operation and maintenance activities. Vaults should be ventilated in accordance with the requirements of the National Electrical Code. Wherever practicable, an exterior wall of the building should be used for one wall of the vault with ventilators through this wall to the outside air and access door direct to the exterior of the building. All transformers in buildings should be non-inflammable liquid- or air-cooled. Conventional transformers should be utilized for installations of less than 100 kva and for isolated power loads such as water pumping sewage disposal plants, etc. All other transformers should consist of factory-assembled unit load centers comprising a high voltage section, transformer section and low voltage section. These units should be located as close to the center of secondary load as practicable. All necessary switching of primary cables should be accomplished in the high voltage section of the transformer unit. Transformers should be of applicable self-cooled rating selected from table I, chapter 1. When required sizes are not listed in the table, the next larger size should be installed. Capacities should be selected so that all transformers will be operating as nearly as practicable to the allowable temperature limits during periods of maximum demand. In general, the capacity of transformers should be equal to approximately 80 percent of the connected load, exclusive of electric ranges. The transformer capacity for each installation, however, will require special study and will vary from a demand factor of 50 percent for large hospital buildings to a demand factor of 100 percent for isolated power installations. Demand factors for electric ranges are approximately as follows:

Number of ranges:	*Demand factor percent*
1	80
2	65
3	55
4	50
5	45
6 to 10	40
10 to 15	32

Number of ranges—Continued	*Demand factor percent*
16 to 20	28
21 to 25	26
26 to 30	24
31 to 40	22
41 to 50	20
51 to 60	18
61 and over	16

The low voltage section should be equipped with air circuit breakers of applicable number and sizes for the secondary feeders. Main circuit breaker should have sufficient capacity to interrupt the transformer short circuit current. If no main circuit breaker is provided, each branch feeder breaker should have sufficient capacity to interrupt the transformer short circuit current.

Exit light circuits, in auditoriums, theaters, and other similar buildings used for large groups of people, should be connected ahead of the main circuit breaker. An automatic preferred-emergency transfer switch should be provided in all general hospitals to pick up essential load on an engine-generator set. Capacity of engine-generator should comply with the requirements of paragraph 1–13, chapter 1.

2–06 METERS. Wherever practicable, one set of master meters will be used for the measurement of all power purchased from the utility company. Meters will not be installed to measure electric energy consumed by individual buildings, pumping stations, and machinery, with the exception of exchanges, exchange enterprises, and theaters. One watt-hour meter should be installed in each exchange to measure the electric service consumed by cooking devices, mechanical equipment, refrigeration, and electrical applicances. A separate watt-hour meter should be installed to measure the electric service consumed by the power devices used in each exchange enterprise, such as restaurants, tailor shops, barber shops, laundry facilities, shoe repair shops, or any other activity operated by civilians for private gain on a concession basis. A watt-hour meter should also be installed in each theater to measure the electric energy consumed by the motion picture equipment.

2–07 WIRING SYSTEMS. Wiring systems generally utilize 115–120 volt branch circuits for lighting and convenience outlets. Circuits of other voltages and characteristics may be required for heavy duty equipment.

a. Characteristics. The selection of the electrical characteristics of the wiring system depends upon the electrical distribution system circuits available and the characteristics required by any heavy duty equipment that will be installed. For small loads consisting essentially of lighting and receptacle circuits and motors of approximately 1 horsepower or less, a 115–230 volt single-phase service may be provided. For connected loads of approximately 100 kva or larger or where three-phase power is required for the operation of large motors or other pieces of equipment a wye connected 120–208 volt, three-phase, four-wire service should be provided. For loads consisting essentially of motors and where the lighting load is but a small portion of the total a delta-connected 220 volt or 440 volt three-phase service should be provided, the lighting load being served by one transformer with a neutral tap or by a separate transformer. Where motors are of relatively large sizes, approximately 75 horsepower or more, consideration should be given to the use of a 2,400-volt service to simplify the control equipment and effect a more economical installation by use of smaller conductors and conduits.

b. Voltage drop. The combined voltage drop on feeders and branch circuits for wiring systems within buildings should not exceed approximately 3 percent. Approximately 1 percent drop may be apportioned to the feeders and 2 percent apportioned to the branch circuits. However, when a transformer installation is made within or immediately adjacent to the building, the voltage drop may be permitted to exceed the above value but should not be in excess of 5 percent for the complete secondary circuit. When equipment is installed which requires a very close voltage control for successful operation, consideration should be given to the use of constant voltage transformers located immediately adjacent to the equipment.

c. Conductors. Conductors for branch circuits should be, in general, not less than number 12 gage and should be provided with 20-ampere overload protection. Larger conductors will be used for branch circuits where loads exceed that permitted on 20-ampere circuits or where required to maintain the voltage drop within the above described limits. Conductors for feeders will be designed in accordance with the connected load to which a suitable demand factor is applied and allowance is made for possible future increase in load. The voltage drop on medium length and long feeders should be checked to insure that the above described limits are not greatly exceeded. The demand factor for any particular feeder should be determined by the type of load served and the probability of simultaneous operation of its various components.

d. Raceways. Except as noted otherwise herein, all raceways should consist of zinc-coated rigid threaded conduit not less than ½ inch inside diameter. For exposed conduit systems, subject to normal hazards and usage, either black enameled conduit or metallic tubing may be utilized as an economy measure. Conduit buried in or in contact with earth should be heavily coated with tar or pitch on the outer surface and allowed to dry for at least 24 hours before being covered. All tool marks or scars should be coated before covering. This requirement refers specifically to underground services, from the pole to the building. Exposed raceways, containing conductors operating at voltages in excess of 600 volts, shall be zinc-coated threaded conduit, each length having painted two red bands, each 1-inch wide, separated 1-inch, and the pair located about 12 inches from each coupling. In addition, where the conductors operate at a voltage of 6,600 or more, the conduit should be visibly stenciled with the operating voltage at the midpoint of each length or fraction thereof.

(1) For buildings of a temporary nature; small buildings related to secondary activities; family quarters, either individual, duplex, or 4-family; all of which are to be essentially of wood frame construction, the wiring system should be with metallic armored cable. Buildings in border line cases to the above or those wherein this type of wiring is obviously suitable, whether within or without the continental limits of the United States, should utilize metallic armored cable as the wiring system upon the specific authorization of the Division Engineer.

(2) For buildings of categories listed in (1) above, non-metallic sheathed cable may be utilized in lieu of the metallic armored cable, subject to specific authorization by the Division Engineer, in all locations except for installations below grade, as in basements, metallic armored cable only should be utilized.

(3) For buildings of categories listed in (1) above, wherein either armored metallic cable or non-metallic sheathed cable is used as the wiring system, branch circuits should each be limited to 900 watts and No. 14 wire utilized in lieu of No. 12 as covered in *c* above. Where No. 14 wire is so utilized, the branch protective device in all cases should be a 15-ampere circuit breaker.

2–08 POWER AND CONVENIENCE OUTLETS. All areas should be provided with a sufficient number of receptacles of proper characteristics to serve all requirements adequately. Convenience outlets should generally be of the duplex type. In normally wet or damp locations where portable tools are regularly used, such as in shops or hangars with concrete floors on grade, receptacles should be of the polarized type with one pole effectively grounded. Portable tools should

be provided with cords having separate conductor for grounding frame of tool through separate pole of cap to the conduit system. Duplex convenience outlets in these areas should be of the 3-pole combination type with contacts arranged to accept either 2-pole caps with parallel blades or 3-pole polarized caps. Outlets should be installed at convenient intervals in corridors and large rooms for the operation of maintenance equipment such as floor waxers, cleaners, sanders, or polishers. In officers' quarters living, dining, and bed rooms, one receptacle should be provided for each 15 lineal feet of gross distance around the room. Screened living porches should be provided with a weatherproof convenience outlet. In areas where a relatively large number of outlets are required along a wall or bench line, consideration should be given to the installation of wiring channels with single receptacles mounted therein. In hospitals, a convenience outlet should be mounted above the head of each bed, or, where two beds are placed within 4 feet of each other, one outlet between the pair of beds will suffice, provided no window or structural member interferes. In operating rooms receptacles must be of the flush explosion-proof type. Power outlets should be of adequate capacity for the loads served. A separate pole for grounding should be provided where required. Duplex convenience outlets mounted approximately 4 feet above the floor should be provided for wall-type oscillating fans in noncommissioned officers rooms, squad rooms, day rooms, wards, mess halls, dining rooms, kitchens, and in offices where other means of mechanical ventilation are not provided. One outlet per 15 to 20 lineal feet of exterior wall space or approximately 300 square feet of floor space is considered sufficient.

2–09 UNDERFLOOR DUCT SYSTEMS. Underfloor duct systems should be installed in administrative or other areas where extensive electric or communication facilities are required and suitable occasional floor outlets or outlets on walls or columns cannot serve the areas adequately. Separate duct systems should be provided for the electric and telephone systems. For administrative areas, a double duct system paralleling the exterior walls and approximately 4 to 5 feet therefrom can be expected to fill most all needs. Ducts should have a nominal cross sectional area of 3 square inches; in exceptional cases ducts of larger cross sectional area may be used. Factory set outlets should be provided on 2-foot centers. Junction or pull boxes should be located at strategic points to facilitate wiring to panels or cabinets and they should be spaced at not more than 50-foot intervals along the duct runs.

2–10 PNEUMATIC TUBE SYSTEMS. Pneumatic tube systems should be installed in airfield operations buildings, general hospitals, and in other buildings where instantaneous floor-to-floor transmittal of papers or small items is considered essential to the proper functioning of the using service. This type of system should not be installed where any other type of communication will meet the requirements of the activity involved. All pneumatic tube system installations will be approved by the Office of the Chief of Engineers prior to completion of building design.

2–11 NURSES' SIGNALLING SYSTEM. Each bed in the medical or surgical ward will be provided with a nurses' signalling system which will give essential call facilities for the patients. System should be of the low voltage locking-button type utilizing equipment of standard commercial manufacture, arranged so that a patient upon pushing a button at a bedside station will cause lamps over the bed ward entrance and in the duty station and a lamp in the annunciator to be lighted. The lamps are to remain lighted until the button is reset at calling station. If more than one call originates in a ward during one interval of time, all lamps common to these stations should remain lighted until all buttons are reset. An audible signal with cut-off switch should be provided at each annunciator. Audible signal should function only when the push button is pressed beyond its normal locked position. Separate stations should be installed for each bed. Pilot lights should be provided at each bedside station. In wards where approximately four beds are segregated into

a cubicle, a dome light should be provided on the ceiling to indicate a call from any bed in that cubicle. Call stations are not to be provided in porches and solariums. Nurses' signalling systems should not be installed in wards used for disturbed patients, but a low voltage alarm system should be provided to enable supervising personnel to summon assistance from adjacent sections or buildings. Flush push buttons should be located in wards of disturbed patients' sections. Push buttons should be of the type to permit continuous operation of bell or gong until reset. All exposed screws should be of the tamper-resisting type. Key-operated cut-off switches with bull's-eye pilot light should be located outside of the restricted areas. Key-operated cut-off switch should be connected in series with the push buttons to prevent sounding of unauthorized alarms when supervising personnel are not in the wards. Attendant upon entering a ward energizes the flush push button and lights the pilot lamp by operating the key-type cut-off switch. Depression of the flush push button on the room station should light the corridor lamp above the room entrance, a pilot light in the annunciator, a pilot light in each duty station and sound an emergency alarm in the annunciator and duty stations. All lamps should remain lighted and alarms should sound until the attendant resets the entrance cut-off switch.

2–12 DOCTORS' PAGING SYSTEMS. Doctors' paging systems should be installed in all general hospitals and other hospitals having a capacity of 500 beds or more. The system should be of the silent flashing lamp type with central control capable of handling three 3-digit calls simultaneously. Annunciators should be located in each ward or clinic section in vicinity of nurses station and in mess halls.

2–13 CLOCK SYSTEMS. Clock systems, comprising master and secondary clocks, should be provided in hospitals having a capacity of 200 beds or more and in administrative buildings having requirements for 25 or more clocks.

2–14 INTERCOMMUNICATION SYSTEMS. Raceways for separate intercommunication systems should be installed only when signalling devices and the central telephone system are definitely inadequate to serve the purpose and only when authorized by the Office of the Chief of Engineers.

In barracks, a ¾-inch conduit system should provide for a master loud speaking intercommunication set in the company officer's office with outlying speakers located in each squad room, day, or recreation room, mess hall, kitchen, and issue room. No equipment or wiring will be required for this system. Outlying speaker station outlets should be approximately 8 feet above the floor and outlet for master station 1 foot above floor adjacent to a receptacle outlet.

2–15 RADIO OUTLETS AND SYSTEMS. Radio outlets should be installed at the head of each patient's bed in hospitals and in each living room, recreation room, day room, and club room. Radio outlets at patients' beds in hospitals should be interconnected by a ¾-inch conduit to cabinets and with feeders from cabinets to control radio receiver. Radio outlets in living rooms of quarters should be provided with a receptacle for antenna and ground connections. An antenna system should be installed in apartment houses when the building construction will have a shielding effect and preclude the successful operation of receivers.

2–16 TELEPHONE SYSTEM. An empty conduit system will be provided in buildings for the installation of telephones by the Signal Corps. In officers' quarters with basement a 2-inch conduit sleeve should be provided through the foundation wall approximately 2 feet below grade for service entrance. A ½-inch conduit should be extended from the basement to an outlet on the first and second floors, the latter should be located in the master bedroom. In quarters without basements, conduits from outlets should be extended to a utility room and underground service sleeve installed from this room through the exterior wall.

In barracks an outlet should be provided in each day or recreation room for public telephones and in each office. A terminal cabinet with an underground service entrance conduit should be located in basement at a convenient and accessible point. Service entrance conduits should be not less than 2 inches and should terminate approximately 2 feet below finished grade and 2 feet from the building. Where entrance cabinets have a maximum dimension of less than 30 inches the service conduits should terminate approximately 2 feet from the cabinet to permit a splice to be made in the cables before entering the cabinets. Outlets should be interconnected with cabinets by raceways of the following sizes:

Number of twisted pair	*Raceway size (inches)*
1	½
2 or 3	¾
4 or 5	1
6 to 8	1¼

Feeder raceways between cabinets should be not less than the following sizes:

Cable size:	*Raceway size (inches)*
25 pair or less	1¼
50 pair	1½
100 pair	2
200 pair	2½
400 pair	3
600 pair	3
900 pair	4
1,200 pair	4

Cabinets should be sized as follows:

Capacity of cabinets, No. of circuits:	*Cabinet size (inches)* W H D
10	10 x 12 x 4
15	10 x 16 x 4
25	12 x 24 x 4
50	16 x 28 x 5
100	24 x 32 x 5
150	36 x 36 x 5
200	30 x 54 x 5
250	30 x 54 x 5
300	36 x 60 x 8
400	48 x 60 x 8

Entrance cabinets for buildings should be not less than 12 x 24 x 4 inches. Not more than two right angle bends should be permitted in any run of feeder conduit. Pull boxes should be provided at intervals not exceeding 75 feet.

2–17 OBSTRUCTION LIGHTING. Obstruction lighting on buildings, boiler house stacks, or towers should be provided only where a definite hazard to flying exists. Latest published regulations contained in the Army Air Forces Regulation §63–6 should be followed for obstruction marking. A thorough study, with reference to surrounding objects terrain, and air traffic should be made before obstruction lights are installed. Adequate provisions should be made for relamping of fixtures. Traffic filament lamps having an average life of approximately 1,800 hours should be used to reduce the number of lamps renewals a year. Several common methods have been developed to facilitate lamp replacements in fixtures installed on stacks. In one method, foot and hand rails are provided around a boiler house stack for access to each fixture. In the second method all fixtures are conduit mounted on a circular track with flexible cord and plug connection, so arranged that lamps may be rotated around the stack to ladder for servicing. Where the height of a stack is not excessive, disconnecting-type fixture hangers with pulleys and wire rope may be used for lowering each fixture to the ground. Unless obstruction lights are connected to a centrally controlled system, they should be controlled by an automatically wound time switch, which, in case of current interruptions, has a carry-over period of a least 10 hours.

2–18 DRY CLOSET OUTLETS. In order to prevent the formation of mildew in closets of buildings in tropical zones used for the storage of clothes, there should be provided an electric outlet near the floor for approximately each 15 square feet of closet area. This outlet should be provided with a keyless porcelain lampholder, rugged wire lamp guard and either a 50-watt resistor or lamp.

2–19 LIGHTING. The design of building lighting systems should be given careful consideration in order to provide comfortable seeing conditions of adequate intensity for the accomplishment of the necessary operations. In many cases the design must be coordinated with the architectural treatment of the building to achieve the atmosphere desired by the architect, especially in living and recreational spaces. Other factors that must be given careful consideration in the design are: the functions to be performed, length of time used per day, lighting intensity required, freedom from glare, initial cost, maintenance and operating costs.

a. Light sources. Fluorescent, incandescent, and mercury-vapor lamps are the most commonly used light sources. The characteristics of each type differ considerably so that careful consideration should be given the use of each when a design is made. Fluorescent lamps, because of their high lumen per watt output, length, and relatively low surface brightness are most suitable for general lighting applications under ordinary conditions where relatively high levels of illumination must be maintained for considerable periods of time. Forty-watt fluorescent lamps should be used for relatively low mounting heights. One hundred-watt fluorescent lamps should be used for installations at medium high mounting heights of approximately 18 to 30 feet. In general fluorescent lighting will be provided in all areas where continuous work is to be performed such as in offices, shops, and laboratories or where medium or high levels of illumination are required for a relatively long number of hours per year. Incandescent lighting should be provided in areas subject to intermittent use such as closets, utility stock and store rooms, or for exterior lighting. Incandescent lighting should also be provided in auditoriums where a change in light intensity is desired by means of dimmers and in living areas, such as living and dining rooms, libraries, lounges, reading or card rooms where the warmth of the yellow color of incandescent lamps is desired; and gymnasiums, where the number and size of lamps and fixtures exposed to injury should be kept to the minimum. Mercury vapor lamps because of their high lumen output are particularly suitable for use at high mounting heights of over 30 feet where the number of fixtures must be kept to a minimum and their high brightness is not a controlling factor. These lamps require a period of several minutes to attain full brilliancy and have a predominately blue green light characteristic. It is therefore desirable to use them in combination with approximately double the wattage of incandescent lamps which have a predominately yellow characteristic. Mercury vapor lamps should be used in areas where they will burn for several hours at a time and where they will not be subject to frequent switching on and off.

b. Design. The first step in the design of a lighting system is the selection of the types of luminaire and light source. The total amount of light required to produce a specified level of illumination may be determined from the formula:

$$L = \frac{A \times F.\,C.}{CU \times M.\,F.}$$

where

L=the lumens required
A=area to be lighted in square feet
$F.\,C.$=foot candle intensity desired
$C.\,U.$=coefficient of utilization
$M.\,F.$=maintenance factor

The values of foot candle intensities considered adequate for efficient performance of duties are listed in table I. These levels are an indication of the average maintained values which should be

provided and they should not be greatly exceeded without prior approval of the Office of the Chief of Engineers. The coefficient of utilization is a factor which takes into account such variables affecting the amount of light reaching the working plane as room proportions, reflecting surfaces, reflector characteristics, etc., and may be determined from tables III or IV. The room index required for use in table III or IV may be determined from table II, and depends upon the room dimensions and type of lighting. The maintenance factor allows for the depreciation in light output of a luminaire due to collection of dust or dirt and aging of lamps and may be determined directly from tables III or IV. The number of fixtures required for an area may be found by dividing the total lumens required by the lumens of the lamp selected.

TABLE I

Schedule of lighting intensities for general illumination and suggested luminaire classification

Area	Luminaire						
	F. C. intensities	Fluorescent			Incandescent		
		D	SD	SI&ID	D	D&SD	SI&ID
Auditoriums—Assembly Rooms	10					X	X
Bakeries:							
Work Rooms	20	X					
Receiving, Shipping	10	X					
Storage Areas	5				X		
Banks—Cages	30		X	X			
Work Space	30		X	X			
Lobby	15		X	X			
Barracks:							
Squad and NCO Rooms	10	X					
Day and Recreation Rooms	20		X	X			
Porches	3				X		
Mess Halls	10	X					
Kitchen and Food Preparation	20	X	X				
Basements and Pipe Spaces	5				X		
Boiler and Furnace Rooms:							
Individual Buildings	5				X		
Central Heating Plants	10				X		
Chapel:							
Nave, Chancel, and Sanctuary, Sacristy Chaplains Rooms	10					X	X
Corridors and Hallways	5		X			X	
Drill Hall Arenas	20				X		
Fire Station:							
Apparatus Room	10				X		
Hose Tower	10				X		
Alarm Room	20	X	X				
Garages:							
Storage	10				X		
Service	20	X					
Repair and Wash	30	X			X		
Gymnasiums:							
Basket Ball Courts	30				X		
Hand Ball Courts	30	X					
Squash Courts	30	X					
Swimming Pool	15				X		
Bowling Alleys, General	10		X		X		
Bowling Alleys, on Pins	50				X		
Hangars—Service Area	20						
Hospitals:							
Clinics and Laboratories	30		X	X			
Examination Rooms	30		X	X			
Morgue	10						
Operating Rooms	50		X				
Reception and Waiting	10			X			X
Wards and Nursery	5			X			X
Solariums	10					X	X
Pharmacy	30		X				

TABLE I—Continued

Schedule of lighting intensities for general illumination and suggested luminaire classification—Continued

Area	F. C. intensities	Luminaire					
		Fluorescent			Incandescent		
		D	SD	SI&ID	D	D&SD	SI&ID
Hospitals—Continued							
Utility and Linen Rooms	10					X	
Nurses' Work, Sterilizing, Surgical Dressing Rooms	20		X				
Radiographic, Fluoroscopic and Therapy Rooms	20						
Therapeutic Rooms	10		X	X			
Kitchens, Pantries, Food Preparing and Dispensing Rooms	20	X	X			X	
Mess Halls, Cafeterias, Dining Rooms, etc	10		X				
Laundries and Dry Cleaning Plants—Work Areas	20	X					
Library—Reading and Periodical Rooms	30		X	X			
Control	30		X	X			
Stack Room	15				X		
Lobbies	10						
Locker Rooms	10				X	X	
Office Spaces:							
Conference, Executive, Intermittent Reading, and Writing, Filing, etc	30	X	X	X			
Prolonged close work, drafting, continuous typing, computing, processing req	50	X	X	X			
Mechanical Equipment Rooms	10				X		
Museums—General	10						
—On displays	30						
Post Exchanges:							
Stores and Shops	20		X				
Bars and Cafeterias	10		X		X	X	
Show Windows	30				X		
Schools:							
Kindergarten and Nursery	20		X	X			
Class Rooms, and Laboratories	30		X	X			
Art and Drawing Rooms	50		X	X			
Shops	30	X					
Shoe Repair	20						
Shops:							
Carpenter, Sheet Metal, Electricians'	20	X					
Automotive Repair	30	X					
Machine Shops, Fine Work	30	X					
Theater:							
Auditorium	5				X		
Foyer	7		X	X			X
Lobby	10		X	X			X
Main Entrance	20	X			X		
Dressing	10		X			X	
Lounge	5			X			X
Stage (Work Lights)	10				X		
Projection and Rewind Rooms	15				X		
Toilets and Wash Rooms	10				X		
Utility and Store Rooms	5				X		
Warehouses:							
Loading Platforms	5	X			X		
Storage Area and Aisles	5	X			X		
Refrigerated Storage	5				X		
Work Areas	10	X					
Post Office:							
Work Space	30	X					
Lobby	10		X				
Swing Room	10					X	
Quarters:							
Nurses and Bachelor Officers:							
Living—Lounge	10						X
Bed Room	5						X
Library and Card	10						X
Dining room	10						X
Kitchens and Pantries*	10						
Porches	3				X		

TABLE I—Continued

Schedule of lighting intensities for general illumination and suggested luminaire classification—Continued

Area	Luminaire						
	F. C. intensities	Fluorescent			Incandescent		
		D	SD	SI&ID	D	D&SD	SI&ID
Quarters—Continued							
Field and Company Officers:							
Living Room	10						X
Dining Room	10						X
Halls	5						X
Kitchens and Pantries*	10				X		
Bed Rooms and Dressing	5						X
Baths	10				X		
NCO Quarters:							
Living Room	10						X
Dining Room	10						X
Kitchens and Pantries*							
Bed Rooms	5						X
Bath	10				X		

For particular applications not covered by the general classes listed above intensities should conform to the minimum foot candle levels of the American Recommended Practice of Industrial Lighting sponsored by the Illuminating Engineering Society.

*Supplemental fluorescent lighting of from 10 to 20 candles should be provided for over work counters in kitchens of quarters.

D, Direct; ID, Indirect; SD, Semi-direct; SI, Semi-indirect.

TABLE II

ROOM INDEX

(Classification of rooms according to their proportions)

For semi-indirect and indirect lighting		Ceiling height—feet										
		9 and 9½	10 to 11½	12 to 13½	14 to 16½	17 to 20	21 to 24	25 to 30	31 to 36	37 to 50		
		Mounting height above floor—feet										
For direct and semi-direct lighting		7 and 7½	8 and 8½	9 and 9½	10 to 11½	12 to 13½	14 to 16½	17 to 20	21 to 24	25 to 30	31 to 36	37 to 50
Room width (feet)	Roof length (feet)	Room index										
9 (8½–9)	8–10	H	I	J	J							
	10–14	H	I	I	J							
	14–20	G	H	I	J	J						
	20–30	G	G	H	I	J	J					
	30–42	F	G	H	I	J	J	J				
	42–up	E	F	G	H	I	J	J				
10 (9½–10½)	10–14	G	H	I	J	J						
	14–20	G	H	I	J	J	J					
	20–30	F	G	H	I	J	J					
	30–42	F	G	G	H	I	J	J				
	42–60	E	F	G	H	I	J	J				
	60–up	E	F	F	H	H	I	J				
12 (11–12½)	10–14	G	H	I	I	J	J					
	14–20	F	G	H	I	J	J					
	20–30	F	G	G	H	I	J	J				
	30–42	E	F	G	H	I	J	J				
	42–60	E	F	F	G	H	I	J				
	60–up	E	E	F	G	H	I	J				
14 (13–15½)	14–20	F	G	H	H	I	J	J				
	20–30	E	F	G	H	I	J	J				
	30–42	E	F	F	G	H	I	J	J			
	42–60	E	E	F	F	H	I	J	J	J		
	60–90	D	E	E	F	G	H	J	J	J		
	90–up	D	E	E	F	F	G	I	J	J		

TABLE II—Continued

ROOM INDEX—Continued

For semi-indirect and indirect lighting		Ceiling height—feet										
		9 and 9½	10 to 11½	12 to 13½	14 to 16½	17 to 20	21 to 24	25 to 30	31 to 36	37 to 50		
		Mounting height above floor—feet										
For direct and semi-direct lighting		7 and 7½	8 and 8½	9 and 9½	10 to 11½	12 to 13½	14 to 16½	17 to 20	21 to 24	25 to 30	31 to 36	37 to 50
Room width (feet)	Roof length (feet)	Room index										
17 (16–18½)	14–20	E	F	G	H	I	J	J	------	------	------	------
	20–30	E	F	F	G	H	I	J	------	------	------	------
	30–42	D	E	F	G	H	H	J	J	J	------	------
	42–60	D	E	E	F	G	G	I	J	J	J	------
	60–110	D	E	E	F	G	G	I	J	J	J	------
	110–up	C	D	E	E	F	G	H	I	J	J	------
20 (19–21½)	20–30	D	E	F	G	H	I	J	J	------	------	------
	30–42	D	E	E	F	G	H	I	J	J	------	------
	42–60	D	D	E	E	F	G	I	J	J	J	------
	60–90	C	D	E	E	F	G	H	J	J	J	------
	90–140	C	D	D	E	F	F	H	I	I	J	J
	140–up	C	D	D	E	F	F	H	H	I	J	J
24 (22–26)	20–30	D	E	E	F	G	H	I	J	J	------	------
	30–42	C	D	E	F	G	G	I	J	J	------	------
	42–60	C	D	D	E	F	G	H	I	J	J	------
	60–90	C	D	D	E	F	F	H	I	J	J	J
	90–140	C	C	D	E	E	F	G	H	I	J	J
	140–up	C	C	D	E	E	F	G	H	I	I	J
30 (27–33)	30–42	C	D	D	E	F	G	H	I	J	J	------
	42–60	C	C	D	D	F	F	H	H	I	J	------
	60–90	B	C	C	D	E	F	G	H	I	J	J
	90–140	B	C	C	D	E	E	F	G	H	I	J
	140–180	B	C	C	D	E	E	F	G	H	I	J
	180–up	B	C	C	D	E	E	F	G	H	I	J
36 (34–39)	30–42	B	C	D	E	F	F	H	I	I	J	------
	42–60	B	C	C	D	E	F	G	H	I	J	J
	60–90	A	C	C	C	E	E	F	H	H	J	J
	90–140	A	B	C	C	D	E	F	G	H	I	J
	140–200	A	B	C	C	D	E	F	F	G	H	I
	200–up	A	B	C	C	D	E	F	F	G	H	I
42 (40–45)	42–60	A	B	C	C	E	F	G	H	I	I	J
	60–90	A	B	B	C	D	E	F	G	H	I	J
	90–140	A	B	B	C	D	D	E	F	G	H	J
	140–200	A	A	B	C	D	D	E	F	G	H	I
	200–up	A	A	B	C	D	D	E	F	F	G	I
50 (46–55)	42–60	A	A	B	C	D	E	F	G	H	I	J
	60–90	A	A	B	C	C	D	F	F	G	H	J
	90–140	A	A	A	C	C	D	E	F	F	G	I
	140–200	A	A	A	C	C	D	E	E	F	G	I
	200–up	A	A	A	C	C	D	E	E	F	G	H
60 (56–67)	60–90	A	A	A	B	C	D	E	F	G	H	I
	90–140	A	A	A	B	C	C	D	E	F	G	H
	140–200	A	A	A	B	C	C	D	E	E	F	H
	200–up	A	A	A	B	C	C	D	E	E	F	H
75 (68–90)	60–90	A	A	A	A	B	C	D	E	F	G	I
	90–140	A	A	A	A	B	C	D	E	F	F	H
	140–200	A	A	A	A	B	B	C	D	E	F	G
	200–up	A	A	A	A	B	B	C	D	E	F	G
90 or more	60–90	A	A	A	A	B	C	D	E	F	G	H
	90–140	A	A	A	A	A	B	C	D	E	F	G
	140–200	A	A	A	A	A	B	C	D	E	F	G
	200–up	A	A	A	A	A	B	C	C	D	E	F

NOTE—Room index is the classification of a room according to its proportions; large and small rooms of the same proportion have the same index. Hence, or large rooms of dimensions greater than those shown, divide each dimension by the same number and use the index determined for the smaller room.

TABLE III

UTILIZATION FACTORS FILAMENT AND MERCURY LUMINAIRES

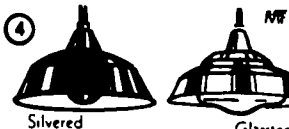
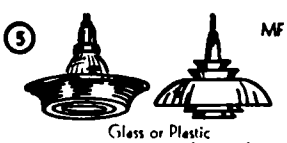
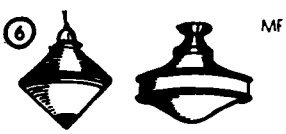
	Ceiling	75%			80%		
	Walls	50%	30%	10%	50%	30%	10%
	Room Index	Utilization factors					
①  MF = .65 ↑ 0 / 70 ↓ High Bay – concentrating Filament or Mercury lamps	J	0.40	0.38	0.36	0.30	0.38	0.36
	I	.48	.46	.46	.47	.48	.48
	H	.51	.51	.50	.50	.50	.49
	G	.55	.54	.54	.54	.52	.52
	F	.58	.56	.55	.55	.58	.54
	E	.60	.59	.58	.59	.58	.57
	D	.64	.61	.60	.62	.60	.60
	C	.65	.63	.61	.63	.62	.60
	B	.65	.64	.63	.64	.62	.62
	A	.66	.65	.64	.64	.63	.62
②  MF = .65 ↑ 0 / 75 ↓ Wide distribution Filament or Mercury lamps	J	.35	.30	.26	.34	.30	.26
	I	.44	.39	.36	.43	.36	.35
	H	.48	.44	.41	.46	.44	.40
	G	.51	.48	.45	.50	.47	.44
	F	.54	.51	.48	.52	.50	.47
	E	.59	.56	.53	.58	.55	.52
	D	.63	.60	.57	.62	.59	.57
	C	.63	.62	.59	.63	.61	.59
	B	.68	.65	.63	.66	.64	.62
	A	.69	.67	.68	.68	.65	.64
③  MF = .65 ↑ 0 / 80 ↓ High Bay trough 3-kw H-9 Mercury	J	.38	.29	.24	.35	.29	.24
	I	.45	.39	.35	.44	.38	.34
	H	.49	.44	.40	.48	.44	.40
	G	.53	.48	.44	.52	.48	.44
	F	.58	.51	.47	.54	.50	.47
	E	.61	.57	.53	.60	.56	.53
	D	.66	.62	.58	.64	.62	.58
	C	.68	.65	.62	.66	.63	.62
	B	.72	.69	.66	.70	.67	.66
	A	.74	.70	.68	.72	.69	.67
④  MF = .65 ↑ 0 / 65 ↓ Silvered Bowl Glassteel Low Bay diffusers	J	.34	.31	.29	.34	.31	.29
	I	.42	.39	.38	.41	.38	.37
	H	.45	.43	.42	.44	.42	.41
	G	.48	.46	.45	.47	.46	.44
	F	.51	.49	.46	.49	.47	.46
	E	.54	.52	.50	.53	.51	.49
	D	.57	.55	.53	.56	.54	.53
	C	.59	.57	.54	.57	.55	.54
	B	.60	.58	.57	.58	.57	.56
	A	.61	.59	.58	.60	.58	.57
⑤  MF = .70 ↑ 25 / 55 ↓ Glass or Plastic prismatic or open louvered	J	.33	.32	.28	.31	.27	.26
	I	.40	.37	.35	.38	.35	.33
	H	.44	.41	.39	.41	.39	.37
	G	.47	.45	.43	.44	.41	.40
	F	.51	.48	.45	.46	.44	.42
	E	.54	.51	.49	.50	.48	.45
	D	.58	.54	.51	.53	.50	.48
	C	.60	.57	.53	.55	.52	.49
	B	.62	.59	.57	.57	.54	.53
	A	.64	.61	.58	.59	.56	.54
⑥  MF = .70 ↑ 35 / 45 ↓ Glass enclosing globes	J	.23	.19	.16	.21	.17	.15
	I	.29	.24	.22	.26	.22	.19
	H	.33	.28	.25	.29	.26	.23
	G	.37	.32	.28	.32	.28	.26
	F	.40	.35	.32	.35	.31	.28
	E	.44	.40	.36	.39	.35	.32
	D	.48	.43	.39	.42	.38	.35
	C	.51	.46	.42	.44	.40	.37
	B	.55	.50	.46	.48	.44	.41
	A	.57	.53	.49	.50	.46	.43
⑦  MF = .70 ↑ 45 / 35 ↓ Glass enclosing or louvered	J	.24	.20	.17	.21	.17	.15
	I	.29	.25	.23	.26	.22	.20
	H	.33	.29	.26	.28	.26	.23
	G	.37	.33	.30	.32	.28	.26
	F	.40	.35	.32	.34	.30	.28
	E	.44	.40	.36	.37	.34	.31
	D	.47	.43	.40	.40	.37	.34
	C	.50	.46	.42	.42	.39	.36
	B	.53	.50	.47	.44	.42	.40
	A	.56	.51	.49	.47	.44	.41

TABLE III.—UTILIZATION FACTORS FILAMENT AND MERCURY LUMINAIRES—Continued

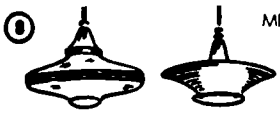
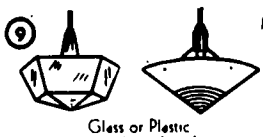
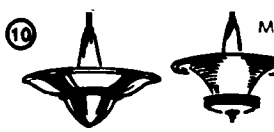
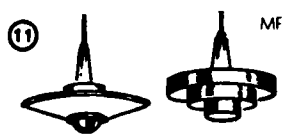
	Ceiling	75%			80%		
	Walls	50%	30%	10%	50%	30%	10%
	Room Index	Utilization factors					
(8)  MF = .65 ↑ 60 / 20 ↓ Glass or Plastic semi-indirect	J	.21	.17	.15	.16	.14	.12
	I	.26	.22	.20	.21	.18	.16
	H	.29	.26	.23	.23	.20	.19
	G	.33	.27	.26	.26	.23	.21
	F	.36	.32	.28	.28	.25	.23
	E	.39	.36	.32	.31	.28	.26
	D	.43	.38	.36	.33	.30	.28
	C	.45	.41	.38	.35	.32	.30
	B	.49	.46	.42	.37	.35	.34
	A	.51	.48	.45	.40	.37	.35
(9)  MF = .65 ↑ 70 / 10 ↓ Glass or Plastic semi-indirect bowls	J	.18	.14	.13	.13	.11	.09
	I	.23	.19	.17	.17	.14	.12
	H	.26	.22	.20	.19	.16	.14
	G	.30	.25	.22	.21	.19	.17
	F	.32	.28	.25	.24	.21	.19
	E	.36	.32	.29	.27	.23	.21
	D	.40	.35	.32	.29	.26	.24
	C	.42	.38	.35	.30	.28	.26
	B	.46	.42	.40	.33	.31	.29
	A	.48	.44	.42	.35	.32	.31
(10)  MF = .60 ↑ 75 / 0 ↓ Open indirect bowl	J	.15	.12	.10	.10	.08	.07
	I	.19	.15	.14	.13	.10	.09
	H	.22	.18	.16	.14	.12	.10
	G	.25	.21	.18	.17	.14	.13
	F	.27	.24	.21	.19	.16	.14
	E	.31	.27	.25	.21	.18	.16
	D	.34	.30	.28	.22	.20	.19
	C	.36	.33	.30	.24	.22	.20
	B	.40	.37	.34	.26	.25	.23
	A	.42	.39	.37	.28	.26	.25
(11)  MF = .70 ↑ 85 / 0 ↓ Silvered bowl indirect	J	.17	.13	.11	.11	.09	.08
	I	.21	.17	.15	.14	.12	.10
	H	.25	.21	.18	.16	.14	.12
	G	.28	.24	.21	.20	.16	.14
	F	.31	.27	.23	.21	.18	.16
	E	.35	.31	.28	.24	.20	.19
	D	.39	.34	.31	.26	.23	.21
	C	.41	.37	.34	.27	.25	.23
	B	.46	.42	.39	.30	.28	.26
	A	.48	.44	.42	.32	.30	.28

TABLE IV

UTILIZATION FACTORS FLUORESCENT LUMINAIRES

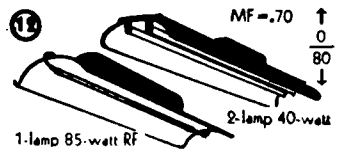
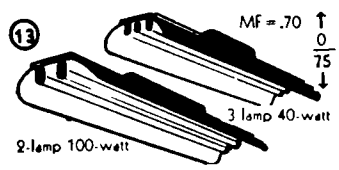
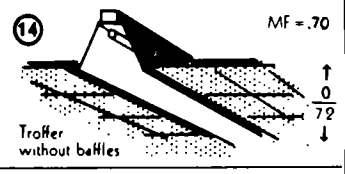
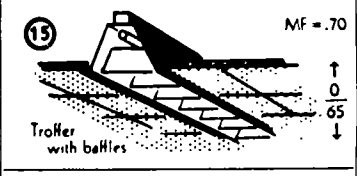
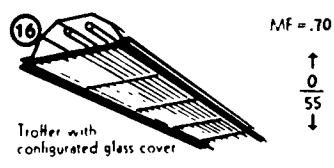
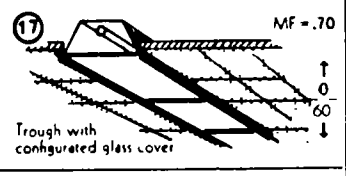
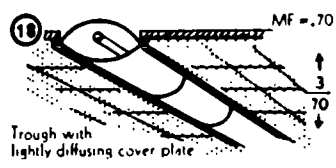
	Ceiling	75%			80%		
	Walls	50%	30%	10%	50%	30%	10%
	Room Index	Utilization factors					
12 	J	0.36	0.29	0.24	0.35	0.29	0.24
	I	.45	.39	.35	.44	.38	.34
	H	.49	.44	.40	.48	.44	.40
	G	.53	.48	.44	.52	.48	.44
	F	.56	.51	.47	.54	.50	.47
	E	.61	.57	.53	.60	.56	.53
	D	.66	.62	.58	.64	.62	.58
	C	.68	.65	.62	.66	.63	.62
	B	.72	.69	.66	.70	.67	.66
	A	.74	.70	.68	.72	.69	.67
13 	J	.35	.30	.26	.34	.30	.26
	I	.44	.39	.36	.43	.38	.35
	H	.48	.44	.41	.46	.44	.40
	G	.51	.48	.45	.50	.47	.44
	F	.54	.51	.48	.52	.50	.47
	E	.59	.56	.53	.58	.55	.52
	D	.63	.60	.57	.62	.59	.57
	C	.65	.62	.59	.63	.61	.59
	B	.68	.65	.63	.66	.64	.62
	A	.69	.67	.65	.68	.65	.64
14 	J	.40	.37	.35	.39	.37	.35
	I	.48	.46	.45	.47	.45	.44
	H	.52	.50	.50	.51	.49	.49
	G	.55	.54	.53	.54	.53	.51
	F	.58	.56	.54	.55	.54	.53
	E	.60	.59	.57	.59	.58	.56
	D	.65	.62	.60	.62	.61	.59
	C	.66	.64	.61	.64	.62	.61
	B	.67	.65	.64	.65	.63	.62
	A	.68	.66	.65	.66	.65	.63
15 	J	.32	.28	.25	.32	.28	.25
	I	.40	.36	.34	.39	.35	.33
	H	.43	.39	.37	.42	.39	.37
	G	.46	.43	.41	.45	.43	.41
	F	.48	.45	.43	.47	.45	.43
	E	.52	.50	.48	.51	.49	.47
	D	.56	.54	.52	.55	.53	.51
	C	.57	.55	.53	.56	.54	.52
	B	.60	.58	.56	.59	.57	.55
	A	.61	.59	.57	.60	.58	.57
16 	J	.28	.24	.22	.27	.24	.22
	I	.34	.31	.29	.33	.30	.29
	H	.37	.34	.33	.36	.34	.32
	G	.39	.37	.36	.38	.37	.35
	F	.42	.39	.37	.40	.38	.37
	E	.44	.43	.40	.43	.42	.40
	D	.47	.45	.43	.46	.45	.43
	C	.49	.47	.45	.47	.46	.45
	B	.50	.48	.47	.49	.47	.46
	A	.51	.50	.48	.50	.48	.47
17 	J	.30	.26	.24	.29	.26	.24
	I	.37	.34	.32	.36	.33	.31
	H	.40	.38	.36	.39	.37	.35
	G	.43	.40	.39	.42	.40	.38
	F	.45	.43	.40	.44	.42	.40
	E	.48	.46	.44	.47	.46	.44
	D	.52	.49	.47	.50	.49	.47
	C	.53	.51	.49	.52	.50	.49
	B	.55	.53	.52	.53	.52	.51
	A	.56	.54	.53	.55	.53	.52
18 	J	.31	.25	.23	.31	.25	.22
	I	.38	.32	.31	.37	.33	.30
	H	.42	.38	.34	.41	.37	.35
	G	.45	.41	.39	.43	.41	.37
	F	.48	.45	.40	.47	.43	.41
	E	.53	.49	.45	.51	.48	.45
	D	.56	.52	.49	.55	.51	.49
	C	.59	.54	.51	.56	.53	.50
	B	.62	.57	.54	.60	.56	.55
	A	.63	.59	.57	.61	.58	.56

TABLE IV.—UTILIZATION FACTORS FLOURESCENT LUMINAIRES—Continued

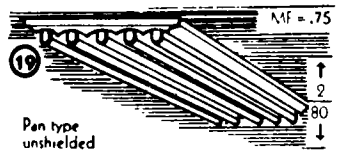
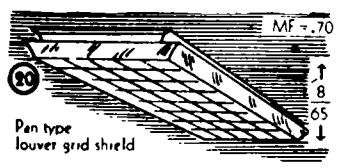
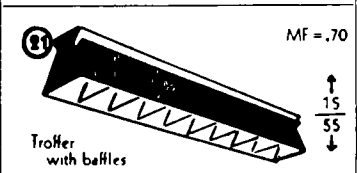
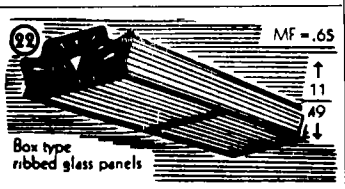
	Ceiling	75%			80%		
	Walls	50%	30%	10%	50%	30%	10%
	Room Index	Utilization factors					
	J	0.37	0.31	0.28	0.37	0.31	0.29
	I	.45	.41	.37	.44	.40	.38
	H	.49	.46	.43	.48	.45	.42
	G	.54	.50	.46	.52	.50	.47
	F	.57	.53	.49	.55	.53	.49
	E	.61	.59	.54	.61	.57	.55
	D	.66	.62	.59	.65	.61	.59
	C	.69	.65	.60	.66	.63	.60
	B	.71	.67	.65	.69	.65	.64
	A	.73	.69	.67	.71	.68	.65
	J	.33	.29	.27	.32	.29	.27
	I	.40	.37	.35	.38	.35	.34
	H	.43	.41	.39	.42	.39	.38
	G	.47	.44	.42	.45	.43	.41
	F	.50	.47	.44	.47	.45	.43
	E	.54	.51	.48	.51	.49	.47
	D	.57	.54	.51	.54	.52	.50
	C	.59	.56	.53	.56	.54	.51
	B	.61	.58	.56	.58	.55	.54
	A	.63	.60	.58	.60	.57	.55
	J	.32	.28	.27	.31	.28	.26
	I	.39	.36	.35	.38	.34	.33
	H	.42	.41	.38	.40	.38	.37
	G	.46	.43	.42	.43	.42	.40
	F	.48	.47	.43	.45	.43	.42
	E	.51	.49	.47	.49	.47	.45
	D	.55	.52	.51	.51	.50	.49
	C	.57	.55	.52	.53	.51	.50
	B	.59	.56	.55	.55	.53	.52
	A	.60	.58	.56	.57	.54	.53
	J	.25	.21	.19	.24	.21	.19
	I	.30	.27	.25	.29	.26	.24
	H	.33	.30	.29	.32	.29	.28
	G	.36	.34	.32	.34	.32	.30
	F	.39	.36	.33	.36	.34	.32
	E	.42	.39	.36	.39	.37	.35
	D	.45	.42	.39	.42	.40	.38
	C	.46	.44	.40	.44	.41	.39
	B	.49	.46	.44	.45	.43	.42
	A	.50	.47	.45	.47	.44	.43

TABLE IV.—UTILIZATION FACTORS FLUORESCENT LUMINAIRES—Continued

	Ceiling	75%			80%		
	Walls	50%	30%	10%	50%	30%	10%
	Room Index	Utilization factors					
23 MF = .70 ↑ 5 / 55 ↓ Channel type fluted diffusing cylinder	J	0.20	0.17	0.14	.19	0.16	0.13
	I	.25	.22	.19	.24	.21	.18
	H	.28	.24	.23	.27	.24	.22
	G	.31	.28	.25	.29	.26	.24
	F	.34	.31	.27	.30	.29	.26
	E	.37	.34	.31	.34	.31	.29
	D	.40	.36	.33	.37	.34	.31
	C	.42	.38	.35	.38	.36	.33
	B	.44	.42	.38	.42	.38	.36
	A	.46	.43	.41	.43	.40	.38
24 MF = .65 ↑ 23 / 43 ↓ Half cylinder Glass or Plastic shield	J	.22	.18	.15	.20	.17	.14
	I	.27	.23	.20	.25	.21	.19
	H	.30	.26	.24	.28	.25	.22
	G	.33	.30	.27	.30	.27	.25
	F	.36	.32	.29	.32	.29	.27
	E	.40	.36	.33	.36	.33	.30
	D	.43	.39	.36	.38	.36	.33
	C	.45	.41	.38	.40	.37	.35
	B	.48	.45	.42	.43	.40	.38
	A	.50	.46	.44	.45	.42	.40
25 MF = .65 ↑ 23 / 43 ↓ Glass or Plastic shield	J	.22	.18	.15	.20	.17	.14
	I	.27	.23	.20	.25	.21	.19
	H	.30	.26	.24	.28	.25	.22
	G	.33	.30	.27	.30	.27	.25
	F	.36	.32	.29	.32	.29	.27
	E	.40	.36	.33	.36	.33	.30
	D	.43	.39	.36	.38	.36	.33
	C	.45	.41	.38	.40	.37	.36
	B	.48	.45	.42	.43	.40	.38
	A	.50	.46	.44	.45	.42	.40
26 MF = .70 ↑ 29 / 43 ↓ Open top louvered bottom	J	.23	.19	.16	.21	.17	.15
	I	.28	.24	.22	.26	.22	.20
	H	.31	.27	.25	.29	.25	.23
	G	.35	.31	.26	.31	.28	.26
	F	.38	.34	.30	.34	.30	.28
	E	.42	.38	.34	.37	.34	.31
	D	.45	.41	.37	.40	.37	.34
	C	.48	.43	.40	.42	.39	.36
	B	.51	.47	.44	.45	.41	.39
	A	.53	.49	.46	.47	.43	.41
27 MF = .65 ↑ 29 / 43 ↓ Wedge type Glass or Plastic sides	J	.23	.19	.16	.21	.17	.15
	I	.28	.24	.22	.26	.22	.20
	H	.31	.27	.25	.29	.25	.23
	G	.35	.31	.28	.31	.28	.26
	F	.38	.34	.30	.34	.30	.28
	E	.42	.38	.34	.37	.34	.31
	D	.45	.41	.37	.40	.37	.34
	C	.48	.43	.40	.42	.39	.36
	B	.51	.47	.44	.45	.41	.39
	A	.53	.49	.46	.47	.43	.41
28 MF = .70 ↑ 28 / 58 ↓ Half cylinder exposed lamps	J	.29	.25	.22	.28	.23	.21
	I	.36	.32	.29	.34	.30	.27
	H	.40	.36	.33	.38	.34	.31
	G	.45	.40	.37	.41	.37	.34
	F	.48	.43	.39	.44	.40	.37
	E	.53	.48	.44	.48	.44	.41
	D	.57	.52	.48	.52	.48	.45
	C	.60	.55	.50	.54	.50	.47
	B	.63	.59	.55	.57	.53	.51
	A	.66	.61	.58	.59	.55	.53
29 MF = .75 ↑ 33 / 48 ↓ Box type open top and bottom	J	.34	.31	.29	.31	.29	.28
	I	.41	.38	.37	.38	.36	.35
	H	.45	.43	.41	.41	.39	.38
	G	.49	.46	.45	.44	.42	.41
	F	.52	.49	.47	.46	.44	.43
	E	.55	.52	.51	.49	.48	.46
	D	.59	.55	.53	.52	.50	.49
	C	.60	.58	.55	.54	.52	.50
	B	.62	.60	.58	.55	.53	.52
	A	.64	.62	.60	.57	.55	.53

TABLE IV.—UTILIZATION FACTORS FLUORESCENT LUMINAIRES—Continued

	Ceiling	75%			80%		
	Walls	50%	30%	10%	50%	30%	10%
	Room Index	Utilization factors					
(30) MF = .75 ↑ 50 / 50 ↓ Lamps or tubes without reflector	J	0.28	0.22	0.19	0.24	0.20	0.17
	I	.35	.29	.25	.30	.26	.22
	H	.39	.33	.30	.34	.30	.26
	G	.44	.38	.34	.38	.33	.30
	F	.48	.42	.37	.41	.36	.32
	E	.53	.47	.42	.46	.41	.37
	D	.58	.52	.46	.49	.45	.41
	C	.61	.55	.50	.52	.47	.44
	B	.66	.61	.56	.56	.51	.48
	A	.69	.64	.59	.59	.54	.51
(31) MF = .70 ↑ 42 / 28 ↓ Open grid deep louvers	J	.24	.21	.20	.21	.19	.18
	I	.29	.26	.25	.25	.24	.22
	H	.32	.30	.28	.28	.26	.25
	G	.36	.33	.31	.31	.28	.27
	F	.38	.35	.33	.32	.30	.29
	E	.41	.38	.36	.35	.33	.31
	D	.44	.41	.39	.37	.35	.34
	C	.46	.43	.41	.38	.36	.35
	B	.48	.46	.44	.40	.38	.37
	A	.50	.48	.46	.42	.40	.38
(32) MF = .65 ↑ 47 / 32 ↓ Box type ribbed glass panels	J	.26	.22	.20	.22	.20	.18
	I	.31	.28	.26	.27	.24	.23
	H	.34	.32	.30	.30	.27	.26
	G	.38	.35	.32	.33	.30	.28
	F	.41	.38	.35	.35	.32	.30
	E	.45	.41	.39	.38	.35	.33
	D	.48	.44	.42	.40	.38	.36
	C	.50	.47	.44	.42	.39	.37
	B	.53	.50	.48	.44	.42	.40
	A	.55	.52	.50	.46	.43	.42
(33) MF = .60 ↑ 80 / 0 ↓ Indirect	J	.16	.12	.11	.10	.09	.07
	I	.20	.16	.14	.13	.11	.10
	H	.23	.20	.17	.15	.13	.11
	G	.27	.23	.20	.18	.15	.14
	F	.29	.25	.22	.20	.17	.15
	E	.33	.29	.26	.22	.19	.18
	D	.36	.32	.30	.24	.22	.20
	C	.39	.35	.32	.26	.23	.22
	B	.43	.40	.37	.28	.26	.25
	A	.45	.42	.39	.30	.28	.26

2–20 DESIGN ANALYSES.

a. General requirements. Design analyses required by Orders and Regulations, Corps of Engineers, chapter VII, paragraph 740.09 will be prepared to accompany all plans and specifications for interior electrical systems, including lighting, power, telephone, nurses' call, radio, intercommunication, pneumatic tube, clock, and public address systems.

b. Scope. Design criteria should include computations for design of main service equipment, emergency generator equipment, loads on panels, loads, demands, and voltage drop on feeders and branch circuits, footcandle intensities in work areas, fixture types and lamp sizes, as applicable.

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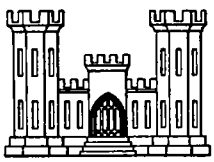
ELECTRICAL DESIGN

LIGHTNING PROTECTION SYSTEM



WAR DEPARTMENT
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

Chapter 3

LIGHTNING PROTECTION SYSTEMS

3–01 GENERAL.
3–02 STANDARDS.
3–03 INSTALLATION.
3–04 REQUIREMENTS FOR LIGHTNING PROTECTION.
3–05 LIGHTNING PROTECTION FOR BUILDINGS, SPIRES, STEEPLES, AND CONTROL TOWERS.
3–06 LIGHTNING PROTECTION FOR FLAG POLES AND WATER TANKS.
3–07 LIGHTNING PROTECTION FOR SMOKESTACKS.
3–08 LIGHTNING PROTECTION FOR CONCRETE IGLOO MAGAZINES.
3–09 LIGHTNING PROTECTION OF FENCING.

Part VI

ELECTRICAL DESIGN

Chapter 3

LIGHTNING PROTECTION SYSTEMS

3–01 GENERAL. The following instructions and information are intended to serve as a guide in determining the major requirements for lightning protection systems. Where special conditions and problems are encountered, which are not covered specifically by these instructions, good engineering practice should be followed. The grounding of metal bodies in buildings and magazines used for manufacturing, storing, packing, loading, handling, or assembling ammunition, should comply with the requirements of Ordnance Department Safety Bulletin No. 152.

3–02 STANDARDS. The current edition of the Underwriters' Laboratories, Inc., Standards for Lightning Protection Systems and the National Bureau of Standards Code for Protection against Lightning, Handbook H40 (A. S. A. Standard C5).

3–03 INSTALLATION. The criteria contained in this chapter pertain to the design of lightning protection systems. For details covering materials and installation, reference should be made to specification CE 303.9.

3–04 REQUIREMENTS FOR LIGHTNING PROTECTION. Lightning protection systems should be provided on all buildings and magazines used for manufacturing, storing, packing, loading, handling, or assembling ammunition, including bombs, fuses, primers, boosters, detonators, and pyrotechnics. Lightning protection systems should also be provided on all buildings, spires, steeples, flagpoles, control towers, water tanks, and smokestacks exceeding 50 feet in height above the surface of the adjacent ground, unless these structures are so located that damage from lightning is considered improbable.

3–05 LIGHTNING PROTECTION FOR BUILDINGS, SPIRES, STEEPLES, AND CONTROL TOWERS. Air terminals should be provided for structural parts that are likely to receive a stroke of lightning. In the case of projections such as gables, chimneys, ventilators, spires, steeples, and control towers, the air terminals should be placed on or attached to the projection, wherever practicable. Where this is not practicable, the air terminals should be located not more than 2 feet from the projection. The top of air terminals above ventilators, stacks, etc., from which explosive dusts, gases, or vapors may be emitted, should be at least 5 feet except where forced draft of such materials are encountered, in which case the height should be at least 15 feet. For all other conditions the top of air terminals should be at least 2 feet above the roof, ventilator, or other projection adjacent to the terminal, except that when the air terminal is installed on a chimney, spire, steeple, or projection of similar character and shape, the top of air terminal should be only about 1 foot above the top of the projection. All air terminals should be connected to each other by means of stranded copper cables or the steelwork of the building. Connection cables should be coursed along contours, such as ridges, parapets, and edges or flat surfaces of flat roofs. Roof conductors surrounding decks, flat surfaces, and flat roofs should be connected to form a closed loop. On buildings where the steelwork of the building is not used as a part of the lightning protection system, the air terminals should be installed at intervals not exceeding 25 feet along ridges, parapets, and edge of flat roofs. On building where the steelwork of the building is used as a part of the lightning protection system, air terminals should be installed at the highest projections for the purpose of relieving any static discharges that may accumulate in the steelwork and to lessen the possibility of damage to the roof in the event of a stroke of lightning.

a. Down conductors. Not less than two down conductors should be installed on any type of building for which lightning protection is prescribed or authorized. Down conductors should be as widely separated as practicable to provide at least two paths in parallel from each terminal to ground. This form of installation will provide a divided path for the lightning. On rectangular structures having gable,

hip, or gambrel roofs exceeding 110 feet in length, there should be at least one additional down conductor for each additional 50 feet of length or fraction thereof. Rectangular structures having mansard, flat, or sawtooth roofs and exceeding 300 feet in perimeter should be provided with at least one additional down conductor for each additional 100 feet of perimeter or fraction thereof. On L or T-shaped buildings there should be at least one additional down conductor, on H-shaped buildings at least two additional down conductors, and on buildings with wings, at least one additional down conductor for each wing. On buildings exceeding 60 feet in height, an additional down conductor should be installed for each additional 60 feet of height or fraction thereof, unless such installation would result in down conductors being less than 50 feet apart. Additional down conductors should also be installed where necessary to avoid dead ends in cable. Abrupt bends or turns in connection and down conductors should be avoided. No bend exceeding 90° or having a radius of less than 8 inches should be permitted. Steelwork having a weight of 0.4 pounds or more per foot may be used in lieu of lightning protection cables provided it forms a protective network over and down the building. All joints in steelwork members comprising the lightning protection system should be bonded to provide an adequate electrical path from the air terminals to the grounding system. All steelwork within 6 feet of these members should be bonded thereto in a manner to provide adequate and permanent electrical contact.

b. Grounding. For buildings having a perimeter at the ground line of 300 feet or less, a ¾-inch by 10 foot ground rod should be installed at the base of each down conductor approximately 3 feet out from the building wall or foundation. A stranded lightning conductor cable should be installed completely around the outside of the building approximately 2 feet below the finished grade. The ground cable should connect to all ground rods and down conductors. For buildings having a perimeter at the ground line of more than 300 feet the ground loop may be either broken into sections of cable, each connecting to at least three ground rods, or omitted and a counterpoise installed at the base of each down conductor. Counterpoise should consist of three ground rods spaced at least 6 feet apart and connected together and to down conductor with stranded lighting conductor cable. Floor reinforcing bars should be wrapped, welded or otherwise bonded at intervals not exceeding 5 feet both ways in a manner to provide continuous electrical path to ground. In the case of welded mesh reinforcement, adjacent overlapping sections should be wrapped, welded, or otherwise bonded for this purpose.

3–06 Lightning Protection for Flagpoles and Water Tanks. Nonmetallic flagpoles and water tanks exceeding 50 feet in height should be provided with one air terminal projecting approximately 10 inches above the top of pole or tank. Two down conductors should be extended to the base of the flagpole or tank structure and should be connected to a counterpoise consisting of three ground rods located not less than 6 feet apart and connected to each other by means of stranded lightning conductor cable. Tops of rods and ground cable should be not less than 2 feet below finished grade. For flagpoles and water tanks made of metallic material the air terminal and down conductor should be omitted and the base of the pole or tank structure connected to the counterpoise.

3–07 Lightning Protection for Smokestacks. Nonmetallic smokestacks exceeding 50 feet in height should have air terminals uniformly distributed about the rim of the stack at intervals not exceeding 8 feet. In no case should the number of air terminals be less than two. The air terminals should project at least 30 inches above the rim of the stack. The bottom of the air terminals should be connected together by means of a closed loop of lightning conductor cable located approximately 2 feet below the top of the stack. Two down conductors should be installed. Down conductors should be located on opposite sides of the stack. On stacks exceeding 160 feet in height the down conductors should be cross-connected about midway between the top and bottom of the stack. Where stacks have a metal lining extending part way up the lining should be connected to the down conductor at its upper end and grounded at the bottom. A ¾-inch by 10-foot ground rod should be installed at the base of each down conductor approximately 2 feet out from the stack foundation. A stranded lightning conductor cable should be installed completely around the base of stack approximately 2 feet below the

finished grade. The ground cable should connect to both ground rods and down conductors. For metallic stacks the air terminals and down conductors should be omitted. All metallic stack guys should be grounded. Metallic stacks should be effectively grounded.

3–08 LIGHTNING PROTECTION FOR CONCRETE IGLOO MAGAZINES. Lightning protection systems for concrete igloo magazines should be installed as follows:

a. At 5-foot intervals along the barrel the extrados barrel reinforcement should be welded to the floor reinforcement to form a continuous ring of reinforcement transversely around the storage space. Where lap splices occur in either the extrados barrel reinforcement or the wire fabric floor reinforcement forming the 5-foot intervals, the lap splice should have at least one welded joint. At 6-foot intervals over the barrel, the extrados barrel longitudinal distribution rods should be welded to the head and end wall reinforcement and the head and end wall reinforcement welded to the floor reinforcement to form a continuous ring of reinforcement longitudinally around the storage space. Where these two reinforcement rings cross they should be welded to form a complete and permanent electrically connected cage of reinforcement around the storage space. Each separate piece of wire fabric near the outside face of the end walls should have at least one welded connection to adjacent pieces. This wire fabric should have at least one welded connection to the end ring of the rings of reinforcement described above. The steel door frame should be welded to the wire fabric reinforcement near the outside face of the head wall.

b. At 20-foot intervals along the barrel, there should be connected to every fourth ring of the rings of reinforcement described above, an air terminal extending vertically 6 feet above the reinforcement through the concrete. Approximately 2 feet from each corner of the structure, a ¾-inch ground rod 10 feet in length should be installed and connected by lightning conductor cable to the reinforcement near the outside of the end walls of the structure or to the end ring of the rings of reinforcement described above. A lightning conductor cable should be installed completely around the magazine about 2 feet below finished floor or finished grade, whichever is the lower, and should be connected to each ground rod. Not less than four ground rods, located at the corners, should be installed for any underground magazine.

3–09 LIGHTNING PROTECTION OF FENCING. Metallic fencing in general should not be grounded unless constructed adjacent to or under electric power lines or where the length exceeds approximately 3,000 feet. When grounding is required, grounds should be installed on each side of each gate, at points approximately 150 feet on each side of the power line crossing and at intervals of not more than 1,500 feet. If the fence consists of wood posts and horizontal metal strands only, down conductors should be run the full height of the fence and securely fastened to each wire to be electrically continuous. If the fence is a chain link fence and the wires are electrically continuous, the connection to ground should be made from the bottom strand or from the post, if it is of metal and is electrically continuous with the fencing.

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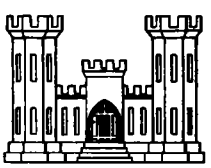
WATER SUPPLY

STERILIZATION OF WATER SUPPLY SYSTEMS



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APPENDIX "A"

STERILIZATION OF WATER SUPPLY SYSTEMS

1. GENERAL - In the construction of water mains, wells, filters, storage tanks and other units of a water supply system, there is danger of contamination resulting from the introduction of harmful bacteria. Flushing the system to remove dirt, waste and surface water which may be introduced during construction will be of value but is not a sufficient safeguard. In order that a safe supply of water be assured, each unit of the system should be thoroughly sterilized before it is placed in operation.

2 MATERIALS - Sterilizing the various units of a water supply system is readily accomplished by using chlorine. The agent is commercially available as liquid chlorine, liquid (sodium) hypochlorite, chlorinated lime (bleaching powder), or high test (dry) calcium hypochlorite. Uniform concentrated solutions of chlorinated lime and calcium hypochlorite are easily prepared by mixing with water. This is often desired to facilitate the measurement and application of the material.

3 AVAILABLE CHLORINE - The sterilizing power of chlorine compounds is measured by the oxygen releasing value of the chlorine, often referred to as the available chlorine. In liquid chlorine, the amount of available chlorine is one hundred percent (100%). In commercial hypochlorites, the amount of available chlorine is usually indicated on the container in percent by weight, but in general, corresponds to the following:

Liquid Chlorine	- 100%	Liquid Hypochlorite	- 10%
Calcium Hypochlorite	- 70%	Chlorinated Lime	- 35%

4 SPECIFICATIONS - The materials used for sterilizing various units of a water supply system shall conform to the following Federal or U. S. Army Specifications:

a. Chlorine - Liquid chlorine shall conform to U. S. Army Specification No. 4-1A, dated 14 January 1938.

b. Hypochlorite - Liquid hypochlorite, chlorinated lime and calcium hypochlorite shall conform to Federal Specification No. 0-B-441 or latest revision thereof.

5 APPLICATION - The method used for applying the chlorine to the various parts of the water supply system will depend upon local conditions. In general, the method selected should allow accurate measurement of the chlorine, insure a uniform mixture and allow sufficient time of contact with the surfaces of the unit being sterilized. The form in which the chlorine is available will also be a factor in determining the method used.

a. Liquid Chlorine - Liquid chlorine, in equipment designed for this purpose, can be measured and applied either as a water solution or direct in gaseous form. The solution feed method may be used if water pressures are available to operate the injector. Direct feed can be applied to open or gravity systems.

b. Liquid Hypochlorite - Liquid hypochlorite may be applied by means of measuring pumps, gravity feed mechanisms, or directly into the suction of a water supply or booster pump. There are several simple homemade devices which, in emergency, can be used for applying liquid hypochlorite solutions. In one method, the hypochlorite solution is mixed in a barrel or small storage tank

and discharged through a hose. Various devices to provide a uniform rate of discharge are available, making use of float operated valves, constant head or variable orifice principle.

c. Dry Hypochlorite - Dry hypochlorite may be applied direct as a powder to the unit to be sterilized. Dry powder may be placed in supply mains as they are laid or in storage tanks and filters to be sterilized. When these units are filled with water, the hypochlorite will be taken in solution. This is a very crude method for applying a sterilizing agent, but is sometimes necessary in the emergency of construction. Since uniform mixtures are difficult to obtain in this manner, it is recommended that excess dosages be applied to insure thorough sterilizing action.

6. DOSAGE CALCULATIONS

a. Chlorine Required - The amount of chlorine required to thoroughly sterilize any unit of a water supply system depends upon the thoroughness of mixing, the time of contact allowed, and the presence or absence of chlorine consuming material such as dirt, mud or algae. In general, if average conditions exist, the following minimum dosages are recommended:

Pipe System	- 50 ppm	Filters	- 100 ppm
Storage Tanks	- 50 ppm	Wells	- 150 ppm

b. Capacity of Pipes - In estimating the amount of chlorine solution required for treatment, the volume of water contained in that portion of the supply main, distribution system or other unit to be sterilized, is computed. The volume in cubic feet is readily converted to gallons by applying factor 1 cu. ft. - 7.5 gallons. In the following table is tabulated the capacity in gallons for various size standard pipe:

Pipe Size Inside Diameter In Inches	Volume Capacity of 1,000 Foot Lengths Gallons
4	653
6	1,469
8	2,611
10	4,081
12	5,876
14	7,997
16	10,440
20	16,320
24	23,500
30	36,720
36	52,880
42	71,960
48	94,020

c. Treating Solution - The treatment can best be accomplished by preparing a strong treating solution of known strength and calculating the amount of such solution required for the desired treatment. A five percent (5%) chlorine colution, equivalent to a chlorine concentration of 50,000 p.p.m., is a convenient treating solution for such use. One gallon of treating solution having a chlorine concentration of 50,000 p.p.m., may be prepared with various strength commer-

cial compounds, as follows:

Weight of Chlorine Compound Required to Make One Gallon of Treating Solution Containing 50,000 ppm of Available Chlorine

Liquid Chlorine (100% available chlorine)	0.4165 lbs.
Calcium Hypochlorite (70% available chlorine)	0.5950 lbs.
Chlorinated Lime (35% available chlorine)	1.19 lbs.
Liquid Hypochlorite (10% available chlorine)	4.165 lbs.

NOTE: The amount of treating solution containing 50,000 p.p.m. available chlorine required to treat a given quantity of water to the required dosage, may be calculated as follows:

$$\frac{\text{Gallons of water to be treated} \times \text{p.p.m. chlorine dosage}}{50{,}000} = \text{gallons treating solution required}$$

7. METHODS - The unit to be sterilized should be thoroughly flushed with water until all entrained dirt and mud has been removed, then the sterilizing agent in some easily applied form should be admitted into the unit and allowed to stand for a sufficient contact period. In detail, the methods of application are as follows:

a. Supply Mains - Supply Mains may be sterilized by introducting small measured quantities of hypochlorite into each length of pipe as the line is laid. After completion, the total line or a section between valves is filled slowly with water. Following a contact period of six (6) to eight (8) hours, the line is then flushed with clean water until the residual chlorine is reduced to less than 0.2 p.p.m. In this method, uniform mixing of the hypochlorite with water is difficult, and for this reason, high dosages and long contact time should be used. A better method involves the introduction of the proper quantities of strong hypochlorite solution at various points in the completed pipe line by means of corporation cocks. The line is then treated as described above. The most desirable method of sterilizing water mains is accomplished by introducting a hypochlorite solution into the suction or discharge of a pump using one of the arrangements previously described. If a pump or pressure feeder is not available and the mains are to be filled by pressure from an elevated storage tank, an injector may be used. If the latter method is employed, it will usually be necessary to measure or estimate the rate of flow by metering or by observing the time required to fill the known volume of the main on a trial run. Tests should then be made to determine the injector suction required under the existing conditions to feed the desired quantities of chlorine.

b. Distribution Systems - Distribution Systems may be sterilized by methods similar to those described for treating supply mains. In construction of new systems, the chlorine or hypochlorite may be mixed with water in the elevated storage tank or in the storage reservoir from which that portion of the distribution system to be sterilized may be filled. Water from the elevated storage tank will flow by gravity into the system and from storage reservoirs it may be pumped with booster pumps. Large distribution systems should be sterilized in sections, and the valves should be set to provide maxi-

mum circulation of the chlorine solution being introduced into the system. All valves should be opened and closed several times while the solution is in the mains.

c. Wells - In sterilizing newly constructed wells, the following method may be used. The total volume of water in the well is estimated and from this is calculated the required amount of chlorine to secure the proper dosage strength. Hypochlorite, in solution form, may be introduced directly into the well by using gravity, pump or drip feeders. Dry hypochlorite may be introduced and thoroughly mixed with the water in the well by using the bailer, if the drilling equipment is still available. After chlorine has been added and allowed to stand for a contact period of twenty-four (24) hours, the well is pumped to waste until the residual chlorine is less than 0.2 p.p.m., or until there is no objectionable odor of chlorine.

d. Filters - In the sterilization of newly constructed filter units, the following methods will apply. Filter unit is thoroughly back-washed and the water level lowered to within two (2) feet of the sand surface, the estimated quantity of hypochlorite is applied to the water surface and the water level lowered to within two (2) inches of the top of the sand and permitted to remain in contact for a period of at least eight (8) hours. The filter is then washed to waste until tests of the water show a residual chlorine not more than 0.2 p.p.m. The filter is then placed in service. As an added precaution, dry hypochlorite may be introduced into the sandbed in layers as the sand is placed in the filter unit. This method will insure a more thorough mixing and better contact with the surface to be sterilized. Liquid chlorine or hypochlorite may also be introduced to the filter unit at the suction or discharge of the back-wash or supply pump.

e. Storage Tanks - Reservoirs, standpipes or elevated storage tanks may be sterilized by methods similar to those used in treating filter units. In small tanks and reservoirs the estimated quantity of chlorine may be introduced to the water by one of the methods previously described and allowed to stand for a contact time of at least eigth (8) hours, after which the tank is thoroughly flushed with clean water until the residual chlorine is reduced to less than 0.2 p.p.m. In very large reservoirs and storage tanks the surface of the walls, floors, and other parts that come in contact with stored water may be thoroughly sterilized by washing or spraying with a strong solution of hypochlorite. The hypochlorite solution used should contain at least 300 p.p.m. of available chlorine and may be applied with a brush or pressure spray. A period of from two (2) to four (4) hours should elapse after application before the reservoir is flushed and placed in service.

8. TESTS FOR RESIDUAL CHLORINE

a. Orthotolidine Test - After the sterilizing agent has been allowed to stand for a sufficient contact period, the unit or portion of the pipe system is thoroughly flushed with water until the residual chlorine tests less than 0.2 p.p.m. A qualitative determination of the amount of chlorine remaining in the water can be accomplished by using orthotolidine as a testing reagent. A sample of the water to be tested is placed in the small test tube to which is added four (4) to five (5) drops of orthotolidine solution. The presence of a strong yellow color indicates a high chlorine residual. If no

color is developed, or if the color is a very faint pale yellow, the chlorine content will be less than 0.2 p.p.m. Test kits for making the standard orthotolidine test for residual chlorine test may be obtained from laboratory supply companies.

b. Test Solution - The orthotolidine test solution is made as follows: Dissolve one (1) gram orthotolidine (m.p. 129°C.) to a total volume of 1,000 ml. by grinding the orthotolidine to a thin paste with 5 ml. of 1:5 HCl in a six (6) inch mortar and then adding one hundred and fifty (150) to two hundred (200) ml. of distilled water. Solution is immediate. The strong solution is washed with distilled water into a 1,000 ml. graduate and brought with distilled water to a total volume of 505 ml., after which 495 ml. of 1:5 are added, making the total volume 1,000 ml.

9. BACTERIAL TESTS - After any given unit or portion of the water supply system has been sterilized and the system has been thoroughly flushed, with fresh water until the chlorine has been removed, samples of the water from several points in the system shall be taken in properly sterilized containers and shall be subjected to bacterial examination. If the supply is known to be of good quality and repeated tests of the samples show the presence of coliform organisms, the sterilizing shall be repeated or continued until tests indicate the absence of pollution. The bacterial examination shall be completed before any unit or portion of the system is placed in operation. Samples may be submitted to local State Boards of Health or to commercial testing laboratories if complete bacterial testing facilities are not available.

F.PTG.P. 1063 GCED. 13-4-46-2M

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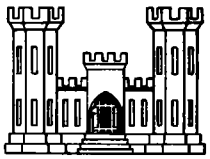
PART VII
APPX. B
FEB. '46

Housing and Home Finance Agency
Office of the Administrator
LIBRARY

WATER SUPPLY

LABORATORY FURNITURE, APPARATUS AND SUPPLIES FOR WATER INFILTRATION PLANTS



ARMY SERVICE FORCES
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

APPENDIX "B"

LABORATORY FURNITURE, APPARATUS AND SUPPLIES FOR WATER FILTRATION PLANTS

1. GENERAL - The following Schedule of Laboratory Furniture, Apparatus and Supplies has been prepared for the various types of Water Filtration Plants, as follows:
   a. Class "A" Plants - Filtration plants serving a population of over 10,000 or treating surface water taken from a polluted source where complete control is required for the operation of the plant. The laboratory equipment provided will permit routine chemical and bacteriological analyses, as well as microscopic examinations.
   b. Class "B" Plants - Filtration plants taking water from a slightly polluted source or from wells where softening or iron removal is required. The laboratory equipment provided will permit routine chemical control tests, bacteriological tests for coli-form organisms and total plate counts.
   c. Class "C" Plants - Plants where chlorination only is provided to insure the bacteriological quality of the supply. The laboratory equipment will permit routine residual chlorine, pH and alkalinity determinations only. The list of Laboratory Furniture and Apparatus is considered to be the minimum required. The equipment listed is complete in itself with all necessary details and accessories.
2. LABORATORY FURNITURE - The following list of laboratory furniture includes those items required in Class "A" and "B" plants. It is the intention that this equipment will meet the minimum requirements for laboratory furniture. However, discretion should be exercised in selecting furniture that will fit the space requirements in the laboratory and harmonize with other facilities. It is recommended that the several units be purchased ready-made, as this type is preferable to built-in furniture. The equipment listed is complete in itself with all necessary details and accessories and the items listed are standard with at least three manufacturers. The tops of the table and the benches are of specially treated materials to resist the action of the chemicals. The furniture required is as follows:

   Item 1. One (1) Laboratory Table of oak, approximately 6'-0" long, 32" deep and 36" high. Table shall be fitted with a maple bottle rack with acid resisting back; rack shall be approximately 60" x 8" x 18". Peg board over sink, 14" x 19½", shall be fitted with 16 pegs. Table top shall be fitted with a lead lined (4 lbs. per square foot) trough, approximately 66" x 4" x approximately 6" at deep end properly pitched to drain. All joints shall be burned with pure lead; soldering not permitted. Sink with back at end of table 14" x 18" x 12" mounted on tubular stand shall be of 1¼" selected soapstone. Sink shall have 2" lead "p" trap; for connection see plumbing. Cabinet supporting frame shall be mortised and tenoned, glued and reinforced with bolts. Drawers shall be dovetailed, doors shall be built up and shall have suitable pulls, catches and hinges. The cabinet

shall be equipped with two long drawers at top, four intermediate drawers and two cupboards. Cupboards shall be fitted with two adjustable removable shelves. Top shall be of Shellstone or approved acid resisting material. Equipment shall have two compression hose bibs over sink for hot and cold water; three straight-way water cocks with hose connection over trough; and ½" pipe conduit with two duplex receptacles with "T" slots, mounted in cast metal conduit fittings. Connections shall be made to floor outlets. All service lines shall be carried to floor with shut-off for each line. Finish for all exposed steel and service piping shall be acid and alkali resisting enamel. Table shall be type #16560 as manufactured by E. H. Sheldon and Company, Muskegon, Michigan or a similar table as manufactured by W. W. Kimball Company, Chicago, Illinois, or Hamilton Mfg. Co., Two Rivers, Wisconsin.

Item 2. One (1) Balance Shelf, 3' long x 2' wide; oak construction, except for 1-5/8" thick birch, black cartonized top; equipped with drawer 21" wide, 15" deep, 3-3/4" high. Shelf to be equivalent to

E. H. Sheldon & Co. - No. 12520
W. W. Kimball Co. - No. 682
Hamilton Mfg. Co. - No. L-1174

Item 3. One (1) Supply Case, 48" wide, 15" deep, 80" high, upper section glazed 44" wide, 60" high with 3 adjustable shelves; cupboard shelves; cupboard section 44" wide, 12" deep, 13" high, of oak.

E. H. Sheldon & Co. - No. 41040
W. W. Kimball Co. - No. 9562
Hamilton Mfg. Co. -

Item 4. One (1) Lower Section Cupboard Unit 37-5/8" long x 24" wide x 36" high containing 1 double cupboard 34" wide x 28¼" high x 20-5/8" deep, with 1 stone sink 14¼" long x 10" wide x 8" deep with 1 set of drain fittings, 1 cold water pantry cock and 1 double electric receptacle for 110-V A.C., table top to be scored to drain to sink.

E. H. Sheldon & Co. -
W. W. Kimball Co. -
Hamilton Mfg. Co. - No. L-804

All furniture shall be oak construction, natural finish throughout except table tops which are to be 1-5/8" birch black carbonized.

Item 5. In laboratories for Class "C" plants, the furniture to be provided shall consist of a work table at least 48" long x 36" wide and 30" high, together with a wall cabinet fitted with doors. The cabinet shall be of adequate size to house equipment and chemicals required for a Class "C" Laboratory. These items need not be of special laboratory construction, as kitchen type or built-in-place furniture will suffice. A laboratory sink should be provided convenient to the work table.

3. LABORATORY APPARATUS - The following list of laboratory apparatus includes those items required in Class A, B and C Plants:

LABORATORY APPARATUS

QUANTITY Type of Plant A	B	C	DESCRIPTION	CATALOG NUMBERS Central Scientific Co.	C. H. Sargent Co.	Fisher Scientific Co.
1	1		Balance, analytical, student model, chain type	1020	S-2675	1-905
1	1		Balance Cover, rubberized cloth, for above	2020	S-3965	1-990
1	1		Set Balance Weights, Class S, 100 mg. to 100 gm.	8171-B	S-4075	2-220
1	1	1	Harvard Trip Scale Balance	3470	S-3215	2-035
1	1	1	Set Balance Weights 1 to 500 grams	9140	S-4285	2-300
1	1		37°C Electric Incubator	46000-A	S-43505-2	11-690-11
1	1		Small Refrigerator			
1	1	1	Two Burner Hotplate Gas	16685	S-41475-A	4-220
1a	1a	1a	Hotplate Electric, 12" x 18" , 3-heat	16650	S-41125	11-500
1	1		Sterilizer Oven, Gas	48242-A	S-76285-A	14-490-A
1a	1a		Sterilizer Oven, Electric, 3-heat	48210	S-76265-A	
1	1		Pressure Sterilizer, 11" x 24", Gas	44120-A	S-76025-A	14-470-A
1a	1a		Pressure Sterilizer, Electric, 11" x 24"	44120-A	S-76005	14-470-A
1			Electric Muffle Furnace, Hoskins Type FD	13675-A	S-36855 Size #202	10-510 Size #202
1	1		Jackson Turbidimeter	29105	S-83705	15-380
1	1		Water Still - Capacity 1 gal. per hour, Gas heated	12760-A	S-27465	9-090
1a	1a		Water Still - Capacity 1 gal. per hour, Electric heated	12750-A	S-27415	9-080
12	12	6	Wide-mouth Bottles, Glass stoppered, 30-32 ounces	10450	S-8395	2-910
18	18		Wide-mouth Bottles, glass stoppered, 125 ml.	10450	S-8395	2-910
6			Dropping Bottles, 30 ml.	10580	S-8785	3-000
6	6	3	Dropping Bottles, 60 ml.	10580	S-8785	3-000
2	2	2	Wash Bottles, 1000 ml.	10710	S-9365	3-395
2	2		Pyrex Bottles for distilled water, 2½ gallons	10480	S-8475	
4	2	2	Cylinders, double graduated, 100 ml.	16125	S-24695	8-555
2	1		Cylinders, double graduated, 500 ml.	16125	S-24695	8-555
2	1		Cylinders, double graduated, 1000 ml.	16125	S-24695	8-555
1	1		Volumetric Flasks, vial mouth, and stoppers, 50 ml.	16226	S-34845	10-205
2	1		Volumetric Flasks, vial mouth, and stoppers, 100 ml.	16226	S-34845	10-205

LABORATORY APPARATUS

QUANTITY Type of Plant			DESCRIPTION	CATALOG NUMBERS		
A	B	C		Central Scientific Co.	C. H. Sargent Co.	Fisher Scientific Co.
2	1		Volumetric Flasks, vial mouth, and stoppers, 250 ml.	16226	S-34845	10-205
2			Volumetric Flasks, vial mouth, and stoppers, 500 ml.	16226	S-34845	10-205
1	1		Volumetric Flasks, vial mouth, and stoppers, 1000 ml.	16226	S-34845	10-205
24	24	6	Erlenmeyer Flasks, Pyrex, 250 ml.	14905	S-34105	10-040
6	6	4	Erlenmeyer Flasks, Pyrex, 500 ml.	14905	S-34105	10-040
2	2		Erlenmeyer Flasks, Pyrex, 1000 ml.	14905	S-34105	10-040
4	2		Beakers, Pyrex, 50 ml.	14265	S-4675	2-540
4	2		Beakers, Pyrex, 150 ml.	14265	S-4675	2-540
12	6	4	Beakers, Pyrex, 250 ml.	14265	S-4675	2-540
4	2		Beakers, Pyrex, 400 ml.	14265	S-4675	2-540
6	2		Beakers, Pyrex, 600 ml.	14265	S-4675	2-540
12	4	2	Beaker Covers, 3½ inches	15850	S-83605	2-610
1			Filtering Flask, 500 ml.	14985	S-34375	10-175
2			Filtering Crucibles, Alundum, RA360, 25 ml.	10065-A	S-24375	8-230
2			Rubber Crucible, Holder	18110	S-24475	8-285
2	2		Funnels, 100 m.m. diam.	15070	S-35305	10-320
4	2		Funnels, 65 m.m. diam.	15070	S-35305	10-320
2	2	2	Funnels, long stem, 100 m.m. diam.	15050	S-35315	10-325
12	12		Nessler Tubes, 100 ml. marked at 50 ml.	29060-C	S-21035	7-055
4	4	2	Burettes, graduated in 0.1 ml., 50 ml.	15926-C	S-10635	3-740
2	2		Burettes, graduated in 0.1 ml.. 25 ml.	15926-B	S-10635	3-740
4	4	1	Pipettes, Volumetric, Exax blue line, 1 ml.	16355	S-69515	13-650
4	4		Pipettes, Volumetric, Exax blue line, 5 ml.	16355	S-69515	13-650
4	4		Pipettes, Volumetric, Exax blue line, 10 ml.	16355	S-69515	13-650
3	2	1	Pipettes, Volumetric, Exax blue line, 25 ml.	16355	S-69515	13-650
3	2	1	Pipettes, Volumetric, Exax blue line, 50 ml.	16355	S-69515	13-650
1	1	1	Thermometer, Centigrade, -5° to 250°	19240-D	S-80005	14-985
1	1		Watch Glasses, counter poised, (pair) 2½ in. dia.	2250-A	S-3785	2-195
2	2	2	Absorption Tube, to hold soda lime	755-A	S-28815	9-215
1			Dessicator, 250 m.m. dia.	14550	S-25085	8-615
6	4	2	Evaporating Dishes, porcelain 75 m.m.	18575	S-25505	8-690

LABORATORY APPARATUS

QUANTITY Type of Plant A	B	C	DESCRIPTION	CATALOG NUMBERS Central Scientific Co.	C. H. Sargent Co.	Fisher Scientific Co.
4	2		Evaporating Dishes, porcelain 90 m.m.	18575	S-25505	8-690
1	1		Pipette Stand	19120	S-78905	14-745
1	1		Burette Support, Medium	19080	S-78335	14-675
1	1		Burette Clamp, steel	12116	S-19105	5-780
1	1		Gas Burner, Mecker or Fisher	11105	S-12195	3-900
2	2	1	Gas Burner, Bunsen, Tirrill Type	11026-A	S-12295	3-960
2	2	1	Stone Jars for waste, 2 gallon	16925-B	S-43945	11-845
4	2		Pinchcocks, Mohr, 2½ inches	12186	S-19495	5-855
2	2	1	Clamps, test tube	12155	S-19555	5-840
1			Spoon, Horn	18775-C	S-75175	14-425
1	1		Spatula, Stainless Steel, 4" blade	18755-B	S-75245	14-365
1			Filter Pump Aspirator		S-33575-A	9-965
2	1	1	File, Triangular, 6"	88325	S-32235	9-725
1	1	1	Funnel Support, Hardwood	19035	S-78815	14-740
1	1	1	Iron Ring Stand; 3 rings, 3", 4", 5"	19072-B	S-78365	14-680
1	1		Nessler Tube Stand	29070-B	S-21075	7-065
2	2	1	Wire Gauze, 4"	19970-A	S-85335	15-590
2	2	1	Triangles, 2½"	19735-C	S-82415-C	15-280
2	2		Tripod with concentric rings	19775-B	S-82515-B	15-305
2	2	1	Tongs, 9"	19600	S-82115	15-200
2	1		Camels Hair Brush, Medium	10938-A	S-9725	3-655
2	2	2	Brushes, flask	10985-B	S-9965-B	3-570
2	2	2	Brushes, tube	10970	S-9985	3-575
2	2	2	Brushes, tube	10974	S-10005	3-635
12			Vacuum Tubing, 1/4" bore, (feet)	18204-C	S-73525	14-165
24	24	12	Rubber Tubing, 1/4" bore (feet)	18202-C	S-73515	14-160
12	12	6	Rubber Tubing, 1/8" bore, (feet)	18250-A	S-73565	
1	1	1	Corks, bags of assorted sizes, 3 to 16	12404	S-23075	7-785
1	1	1	Cork Borer, size 5 to 11 m.m. (set)	12465-B	S-23175	7-845
1	1	1	Rubber Stoppers, assorted (pounds)	18153-A	S-73305	14-130
4	4	2	Filter Paper, 9 c.m. (boxes)	13250	S-32915	9-795
2	2	1	Filter Paper, 12.5 c.m. (boxes)	13250	S-32915	9-795
1	1		Filter Paper, Quantitative, 9 c.m. (box)	13355	S-32785	9-915
12	6	2	Glass Marking Pencils	14015-C	S-65765	13-380
			HYDROGEN ION COMPARATORS			
1	1	1	Hellige Comparator, Pocket Model, 4.0/5.6	21409-C	S-41765-E	
1	1	1	Additional disc, pH Range 5.2/6.8 Chlorphenol Red	21451-E	S-41775-H	
1	1	1	Additional disc, pH Range 6.0/7.6 Bromthymol Blue	21451-F	S-41775-I	

LABORATORY APPARATUS

QUANTITY Type of Plant A	B	C	DESCRIPTION	CATALOG NUMBERS Central Scientific Co.	C. H. Sargent Co.	Fisher Scientific Co.
1	1	1	Additional disc, pH Range 6.8/8.4 Phenol Red	21451-G	S-41775-K	
1	1	1	Additional disc, pH Range 8.0/9.6 Thymol Blue	21451-H	S-41775-M	
1	1	1	Chlorine II, 0.1-1.0 ppm	29175-J		
1a	1a	1a	LaMotte Block Comparator, pH Range, 3.8/5.4 Bromcreosol Green	21500-E	S-41725-E	
1a	1a	1a	LaMotte Block Comparator, pH Range, 5.2/6.8 Chlorphenol Red	21500-G	S-41725-G	
1a	1a	1a	LaMotte Block Comparator, pH Range, 6.0/7.6 Bromthymol Blue	21500-H	S-41725-H	
1a	1a	1a	LaMotte Block Comparator, pH Range, 7.2/8.8 Cresol Red	21500-K	S-41725-K	
1a	1a	1a	LaMotte Block Comparator, pH Range, 8.0/9.6 Thymol Blue	21500-L	S-41725-L	
1a	1a	1a	Enslow Chlorine Comparator, LaMotte 0.05-0.1-0.2-0.5-0.8-1.0 ppm	29255		
			BACTERIOLOGICAL			
1			Microscope, Monocular, Bausch & Lomb	51050-B8	S-52085-H8	12-315-FFS-10
24	24		Pipettes, 1.1 ml. capacity graduated at 1.0 ml.	24115-B	S-60025	
24	24		Pipettes, 11 ml. capacity, graduated at 10 ml.	24115-H	S-60045	
30	30		Culture Dishes with Covers, 100 m.m. x 15 m.m.	44370-D	S-25925-B	8-755
1	1		Culture Tubes, large, 7" x 7/8" (Gross)	44500-K	S-79525	
1	1		Vials for large culture tubes (Gross)	44500-K	S-79525	
1	1		Culture Tubes, small, 6" x 3/4" (Gross)	44500-J	S-79525	
1	1		Vials for small culture tubes (Gross)	44500-J	S-79525	
1	1		Thermometer, Centigrade, 0° to 110°	19255-A	S-80305	14-985
1			Glass Slides, 25 m.m. x 75 m.m. (Gross)	66310	S-58785	12-550
1			Cover Slips (Gross)	66510-A	S-58715	15-520
1			Lens, Reading Glass - 4"	60410-D	S-44495-C	12-070
1	1		Counter, Tallying Machine	73320	S-23285	7-905
1	1		Counting Apparatus		S-23395	7-925
2	2		Culture Dish Holder	44400	S-26055	8-775
2	2		Pipette Sterilizing Boxes, Copper, 2½" x 16"	46670-B	S-69815	3-465

LABORATORY APPARATUS

QUANTITY Type of Plant A	B	C	DESCRIPTION	CATALOG NUMBERS Central Scientific Co.	C. H. Sargent Co.	Fisher Scientific Co.
2	2		Test Tube Support	19200-A	S-79005	14-770
4	4		Test Tube Basket	48515-B	S-79835	14-970
1	1		Double Boiler, 2 qts.	12970	S-8215	2-750
1			Inoculating Needle Holder	46220	S-62765	13-090
1			Forceps, Cover Glass, Cornet	66600	S-35225	10-305
1			Inoculating Needles, (24 B & S Gauge) (Package), Chromel	46210	S-62755	13-095
1			Lens Paper (quire)	12290	S-44325	11-995
			MICROSCOPICAL			
1			Sedgewick Rafter Filter	29032	S-84005	15-405
24			Cloth Disks to support filter sand	29034	S-84025	15-415
1			Counting Cell	29035	S-84045	15-425
12			Cover Glass	29036	S-84055	15-430
1			Eye Piece Micrometer Disc, Whipple	29037	S-84065	15-435
			BOOKS			
1	1	1	Standard Methods of Water Analysis, Latest Edition, A.P.H.A. and A.W.W.A.			
1	1	1	Laboratory Manual for Chemical and Bacteriological Analysis of Water and Sewage -- Eldridge, Theroux and Mallman, Latest Edition, McGraw Hill Co.			

NOTE: 1a, Alternate Item

STANDARD SOLUTION FOR WATER ANALYSIS ACCORDING TO AMERICAN PUBLIC HEALTH ASSOCIATION STANDARD METHODS OF WATER ANALYSIS, EIGHTH EDITION, 1936

Platinum-Cobalt Standard, Color 500.	200 ml.
Standard Calcium Chloride Solution	500 ml.
Standard Soap Solution	1000 ml.
Standard Ferric Iron Solution.	500 ml.
Standard Silver Nitrate.	500 ml.
Soda Reagent	1000 ml.
Acid Sulphuric, N/50 Solution.	1000 ml.
Sodium Hydroxide, N/50 Solution.	500 ml.
Sodium Hydroxide, N/44 Solution.	500 ml.
Potassium Thiocyanate.	500 ml.
Acid Hydrochloric Dilute, Approximately 3 N.	500 ml.
Potassium Permanganate, Approximately N/5.	500 ml.
Acid Nitric, 6N Solution	500 ml.
Methyl Orange Indicator.	500 ml.
Phenolphthalein Indicator.	500 ml.
Erythrosine Indicator.	500 ml.
Potassium Chromate Indicator	100 ml.
Orthotolidine Indicator.	500 ml.
Sodium-meta-arsenite 0.5% Solution	500 ml.

CULTURE MEDIA FORMULAE OF "STANDARD METHODS OF WATER ANALYSIS"

Bacto-Nutrient Agar, Dehydrated	1 lb.
Bacto-Lactose Broth, Dehydrated	1 lb.
Levine's-Eosin Methylene Blue Agar, Difco	¼ lb.

BACTERIOLOGICAL STAINING SOLUTIONS ACCORDING TO "STANDARD METHODS OF WATER ANALYSIS"

Bismark Brown.	¼ lb.
Carbol Fuchsin	¼ lb.
Carbol Gentian Violet.	¼ lb.
Gram's Iodine Stain.	¼ lb.
Methylene Blue, Koch's	¼ lb.
Safranin Stain	¼ lb.
Potassium Iodine	½ lb.

NOTE: For Class A plants chemicals should be bought in bulk and standard solutions and reagents prepared by the Plant Chemist. In many instances this may apply to Class B Plants.

F.PTG.P. 1064 GCED-13-4-46-2M

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ENGINEERING MANUAL
FOR WAR DEPARTMENT CONSTRUCTION

PART VII
APPX. C
FEB. '46

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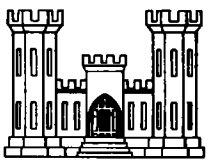
WATER SUPPLY

TYPICAL DESIGN ANALYSES FOR WATER SUPPLY SYSTEMS



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APPENDIX "C"

TYPICAL DESIGN ANALYSES FOR WATER SUPPLY SYSTEMS

The following typical design analyses illustrate the application of capacity factors, per capita allowances, domestic requirements, fire demands, etc. in determining capacity of various components entering into the design of the water supply systems.

1. EXAMPLE NO. 1:

Prisoner of War Camp with authorized population of twenty-five hundred (2,500) (including guards, etc.), Theater of Operations Type Construction, water from wells which are expected to yield one hundred and fifty (150) g.p.m. each and water requires no treatment except chlorination.

a. Required Demand and Fire Flow.
Authorized population = 2500; capacity factor = 1.5
Design population = 2500 x 1.5 = 3750
Per capita allowance = 70 gallons per day
3750 x 70 = 262,500 gallons per day = 182 g.p.m. average rate
Fire flow = 750 g.p.m. for 2 hours

b. Well Requirements.
Not less than two (2) wells are required to deliver the required demand in sixteen (16) hours. $182 \times \frac{3}{2} = 243$ g.p.m. total well yield. Therefore, two (2) wells each equipped with pumps delivering 125 to 150 g.p.m. will be satisfactory. Both pumps should have electric motor drive and one pump should also be gasoline engine driven.

c. Storage Requirements.
Domestic requirement = 50% of 262,500 = 131,250 gallons
Fire demand = $(750 + \frac{182}{2}) \times 60 \times 2$
= 100,920 gallons
The domestic requirement being greater will govern. Storage of not less than 131,250 gallons should be provided. In this case it is suggested one elevated tank, 150,000 gallons, be constructed or that the well pumps discharge into a 100,000 gallon ground storage tank from which booster pumps would deliver water into a 50,000 gallon elevated tank floating on the distribution system.

d. Water Main Sizes.
Fire demand rate = $750 + \frac{182}{2} = 841$ g.p.m.
Peak domestic demand = 182 x 2.5 = 455 g.p.m.
The fire demand being greater will govern in determining pipe sizes in this case. Peak domestic demand will be distributed while fire flow will be concentrated.

2. EXAMPLE NO. 2:

General Hospital with a capacity of fifteen hundred (1,500) beds, water from nearby municipal system capable of supplying seven hundred (700) g.p.m. with adequate pressure at the hospital.

a. Required Demand and Fire Flow.
For purpose of design it can be assumed that total population at the hospital will be approximately twice the number of beds.

Authorized total population 3,000; capacity factor = 1.5
Design population = 3000 x 1.5 = 4500
Per capita allowance = 150 gallons per day
4500 x 150 = 675,000 gallons daily = 469 g.p.m. average
Fire flow = 2000 g.p.m. for 4 hours

b. Storage Requirements.

In determining the amount of storage for this project, conditions as outlined in Paragraph 4-02a of Chapter IV should be considered. The number and delivery capacity of mains connecting with the city must also be considered.

If a single connecting main is used the following figures show the amount of storage required:

50% of daily consumption = $\frac{675,000}{2}$ = 337,500 gallons

Fire demand = $(2000 + \frac{469}{2}) \times 60 \times 4$ = 536,400 gallons

50% of daily consuption plus fire demand equals
337,500 + 536,400 = 873,900 gallons

A break in the supply main would constitute the most serious emergency condition as no water would be available from the city. Therefore, storage would be required in the amount of 873,900 gallons which is the largest of the three figures listed.

If two connecting mains are used, each capable of delivering 700 g.p.m. to the hospital, the following figures are pertinent:

50% of daily consumption = $\frac{675,000}{2}$ = 337,500 gallons

Fire demand = $(2000 + \frac{469}{2}) \times 60 \times 4$ = 536,400 gallons

50% of daily consumption plus fire demand minus amount of water available in 24 hours through one main, assuming the other is out of service is 337,500 + 536,400 - (700 x 60 x 24) = 124,100 gallons.

The greatest figure in this case is 536,400 gallons which is the basic amount of required storage. However, this quantity can be reduced by the amount of water available from the city during the peak demand period, which in this case would be a 4-hour fire. In 4 hours 168,000 gallons (700 x 60 x 4) would be delivered from the city. The amount of storage to be provided would, therefore be

536,400 - 168,000 = 368,400 gallons

If three connecting mains are used two of which will deliver 200 g.p.m. each and the other main delivers 300 g.p.m., then the most serious emergency condition would be a break in the main delivering 300 g.p.m. The following figures are pertient to this assumed condition:

50% of daily consumption = $\frac{675,000}{2}$ = 337,500 gallons

Fire demand = $(2000 + \frac{469}{2}) \times 60 \times 4$ = 536,400 gallons

50% of daily consumption plus fire demand minus amount of water available in 24 hours through the two mains

in service is 337,500 + 536,400 - 2(200 x 60 x 24) = 297,900 gallons

The greatest figure in this case is 536,400 gallons which is the basic amount of required storage. However, this quantity can be reduced by the amount of water available from the city during the peak demand, which would be a 4-hour fire. In 4 hours 96,000 gallons (400 x 60 x 4) would be delivered from the city. The amount of storage to be provided would, therefore, be

536,400 - 96,000 = 440,400 gallons

The above calculations show the method of determining the amount of storage to be provided under varying local conditions. While the fire flow respresents the peak demand in this example yet the peak domestic demand may be a larger figure in other cases. The peak domestic demand period, however, should not exceed two hours.

The storage for this project may be elevated or ground type; however, elevated storage would be favored, if economically justified, as water is delivered from the city under adequate pressure and additional pumping would not be necessary.

c. Water Main Sizes.

Fire Demand Rate = $2000 + \frac{469}{2}$ = 2235 g.p.m.

Peak Domestic Rate = 469 x 2.5 = 1172 g.p.m.

Fire demand rate governs. Consideration must be given to pressure required for operation of automatic sprinkler systems in accordance with Engineering Manual requirements.

3. EXAMPLE NO. 3:

Permanent Storage Depot having approximately one million (1,000,000) square feet of warehouse storage and approximately one million (1,000,000) square feet of open storage area, population sixteen hundred (1,600) daily employees living off post and fifty (50) military and one hundred (100) civilians living on post, adjacent to city with water system capable of supplying five hundred (500) gallons per minute under a remaining pressure of fifty (50) pounds per square inch.

a. Required Demand and Fire Flow

Per capita allowance = 30 gallons per day for civilian employees
= 100 gallons per day for military personnel
= 100 gallons per day for civilian residents

1600 x 30 = 48,000
50 x 100 = 5,000
100 x 100 = 10,000

63,000 gallons = 44 g.p.m. average

NOTE: While the average water requirement is 44 g.p.m., yet assuming the 1600 civilian employees are all present during the day shift, then the average requirement during the shift will be approximately 110 g.p.m. with a peak rate of 275 g.p.m.

Fire flow = 4,000 g.p.m. for 4 hours

b. Storage Requirements.

No elevated storage for domestic demand is required as the supply from the city will supply the demand. However, the city supply is not adequate to supply initial sprinkler requirements so a 75,000 gallon elevated tank will be required for this purpose.

Local conditions must be considered in determining the total amount of storage to be provided. If a single main connects the depot with the city, then the following figures are applicable:

50% of daily consumption $= \frac{63,000}{2} =$ 31,500 gallons

Fire demand $= (4,000 + \frac{44}{2}) \times 60 \times 4 =$ 965,280 gallons

50% of daily domestic plus fire demand equals 31,500 + 965,280 = 996,780 gallons

A break in the supply main would constitute the most serious emergency condition as no water would be available from the city. Therefore, storage should be provided in the amount of 996,780 gallons which is the largest of the three figures listed.

If two mains connect the depot with the city and each main will deliver 500 g.p.m., then the following figures are applicable:

50% of daily consumption $= \frac{63,000}{2} =$ 31,500 gallons

Fire demand $= (4,000 + \frac{44}{2}) \times 60 \times 4 =$ 965,280 gallons

50% of daily consumption plus fire demand minus amount of water available in 24 hours through one main, assuming the other is out of service, is 31,500 + 965,280 - (500 x 60 x 4) = 276,780 gallons

The greatest figure under these conditions is 965,280 gallons which is the basic amount of required storage. However, this quantity can be reduced by the amount of water available from the city during the peak demand period, which in this case would be a 4-hour fire. In 4 hours 120,000 gallons (500 x 60 x 4) would be delivered from the city. The amount of storage to be provided would, therefore, be

965,280 - 120,000 = 845,280 gallons

If three connecting mains are constructed two of which will deliver 150 g.p.m. each and the other main 200 g.p.m., then the most serious emergency conditions would be a break in the main delivering 200 g.p.m. The following figures apply to this assumed condition:

50% of daily consumption $= \frac{63,000}{2} =$ 31,500 gallons

Fire demand $= (4,000 + \frac{44}{2}) \times 60 \times 4 =$ 965,280 gallons

50% of daily consumption plus fire demand minus amount of water available in 24 hours through the two mains remaining in service is 31,500 + 965,280 - (300 x 60 x 24) = 564,780 gallons

The greatest figure in this case is 965,280 gallons which is the basic amount of required storage. However, this quantity may be reduced by the amount of water available from the city during the peak demand period which would be a 4 hour fire. In 4 hours 72,000 gallons (300 x 60 x 4) would be delivered by the city. The amount of storage actually required would, therefore be

965,280 - 72,000 = 893,280 gallons

While all of the above calculations show a storage requirement less than 1,000,000 gallons, yet in view of the nature of the project the construction of a 1,000,000 gallon ground storage reservoir with pumping station would be logical. Requirements for pumping station and pump operation are covered in the Manual.

c. Water Main Sizes.
The fire flow requirements will be the governing factor in this case.

4. EXAMPLE NO. 4:

Permanent camp with authorized population of twenty thousand with surface supply from nearby creek.

a. Required Demand.
Authorized population = 20,000; capacity factor = 1.15
Design population = 20,000 x 1.15 = 23,000
Per capita allowance = 150 gallons per day
23,000 x 150 = 3,450,000 gallons = 2,395 g.p.m. average
To meet this demand a filtration plant with pumping stations and appurtenances having a rated capacity of approximately 3.5 m.g.d. would be provided.

b. Domestic and Fire Flow Demands.
Peak domestic = 2,395 x 2.5 = 5,987 g.p.m.
Fire flow for two fires in quarters area each requiring 1.000 g.p.m. for four (4) hours or one fire in warehouse area requiring 2,000 g.p.m. for four (4) hours.
Fire demand = $(2{,}000 + \frac{2{,}395}{2}) \times 60 \times 4 = 767{,}280$

c. Storage Requirements.
Domestic requirements will govern in this case
50% of 3,450,000 = 1,725,000 gallons
At least 50% of storage should be elevated. Two 500,000 gallon tanks or three (3) 300,000 gallon tanks would be satisfactory. The remainder of the required storage could be provided in the clear water storage reservoir at the filtration plant.

d. Filtration Plant.
The filtration plant could be designed using seven (7) 0.5 M.G.D. filters or preferably four (4) 0.9 M.G.D. filters.

Filter areas would be based upon a flow rate of two (2) gallons per square foot per minute.

e. Raw Water Pumping Station.
Provide two (2) 2,450 g.p.m. electric motor driven pumps
one (1) 1,225 g.p.m. electric motor driven pump
one (1) 1,225 g.p.m. gasoline engine driven pump

f. High Lift Pumping Station.
Provide pumps having similar capacities and power as for raw water station.

g. Water Main Sizes.
The peak domestic rate is 5,987 g.p.m.
The fire demand is 3,197 g.p.m. with a concentrated flow of 2,000 g.p.m. to the warehouse area. It is, therefore, indicated that both domestic and fire flows must be considered in determining water main sizes. Peak demands for water will be supplied by a combination of pump output and withdrawal from storage. A post of this size would have a station hospital of approximately 600 beds and would require a fire flow of 1500 g.p.m. Automatic sprinkler supply and pressures for satisfactory operation must be taken into consideration in determining water main sizes to the hospital area.

5. EXAMPLE NO. 5:

Permanent airfield with authorized population of two thousand (2,000), hydraulically operated gasoline fueling system with three (3) two-hose truck fill stations and six (6) double fueling pits, water obtained from wells capable of yielding two hundred (200) g.p.m. each, elevated tank not permitted.

a. Required Demand and Fire Flow.
Authorized population 2,000; capacity factor 1.5
Design population 2,000 x 1.5 = 3,000
Per capita allowance = 150 gallons per day
3,000 x 150 = 450,000 gallons per day
Add 30,000 gallons for three (3) truck fill stations, this being greater than 18,000 gallons for fueling pits
450,000 + 30,000 = 480,000 gallons per day
= 333 g.p.m. average
Fire flow = 1,000 g.p.m. for two (2) hours in the quarters area and 1,000 g.p.m. for four (4) hours in the warehouse area.

b. Well Requirements.
As the number of wells should be based upon 16 hours operation per day, a total well capacity of $333 \times \frac{3}{2}$ or approximately 500 g.p.m. will be required.
Each well is expected to yield 200 g.p.m. Therefore, at least three (3) wells will be necessary. All wells should be equipped with pumps having electric power and two (2) of the pumps should also have gasoline engine power.

c. Storage Requirements.
Domestic requirement = 50% of 480,000 = 240,000 gallons
Fire demand = $(1,000 + \frac{333}{2}) \times 60 \times 4$ = 279,840 gallons

As fire demand governs provide a gound storage reservoir With a capacity of approximately 300,000 gallons No elevated storage is permitted and well pumps will deliver into the ground storage reservoir.

d. Booster Pumps (Direct Pressure System).

The peak domestic rate = 333 x 2.5 = 832 g.p.m.

The fire demand rate = $1,000 + \frac{333}{2}$ = 1166 g.p.m.

Provide three (3) electric motor driven pumps, automatically controlled, which when operating together will deliver approximately 1,200 g.p.m. If these pumps are also provided with gasoline engine standby power, then no other pumps should be necessary. If dual powered pumps are not installed, then gasoline engine driven pumps must also be provided. One 1,200 g.p.m. pump or two (2) 600 g.p.m. pumps would be satisfactory.

e. Water Main Sizes.

Water mains should be sized to allow delivery of maximum rates as follows:

Peak domestic = 832 g.p.m.
Fire demand = 1,166 g.p.m.
Gasoline fueling system = 60% of fueling pit + truck fill demand
= 0.6 (3 x 100 + 6 x 100)
= 900 g.p.m.

Peak domestic demands will be distributed throughout the system while the fire demand and probably the gasoline fueling demands will be concentrated.

6. EXAMPLE NO. 6:

Large permanent Air Depot, population fifteen hundred (1500) employees, on one eight (8) hour shift, living off the post and one hundred and fifty (150) military and one hundred (100) civilians living on the post, industrial demand of nine hundred (900) g.p.m. which cannot be reduced during fire period. Water supply is from wells on the post.

a. Required Demand and Fire Flow.

Per capita allowances
30 gallons per day for civilian employees
100 gallons per day for military personnel
100 gallons per day for civilian residents

1500 x 30 = 45,000 g.p.d. (8) hrs.) = 94 g.p.m.
150 x 100 = 15,000 g.p.d. (24 hrs.) = 11 g.p.m.
100 x 100 = 10,000 g.p.d. (24 hrs.) = 7 g.p.m.

Total 70,000 g.p.d. 112 g.p.m. average

Peak domestic demand = 112 x 2.5 = 280 g.p.m.
Industrial demand = 900 g.p.m. for 8 hrs. = 432,000 g.p.d.
Total daily demand
Domestic - 70,000 gallons = 112 g.p.m. average
Industrial- 432,000 gallons = 900 g.p.m. average

Total 502,000 gallons = 1012g.p.m. average

The industrial demand cannot be reduced during fire.

Maximum fire demand = $(4000 + \frac{112}{2} + 900) \times 60 \times 4 = 1,189,440$ gallons

b. Storage Requirements.

Where elevated storage is not objected to by the using service, the tank should have a minimum capacity of 75,000 gallons for initial sprinkler demand.

In this example it is assumed the wells discharge directly into the distribution system. Since the total daily demand of 502,000 gallons must be obtained from wells in 16 hours operation, the well capacity will be 523 g.p.m. Two wells producing approximately 300 g.p.m. each are required. One of the wells will be equipped with standby gasoline engine. Since the average daily demand during the eight (8) hour work shift is 1,012 g.p.m. and the wells produce only 600 g.p.m., 412 g.p.m. for eight (8) hours or a total of 197,760 gallons must be supplied from storage. Therefore, the elevated tank must have a capacity of 197,760 gallons plus 75,000 gallons for sprinkler demand or 272,760 gallons. A 300,000 gallon tank would be satisfactory. The four (4) hour 4,000 g.p.m. fire demand will be supplied by a 1,000,000 gallon ground storage reservoir with necessary fire pumps.

The capacity of the elevated tank discussed above can be reduced if the size of the ground storage reservoir is increased accordingly with booster pumps provided to maintain the high water level in the elevated tank under peak domestic and industrial demand.

c. Water Main Sizes.

The fire flow requirements will govern the size of mains in this case.

The industrial demand must be supplied at a residual pressure of at least 30 p.s.i. although pressures in other parts of the post may drop to 10 p.s.i. during a 4,000 g.p.m. fire demand. At the sprinklered buildings the pressure must be maintained at a 15 p.s.i. residual at the highest sprinkler head during a 200 g.p.m. fire flow.

NOTE: The calculations set forth in preceeding examples have been set up to illustrate methods of procedure in determining approximate capacities of various components of water supply systems at Army projects as covered by the Engineering Manual. While exact figures are used in the calculations, yet in the final selection of pump capacities, filter areas, amount of storage in reservoirs and tanks etc., consideration should be given to standards already established by equipment manufacturers and Office, Chief of Engineers and equiment and structures selected for use which will be consistent with these standards and also be suitable for the actual conditions which will exist at the project being studied. The exact figures are considered to be flexible and may be modified, within reasonable limits, to permit use of standard equipment and structures in the final design. If any difficulties are encountered in determining the capacity of equipment or structure, then the problem should be submitted in full detail to Office, Chief of Engineers for decision and recommendation.

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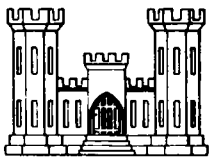
WATER SUPPLY
GENERAL CONSIDERATIONS



ARMY SERVICE FORCES
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CHAPTER 1

GENERAL CONSIDERATIONS

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PART VII

WATER SUPPLY

CHAPTER 1

GENERAL CONSIDERATIONS

1-01 SCOPE OF THESE INSTRUCTIONS. The instructions contained in this part of the Manual relate to the utilization of existing supplies, the development and purification of new water supplies using underground or surface sources, and water distribution and storage for serving Army Projects. The scope of the Manual is limited to broad phases and policy determination due to the wide variation in conditions to be encountered. The instructions are for general guidance and standardization to provide uniform policy insofar as possible. Deviation from the standards may be necessary in certain special cases; however, such deviations should be presented to and approved by Office, Chief of Engineers. Established and accepted engineering practice will be followed in the absence of specific instructions for special conditions, problems and details.

1-02 DESIGN PROCEDURE. Planning for the development of the water supply system for any project should proceed simultaneously with the planning for other facilities to insure proper coordination. The final design of the distribution system must of necessity await the final site plan and the completion of field surveys to obtain necessary topography. The development of ground water supplies, the design of surface water supply works and filtration plants, and the design of water distribution systems with storage facilities should be regarded as highly specialized and requiring the attention of engineers experienced in this type of work.

1-03 SELECTION OF MATERIALS AND EQUIPMENT. Materials should be selected taking into consideration the degree of permanence and the expected life of the project. Current policies of the War Department with respect to the use of critical materials must be observed in the planning and construction of any water supply works. To avoid delays in securing delivery of equipment every effort should be made to utilize types of equipment which can be supplied by several manufacturers. The ability of equipment manufacturers to make delivery within the time required must be carefully investigated prior to making commitment for the purchase of mechanical equipment. As a general rule other types of equipment should be placed in competition with patented equipment peculiar to one manufacturer. Equipment of experimental nature and equipment which has not been proven by actual usage should not be used.

1-04 DEFINITIONS. For the purpose of clarification, the following definitions are established for this part of the Manual.

a. Water Works. All construction for the collection, transportation, pumping, treatment, storage and distribution of water.

b. Supply Works. Dams, impounding reservoirs, intake structures, pumping stations, wells and all other construction for the development of a source of water supply.

c. Supply Line. The pipe line from the source of supply to the treatment works or the distribution system.

d. Treatment Works. Filtration plant, reservoirs and all other construction required for the treatment of a water supply.

e. Distribution System. The pipe line grid throughout the building

area including hydrants, valves and other appurtenances used to supply water for domestic and fire fighting purposes.

f. Feeder Mains. The principal pipe lines of the distribution system.

g. Distribution Mains. The pipe lines which comprise the distribution system.

h. Service Lines. Small pipe lines connecting individual buildings to distribution mains.

i. Capacity Factor A multiplier used with the authorized population to obtain the design population.

j. Design Population. The design population is obtained by multiplying the authorized military and tributary population by the proper capacity factor.

k. Required Demand. The required demand or required daily demand is the amount of the total daily water supply requirement and is obtained by multiplying the design population by the per capita water allowances, and adding to this quantity any special industrial demands.

l. Rated Capacity. The rated capacity of a filter of pumping unit is the amount of water which can be passed through the unit when operating under design conditions.

m. Direct Pressure System. A water distribution system supplied entirely by pumps with no elevated storage. Pneumatic or ground storage tanks may be included.

n. Balanced Pressure System. A water distribution system supplied in part from elevated tanks or high level storage tanks located at strategic points on the system.

o. Fire Flow. The amount of water required in gallons per minute at the actual site of the fire expressed in gallons per minute at a specified residual pressure.

p. Fire Demand. The amount of water required during a fire period. The fire demand is determined by the sum of the fire flow, fifty percent (50%) of the average domestic demand rate, and any industrial demand which cannot be reduced during a fire period, all expressed in gallons per minute, at the residual pressure specified for either the fire flow or essential industrial demand, whichever is the higher.

1-05 DOMESTIC WATER REQUIREMENTS. In the design of water supply systems the number of gallons indicated in Table I below will be used for per capita allowances in determining the capacity of the water supply system. (See Par. 1-13a).

TABLE 1 PER CAPITA WATER ALLOWANCES FOR ARMY PROJECTS

TYPE OF PROJECT*	PERMANENT POSTS	MOBILIZATION TYPE CONST.	THEATER OF OPER. CONST.	FIELD TRAINING CAMPS
Air fields, Camps and Cantonments	150	100***	70***	50
Hospital Units (Including hotels and similar facilities converted to Hospital use)	150	150	125***	100
Armored Divisions	150	150	100***	75
Prisoner of War Camps Internment Camps			70**	50**
Hotels and Similar facilities converted for troop housing	70 gallons per capita			
Plant, Port and Storage Projects, including Civilian War Workers	30 gallons per employee per 8 hour shift and 100 gallons for Resident Personnel			
Animals	25 gallons per day			

*The allowances set forth above include water used for laundries to serve the resident personnel, washing vehicles, limited watering of planted and grassed areas and similar uses. Special allowance will be made for operation of hydraulically operated gasoline fueling systems under certain conditions described herein-after (See Par. 1-10). The allowances contained in this table do not cover special industrial or irrigation requirements.

** For prisoner of war base camps having a strength of less than 300, 50 gallons will be used. For branch camps having a strength of less than 300, 25 gallons will be used.

***Where mobilization or theater of operations type is to be retained at posts selected for post war retention, per capita allowances will be those shown for permanent posts (based on post war authorized housing).

1-06 FIRE REQUIREMENTS FOR AIRFIELDS, CAMPS AND STATION HOSPITALS.

a. Permanent and Mobilization Type Construction. For permanent airfields, cantonments and similar mobilization type construction projects, where the authorized strength is more than one thousand (1,000) and less than six thousand (6,000) the design of the water system shall be limited to a single fire with a fire flow of one thousand (1,000) gallons per minute for two (2) hours, delivered to any point within the developed area except the warehouse area for which a fire flow of one thousand (1,000) gallons per minute for four (4) hours should be provided. Where the authorized strength is six thousand (6,000) or more the design of the water system shall be limited to two (2) concurrent fires with a fire flow of one thousand (1,000) gallons per minute for a period of four (4) hours to each fire occurring at remotest points, except the warehouse area, for which a fire flow of two thousand (2,000) gallons per minute for a period of four (4) hours will be provided. In all cases it will be assumed that a warehouse fire will not occur simultaneously with a fire in other areas (See Par. 5-06c below). (For fire flows in station hospital areas, See Table II.)

Due to the fact that many permanent posts have non-standard types of construction, requirements in areas having such types of construction may be greater than indicated in this paragraph. A study to determine whether an increase in fire flow requirement is necessary to take care of such construction should be made in each individual case. Hangar areas and utility and shop areas where undivided fire areas approach those of warehouses should be provided with fire flow equivalent to that provided for warehouse areas.

b. Theater of Operations Type Construction. For airfields, cantonments and similar theater of operations type construction projects, where the authorized strength is more than one thousand (1,000) and less than six thousand (6,000) the design of the water system shall be limited to a single fire with a fire flow of seven hundred fifty (750) gallons per minute for two (2) hours, delivered at any point within the developed area, except the warehouse area, for which a fire flow of seven hundred fifty (750) gallons per minute for a period of three (3) hours will be provided. Where the authorized strength is six thousand (6,000) or more the design of the water system shall be limited to two (2) concurrent fires with a fire flow of seven hundred fifty (750) gallons per minute for a period of three (3) hours to each fire occurring at remotest points, except the warehouse area, for which a fire flow of fifteen hundred (1,500) gallons per minute for a period of three (3) hours will be provided (See Par. 1-13b). In all cases it will be assumed that a warehouse fire will not occur simultaneously with a fire in other areas (See Par. 5-06c below). Hangar areas and utility and shop areas where undivided fire areas approach those of warehouses should be provided with fire flow equivalent to that provided for warehouse areas. (For fire flows in hospital area, See Table II.)

c. Dispersed Layouts. Water distribution systems serving dispersed housing areas will, in general, consist of a single loop supply main from which service lines will be extended to serve the housing units. Fire hydrants should be provided along the distribution loop capable of delivering a fire flow of five hundred (500) g.p.m. for two hours, and warehouses, mess halls and assembly buildings should be located so as to be protected by fire hydrants within five hundred (500) feet of these buildings. In carrying out the element of dispersion the distances between individual housing units will serve as effective fire breaks and no special provision will be made to provide

fire protection for individual barracks not accessible from hydrants located on the main supply loop. Dispersed layouts will not be confused with camouflaged layouts.

d. Small Camps With Less Than 1,000 Population. For camps with a population less than three hundred (300) the fire flow will be incidental to domestic requirements. With a population from three hundred (300) to four hundred and ninety-nine (499) a fire flow of one hundred fifty (150) to two hundred fifty (250) g.p.m. for two (2) hours is required, without fire pumpers. With a population from five hundred (500) to one thousand (1,000) it is contemplated that fire pumpers will be provided and a fire flow of five hundred (500) g.p.m. for two (2) hours will be provided.

Note: It is not possible to establish a definite policy which will govern all cases of fire protection for small camps and final decisions must be made after due consideration has been given to all factors including initial cost, operating cost, availability of water, use of critical materials and equipment and the nature of the project.

e. Prisoner of War Camps. For prisoner of war camps the fire flow will be in accordance with the requirements for other projects discussed above.

f. Station Hospitals. The fire flow for station hospitals will vary with the number of beds (See Table II).

g. General Hospitals. All general hospitals will require a fire flow of two thousand (2,000) g.p.m. for four (4) hours.

1-07 FIRE REQUIREMENTS FOR GENERAL HOSPITALS. All general hospitals will require a fire flow of two thousand (2,000) g.p.m. with a residual pressure of ten (10) pounds per square inch for a period of four (4) hours. As an additional requirement the water system shall also be capable of delivering an initial sprinkler demand of five hundred (500) g.p.m. under a residual pressure of fifteen (15) pounds per square inch at the elevation of the highest sprinkler head if automatic sprinklers are installed.

If storage tanks (elevated or ground) are provided then Chapter IV should be followed. If ground storage only is used, which cannot be located to deliver the full fire demand into the distribution system by gravity, then a booster pumping station should be provided. The pumping station should be equipped with two (2) one thousand (1,000) g.p.m. pumps, one of which should be gasoline engine driven and the other gasoline engine-electric motor driven. The dual powered pump should be arranged for automatic electric motor starting in case of low pressure in the distribution system. If a dual powered pump cannot be obtained, then two (2) one thousand (1,000) g.p.m. gasoline engine driven pumps and one (1) five hundred (500) g.p.m. electric motor driven pump arranged for automatic operation will be acceptable. The one thousand (1,000) g.p.m. pumps should develop sufficient head to deliver their capacity into the distribution system when operating together. The gasoline engine driven pumps may all be electric motor driven only if electric power is avilable from two (2) dependable sources preferably with underground connections to the pumping station so that possible power failure is extremely remote.

1-08 FIRE REQUIREMENTS FOR DEPOTS, PORTS AND SPECIAL PROJECTS.

a. General. The amount of water required for fire protection at large depots, ports, Air Forces control depots and similar storage projects may vary with the size of the project and local conditions. For projects using standard warehouses, which may or may not be provided with sprinkler systems,

two conditions must be satisfied and the necessary mains, storage tanks, and pumping stations constructed to meet the most severe condition. A fire flow of four thousand (4,000) g.p.m. for four (4) hours with a residual pressure of ten (10) pounds per square inch in the vicinity of any warehouse must be provided. In addition to the preceding requirement the system shall also be capable of supplying two thousand (2,000) g.p.m. to any warehouse with a residual pressure of fifteen (15) pounds per square inch at the elevation of the highest line of sprinkler heads in the respective buildings. In addition to the fire flow, consideration shall also be given to current domestic and industrial demands, which cannot be restricted during a fire, in establishing the fire demand. It is assumed the actual sprinkler demand will not exceed one thousand (1,000) g.p.m. which will leave one thousand (1,000) g.p.m. for hose streams. If the sprinkler demand exceeds one thousand (1,000) g.p.m., then the water system should be designed to supply the highest sprinkler demand plus one thousand (1,000) g.p.m. for hose streams with the required fifteen (15) pounds per square inch residual pressure at the sprinkler heads. In open storage areas without buildings, a fire flow of two thousand (2,000) g.p.m. for four (4) hours at a residual pressure of ten (10) pounds is required.

b. Fire Mains and Hydrants. Fire mains will be provided on both sides of each warehouse with hydrants located at three hundred (300) foot intervals. In open areas one hydrant will be provided, strategically located, for each one hundred thousand (100,000) square feet of open storage area. The distribution piping should be properly sized to permit delivery of the entire flow at four (4) hydrants in the immediate vicinity of a warehouse or shop. The underground distribution system should be designed in the form of a grid suitably valved to provide flexibility of control. The design is to be based upon the assumption that one hundred percent (100%) of the mains are in service.

c. Storage Tanks and Pumping Stations. If storage tanks and pumping stations are necessary, then fire flow requirements can most economically be met by providing the entire amount of water required for fire fighting in a ground storage reservoir with sufficient fire pumps to deliver the required rate. For flexibility of operation the capacity of individual pumping units should not exceed one thousand (1,000) g.p.m. each and the pressure at the pumps should not exceed one hundred (100) pounds per square inch. All fire pumps should generally be gasoline engine-driven only and manually controlled except where automatically controlled electric motor driven pumps are necessary for supplying initial sprinkler demand as discussed herein. The system should be protected by pressure relief valve discharging into the ground storage reservoir.

In some cases automatically controlled electric motor driven pumps may be required to supply initial sprinkler demand if the elevated tank discussed below is not provided. Where, under normal operation without fire pumps, two thousand (2,000) g.p.m. at a residual pressure suitable for sprinkler operation is available in addition to the average daily demand, fire pumps may be manually controlled. Where, in addition to the average daily demand, between five hundred (500) g.p.m. and one thousand (1,000) g.p.m. is available, one (1) one thousand (1,000) g.p.m. electrically driven pump will be equipped for automatic starting. Where less than five hundred (500) g.p.m. is available, two (2) one thousand (1,000) g.p.m. electrically driven pumps will be equipped for automatic starting. Dual electric motor-gasoline engine driven pumps would be satisfactory.

Elevated storage floating on the distribution system, in an amount equal to twenty-five (25) gallons per capita, but not less than seventy-five thousand (75,000) gallons should be provided to supply initial sprinkler demand; however, if an existing fifty thousand (50,000) gallon capacity tank has sufficient height to provide an initial sprinkler demand of one thousand (1,000) g.p.m. at a residual pressure of fifteen (15) pounds per square inch, then such tank will be acceptable. Where a fifty thousand (50,000) gallon tank is considered acceptable as outlined above, one of the fire pumps should be electrically driven and automatically controlled. Automatically controlled electric motor driven pumps should be provided to deliver domestic demands and maintain the elevated tank practically filled at all times. The elevated tank must be equipped with a control valve if it is necessary to take the tank out of service when the distribution system is under fire pressure. If more than one ground reservoir is used, the connections to the reservoirs should be valved so that either may be taken out of service without affecting the supply to the pumps from the others. Suction for the fire pumps may be through a common header with properly sized valve and connected to the ground reservoir to permit maximum flexibility of operation (See Par. 2-09d below). Piping connections to the reservoir will depend upon source of supply and local conditions.

The elevation of the site selected for the fire protection ground reservoir or reservoirs should be taken into account in determining the type of system to be employed. If the reservoir site is sufficiently elevated to provide the required residual pressure for the delivery of the fire flow to the point of use, pumps may be omitted. However, where it is proposed to omit pumps a careful economic analysis should be made to determine that the delivery by gravity does not require larger mains involving increased cost and the use of more critical material than would be required if the low level storage with pumping station were installed.

d. Surplus Property Installations. Water supply will be based on a two thousand (2,000) g.p.m. fire flow requirement at ten (10) pounds residual pressure for a four (4) hour period, but in each instance available mucincipal water supplies or natural sources of water, such as rivers, ponds, etc. will be utilized before comprehensive works to obtain this quantity are authorized. It is not contemplated that elaborate underground systems will be provided, but single feeder mains, ramps to natural water supplies, or suction reservoirs will be provided so that water supplies for fire fighting will be available within one thousand (1,000) feet of each part of the storage area or within five hundred (500) feet of each building.

e. Plant Requirements. Requirements for plants vary widely, according to type of project and location. Generally, large quantities of water must be available for long periods. Usually, it is not necessary to have a separate fire protection system, although in certain cases it may be necessary, under exceptional circumstances, to maintain a non-potable supply for fire protection purposes. If such a supply is utilized, provision should be made for the chlorination of the non-potable supply, while it is in use, and for flushing out the system afterwards.

1-09 SUMMARY OF FIRE FLOW REQUIREMENTS. The following Table II is a summary of the fire flow requirements for projects of various type. (See Par. 1-13b).

TABLE II FIRE FLOW REQUIREMENTS FOR ARMY PROJECTS
(Note: 1-2 = 1 fire for 2 hours; 1-4 = 1 fire for 4 hours, etc.)

TYPE OF PROJECT	GALLONS PER MINUTE FIRE FLOW						
	150 to 250	500	750	1000	1500	2000	4000
I. Airfields, Camps & Cantonments							
(a) Permanent & Mobilization Construction							
1. Less than 6000 pop. but more than 1000				1-2			
Warehouse Area				1-4			
2. 6000 pop. or more				2-4			
Warehouse Area						1-4	
(b) Theater of Oper. Const.							
1. Less than 6000 pop. but more than 1000			1-2				
Warehouse Area			1-3				
2. 6000 pop. or more			2-3				
Warehouse Area					1-3		
(c) Dispersed Layouts		1-2					
(d) Small Camps & Cantonments less than 1000							
1. Less than 300 pop.	Fire Flow Incidental to Domestic Flow						
2. 300 to 499 pop.	1-2						
3. 500 to 1000 pop.		1-2					
(e) Station Hospitals							
1. Below 250 beds				1-2			
2. 250 to 499 beds				1-3			
3. 500 to 999 beds					1-3		
4. 1000 beds or more						1-4	
II. General Hospitals						1-4	
III. Storage Projects							
(a) Warehouse Areas							1-4
(b) Open Storage Area						1-4	
(c) Surplus Property Installations						1-4	
IV. Tent or Hutment Camps	For tent or hutment type camps it is necessary to provide fire protection only for warehouses, mess halls, latrines and similar structures. Fire protection for these structures will be in accordance with the requirements set forth above for Theater of Operations Type Construction, unless a dispersed layout is used. If a dis-persed layout is used the fire protection will be as set forth above for Dispersed Layouts.						
V. Plants	As determined for individual projects						

1-10 RELATIONSHIP BETWEEN DOMESTIC AND FIRE FLOW DEMANDS. Each system must be analyzed to determine whether the capacities are fixed by the domestic requirements or by the fire demands. For airfields, camps, cantonments and other housing projects the amount of the supply is fixed by the domestic requirements and fire demands are generally supplied from storage. For port and storage projects the amount of water supply may be fixed by the fire demands and if these are supplied entirely from storage, the supply should be sufficient to replenish the storage in forty-eight (48) hours. Fire demands will usually govern in the design of distribution mains. These are designed to deliver the necessary fire flow requirements plus fifty percent (50%) of the average domestic requirements plus industrial demands which cannot be restricted during the period of the fire.

1-11 HYDRAULIC GASOLINE SYSTEMS. The flow of water required for operating hydraulic gasoline systems depends upon the number and type of fueling pits or truck fills. Each fueling pit, with two (2) hose lines, requires one hundred (100) gallons per minute. Single hose type requires fifty (50) gallons per minute. Each two-hose truck fill requires three hundred (300) gallons per minute. A minimum pressure of thirty-five (35) pounds per square inch is required at the gasoline storage tanks for proper operation of the system. Demand flows will be taken at sixty percent (60%) of the combined installed fueling pit and truck fill capacity. At Army airfields where the authorized personnel is less than four thousand (4,000) and where a hydraulic system is used, the daily water supply should be increased by three thousand (3,000) gallons for each fueling pit installed or ten thousand (10,000) gallons for each truck fill installed, whichever is greater. Where the authorized personnel is four thousand (4,000) or greater, no additional water is required for the hydraulic fueling system.

1-12 CAPACITY OF WATER SUPPLY SYSTEM.

a. Initial Design Capacity. The initial capacity of the water supply system will be based on the authorized military and civilian project population but will be increased by the following capacity factors:

Specified Project Population	Capacity Factor
5,000 and less	1.50
10,000	1.25
20,000	1.15
30,000	1.10
40,000	1.05
50,000 and over	1.00

Capacity factors determined by arithmetical interpolation will be used for intermediate project population figures. Capacity factors will be applied to the supply works, supply lines, treatment works, principal feeder mains, and storage reservoirs. The capacity factors will be used in planning water supplies for all projects including general hospitals, internment and prisoner of war camps, unless future expansion is improbable. The capacity factor will not be applied in determining distribution main sizes to serve areas which are fully developed and are not susceptible to further expansion. Capacity factors will not be used for hotels and similar structures which are acquired or rented for hospital and troop housing.

b. Capacity Factor. The capacity factor is applied by multiplying the authorized military and tributary population by the proper capacity factor stated above. This gives the design population and the design of all elements of the system, except as noted above, should be based on the design population. The capacity factor is to provide for reasonable increases in population,

variations in water demands and uncertainties as to actual water supply requirements for projects of the same type, and for unusual peak demands, the magnitude of which cannot be accurately estimated in advance.

c. Special Design Capacity. Where special demands for water exist, such as irrigation, industrial processes, cooling water and similar purposes, consideration shall be given to these special demands in determining the capacity of the water supply facilities.

1-13 UTILIZATION OF WAR TIME CONSTRUCTION. At many posts constructed during the war it is possible that certain emergency materials were used in the water supply systems which will eventually require replacement. Mention is made of wood storage tanks, wood stave and thin wall steel water mains, temporary type buildings at pumping stations and water treatment plants, and wood covers on reinforced concrete storage reservoirs as falling in this category. If such posts are selected for permanent retention, then the less permanent facilities in the water supply system should normally be continued in service at the permanent post until maintenance and repair costs show that this action is no longer economically justified. When this condition develops, then replacement of the facilities should be made using permanent type materials in accordance with the criteria contained in the Engineering Manual and current policies.

a. Domestic Water Allowance. In the design of water supply systems, the number of gallons indicated in Table I will be used for per capita allowances in determining the capacity of the systems. However, where a camp having mobilization or theater of operations type construction is selected for a permanent post, then the per capita allowance for a permanent post should be used in connection with the authorized population to determine the overall adequacy of the water supply facilities.

b. Fire Flow Allowance. Where a camp having theater of operations type construction is selected for permanent use and the buildings are continued in use, then fire flow allowance as set forth in Paragraph 1-06b will be used. However, if the buildings are replaced with permanent type construction, then the water supply system should be reviewed with application of requirements as covered in Paragraph 1-06a to determine that the facilities are adequate.

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FOR WAR DEPARTMENT CONSTRUCTION

PART VII
CHAP. 3
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WATER SUPPLY
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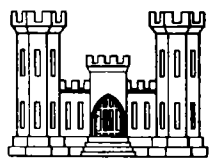

ARMY SERVICE FORCES
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

CHAPTER 3

WATER TREATMENT

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PART VII
WATER SUPPLY

CHAPTER 3
WATER TREATMENT

3-01 GENERAL. Water treatment is a specialized field of sanitary engineering and the services of experts should be obtained in planning this part of the work. The chemical and physical properties of the water have a direct bearing on the method of water treatment to be selected. State Board of Health officials are usually familiar with accepted methods of water treatment and offer a source of valuable information in arriving at a decision in selecting a method of water treatment for a specific project. In addition to selecting a method of water treatment for a specific project. In addition to the usual treatment which may be required for clarification, color reduction, bacteria removal, and sterilization to insure delivery of a safe and potable water, consideration must also be given to the necessity for special treatment to protect pipe lines, water heaters, plumbing fixutres and other equipment against scaling, corrosion, staining and "red water" difficulties.

Owing to the widely varying conditions and the multiplicity of types of water it is not possible to establish criteria to be followed in all cases of special water treatment. Treatment for the prevention of scaling and corrosion may not be entirely effective and in many cases a decision as to the necessity for special treatment cannot be reached prior to actual operating experiences. In general, special treatment will be provided only in cases where a study of the water analysis and actual experience with the water definitely show that severe corrosion of the water system will exist or that severe scaling of hot water heaters, storage tanks and other parts of the plumbing system will occur, thereby resulting in high cost for replacement and use of critical materials. Marginal cases will be deferred and treatment provided only after operating experience determines treatment to be necessary.

3-02 CHEMICAL ANALYSIS After decision has been made concerning the source of water for a new project, arrangements should be made to secure a representative sample (approximately one gallon) and have a complete chemical analysis made by a commercial laboratory sufficiently experienced in completing water analyses to insure reliable results. The results of this analysis will be forwarded to the Office of the Chief of Engineers, attention, Engineering Division, for information.

a. Form of Analysis. For purposes of comparison and standardization all analyses should be reported in the following form:

Water Analysis

pH Value ------	
Total Solids ----------	Parts per Million
Calcium as Ca----------	
Magnesium as Mg----------	
Sodium and Potassium as Na----------	
Iron as Fe ----------	
Silica as SiO_2----------	
Sulphates as SO_4----------	
Chlorides as CL----------	
Nitrates as NO_3----------	
Alkalinity (Methyl Orange) as $CaCO_3$--------	
(Phenolthalein) as $CaCO_3$--------	
Total Hardness as $CaCO_3$----------	
Carbonate Hardness as $CaCO_3$----------	
Non-Carbonate Hardness as $CaCO_3$----------	
Free Carbon Dioxide as CO_2----------	

b. Information on Existing Supplies. When water is to be purchased from a city supply or other source already developed, it may be possible to secure a representative analysis immediately. However, if the available analysis is not complete, a separate analysis should be made as noted herein. A brief description of the source of water and any treatment which may have been given prior to delivery to the distribution system should be furnished with the analysis. If possible, supplementary data should be furnished with all analyses describing the effect of the water on water heaters and related equipment. Any unusual scaling or corrosion difficulties should be covered in detail.

c. U. S. Geological Survey Laboratory. If the services of a reputable commerical, municipal or State laboratory are not readily available, a representative one gallon water sample may be shipped in one or more clean glass containers, addressed to the WATER RESOURCES LABORATORY, United States Geological Survey, Washington, D.C., for analysis. The samples should be labeled with name and location of post, date of collection, and name of engineer. To assist the U.S. Geological Survey Laboratory in making analyses and in order that their records may be complete, it is essential that samples be carefully taken and marked for identification and that certain information accompany the samples forwarded to the Laboratory. The authorities at the Laboratory have requested that, in addition to a gallon sample, a smaller sample (four to eight ounces) be also furnished to simplify the analytical work in the Laboratory. Care should be taken to see that sample bottles are thoroughly cleaned and rinsed with the water being sampled. Bottles should be filled, with an air space of about one-half(½) inch in the neck of a four (4) ounce bottle, one inch in an eight (8) ounce bottle and one and half (1½) inches below the stopper in a gallon sample to allow for expansion. A gallon sample will expand about twenty-five (25) cc when the temperature changes from 39° F. to 95° F. Too large an air space may permit some change in the composition of the water. Samples when collected from wells should be representative of the water in the underground formation and not that which has stood in contact with the well casing or pump. If possible, the well pump should be allowed to operate ten (10) minutes or longer before collecting the sample. When collecting a sample from a water distribution system, water should be permitted to flow from the spigot for at least five (5) minutes before collecting the sample. After samples are collected, each sample should be clearly marked for identification.

3-03 INFORMATION WITH SAMPLES. The information as covered below should be attached to the sample bottle or placed in the shipment with the water samples, properly identified with respect to the samples.

a. Well Water Samples. Furnish owership and location of well, including county and state, together with distance and direction to nearest town; record date well was drilled; give depth and diameter of well and length of casing; furnish yield in gallons per minute, stating whether quantity was measured or estimated; record distances to water level in well both when idle and when being pumped; list date and temperature of water when sample was collected; describe particularly the appearance of any suspended matter and note color, as this information is necessary to determine the procedure for analysis of a sample which is turbid when received.

b. Surface Supply Samples. Describe source such as river, lake, spring, describe briefly any treatment given to water, mentioning the various chemicals used and average dosage in parts per million or grains per gallon prior to delivery to system.

c. Distribution System Samples. If from a city system, state name of city and furnish information as listed under a. or b. above as applicable; if from post distribution system, state name of post and furnish information

as listed under a. or b. above as applicable.

3-04 WATER SOFTENING. Whether water softening is provided will depend entirely on the type of project under consideration. For temporary and war time construction the entire post supply will not be softened unless the total hardness exceeds four hundred (400) p.p.m. expressed as equivalent $CaCO_3$. However, when a treatment plant is constructed for the removal of turbidity or iron, the plant may be designed to also accomplish partial softening. For permanent posts softening of the entire supply may be favorably considered if the hardness exceeds two hundred fifty (250) p.p.m. and investigation indicates that the treatment facilities can be economically provided. Softening of a post water supply to a total hardness of less than one hundred (100) p.p.m. is not required; however, softening to less than this amount is justified for special purposes and services.

a. Water for Laundries. Water for laundries should be softened if the total hardness is two and five tenths (2.5) grains per gallon (43 p.p.m.) or more, expressed as equivalent $CaCO_3$. Installation of zeolite softeners for this treatment is recommended and the equipment for this treatment is covered by standard plans and specifications, O.C.E., for laundry construction.

b. Boiler Water Treatment. Water for power plants and heating plants may require softening by means of ziolite softeners or other means of treatment depending upon local conditions. In connection with boiler water treatment, satisfactory results can often be obtained by internal treatment using boiler compounds in case feed water has a low mineral content. Removal of oxygen to lowest possible amount (0.005 cc per liter) is always desirable to reduce corrosion. Attention is also invited to the use of sodium-hydrogen zeolites and resinous anion exchangers by means of which feed water may be produced having practically any chemical content desired, even approaching distilled water. The selection of these special zeolites requires a thorough study of the local conditions, water analysis and economy before decision is reached concerning the type of zeolite to be used.

c. Softeners for Mess Halls. The installation of softeners for small mess halls, latrines and bath-houses is not recommended. The installation of zeolite softeners may be justified for large central mess halls to protect equipment and insure satisfactory washing of dishes.

d. Softening Water for Hospitals. Partial softening of water delivered to hospitals and hospital areas may be justified to protect expensive and critical equipment in case the hardness exceeds two hundred fifty (250) p.p.m. However, before a decision is reached to soften all water delivered to the hospital area, consideration should be given to the use of small zeolite softeners to supply softened water only to operating rooms, dispensaries, and mess halls. As a general rule softening of the entire supply to less than one hundred (100) p.p.m. is not warranted unless large quantities of water are used for bathing, dishwashing, laundry work and other purposes requiring soap.

3-05 SCALE PREVENTION. Many waters when heated cause excessive scale and clogging of hot water heaters, piping and storage tanks. This scaling usually occurs in waters containing a high percentage of calcium and magnesium bicarbonate. If permitted to accumulate, the scale causes cracked heaters, reduced efficiency of heating equipment and necessitates the replacement of piping. It has been found that scaling is usually encountered with waters containing calcium in excess of fifty (50) p.p.m.

The excessive deposition of scale in hot water heaters and piping can be largely controlled by the addition of non-toxic chemical compounds. In

the case of moderate corrosion with scale forming conditions, experience indicates that a combined treatment with special phosphates and sodium silicate may be effective in protecting water heaters and piping. These chemicals when applied in small amounts may be expected to accomplish satisfactory results even though the water may contain as much as three hundred (300) p.p.m. of bicarbonate alkalinity. The chemicals may be easily applied to well or pump discharge lines by means of small electric motor driven chemical feed pumps actuated by the starting equipment controlling the well or booster pumps. Chemical feeding equipment should not be installed indiscriminately and should be limited to those projects using water which is definitely known to be scale forming. The Office, Chief of Engineers, will assist in determining the procedure to be followed with respect to treatment for corrosion and scale forming difficulties at any installation upon receipt of detailed information concerning the project and the type of water to be used.

3-06 IRON REMOVAL. Treatment for iron removal or the correction of "red water" difficulties is usually necessary for water supplies obtained from wells or other sources having an iron content in excess of five tenths (0.5) p.p.m. If the iron is present in a soluble or ferrous state it may become oxidized to the ferric state if the water is exposed to the air or if air is drawn into the water system. A red precipitate will then be formed which will cause deposits in hot water tanks, staining of plumbing fixtures, staining of laundry, may cause objectionable tastes and promote the growth of iron bacteria in water mains with clogging and reduction of carrying capacity.

a. Treatment with Sodium Hexametaphosphate. Operating experience indicates that for waters containing not more than three (3.0) p.p.m. of iron, the iron may be stabilized and kept in solution by feeding sodium hexametaphosphate. For maximum effectiveness it is necessary to introduce the chemical into the water before it has become exposed to the air and in the case of the treatment of well waters the hexametaphosphate is usually introduced into the suction of the well pump. The customary dosage varies with the amount of iron present and the minimum treatment is usually at the rate of one (1.0) p.p.m. of sodium hexametaphosphate for each part per million of iron in the water.

b. Conventional Methods of Iron Removal. When the iron content exceeds three (3.0) p.p.m. a conventional iron removal plant including aeration, lime treatment, sedimentation, contact beds or filtration may be necessary. This treatment is more desirable from the standpoint of the use of critical materials than the use of chlorine for the oxidation of iron followed by contact beds or treatment by filtering through beds of synthetic resins. In some cases well water supplies, having a high iron content when the wells are first completed, show a reduction under continuous pumping thereby obviating the necessity for iron removal. It is, therefore, important that the true quality of well supplies be ascertained before planning treatment works.

3-07 CORROSION CONTROL. Water is a universal solvent and since iron is slightly soluble in water it is possible under certain conditions to have serious corrosion of the water lines in the water distribution system as well as house plumbing, hot water heaters and storage tanks. Corrosion difficulties are usually associated with waters having a low alkalinity, low pH value, high free CO_2 and low total mineral content. The action of corrosive water on ferrous materials will cause "red water" difficulties, reduction in carrying capacity of mains and the rapid deterioration of hot water storage tanks.

These become perforated in a short time, necessitating replacement with the use of critical materials. Where a study of water analysis and local conditions show that rapid corrosion of hot water tanks may occur, the policy is established of using cement lined tanks for those projects. Accelerated tests have been conducted by the Office, Chief of Engineers, using cement lined tanks, and it is known that these tanks are satisfactory for use with fluctuating temperatures and pressures and that the cement lining will definitely prevent the corrosion of the interior. The lower the pH value of the water the more rapid will be the rate of corrosion. Water with a pH value of nine (9.0) will dissolve only traces of iron whereas water with a pH value of six (6.0) will dissolve appreciable quantities of iron.

a. Methods of Corrosion Control. Owing to the wide variation in the chemical properties of water it is difficult to establish the exact methods and types of treatment for the prevention of corrosion. For that reason treatment for the control of corrosion should be installed initially only at those locations where a study of the water analysis or experience with the water show conclusively that it will be definitely corrosive. Generally a water saturated with calcium carbonate will not be corrosive. Certain waters not saturated with calcium carbonate may also not be corrosive if dissolved oxygen is absent. Corrosion may be reduced by adjusting the chemical balance of the water to a condition approaching calcium carbonate saturation. This may be secured by the addition of lime, soda ash or caustic soda. Lime is most effective when the calcium content of the water is less than twenty-five (25) p.p.m. Since hydroxide alkalinity does not contribute to the saturation of the water with respect to calcium carbonate, there must be present sufficient CO_2 and bicarbonate alkalinity to convert only added lime to calcium carbonate. Therefore, if hydrated lime, $Ca(OH)_2$ is used, the dosage in parts per million of pure chemical should not exceed the sum of one and sixty-eight hundredths (1.68) times the parts per million of CO_2 plus seventy-four hundredths (0.74) times the p.p.m. of bicarbonate alkalinity, expressed as $CaCO_3$. Any lime added in excess of these quantities has the effect of adding lime only. If lime sulphate is present, it may be converted to calcium carbonate by the addition of soda ash, Na_2CO_3, which will assist in building up the calcium carbonate concentration. Caustic soda is of limited value in correcting corrosion owing to the fact that it raises the pH value and alkalinity only and does not add to the concentration of calcium carbonate.

b. Treatment of Surface Waters. If alum is used for the coagulation of surface water prior to filtration, the filtered water may be corrosive unless it is treated for pH correction. This may be accomplished either by feeding lime with the alum or by applying lime to the filter effluent. Treatment of the filter effluent will be necessary when coagulation at low pH is required for the removal of color and in such case the chemical may be applied to the clear well at a point which will permit thorough mixing before the water is pumped into the distribution system.

c. Treatment of Well Waters. Where treatment of well waters is required, it may be necessary to collect the water from all wells in a central ground reservoir to permit the application of the chemical prior to delivery to the distribution system. Where the calcium content in low, lime treatment will be effective for corrosive control. In some instances the calcium content and pH value may be such that the application of soda ash or sodium silicate will be satisfactory for corrosion control.

d. References. Reference is made to the numerous texts and published articles for a complete discussion of the theory involved in the treatment of waters to prevent corrosion. The following references are quoted for information:

Water Supply and Treatment, by Charles P. Hoover, available from the National Lime Association, Washington, D. C. and designated as Bulletin 211, 4th Edition, Chapter VII and Chapter XV.

Journal of the American Water Works Association, Vol. 15, 1926, Page 598, Prevention of Corrosion and "Red Water" by J. R. Baylis.

Journal of the American Water Works Association, Vol. 28, 1936, Page 1500, the Alkalinity Control of Anti-Corrosion Water Treatment by W. F. Langelier.

Journal of the American Water Works Association, Vol. 30, 1938, Page 1802, Practical Application of the Langelier Method by Charles P. Hoover.

Journal of the American Water Works Association, Vol. 34, 1942, Page 1667, Calcium Carbonate Saturation Index and Alkalinity Interpretations by T. E. Larson and A. M. Buswell.

Journal of the American Water Works Association, Vol. 34, 1942, Page 1807, The Value of Sodium Hexametaphosphate in the Control of Difficulties Due to Corrosion in Water Systems, Committee Report.

Manual of Water Quality and Treatment, published by American Water Works Association.

Water Purification Control by Edward S. Hopkins, Chapter 6, Corrective Treatment, Published by Williams and Wilkins Co., Baltimore, Maryland.

Water Purification for Plant Operators by George D. Norcom and Kenneth W. Brown, Published by McGraw Hill Book Co., New York City.

3-08 CHLORINATION. Adequate and effective chlorination of water supplies is considered necessary to protect the health of personnel served by the systems. Chlorinating equipment shall, therefore, be provided for treating all water supplies in accordance with the following:

a. Chlorine Residual. Facilities for maintaining a chlorine residual of not less than four tenths (0.4) p.p.m. in the active parts of the potable water distribution system shall be provided at all posts where the water supply works are constructed and operated by the Army. Active parts of the distribution system are described as those parts under constant circulation and include all installations in buildings where water is used for human consumption. This applies to both well and surface supplies.

b. Chlorination of Municipal Supplies. Facilities for the chlorination of water obtained from municipal or privately owned sources will be provided where the water has not been chlorinated by the municipality or utility company prior to delivery to the post, or where sanitary, physical or operating defects in the public water supply system or other special hazards are known to exist or where water of a uniformly satisfactory quality,

as evidenced by the results of bacteriological examinations, cannot be obtained without rechlorination.

c. Chlorination at Leased Buildings. Water supplies to leased buildings and similar facilities served directly and individually by a public water supply distribution system will not be rechlorinated except where warranted in individual cases.

d. Chlorine Contact Period. In all cases where provision is made for the chlorination of water supplies the point of chlorine application shall be such as to provide not less than thirty (30) minutes contact period except in the case of suitable ground water supplies where additional reservoirs would be required. In general the chlorine dosage shall be sufficient to maintain a chlorine residual of not less than 0.4 p.p.m. in the active parts of the distribution system. This requirement is not to be considered mandatory in two cases: first, where the presence of iron, manganese or other chlorine consuming compounds makes it impractical to maintain a chlorine residual of 0.4 p.p.m. in the active parts of the distribution system, provided these compounds are not of such character or in such an amount as to prevent effective initial chlorination; and second, where the water is stored for long periods in properly protected distribution reservoirs following chlorination. In these cases the chlorine treatment shall be sufficient to insure a potable water supply as evidenced by satisfactory bacteriological samples. In the event the presence of mineral or organic compounds makes it impossible to produce a water of acceptable quality, treatment for the removal of such compounds will be required.

e. Type of Chlorinating Equipment. Chlorination equipment may be either the gas type or hypochlorite type, depending upon local conditions and type of project. Guide specifications for non-automatic, semi-automatic and fully automatic chlorinators and hypo-chlorinators have been completed and are available for use. Where required chlorinating equipment shall be purchased with sufficient capacity to provide a chlorine residual as set forth above.

f. Use of Ammonia with Chlorine. If the use of chlorine alone results in objectionable tastes as a result of presence of phenols or other foreign matter, or due to the chlorine dosage itself, ammonia in conjunction with chlorine may be used provided satisfactory bacteriological results are obtained. In some cases break point chlorination can be used to minimize taste and odor problems; however, before break point chlorination is adopted, complete investigations and studies should be made to determine whether this method of treatment can be justified.

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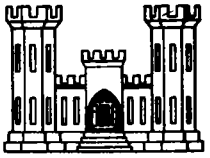
WATER SUPPLY
WATER STORAGE



ARMY SERVICE FORCES
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CHAPTER 4

WATER STORAGE

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PART VII

WATER SUPPLY

CHAPTER 4

WATER STORAGE

4-01 GENERAL. The judicious use of water storage tanks with respect to the distribution system and source of supply will permit the use of economical pipe sizes in the distribution system, will provide uniform pressures and allow the water production facilities to operate at average rate rather than at varying rates. In general water storage tanks, should be located near centers of high water demand and situated so as to equalize pressures during periods of peak demand. Elevated or high level storage is considered more desirable than ground or low level storage; however, in some instances it would not be economical to provide elevated or high level storage, in which cases it will be necessary to utilize ground or low level storage with required pumping equipment to deliver the stored water into the distribution system during peak domestic and fire demand periods. In designing any water supply system due consideration must be given to all factors involved such as peak domestic demands, fire demands including initial sprinkler requirements (See Par. 1-06 to 1-08 incl.), topography, economical plant operation, etc., and storage facilities should be provided accordingly to insure satisfactory operation of the water supplyssystem.

4-02 STORAGE CAPACITY. The amount of water storage provided shall in general conform to the requirements set forth herein; however, in certain cases departure from the standards may be justified. Such cases should be brought to the attention of Office, Chief of Engineers, for consideration and approval.

a. Airfields, Cantonments, Camps, Storage Projects and General Hospitals. Generally total storage capacity, including elevated and ground storage, should be provided in an amount not less than the following, whichever is the greatest:

Fifty percent (50%) of the total daily consumption

The fire demand

An amount, which under the most serious emergency condition caused by the shutdown or failure of any single main, pump, filter, power supply, or other similar element of the system would provide at least fifty percent (50%) of the total daily consumption in addition to the fire demand over a twenty-four (24) hour period, when considered in connection with the supply facilities remaining in service.

Where the water supply is obtained from wells, all of which are equipped with standby power, and located within the distribution area, then reduction in the amount of storage is justified. However, the amount of storage should be not less than twenty-five percent (25%) of the total daily demand and also the amount of storage plus the output of the well pumps during a fire period should at least equal the requirements for water during the period. If only fifty percent (50%) of the wells have standby power, then the basic required amount of storage will not be reduced.

The basic amount of storage as determined above may be reduced in some cases if the project is supplied by an existing, dependable source, such as a municipal system, with adequate storage or standby facilities through supply lines not subject to damage by floods, high pressure or other unusual conditions. If the supply is delivered through a single supply main capable of delivering the peak demand for water, then the full amount of storage as determined above should be provided. However, if the supply is delivered through two (2) or more supply lines and the lines are of such size as to permit the peak demand for water (peak domestic or fire demand whichever is greater) being delivered to the project with not more than any one line out of service, then no storage will be required.

If the supply is delivered through two (2) or more supply lines which are capable of delivering the peak demand for water with all lines in service, but not capable of delivering this flow with one line out of service, then required storage should be calculated as outlined above but the greatest calculated amount of storage may be reduced by the quantity of water available from the source during the peak demand period with the largest capacity main out of service. (See Examples 2 and 3 Appendix "C")

The method to be used in providing storage or auxiliary supply mains will in general be governed by lowest economical costs. In some instances it is possible that the installation of an additional supply main will be more economical in first cost than providing storage facilities or booster pumps.

In determining the storage requirements for fire fighting purposes it is assumed that no water will be used for hydraulic gasoline storage during a fire period. When water is purchased and no storage is provided, the distribution system should be designed to deliver one-half (½) the rate for average domestic concumption in addition to the required fire flows (See Par. 1-06 above).

b. Plant Projects. The amount of storage required for plant projects will be based on the industrial, domestic and fire protection requirements. Each project must be considered on the basis of specific needs.

4-03 HIGH LEVEL STORAGE. High level storage can be most economically provided by constructing ground storage reservoirs on high ground. In the absence of suitable terrain for high level ground reservoirs, not less than fifty percent (50%) of the total storage should be provided in elevated tanks, except where this type of storage is not desirable for military reasons. For projects with a population of ten thousand (10,000) or less, consideration may be given to providing all storage in elevated tanks.

4-04 LOCATION OF STORAGE TANKS. Elevated tanks should be located near load centers to equalize pressures over the post area. In large areas, such as a division area, the total storage should be provided in at least two (2) tanks located in separate areas on the post. The location of tanks at airfields shall be approved by the Office of the Chief of the Army Air Forces or his designated representative from the standpoint of flying hazards. In locating elevated or ground storage facilities due consideration must be given to the size of water mains in the distribution system so that domestic requirements and fire demand can be delivered throughout the area as covered by Paragraph 5-06 below.

4-05 STATIC PRESSURE. Reservoirs should be so located, or heights of elevated tanks established, to provide a static pressure of not less than forty (40) pounds per square inch at the highest ground elevation in the post area. Where variations in topography will result in a pressure exceeding one hundred (100) pounds per square inch in small low areas, pressure reducing valves should be installed in the mains serving these areas. If a substantial portion of the post will be subjected to high pressures when maintaining a minimum of forty (40) pounds per square inch in the high areas, consideration should be given to dividing the water distribution system into a two-level system, each being provided with its own water storage facilities. If a two-level system is adopted, booster pumps to deliver water from the low level system to the high level system may be required.

4-06 CONCRETE GROUND STORAGE TANKS. Standard designs and typical specifications for circular concrete storage reservoirs, having capacities of one hundred thousand (100,000), two hundred thousand (200,000), five hundred thousand (500,000) and one million (1,000,000) gallons and for rectangular concrete reservoirs with varying capacities ranging from two hundred and forty-five thousand (245,000) to one million (1,000,000) gallons have been prepared in the Office of the Chief of Engineers and are available for use.

4-07 WOOD STAVE TANKS. Wood Stave tanks are particularly suitable for use for Theater of Operations cantonments and they should be utilized to the maximum extent possible. Wood stave tanks can be easily adapted for low level storage and are economical for high level storage when suitable terrain permits their installation on low trestles. Wood tanks may be installed on either wood or structural steel towers as regulated by current policy. Wood tanks are not recommended for permanent projects. (See Par. 1-13).

4-08 STEEL TANKS

a. Standard Specifications. Steel elevated tanks and standpipes may be riveted or welded and shall be in accordance with Standard Specifications for Elevated Steel Water Tanks, Standpipes and Reservoirs, as approved by the American Water Works Association, 26 June 1941, and by the American Welding Society, 23 July 1941. Used steel tanks may be utioized where available at an economical cost and if in suitable condition for re-erection. Foundations for used steel elevated tanks should be designed for safety and in accordance with good engineering practice and preferably in accordance with the recommendations of the tank manufacturer.

b. Tank Risers. Risers to elevated tanks shall be large enough in diameter to prevent freezing.

c. Tank Foundations. Foundations for elevated tanks shall be in accordance with the requirements of, and shall be checked and approved by, the tank manufacturer.

4-09 CONCRETE ELEVATED TANKS. Standard Plans and Guide Specifications for Concrete Elevated Tanks, having capacities of two hundred fifty thousand (250,00), five hundred thousand (500,000), seven hundred fifty thousand (750,000) and one million (1,000,000) gallons, have been prepared in the Office of the Chief of Engineers and are available for use. The design of these structures provides for tower heights of approximately one hundred (100) feet to the base of the tank which can be reduced in the event the topography is such that lower heights can be used. Before decision is made to use these tanks careful investigation should be made to determine whether steel tanks will be more economical.

4-10 RESERVOIR COVERS. All water storage tanks should be provided with covers to prevent possible contamination and algae growths. Properly screened vents and overflows are also required. All entrance manholes shall be either watertight or designed to prevent entrance of rain or surface water. All drain lines shall be designed and located to prevent entrance of flood waters or other sources of contamination. No drains should be connected to sanitary sewers.

4-11 ALTITUDE VALVES. Altitude valves should be installed where necessary to prevent overflow from elevated tanks or standpipes. Altitude valves when used should be installed in concrete pits. Provision shall be made for draining concrete pits either by gravity or pumping. Drains shall not be connected to sanitary sewers. Every precaution shall be taken to prevent entrance of contamination to the water supply through valves, valve pits and appurtenances.

4-12 AUTOMATIC CONTROL. Automatic control of pumping equipment at wells or booster stations by control equipment actuated by water levels in storage tanks is desirable to reduce operating labor costs. Automatic controls will not usually be installed where pump operators are always in attendance.

4-13 DESIGN ANALYSIS. A design analysis, required by Paragraph 740-09 or latest revision, Orders and Regulations, Corps of Engineers, will be prepared to accompany all plans and specifications for Water Storage Tanks and Reservoirs. The design analysis will indicate the method used in determining the storage requirements and the basis of design for each unit.

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WATER SUPPLY
DISTRIBUTION SYSTEMS



ARMY SERVICE FORCES
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CHAPTER 5

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WATER SUPPLY

CHAPTER 5

DISTRIBUTION SYSTEMS

5-01 GENERAL. In planning the water distribution system consideration should be given to topography, sites for storage tanks, areas of peak domestic, fire and special demands for water together with the source of water so that the system will be properly coordinated. The design of the distribution system should be as simple as possible and at the same time provide adequate service for maximum domestic requirements and fire protection. The judicious location of elevated storage tanks and inter-connected and looped feeder mains will enable the use of minimum pipe sizes.

5-02 DUAL SYSTEMS. In general dual water systems, such as a domestic supply from a safe source and a contaminated or questionable supply for irrigation, sprinkling or fire protection uses or for process or cooling purposes, will not be permitted, except where there are some very special reasons for the necessity of such a dual system. Where these reasons exist, they shall be reported and prior approval obtained from the Office of the Chief of Engineers and the Surgeon General. If approval is given, the pipe lines used for the two (2) services shall, if possible, be of different materials and each service shall be clearly and definitely identified.

5-03 DIRECT PRESSURE SYSTEMS. Direct pressure distribution systems should be considered only where the military use or other special requirements will not permit the utilization of elevated storage tanks. For such systems, a sufficient number of gasoline engine-driven pumping units should be installed to supply the peak requirements. For most systems of this type the installation of three (3) electric motor driven pumps capable of supplying the peak domestic demand when operating simultaneously and one or more units equipped with dual drives and gasoline engines or separate gasoline engine-driven pumps capable of supplying the fire demand (fire flow plus fifty percent (50%) of the average domestic demand) will provide the necessary flexibility of operation (See Par. 4-02 above).

5-04 BALANCED PRESSURE SYSTEMS. High level storage either in surface reservoirs located on high ground or in elevated tanks should be utilized wherever conditions will permit (See Par. 4-02 above). This will enable the use of minimum pipe sizes in the distribution system.

5-05 CROSS CONNECTIONS. Special consideration shall be given to the question of cross connections to prevent possible contamination of the potable water supply. If two (2) independent safe water supplies are to be interconnected, approval of the respective water companies or minicipalities will be obtained. A connection between a water supply of good quality and one which is unsafe is not permitted. There shall be no physical connection between the water supply and sanitary or storm sewerage systems including manholes, pumps, valve pits or at any other location which would allow unsafe or contaminated water to enter the water system by direct pressure, vacuum, gravity or other means. At piers and ports where salt water may be used for fire protection, the hazard of contaminating the potable water mains should be particularly guarded against. Where sprinkler or fire lines are supplied by the potable water system, no siamese or pump connections through which salt water might be pumbed by fire boats or other means are allowed. In regard to cross connec-

tions reference is made to ASF Circular No. 234, dated 26 July 1944, Part Two, Section III, and to National Research Council Committee Sanitary Engineering Report on Cross and Back-Siphonage Connections.

5-06 DISTRIBUTION MAINS.

a. Sizes of Mains. Sizes of mains are dependent upon fire demand, special requirements and the domestic demand. All items should be considered and the size of mains determined from the greatest flow to be met, due consideration being given to residual pressures required for each demand (See Chap. I).

b. Domestic Requirements. For domestic supply, the lines should be designed for a peak flow of two and one-half (2½) times the daily average (domestic) requirements, with residual pressure of not less than thirty (30) pounds per square inch. For plant projects, the total daily consumption will take into consideration the total number of employees per shift, number of shifts and whether or not showers and laundering of workers' garments are compulsory on the premises.

c. Fire Demands. Distribution mains should be designed to deliver the necessary fire flow requirements plus fifty percent (50%) of the average domestic requirements plus any industrial or process demands which cannot be reduced during a fire. The pressure during period of fire demand will be determined by local conditions. A residual pressure of ten (10) pounds per square inch is satisfactory for operation of fire pumpers. If sprinkler systems are provided a residual pressure of not less than fifteen (15) pounds per square inch must be available at the top line of sprinkler heads (See Chap. I).

d. Friction Losses. In computing friction losses for distribution mains, use C = 100 in the Williams and Hazen formula. In computing friction losses for supply mains, consideration may be given to higher co-efficients which may be applicable to the type of pipe used.

e. Hydrant Branches. Fire hydrant branches (from main to hydrant) should be not less than six (6) inches in diameter and as short in length as possible and preferably not longer than fifty (50) feet with a maximum limit of three hundred (300) feet.

5-07 LOCATION OF MAINS. Mains should be located along streets in order to provide short hydrant branches and service connections. Looped grid systems are desired for distribution systems and dead ends should be eliminated on mains wherever possible. If dead ends in mains are unavoidable, provision should be made for blowing off the line by means of a valve or hydrant. Water mains will not be installed in the same trench with sewer lines. Where water mains and sewer lines are installed parallel to roadways, they should, if practicable, be located on opposite sides of roadways. Minimum horizontal separation between water mains and sewer lines, including building service connections, will be six (6) feet; ten (10) feet or more is desirable. Where water mains and sewer lines cross, the water main will be above the sewer line if practicable. Water mains may cross under gravity sewer lines, where necessary, provided the sewer lines are constructed of cast iron, steel, or other pressure pipe for a distance of at least ten (10) feet on either side of the crossing. However, water mains will, in all cases, cross above sewers under pressure, such as force mains, inverted siphons, etc. and will be installed not less than two (2) feet above the sewer main.

5-08 LOCATION OF VALVES. Valves should be installed at intervals of approximately five thousand (5,000) feet in long supply lines and at intervals of from twelve hundred (1,200) to fifteen hundred (1,500) feet on main distribution loops or feeders and on all primary branches connected to these lines. Valves should also be installed at selected points throughout the distribution system to provide control over reasonably sized areas. Where mains supply automatic sprinkler systems, valves should be installed so that the number of systems affected by a single break or repair in any main will be a minimum. At intersections where several valves are required, the number of valves should ordinarily be one less than the number of radiating lines. Valves are not required on hydrant branches except where hydrants are installed on main distribution feeders so laid out that repairs to a hydrant would cause closing off a considerable area from water service and fire protection or where hydrants are particularly subject to damage by unusual traffic hazards and cannot be protected against damage by means of post barriers or other means using non-critical materials.

5-09 FIRE HYDRANTS.

a. Hydrant Spacing. Hydrants should be spaced approximately four hundred (400) feet apart in housing areas and so located that each building can be reached from two (2) hydrants with a maximum length of three hundred (300) feet of hose. In warehouse areas fire mains should be installed on both sides of each building. Fire hydrants in warehouse areas and at airfield hangar areas should be located approximately three hundred (300) feet apart. Fire hydrants for fire protection along parking aprons not adjacent to hangars at airfields will not be required. However, where mains for servicing of planes extend along or to parking aprons, hydrants or two and one-half (2½) inch outlets, depending upon the size of the main installed, may be provided. If possible, hydrants should be located at least fifty (50) feet distant from the nearest building, and in no case should hydrants be located closer than twenty-five (25) feet to a building, or within the paved service apron area at airfields.

b. Location of Hydrants. Safety for traffic and protection for fire hydrants make it desirable that hydrants be located not less than six (6) feet from the edge of the paved roadway surface and where practicable on primary roads a greater distance should be secured. Hydrants should be located so that connection with the hydrant can be made by the pumper, using a single length of ten (10) foot suction hose. In order to meet this condition, it will be necessary for the pumper to be placed not more than seven (7) feet from the face of the suction connection on the hydrant to the pumper connection. If hydrants are located more than seven (7) feet from the edge of the paved roadway surface and if the shoulders are such that the pumper cannot be placed within seven (7) feet of the hydrant, then consideration may be given to stabilizing or surfacing a portion of wide shoulders adjacent to hydrants to permit the connection to the pumper with a single ten (10) foot length of suction hose.

In exceptional cases, where ditches or other conditions prohibit locations meeting the above requirements, hydrants may be so located as to permit connection to the pumper, using two lengths of suction hose (a distance not to exceed sixteen (16) feet from the face of the suction connection on the hydrant to the pumper connection). Isolated cases may require special consideration to provide a location for the pumper to permit access to a hydrant.

Hydrants should not be located closer than three (3) feet to any obstruction nor in front of entrance ways. Hydrants should be set so that the center of the lowest outlet is not less than eighteen (18) inches above the surrounding grade and the operating nut not over four (4) feet above the surrounding grade. The principal (pumper) discharge should face the nearest roadway. No pipe connections should be made to hydrants, either for permanent or temporary use, except by specific authority and such authority should be limited to strictly emergency conditions.

5-10 AIR RELEASE AND VACUUM VALVES. Air release and vacuum valves should be installed at prominent peaks on long supply mains only. These valves should act automatically, permitting the escape of air from the pipe line while it is being filled and permitting the entrance of air while it is being emptied. Air valves will not generally be necessary in the grid distribution system of the project, as ir accumulations will normally be released through service lines.

5-11 MINIMUM COVER OVER PIPES. Minimum cover over lines will be dependent on locality and depth of frost. Where frost does not govern, the minimum cover should be not less than two (2) feet. Where lines pass under railroad right-of-way, pipe shall be encased in rigid conduit in accordance with railroad company's standard practice.

5-12 SERVICE CONNECTIONS. It is desirable and in the interests of economy that the service ends of buildings be located adjacent to streets and that one water main be installed along the street serving buildings on either side. Combination stop and waste cocks on underground service lines for draining building lines are not desirable because of potential contamination of the water supply. To prevent freezing, service lines to buildings should be installed below frost line. Risers from frost line to floor lines of buildings should be adequately insulated. Water service connections are required for servicing aircraft at airfields. These connections should normally be located adjacent to the parking apron at non-dispersed stations or adjacent to the servicing apron at dispersed stations.

5-13 CLEANING AND LINING OLD WATER LINES. Where old existing mains are to be used and these mains have become incrusted to such a degree that the flow has been materially reduced, it may be advisable and economical to clean them and line with cement. This work should be accomplished by contract with well-established and experienced firms specializing in this work.

5-14 STERILIZATION OF WATER SUPPLY SYSTEMS. In order that a safe supply of water can be assured, each unit of the system shall be thoroughly sterilized before it is placed in operation. For methods of sterilization, See Appendix "A"

5-15 SELECTION AND USE OF WATER PIPE MATERIALS. Current policies of the War Department with respect to the conservation of critical materials must be strictly observed in the selection of water pipe line materials. Full consideration should be given to the use of materials and to types of construction which will result in the greatest savings in critical material, transportation and labor costs. For Army projects of a permanent nature materials should be selected for the water distribution system of a permanent type which will give adequate length of service.

a. Cast Iron Pipe. Cast iron pipe has long been considered a standard and permanent type of pipe to be used for water distribution systems. Cast iron pipe can be obtained in various pressure ratings to suit the requirements. Where corrosive water conditions are encountered, cement linedcast iron pipe, with or without interior bituminous coating, may be considered for use in order that a high friction coefficient will be maintained. Cast iron pipe is particularly applicable for projects of a permanent nature and may also be considered for projects of a temporary or semi-permanent nature provided it is available under current regulations.

b. Asbestos Cement Pipe. Asbestos cement pressure pipe should be given consideration in competition with other materials. Past experience indicates that asbestos cement pipe will render satisfactory service over a long period of years and will also maintain a high carrying capacity, particularly where corrosive waters are encountered. It is considered desirable to place asbestos cement pipe in competition with cast iron pipe.

c. Steel Pipe. Steel pipe is generally not favored for water distribution systems. However, steel pipe when properly protected against interior and exterior corrosion by approved coatings may be considered for water supply lines extending between the source and the distribution system. For projects of a temporary nature, steel pipe may also be considered for water distribution systems.

d. Reinforced Concrete Pressure Pipe. Reinforced concrete pressure pipe is particularly well suited for large diameter supply lines and should be given consideration in competition with cast iron pipe, asbestos cement pipe and steel pipe for such lines.

e. Wood Stave Pipe. Wood stave pipe for water distribution and water supply lines is generally not favored, particularly for permanent installations. Wood stave pipe may be considered where readily available for temporary projects and for war time construction in case the more permanent type materials are not available (See Par. 1-13).

f. Joint Materials. In installing cast iron bell and spigot pipe, calking lead and sulphur joint compound should be placed in competition.

g. Service Lines. As a general rule cast iron pipe should be used for service lines four (4) inches and larger in diameter. For service lines three (3) inches and smaller, cast iron pipe, galvanized steel pipe, galvanized wrought iron pipe and copper tubing should be considered.

5-16 STANDARD DETAILS. Standard Construction Details are shown on Standard Drawong No. 671-154 and Standards showing typical layouts are issued from time to time by the Office, Chief of Engineers.

5-17 LAYOUT MAPS. A layout map to suitable scale showing the entire distribution system, together with unit maps to a scale of one (1) inch to two hundred (200) feet should be prepared.

5-18 DESIGN ANALYSIS. A design analysis, required by Paragraph 740.09, or latest revision, Orders and Regulations, Corps of Engineers, will be prepared to accompany all plane and specifications for water distribution lines. The design analysis will indicate the total tributary population to be served by the system and the method used in determining main sizes.

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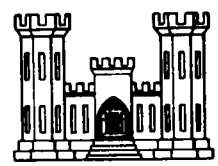
SEWAGE AND WASTE DISPOSAL

SANITARY SEWERS



ARMY SERVICE FORCES
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

CHAPTER 1

SANITARY SEWERS

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PART VIII

SEWAGE AND WASTE DISPOSAL

CHAPTER 1

SANITARY SEWERS

1-01 SCOPE. These instructions relate to the collection and disposal of domestic sewage and such other organic matter, including laundry wastes, as might be found normally in sanitary sewers serving Army projects of all types. The design of storm water drains is not included in these instructions. Storm water or surface run-off should not be discharged into sanitary sewers. These instructions are written primarily with new projects and major additions to existing projects in view. The principles set forth, however, apply to minor additions and should be followed.

1-02 DEFINITIONS. The following definitions are quoted from the American Society of Civil Engineering Manual Number 2:

a. Sewerage Works. All construction for collection, transportation, pumping, treatment and final disposition of sewage.

b. Collecting System. All sewers and appurtenances from the house to the outfall.

c. House Sewer. A pipe conveying the sewage from a single building.

d. Lateral Sewer. A sewer which discharges into a branch sewer or other sewer and has no other common sewer tributary to it.

e. Branch Sewer. A sewer which receives sewage from a relatively small area.

f. Main Sewer. A sewer which receives sewage from one or more branch sewers as tributaries.

g. Trunk Sewer. A sewer which receives sewage from many tributary branches and serves as an outlet for a large area.

h. Force Main. A pipe line carrying sewage under pressure from a sewage pumping station.

i. Outfall Sewer. A sewer which receives the sewage from the collecting system and conducts it to a point of final discharge or to a disposal plant.

j. Outlet Sewer. A sewer which conveys the effluent from a treatment plant to its final point of disposal.

k. Inverted Siphon. A sewer depressed below the hydraulic grade line so that the pipe or pipes are full at all times.

1-03 LIMITATIONS ON THE USE OF SANITARY SEWERS. Storm water and wastes from hydraulic gasoline storage systems, wash racks and garage and shop floor drains should not be permitted to enter the sanitary sewers but should be discharged through separate drains. In general, industrial wastes, such as pickling liquids, caustic solutions and other wastes from manufacturing plants should not be combined with domestic sewage and special provision for separate treatment of such wastes should be provided, if treatment is required. However, in certain cases, it may be feasible and economical to combine the domestic sewage with the industrial waste for joint treatment and disposal. The hydraulic factors of design for sanitary sewers also apply to conduits carrying industrial wastes. In some cases, the industrial wastes may be of such nature as to require the use of special materials for conduits.

1-04 SEWER LAYOUT AND ARRANGEMENT OF STRUCTURES. The development of sewer plans, of necessity, must await the final site plan and the completion of field surveys to obtain the necessary topography. The lateral sewers and branch sewers should conform as nearly as practicable to the street system so as to reduce the crossing of streets with house sewers to a minimum. Main sewers, trunk sewers and outfall sewers should follow the most practicable route to the point of disposal. In general, this route will be along natural drainage courses. Pumping facilities should not be installed except in cases where an analysis of the initial and operating costs conclusively indicate that pumping is more economical than gravity flow. Consideration should be given to the situation which pump failure would create.

a. Sewers. Where otherwise feasible, sewers should not be built longitudinally under paved roadways, and the number of pavement crossings should be kept to a minimum. The cutting of roadways for house sewers should be avoided when practicable to do so. At railroad crossings special construction consisting of metal pipe or sewer pipe encased in concrete should be used. Sewers should not be installed in the same trench with water lines, but should be located six (6) feet or more from them horizontally and on opposite sides of roadways where practicable. Where sewer and water mains cross, the sewer should, if possible, be located below the water main. If conditions necessitate, a gravity sewer may cross over a water main, provided the sewer for ten (10) feet either side of the crossing is constructed of cast iron, steel or other pressure pipe. Sewers under pressure, such as force mains, inverted siphons, etc., should in all cases cross under and be installed not less than two (2) feet below the water main.

b. Manholes. Manholes should be constructed at the end of each lateral and at each change of direction, slope or grade. The distance between manholes should not exceed 400 feet, except on long outfall sewers of large pipe sizes where distances of 600 feet between manholes may be used. The crown of the outlet pipe from the manholes should be on line with or below the crown of the inlet pipe. Drop manholes should be used when the invert of the inlet sewer is more than 12 inches above the manhole floor.

c. Flush Tanks. Flush tanks are not considered advisable or necessary in sanitary sewer systems.

d. Cover. In general, sewers should not have less than 2 feet of cover to provide protection from traffic. For allowable sewer trench loadings see paragraph 1-09.

e. Grease Traps. The removal of grease is necessary for the proper functioning of sewage treatment plants. This should normally be accomplished by the installation of grease traps in mess halls and kitchens as outlined in Part V, Chapter 4, Plumbing, and in the current specifications relating thereto.

f. Cross-Connections. There shall be no possible or actual physical connection between sewer and water supply systems.

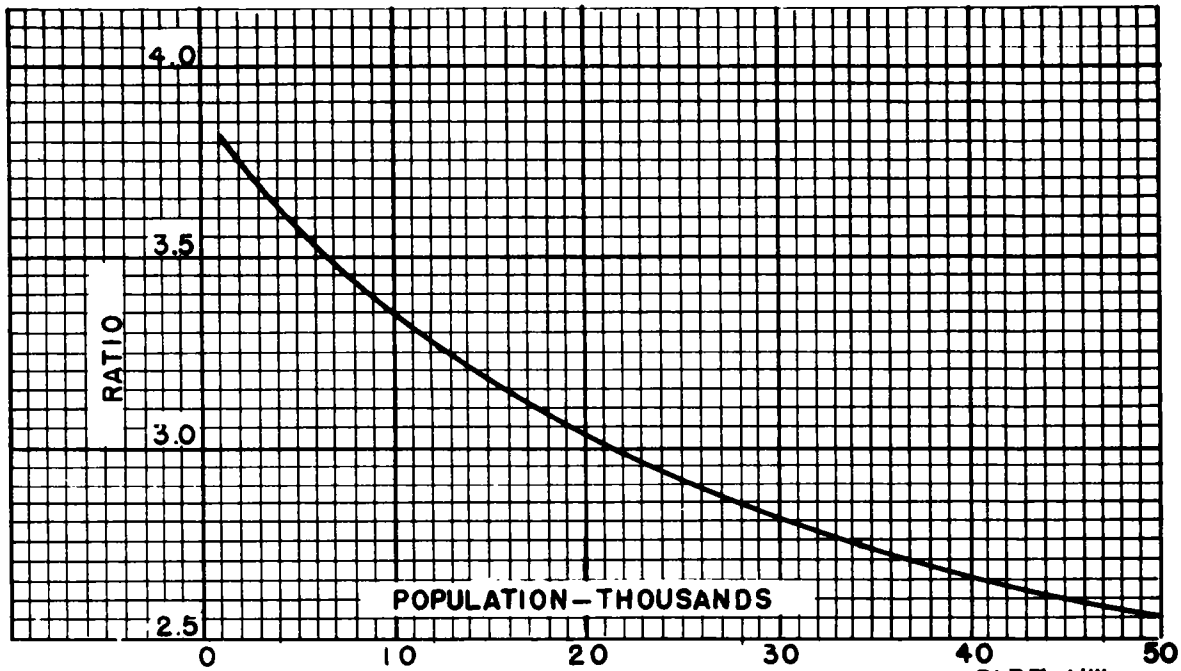
g. Building Connections. All building connections into sewer lines less than 24 inches in diameter should be made only with commercially manufactured Wye branches or Tees. Where convenient, such connections may be made directly into manholes. House sewers should be separated not less than six (6) feet horizontally from the water service pipes.

1-05 BASIS OF DESIGN. All sewers should be designed to discharge the expected peak rate of flow. The sewage quantities used in the design should, in general, be computed on a contributing population basis. The design population should be based on the full capacity of all military quarters within the tributary areas and should include the civilian personnel. Only one-third the number of non-residents should be included except as otherwise indicated in Table I. The ratios of peak flows to average flows for various populations are indicated in Figure 1. The average daily per capita flows to be used in the design are indicated in Table I. Where unusual ground water conditions are known to exist, an allowance of 10,000 gallons per mile of sewer per day may be added to the peak flow as determined from Table I and Figure 1.

TABLE I-- TABLE OF PER CAPITA DAILY SEWAGE FLOWS

Type of Unit	Gallons per Capita per Day			
	Permanent Posts	Mobilization Type	T. of O. Type	Field Training Camps
Airfields, Camps, Cantonments and Troop Facilities	100	70	50	35
Hospital Units	100	100	85	70
Plant, Port and Storage Projects	30 per 8-hour shift 100 for resident personnel			

The per capita sewage quantities include laundry wastes incidental to laundering for the resident population and normally no additional allowances will be made for such wastes.



CURVE SHOWING RATIO OF PEAK FLOW TO AVERAGE FLOW

PART VIII
CHAPTER 1

FIG. 1

1-06 FUTURE CAPACITY. Aditional capacity to provide for population increases will not be considered for lateral and branch sewers where the areas served are fully developed. In the design of long outfall sewers and main sewers serving areas which may further develop, 25 per cent additional capacity over the computed initial requirements should be provided. The sewers will often have this increased capacity without increasing the size, in which case no increase in size will be necessary. For example, the computed peak flow may be 800 g.p.m. A 12-inch pipe will discharge only 700 g.p.m. at a velocity of 2 feet per second, and a 15-inch pipe will be required. The 15-inch pipe will discharge 1100 g.p.m. at a velocity of 2 feet per second or an excess of 27½ per cent above the initial requirement.

1-07 SPECIAL CASES. There are exceptions to the general rule that sanitary sewers will be designed on a population basis. Among these exceptions are industrial sewers, laundry sewers and house sewers.

a. Industrial Sewers. Obviously industrial waste sewers serving Ordnance plants and such industries cannot be designed on a population basis and should be designed for the flows which the individual cases indicate.

b. Laundry Sewers. Sewers serving laundries should have capacity to discharge the waste from one-third the number of washers when completely emptied in two minutes, plus the back-wash from the water softeners. In view of the statement in paragraph 1-05 above, regarding laundry wastes, the size of outfall sewers will not be influenced by the discharge from a laundry which serves the post only. When sewers from laundries connect to smaller sewers than trunk sewers, some consideration should be given to the influence upon the peak flows in the smaller sewers. This also may apply to trunk sewers and outfall sewers in the case of large laundries which serve more than one post. Such cases should be individually considered.

c. House Sewers. Normally the size of 6 inches as indicated in paragraph 1-08 below will be sufficiently large for house sewers, including the house sewers from mess halls, theaters, clubs and other such buildings, but in all cases they should be large enough to discharge the flow computed on a fixture units basis as set out in Part V, Chapter 4, Plumbing. This applies to house sewers only and not to the lateral sewers or other sewers to which they connect.

1-08 SIZES AND SLOPES. Sanitary sewers should be designed as to size and slope for the discharge of the expected peak flow. Regardless of quantity, however, the minimum size for house sewers should be 6 inches and the minimum size for all other sewers should be 8 inches. In general, all sewers should be laid on slopes sufficient to provide a minimum velocity of 2 feet per second when flowing full or half full, and a minimum velocity of 1.6 feet per second under conditions of average flow. There is a tendency on the part of some designers to increase the size of the sewer, when flat grades are necessary, in order to maintain a theoretical minimum velocity of 2 feet per second. Actually the increased pipe size may result in a decrease in depth of flow such that the resultant velocity is no more than would be obtained by using a smaller sewer at the same slope. The net result of increasing the pipe size is to increase the cost and this practice should be avoided. In unfavorable terrain, velocities of 1.5 feet per second, pipe flowing full, and 1.2 feet per

second at average flow may be used, if excessive depths of sewer or the use of sewage lift stations can be eliminated thereby, or when other conditions are such that higher velocities are not practicable. These low velocities should be avoided as far as practicable.

a. Hydraulic Design. Design capacities of sewers should be computed by Kutter's Formula using n = 0.013 with pipe flowing full or by Manning's Formula with n = 0.013 for 12-inch pipes and larger and with n = 0.015 for 10-inch pipes and smaller. Figures 2 and 3, respectively, are pipe flow charts, indicating the discharge of pipes computed by the two formulas as noted. It should be noted that these charts are for pipes flowing full. The velocity should also be determined under conditions of average rate of flow. Figure 4 is a diagram giving the ratio of the velocity when the pipe is flowing partly full to the velocity when the pipe is flowing full. Table II indicates the required slopes for various sizes of pipes flowing either full or half full at velocities of two feet per second and 1.5 feet per second.

TABLE II - TABLE OF SIZES AND SLOPES

Diameter in inches	Slope in feet /1000 ft. for Velocity of 2 ft/sec.	Slope in ft./1000 Ft. for Velocity of 1.5/ft. sec.
6	6.0	3.6
8	4.0	2.3
10	2.9	1.6
12	2.2	1.2
15	1.5	0.86
18	1.2	0.67
21	0.95	0.53
24	0.80	0.44
27	0.67	0.38
30	0.58	0.33

b. Design Procedure. After a preliminary layout has been made a tabulation should be prepared in convenient form setting forth the following: designation of manholes by numerals or letters; distance between manholes; total population contributing to the sections of sewer between manholes; average daily sewage flow; peak rate of sewage flow; pipe diameters; slope; capacity of the sewer; velocity when the pipe flows full; velocity at average flow; and the pipe invert elevations at the manholes. Each section between successive manholes should be analyzed and corrections should be made in the layout and design, as appears advisable.

1-09 EXTERNAL LOADS ON SEWERS. The loads on sewers should be computed by the appropriate method for the type of loading as follows:

a. Trench Loading. Experiments conducted at Iowa Engineering Experiment Station, Ames, Iowa, clearly indicate that trench width below the top of the pipe has a decided influence upon the load on the sewer pipe. For this reason the trench width below the top of the pipe should be as narrow as practicable, 16 inches plus outside pipe diameter being recommended as a maximum. For a full understanding of the theory, reference is made to Bulletins Nos. 96 and 108, which are obtainable from the director of the experiment station. The Marston-Anderson Formula for dead loads on

pipes in trenches, developed from the results of the experiments, is $L = CWB^2$. Legend in this formula and in Table III, is as follows:

L = dead load on the pipe in pounds per linear foot

W = weight of trench filling material in pounds per cubic foot

B = width of trench in feet at the top of the pipe

H = height of fill in feet above the top of pipe

C = coefficient of load on pipe in trenches determined from Table III

For practical design the values of "C" can be taken from Table III and the value of "W" can be taken as 110 pounds for saturated silt and loam, 120 pounds for wet sand and 130 pounds for saturated clay.

Bulletin No. 96 also indicates the effect of concrete cradles and encasements upon the resistance of pipes to trench loadings. Concrete cradles should be used where the dead loads exceed the safe loads of the pipe or if yielding soil conditions so require. Normally, allowances for live loads over sewer trenches are not made, but under railroad tracks and in other such locations, live load should be considered and metal pipe, concrete encasement or a protective conduit may be required. Bulletin No. 96 outlines a method of computing the live load effect on pipes.

TABLE III - COEFFICIENT "C" In MARSTON-ANDERSON FORMULA

Ratio of Trench Depth to Width H/B	Coefficient "C"		
	Wet Sand	Saturated Silt and Loam	Saturated Clay
1.0	0.9	0.9	0.9
1.5	1.2	1.2	1.3
2.0	1.5	1.5	1.6
2.5	1.7	1.8	1.9
3.0	1.9	2.0	2.2
3.5	2.1	2.2	2.4
4.0	2.2	2.4	2.7
4.5	2.3	2.5	2.9
5.0	2.5	2.6	3.0
6.0	2.6	2.8	3.3
7.0	2.7	3.0	3.6
8.0	2.8	3.1	3.7
9.0	2.9	3.1	3.9
10.0	2.9	3.2	4.0
12.0	3.0	3.3	4.2

b. Embankment Loading. In all cases where sewers are laid directly on the subgrade of an embankment or in a trench which is shallow in comparison with the height of the overlying fill, the dead load on the pipe should be computed as 150% of the weight of the vertical prism of earth

overlying the pipe and the horizontal pressure as 50% of the weight of the prism. These loadings are based on the results of experiments conducted at Iowa State College, at the University of North Carolina, and by the American Railway Engineers' Association at Farina, Illinois. References are made to Bulletin No. 96, referred to previously, to "Earth Pressures on Culvert Pipes" published in Public Roads, Vol. 7, No. 11, Jan. 1927, page 223, and to "Culvert Load Determination" published in AREA Bulletin 284, Vol. 27, 1926.

1-10 MATERIALS FOR SANITARY SEWERS. Vitrified clay sewer pipe may be used in all sizes for which it is readily available. Bituminized fiber sewer pipe and asbestos-cement sewer pipe may be used in the 6-inch and larger sizes as available. Concrete pipe should not be used where local experience has indicated that it is not suitable; where the sewer receives acid waste that is not sufficiently diluted with alkaline sewage; where acid in the soil, such as cinder fills, may gradually attack and destroy the pipe. An investigation should be made to determine whether or not Portland cement concrete pipe has been used in municipalities in the vicinity of the project and if the results were satisfactory. The investigation should also determine whether or not competition can be had with other acceptable types of material. When it is determined that the use of concrete pipe will be satisfactory, unreinforced concrete pipe may be used, in competition with vitrified clay, for sizes 24-inch and smaller, and reinforced concrete pipe may be used for sizes over 24-inch. Pipe of any permitted material should conform to current applicable O.C.E. Specifications. Contract specifications should be so drawn as to permit any or all acceptable types of materials.

1-11 SEWER PIPE JOINTS. Sewer pipe joints should preferably be made with hot poured bituminous material, preformed or poured in place. This type of joint is advantageous in the reduction of infiltration and of the entrance of roots into the pipe. Other types of joints may be used where their suitability is indicated.

1-12 MANHOLES. Manholes should conform to the general dimensions shown on current O.C.E. Standard Drawings. The walls may be constructed of brick, concrete block masonry, reinforced concrete rings or monolithic concrete. The foundations should be of unreinforced concrete except where the ground is unstable and reinforced concrete is necessary. The invert channels may be formed in the concrete, built up with brickwork and mortar, constructed of half tile or made by laying pipe straight through the manhole with the top half broken out and removed after construction. Manholes should be provided with steps of cast iron or wrought iron. The frames and covers should be cast iron or reinforced concrete.

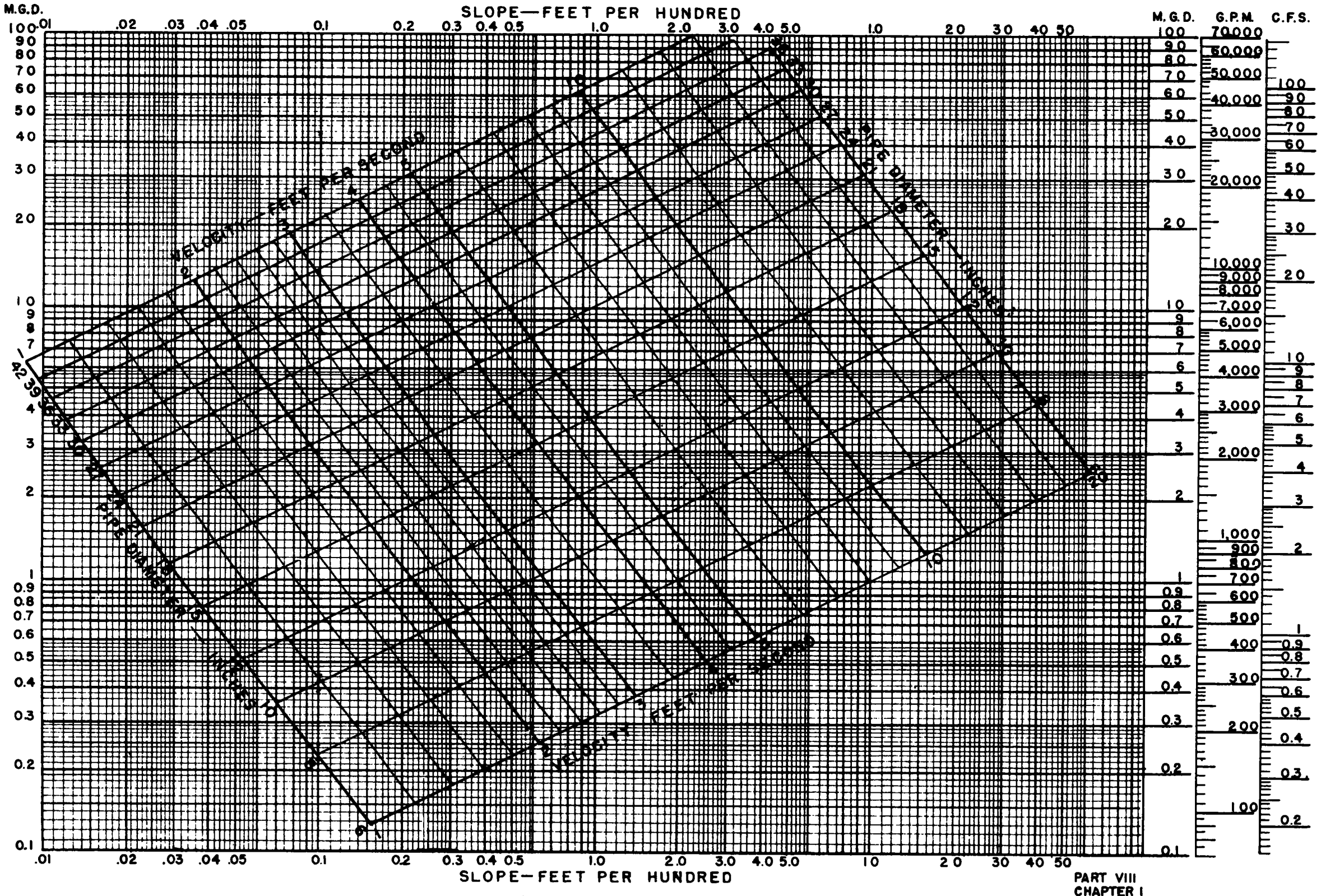
1-13 FORCE MAINS. Sewage force mains should be constructed of asbestos-cement, cast iron or steel pipe. They should be of adequate strength to withs and the internal pressures and external loads and should be water-tight. The lines must be large enough to handle peak rates of flow without excessive loss of head due to friction. In general, friction losses through long force mains should not exceed 100 feet when the combination of pumps producing the maximum discharge are in operation. Consideration should be given to venting all summits in force mains, to providing drainage at low points, and to protecting against surge in long lines.

1-14 INVERTED SIPHONS. Inverted siphons should not be used if it is practicable to avoid doing so. When an inverted siphon is required, spec-

ial care should be used in the design to secure velocities that will prevent clogging due to sedimentation, particularly when the sewage is subject to intermittent flow. The minimum size should be six (6) inches in diameter and preferably eight (8) inches if sufficient velocity can be obtained with 8-inch pipe. Except as noted in regard to minimum size, the siphon should be as small as the available head permits. When the flow is large and the available head is too low for satisfactory velocities with one pipe, it may be advantageous to construct the siphon of two smaller pipes. In such cases an entrance box should be provided with a diversion gate for the periodic alternating of flow from one pipe to the other and with an overflow weir so that flows in excess of the capacity of one pipe can overflow to the other.

1-15 LAYOUT MAPS. A layout map showing the entire collecting system, together with unit maps to a scale of 1 inch to 50 feet, should be prepared.

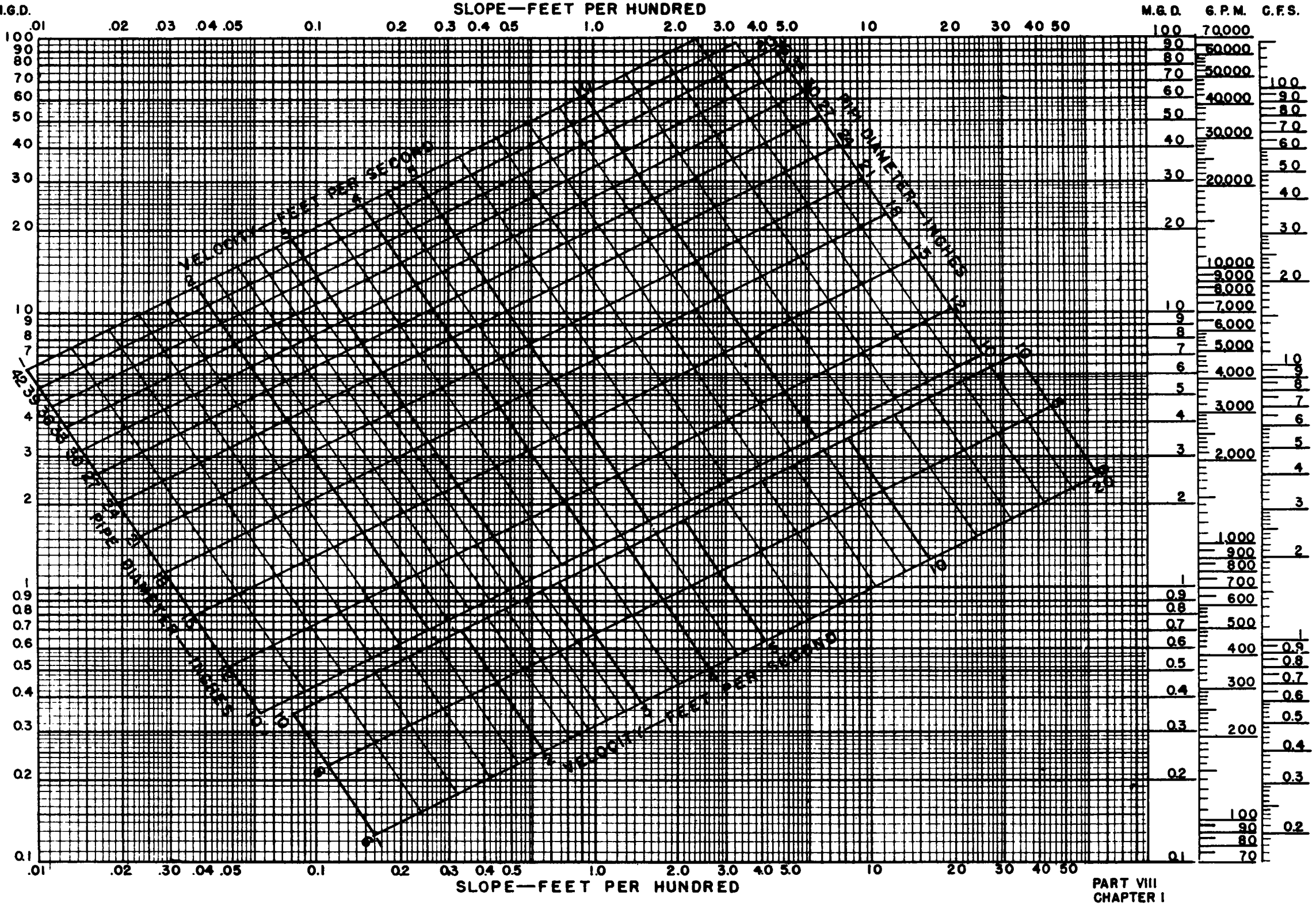
1-16 DESIGN ANALYSIS. A design analysis, required by paragraph 740-09 (or latest revision), Orders and Regulations, Corps of Engineers, will be prepared to accompany all plans and specifications for sanitary sewers. The design analysis will indicate the data outlined in paragraph 1-08 b.



PIPE FLOW CHART

KUTTER'S FORMULA (N=.013)

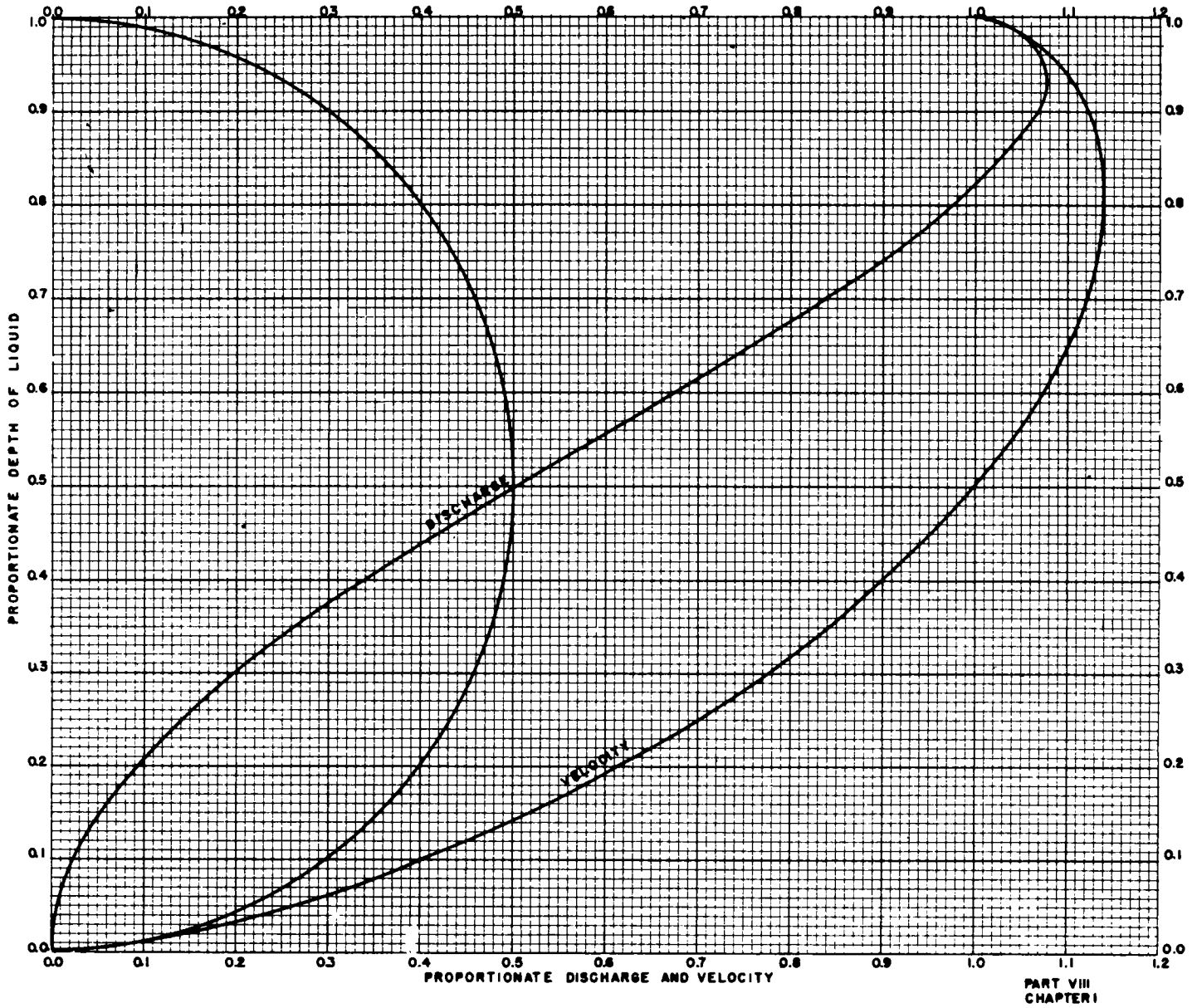
FIG. 2



PIPE FLOW CHART

MANNING'S FORMULA N=.013 FOR 12" PIPE AND LARGER
N=.015 FOR 10" PIPE AND SMALLER

FIG. 3



PART VIII
CHAPTER I

PROPORTIONATE FLOW CHART
BY MANNING'S FORMULA
FIG. 4

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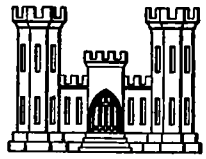
SEWAGE AND WASTE DISPOSAL

SEWAGE PUMPING STATIONS



DEPARTMENT OF THE ARMY
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Chapter 2

SEWAGE PUMPING STATIONS

2–01 GENERAL
2–02 LOCATION OF SEWAGE PUMPING STATIONS
2–03 PUMPING STATION CAPACITY
2–04 RESERVE CAPACITY
2–05 SELECTION OF PUMPING UNITS
2–06 STORAGE WELL
2–07 PUMP SEAL
2–08 PUMP CHARACTERISTICS
2–09 PNEUMATIC SEWAGE EJECTORS
2–10 OVERFLOWS
2–11 STAND-BY POWER
2–12 SURGE PROTECTION
2–13 DESIGN ANALYSIS
APPENDIX A — ILLUSTRATIVE EXAMPLE

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PART VIII

SEWAGE AND WASTE DISPOSAL

Chapter 2

SEWAGE PUMPING STATIONS

2—01 GENERAL. This chapter applies to sanitary sewage pumping stations which are required for year-round operation. The instructions do not apply to flood control projects where pumping would be required only during periods of high water. Sewage pumping stations may be required to pump the sewage from areas which cannot be served by the main gravity system or at sewage treatment plants where pumping is required to handle the sewage through the plant. Sewage pumping stations, in general, will comprise a screen, a sump or storage well and a dry well for the pumping equipment. Submerged pumps should be used only in pumping stations of very small capacity or in stations where conditions are such that dry wells are not practicable.

2—02 LOCATION OF SEWAGE PUMPING STATIONS. The location of sewage pumping stations serving portions of a system will usually be determined by the topography. Such stations should be located as far from buildings as practicable, but should be readily accessible from an improved road. Sewage pumping stations at treatment plants will usually be constructed adjacent to and in connection with the other plant elements.

2—03 PUMPING STATION CAPACITY. The capacity of the pumping station should be sufficient to handle maximum rates of sewage flow as outlined in Part VIII, Chapter 1, paragraph 1–05 (see also pt. VIII, ch. 3, par. 3–09a). This capacity should still be available when the largest pump is out of service if no overflow is provided (see par. 2–10 on overflows). Where a suitable overflow is provided, combined capacity for at least twice the average rate of sewage flow should still be available when the largest pump is out of service. The design should be such that long intervals between the operation of a pump during periods of maximum flow will not occur, especially if such intermittent discharge would adversely affect the operation of a sewage treatment plant by introducing high-rate flows at infrequent intervals.

2—04 RESERVE CAPACITY. Additional capacity to provide for population increase will not be considered for sewage pumping stations serving areas which are fully developed. If the pumping station serves an area which may be expanded, it is wise to provide space in the building for the installation of an additional or larger pump at a later date. Additional capacity can often be provided by installing a larger impeller in an existing pump. This may or may not require a larger motor, depending upon the load. Table I, in paragraph 2–08, illustrates this point. In the design of sewage pumping stations constructed in connection with sewage treatment plants, additional capacity should be provided by applying the same capacity factor used in the design of the sewage treatment works.

2–05 SELECTION OF PUMPING UNITS. Horizontal or vertical centrifugal pumps installed in dry wells are usually best suited for sewage pumping installations. For small stations serving populations less than 1, 500, pneumatic sewage ejectors or pumping units of the duplex, submerged pump type may be used. The use of pneumatic ejectors eliminates the need of screens and storage wells, the ejectors being connected directly to a collecting manhole. For stations serving popu-

lations of 5,000 or less, two pumping units, each capable of handling the maximum rates of sewage flow, would often suffice. For stations serving populations greater than 5,000, and for stations pumping a relatively large portion of the total sewage flow ahead of a sewage treatment plant, three or more pumping units may be required, depending on the head capacity characteristics of the station as a whole. All centrifugal pumps should be capable of passing 2-inch spheres and the size of the suction and discharge piping should not be less than 4-inch. All pumps normally will be actuated by float-operated switches.

2–06 STORAGE WELL. The storage well should be carefully designed to eliminate the possibility of sludge deposits. In order to prevent the sewage from becoming septic due to long retention during periods of minimum flow, the capacity of the storage well should be large enough only for the proper operation of the pumps. For pumping stations serving a population of less than 3,500, the storage well should provide storage for about ten minutes at the average rate of flow. For stations serving a population greater than 3,500, storage of 3 to 5 minutes at the average rate of flow is sufficient. (See also pt. VIII, ch. 3, par. 3–22b, Chlorine Contact Tank.)

2–07 PUMP SEAL. Water seals should be specified for sewage pumps in preference to grease seals if a clear water line is accessible within a reasonable distance. The principal advantage of a water seal over a grease seal is that a positive pressure is maintained inside the stuffing box and a small amount of clear water flows from the stuffing box into the pump casing. Grit and other abrasive materials which may be in the sewage are thereby prevented from entering the stuffing box, thus reducing wear on the shaft and the packing. The advantages of less frequent repairs to the shaft and less frequent repacking should be considered in relationship to the cost of providing the water line and other necessary facilities for the water seal. Where freezing of seal water is likely to occur, protective measures against this possibility should be considered. There should not be, under any circumstances, any direct connection between the pumps and a potable water system, nor any possibility of backflow of sewage into a potable water system.

2–08 PUMP CHARACTERISTICS. In cases where pumps have practically free discharge, such as into a large adjacent conduit or directly into the primary sedimentation tank of a sewage treatment plant, there will be little increase in friction head as the rate of pumping increases. Under these conditions each pump can deliver approximately its rated capacity when operating in parallel with other pumps and all pumps or any required number can be effectively used together. If the pumps discharge into a long force main there will be considerable increase in friction head as the rate of flow is increased and if the total head is in proximity of the rated head of the individual pumps, not more than two and probably not more than one can be used effectively at a time. Under such conditions it will be necessary for one of the pumps to have head and capacity characteristics capable of handling the maximum rate of flow. Table I, which is hypothetical data, similar to data taken from characteristic curves of one of the pumps of a well-known manufacturer, will illustrate these points if considered in connection with typical problems. A study of table I will also illustrate the necessity for careful determination of the services required before a pump is selected. For example, if the requirements were specified as 600 g. p. m. discharge against a total head of 27.9 feet, the supplier would probably furnish a pump with a 14-inch impeller and a 7½ hp. motor, the B. H. P. for the pump under these conditions being 6.79. A slight error in the computation of total head or the installation of a larger discharge pipe than was used in the computation might result in an overloaded motor. The total head under a flow of 1,200 g. p. m. might be only 24.4 but the B. H. P. for this pump under these conditions would be 9.20 and the 7½ hp. motor would be approximately 25 percent overloaded. Also, the operation of a sewage treatment plant could be seriously affected.

TABLE I.—*Illustrative Range of Pump Capacity*

(Similar to data taken from actual characteristic curves of a particular pump)

Impeller diameter (inches)		Capacity in gallons per minute						
		400	600	800	1,000	1,200	1,400	1,600
14	Head	29. 2	27. 9	26. 8	25. 7	24. 4	23. 0	21. 0
	% Eff	50. 4	62. 4	70. 5	76. 3	80. 4	82. 5	83. 0
	B. H. P	5. 89	6. 79	7. 67	8. 51	9. 20	9. 87	10. 2
13½	Head	26. 0	25. 0	23. 8	22. 5	21. 0	19. 4	17. 5
	% Eff	51. 3	63. 4	71. 1	76. 5	79. 7	81. 0	80. 0
	B. H. P	5. 12	5. 98	6. 75	7. 43	7. 99	8. 48	8. 83
13	Head	23. 2	22. 0	20. 8	19. 5	18. 0	16. 2	14. 0
	% Eff	52. 3	64. 3	72. 0	76. 9	79. 0	79. 0	76. 6
	B. H. P	4. 45	5. 19	5. 84	6. 41	6. 90	7. 27	7. 38
12½	Head	20. 0	19. 3	18. 0	16. 6	15. 0	13. 3	11. 2
	% Eff	53. 7	65. 0	72. 1	76. 4	77. 1	75. 0	72. 0
	B. H. P	3. 78	4. 50	5. 04	5. 49	5. 88	6. 22	6. 28
12	Head	17. 6	16. 5	15. 3	14. 0	12. 2	10. 5	8. 5
	% Eff	55. 0	65. 8	72. 3	75. 6	75. 1	72. 2	66. 0
	B. H. P	3. 21	3. 80	4. 27	4. 67	4. 92	5. 15	5. 20

2–09 PNEUMATIC SEWAGE EJECTORS. The design of a pneumatic ejector station normally should be based on the use of standard equipment. The size of sewage receiver and the actual intermittent rate of discharge to meet the particular ejector station requirements would probably vary with different manufacturers. For this reason the contract specifications should clearly state the continuous peak rate of flow to the ejector station, the static head and the friction loss in the discharge pipe based on the continuous rate of flow to the station. With this information, the manufacturer could recompute the friction loss on a basis of the actual intermittent rate of discharge from his particular equipment, and size the equipment to be furnished accordingly.

2–10 OVERFLOWS. An overflow, which is for operation only in case of power outages or short periods of shut-down, from the sump or storage well to a point of outlet, should be provided wherever possible. The elevation of the overflow must be low enough to prevent the backing up of sewage into buildings. Generally the operation of an overflow into an adjacent drainage course during a power outage will not create a serious menace to public health because of the infrequency of use, and the overflow, if it can be provided, should be omitted only in cases where a water supply would be definitely endangered.

2–11 STAND-BY POWER. Stand-by power will be required only where it is impossible to provide a suitable overflow. Where stand-by power is required, one pumping unit capable of handling the peak flow should be equipped with both electric motor and stand-by gasoline engine, or a separate gasoline engine driven pumping unit should be provided.

2–12 SURGE PROTECTION. When the location of the pumping station requires a force main of several thousand feet, provision should be made for protection against surge or water hammer and for venting and draining the force main. A suitable air chamber at the pumping discharge will usually provide adequate surge protection. The air chamber should be provided with a sight glass and with means for refilling the chamber with air.

2–13 DESIGN ANALYSIS. A design analysis, required by paragraph 4106.13 (or latest revision), Orders and Regulations, Corps of Engineers, will be prepared to accompany all plans and specifications for sewage pumping stations. The design analysis will indicate the total tributary population to be served by the pumping station, the operating sequence of the various pumps, the static head between low level in the wet well and point of final discharge, the total head under the various operating sequences, the pumping capacity of each pump under a specified total head, and the approximate capacity of each pump under one other total head condition.

APPENDIX A

ILLUSTRATIVE EXAMPLE

Problem. Design a sewage pumping station, as regards pump selection, to pump sanitary sewage to a treatment plant through a 12-inch force main 1,000 feet long. The population served is 7,000, housed in permanent-type buildings. A suitable overflow from the wet well is provided 4.5 feet above the pump intake. The static head above pump intake is 33.0 feet.

Solution. Determination of the required pump capacities and head characteristics is as follows:

Rate of sewage flow	*g. p. m.*
Average	486
Peak	1, 690
4-hour maximum	850
4-hour minimum	195

With the aid of manufacturer's pump data, the following tabulation has been prepared:

Tabulation of Data

Pumps in service	Capacity (g. p. m.)	Combined capacity	Depth in well above pump intake (ft.)	Head (ft.)		
				Static	Friction	Total
No. 1	300		1. 0	32. 0	0. 9	32. 9
No. 2a	600		2. 0	31. 0	1. 5	32. 5
No. 2b	600		2. 0	31. 0	1. 5	32. 5
No. 3	1, 100		3. 5	29. 5	4. 8	34. 3
No. 2a	375					
No. 2b	375					
No. 3	950	1, 700	4. 5	28. 5	10. 5	39. 0
No. 2a	560					
No. 2b	560	1, 120	4. 5	28. 5	4. 9	33. 4

By proper arrangement of starting and stopping sequence and float switch setting, the normal pump operations would be: No. 1 during low flows; Nos. 2a and 2b (alternately) during average

flows; No. 3 during the 4-hour maximum flows; and Nos. 2a, 2b, and 3 during extreme peak flows. In compliance with the requirements of paragraph 2–03, the station would have combined capacity for the peak rate of flow and would still have capacity for twice the average rate of flow with the largest pump out of service, without the depth in the wet well reaching the overflow point. Accordingly, the following should be specified:

Pump No.	Required capacity		Approximate capacity	
	g. p. m.	head (ft.)	g. p. m.	head (ft.)
1	300	33. 0	200	40. 0
2a	600	32. 5	375	39. 0
2b	600	32. 5	375	39. 0
3	1, 100	34. 5	950	39. 0

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ENGINEERING MANUAL

MILITARY AND CIVIL WORKS CONSTRUCTION

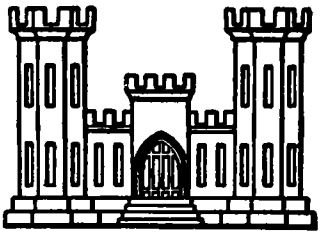
PART VIII
CHAP. 1
JUNE 1955

SUPERSEDING
CHAP 1, JUN. 50

Housing and Home Finance Agency
JUN 19 1956

SEWAGE AND WASTE DISPOSAL

SANITARY AND INDUSTRIAL-WASTE SEWERS



DEPARTMENT OF THE ARMY
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PART VIII
SEWAGE AND WASTE DISPOSAL
CHAPTER 1
June 1955

Superseding Chap. 1, Jun 50

Chapter 1

SANITARY AND INDUSTRIAL-WASTE SEWERS

1-01 SCOPE
1-02 DEFINITIONS
1-03 LIMITATIONS ON THE USE OF SANITARY SEWERS
1-04 SEWER LAYOUT AND APPURTENANCES
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b. Safety Precautions
c. Pumping Stations
d. Cover
e. Manholes
f. House Connections
g. Grease Traps
h. Flush Tanks
1-05 BASIS OF DESIGN
a. Sewage Flows
b. Future Capacity
1-06 SPECIAL CASES
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b. Laundry Sewers
c. House Connections
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1-14 PRELIMINARY DRAWINGS AND DESIGN ANALYSIS

Part VIII

SEWAGE AND WASTE DISPOSAL

Chapter 1

SANITARY AND INDUSTRIAL-WASTE SEWERS

1-01 SCOPE. The instructions and information contained in this chapter relate to the design of sewers for the collection of domestic sewage and such other matter, including laundry waste, as normally might be discharged into sanitary sewers. The principles of design would be the same for emergency facilities as for permanent facilities, except in regard to rates of sewage flow. Paragraph 1-05*a* sets up a table of flows to be used in the design of various types of construction. Instructions relating to the design of storm water drains are included in another part of this manual.

1-02 DEFINITIONS. The following definitions are quoted from "Glossary—Water and Sewage Control Engineering" sponsored jointly by American Public Health Association, American Society of Civil Engineers, American Water Works Association, and Federation of Sewage Works Associations and published in 1949.

a. Branch Sewer. A sewer which receives sewage from a relatively small area, and discharges into a main sewer.

b. Collecting System (same as *Sewerage System*). A system of sewers and appurtenances for the collection, transportation, and pumping of sewage and industrial wastes.

c. Combined Sewer. A sewer receiving both surface runoff and sewage.

d. Force Main. A pipeline on the discharge side of a water or sewage pumping station.

e. House Connection. The pipe carrying sewage from the building to a common sewer. Also called *Building Sewer* and *House Sewer.*

f. Industrial-Waste Sewer. A sewer in which industrial wastes predominate.

g. Inverted Siphon (same as *Depressed Sewer*). A section of a sewer constructed lower than adjacent sections, to pass beneath a valley, watercourse, or other obstruction. It runs full or at greater than atmospheric pressure because its crown is depressed below the hydraulic grade line.

h. Lateral Sewer. A sewer which discharges into a branch or other sewer and has no other common sewer tributary to it.

i. Main Sewer. A sewer to which one or more branch sewers are tributary. Also called *Trunk Sewer.*

j. Outfall Sewer. A sewer which receives the sewage from a collecting system and carries it to a point of final discharge. See *Pipe Outlet.*

k. Pipe Outlet. A pipeline which conveys the effluent from a reservoir, sewage treatment plant, or other structure to its point of discharge.

l. Sanitary Sewer (same as *Separate Sewer*). A sewer which carries waste from sanitary conveniences and to which storm, surface, and ground waters are not intentionally admitted.

m. Submain Sewer. An arbitrary term used for relatively large branch sewers.

n. Trunk Sewer. A sewer which receives many tributary branches and serves a large territory. See *Main Sewer.*

1-03 LIMITATIONS ON THE USE OF SANITARY SEWERS. Wastes from hydraulic gasoline dispensing systems, wash racks, garages, and shop floor drains should be completely excluded from sanitary

sewers. Other types of industrial waste may or may not be discharged into the sanitary sewer system depending upon their effect on sewer pipe material and sewage treatment processes. Storm water run-off from ground surface, pavements, and roofs should not be permitted to enter sanitary sewers except under rare conditions. Unpolluted waste water, such as that used for cooling and air conditioning, should not be discharged into sanitary sewers. Combined systems for sanitary sewage and storm water are seldom advisable even in cases where the pumping or treatment of sewage is not involved. It is difficult to obtain flow conditions in combined sewers that would be adequate during dry weather for the prevention of the deposit of sewage solids in the sewer and the consequent septic action. Also, as considerably larger pipe would be required for combined sewers than for sanitary sewers, the cost of installing the larger pipe at the greater depth usually required for sanitary sewers often would equal and sometimes exceed the cost of separate sewer systems. However, where sewage treatment is not required and is not likely to be required in the future, combined sewers may be considered if definite and considerable saving in cost could be effected and if slopes are available to produce the velocities hereafter prescribed.

1-04 SEWER LAYOUT AND APPURTENANCES. The development of final sewer plans must await the final site plan, the completion of field surveys and, to some extent, the establishment of floor grades. However, the development of economical site plans often requires concurrent preliminary planning of the sewer system.

a. Sewers. The location of lateral and branch sewers will depend not only upon topography but upon the type and layout of the housing to be served. Normally, the most practical location would be along one side of the street. In other cases they may be located behind the buildings midway between streets. In still other cases, in closely built-up areas and particularly where the street is very wide or already paved, it may be advantageous and economical to construct laterals on each side of the street. Main, trunk, and outfall sewers should follow the most feasible route to the point of disposal. All sewers should be located outside of roadways as much as practicable and so that the number of roadway crossings would be reduced to a minimum. A sewer from one building should not be constructed under another building or remain in service where a building is subsequently constructed over it if any other practical location for the sewer is available. Where no other location is suitable, necessary measures should be taken to assure accessibility for future excavation and complete freedom of the sewer from superimposed building loads.

b. Safety Precautions. The following safety precautions must be strictly observed in the sewer layout. No physical connections shall exist between sewer and water supply systems. Sewers and water lines shall be at least 10 feet apart horizontally, except that where the bottom of the water pipe will be at least 12 inches above the top of the sewer the horizontal spacing may be a minimum of 6 feet. Where conditions require a sewer to cross above a water line, the sewer shall be constructed of cast iron, steel, or other pressure pipe for 10 feet each side of the crossing and preferably without a joint in the sewer pipe coming immediately above the water pipe. At crossings of force mains or inverted siphons and water lines, the sewer in all cases shall be at least 2 feet below the water line.

c. Pumping Stations. Pumping should be avoided in the design of a collection system unless analysis of the initial and operating costs conclusively indicates that it would be more practical than gravity flow, with due consideration given to the situation which might result from pump failure. Design of pumping stations is covered in part VIII, chapter 2.

d. Cover. The cover should be at least 2 feet to protect the pipe from superimposed live loads of ordinary traffic and more for heavy trucks. (See paragraph 1-10 for determination of transmitted loads.) Generally, 2 feet of cover will be sufficient to protect the sewer against freezing. Where frost penetrates to considerably greater depth and lasts for an appreciable length of time, the sewage may not contain sufficient heat to prevent the gradual cooling of the surrounding earth and the building up of an ice film inside the pipe. Under these conditions greater cover should be provided.

e. Manholes. Manholes are required at the end of laterals and at each change of direction or slope, except as noted hereafter for house connections. The distance between manholes should not exceed 400 feet in sewers of less than 18 inches in diameter. For sewers of 18-inch pipe or larger and for outlets from

sewage treatment plants a spacing of 600 feet may be used provided that the velocity is sufficient to prevent sedimentation. The crown of the outlet pipe from a manhole should be on line with or below the crown of the inlet pipe. Where conditions are such as to produce unusual turbulence in the manhole and especially where the size of the outlet pipe is to be smaller than the inlet pipe because of the availability of a more favorable slope, it may be necessary to lower the invert of the pipe to provide for entry head or increased velocity head or both. With this exception, the value of the practice of lowering the invert of the outlet pipe to theoretically compensate for entry head and similar losses in the manhole is questionable from a practical point of view. Where the invert of the inlet pipe would be more than 12 inches above the manhole floor a drop connection should be provided. (See OCE Standard Manhole Drawing 40-08-02.)

f. House Connections. House connections should be planned with a view to eliminating as many bends as practicable and providing convenience in rodding when required. Generally, connections of house sewers to other sewers should be made directly to the pipe with commercially manufactured fittings rather than through manholes. Manholes may be used, however, if no extra expense would be incurred and should be used if the connection is at greater distance than 150 feet from the nearest cleanout. Where the cleanout inside the building would not be adequate for complete rodding, outside cleanouts, or manholes if cleanouts are not feasible, should be provided.

g. Grease Traps. The presence of grease in sewage is the cause of one of the most serious difficulties in sewage treatment and, where sewage is discharged into a stream without treatment, grease film on the surface of the water retards reoxygenation. Therefore, the removal of as much of the grease as feasible is necessary. In order to obviate the depositing of grease on the walls of the sewer and in view of the fact that the grease would lose its salvage value after mixing with sanitary sewage, removal at the source is advisable. At Army posts this is usually accomplished by means of grease traps installed as outlined in the part of this manual relating to plumbing.

h. Flush Tanks. Flush tanks are not considered necessary in Army sanitary sewer systems. For the rare occasions when flushing might be necessary, improvised means can be used.

1-05 BASIS OF DESIGN. The sewage quantities used in design normally are to be computed on a contributing population basis except in special cases as noted in paragraph 1-06. The population to be used in design depends upon the type of area which the sewer serves. If the area is strictly residential, the design population is based on full occupancy of all quarters served. If the area served is entirely industrial, the design population would be the greatest number, military and civilian, employed in the area at any time, even though some of these persons may also be included in the design of the sewers in the residential area. For sewers serving both residential and industrial areas the design population includes residents and nonresidents, but in the design of these sewers obviously no person should be counted more than once.

a. Sewage Flows. The average quantity of sewage per capita for different types of posts and classes of installation are given in table I.

Table I. Table of per capita sewage quantities

Type of post	Gallons per day per resident			
	Permanent posts	Mobilization camps	Theater of operation camps	Field training camps
Hospitals (including station hospitals)	100	100	85	70
All other types of posts—airfields, forts, camps, depots, plants, etc	100	70	50	35
All types	30 gallons per 8-hour shift per nonresident or worker in an industrial area (90 gallons per day rate)			

The normal range of the rate of flow throughout the day is from about 40 percent to about 225 percent of the average rate. The ratios of the extreme rates of flow, which occur occassionally, to the average rates of flow are indicated in figure 1.

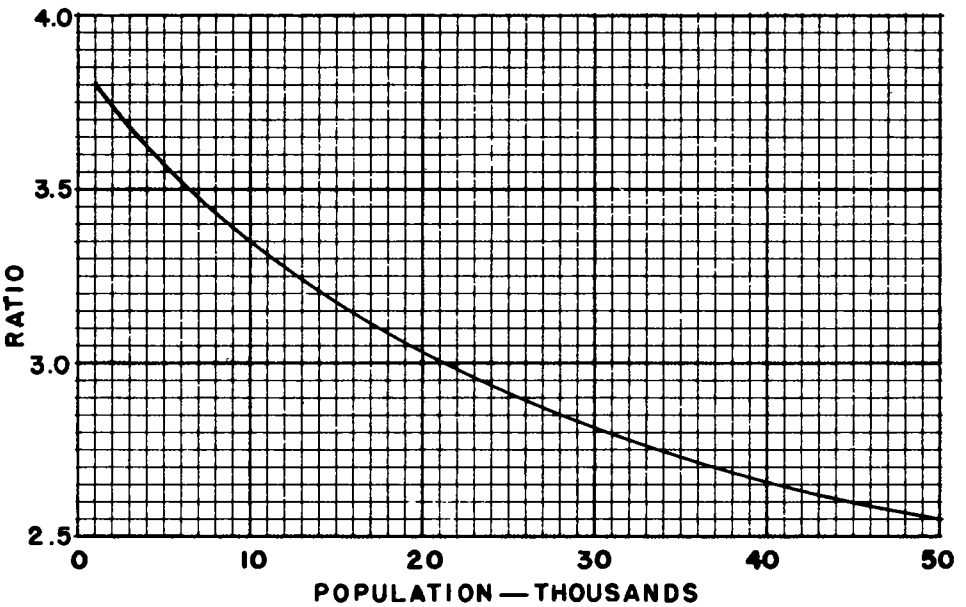


Figure 1. Curve showing ratio of peak flow to average flow.

The sewers must have capacity for these extreme peak rates of flow. The design flow is obtained by multiplying the product of the number of contributing persons and the average per capita flow by the ratio of peak flow to average flow. It should be noted that by proper placement of the decimal point the design flow may be obtained in terms of million gallons per day, which is the most convenient unit of measure to use with the flow charts hereafter described, thus eliminating the need for converting to smaller units. These per capita sewage quantities include laundry wastes incidental to laundering for the resident population and normally no additional allowances will be made for such wastes. Where unusual ground water conditions are known to exist, an allowance for infiltration of 10,000 gallons per day per mile of sewer may be added to the peak flow computed on a population basis.

b. Future Capacity. Additional capacity to provide for population increases will not be considered for lateral and branch sewers where the areas served are fully developed. In the design of long outfall sewers and main sewers serving areas which are likely to continue to develop, provision of approximately 25 percent additional capacity over the computed initial requirements is advisable. The sewers will often have this surplus capacity without increasing the pipe size over that necessary for the initial requirements. For example, the computed peak flow may be 800 gallons per minute. A 12-inch pipe would discharge only 700 gallons per minute at the required velocity of 2 feet per second and 15-inch pipe, the next larger size, would be required. The 15-inch pipe would discharge 1,100 gallons per minute at 2 feet per second velocity or 27½ percent more than the initial requirement.

1-06 SPECIAL CASES. There are exceptions to the general rule that sanitary sewers will be designed entirely on a population basis. Among these exceptions are industrial-waste sewers, laundry sewers, and house connections.

a. Industrial Waste Sewers. Obviously, industrial-waste sewers serving ordnance plants, experimental laboratories, airplane wash racks, plating shops, and such industries cannot be designed on a population

basis. The flows from such plants depend upon the type and extent of the activities. Cooling water and similar unpolluted waste waters should not be discharged into industrial-waste sewers leading to treatment works. Sewers serving one or more aircraft wash racks should be designed for a peak rate of flow of 75 g. p. m. for each wash rack served. Other industrial-waste sewers will be designed for the peak flow as determined for the particular activity. Sewers serving both aircraft wash racks and other industrial activities should be designed for the combined peak flows. Outlet sewers from treatment works should be designed for the peak rate of treatment contemplated in the design of the treatment plant. The pipe size should not be less than 6-inch for any industrial-waste sewer.

b. Laundry Sewers. For sewers serving laundries, capacity to discharge the waste from one-third the number of washers when completely emptied in two minutes plus the back-wash from one of the water softeners is required. In view of the statement in paragraph 1-05*a* that laundry wastes are included in the table of per capita sewage quantities, the flow in a trunk or outfall sewer would not be influenced by the discharge from a laundry which serves the post only. However, when the laundry sewer connects to a relatively small main, branch or lateral, the influence upon the peak flows in such sewers might require consideration. This might apply also to trunk and outfall sewers if the laundry serves more than one post and is considerably larger than would be required if it served only the one post. These cases should be considered individually.

c. House Connections. The size of house connections, including those from mess halls, theaters, clubs, and other such buildings, should in all cases be large enough to discharge the flow computed on a fixture-units basis as set out in the part of this manual relating to plumbing. This applies to house sewers only and not to the lateral or other sewers to which they connect.

1-07 HYDRAULIC DESIGN OF GRAVITY SEWERS. All sanitary sewers should be designed to discharge the expected peak rate of flow when the pipe is running full or slightly less than full except that, regardless of sewage quantity, the minimum sizes to be used are 6-inch for house connections and 8-inch for all other sewers. In general, the sewers should be laid on sufficient slope to provide a velocity of at least 2 feet per second when the pipe is running full and 1.6 feet per second at average rate of flow. In unfavorable terrain, designs for velocities of 1.5 feet per second when the pipe is running full and 1.2 feet per second at the average rate of flow may be used when conditions are such that higher velocities could not be obtained practicably or when lift stations serving small areas could be eliminated thereby. These low velocities, however, often would result in sedimentation in the sewer with attendant operating difficulties and formation of hydrogen sulfide and should be avoided as much as feasible.

a. Design Formulas and Charts. The formula that probably has had the widest acceptance among engineers for sewer design in the past is known as Kutter's formula, which, in the simplified form usually used in design, is as follows:

$$(1) \qquad V=\frac{\frac{1.81}{n}+41.66}{1+\frac{n(41.66)}{\sqrt{R}}}\sqrt{RS} \quad \text{.... (Kutter's formula)}$$

in which V = velocity in feet per second;
n = a coefficient, dependent primarily upon roughness and, to some extent, upon size and shape of the conduit;
R = hydraulic radius in feet;
S = slope in feet per foot.

The Manning formula, which uses the same nomenclature and is much simpler in form than Kutter's formula, is as follows:

(2) $V=\frac{1.486}{n} R^{2/3}S^{1/2}$ ..... (Manning's formula)

The results obtained by the two formulas are practically the same except that for pipe sizes smaller than 12 inches the Manning formula requires slightly larger values of n for comparable results. It is recommended that 0.013 be used as the value of n in Kutter's formula for all sizes of pipe and in Manning's formula for pipe larger than 10 inches and that 0.014 be used in Manning's formula for pipe sizes of 10 inches and smaller. Figures 2 and 3, respectively, are pipe flow charts based on the two formulas using the values of n as recommended. Either chart may be used. It should be understood that these charts are for pipes running full. Figure 4 is a diagram giving ratio of velocity when the pipe is running partly full to velocity when the pipe is running full. Although figure 4 is based on Manning's formula, for practical purposes it can be used also in connection with Kutter's formula.

(*Note.* A circular slide chart based on Manning's formula and titled "Feild's Hydraulics Calculator for Gravity Flow in Pipes" is available in limited quantities from the Office of the Chief of Engineers for official use.)

b. Velocity Analysis. In all cases where doubt exists as to adequate velocities throughout the expected range of flows, a velocity analysis should be made at both the peak and average rates of flow. There is a tendency on the part of some designers to increase the size of the sewer in order to obtain a theoretical velocity of 2 feet per second when the available slope would not produce this velocity in a smaller pipe. Actually, in the larger pipe the depth of flow would be decreased to such extent that the velocity might be no greater and perhaps less than in a smaller pipe laid on the same slope. In such case the net result of increasing the pipe size would be to increase the cost without improving the flow conditions. Errors of this nature often could be eliminated through analysis of the velocity at various rates of flow.

(*Note.* The slide chart mentioned in 1-07a is particularly convenient in making this analysis.)

c. Design Procedure. After a preliminary layout has been made, a tabulation should be prepared in convenient form setting forth the following: designation of manholes by numerals or letters; distance between manholes; slopes; pipe diameters; pipe invert elevations at the manholes; total population contributing to the sections of sewer between manholes; average daily flow; peak rate of flow; capacity of the sewers; percentage of excess capacity over peak flow; velocity when the pipe runs full; velocity at average rate of flow. Each section between successive manholes should be analyzed and corrections made as appear advisable. Such analysis will frequently indicate that, because of differences in available slopes, smaller pipe can be used in some sections of the sewer than might be required in an upper section of the same sewer. Reducing sizes in such cases is a sound principle from a point of view of hydraulics if head is provided to compensate for entry loss and increased velocity and should be followed whenever it would result either in better flow conditions or in appreciable saving in cost. Reduction to smaller than 12-inch pipe in such cases, however, is not recommended.

1-08 HYDRAULIC DESIGN OF FORCE MAINS. Force mains should be not less than 4 inches in diameter and large enough to handle the maximum rate of pumping without excessive friction loss, yet sufficiently small that a velocity of at least two feet per second would obtain at the average rate of pumping for which the pumping station is designed and preferably at lower rates. Obviously this would require close coordination of the designs of the pumping station and of the force main. Figure 5, Pipe Flow Chart, based on the Hazen and Williams formula, is for use in computing friction loss. In general, friction loss should not exceed 100 feet. Consideration should be given to providing manually operated vents at summits and drains at low points. The pipe should be of adequate strength to withstand the internal pressure, including that caused by water hammer.

a. Water Hammer. When the flow of water is suddenly checked by the closing of a valve, its kinetic energy is expended in compressing the water and in expanding the walls of the pipe, resulting in increased pressure. This condition occurs in the entire length of pipe from the valve back to the origin. The increase in pressure causes reversal of flow or conditions which would reverse the flow. The pressure then

drops below normal, the walls contract and again the direction of flow is reversed. A pressure wave is thus set up in the pipe, its intensity being first above and then below normal. This wave travels up and down the pipe with diminishing variation of intensity until completely damped out by friction. The same condition exists in varying degree when a valve is partially closed. A similar condition exists when a pump is shut down, except that the first effect in the discharge pipe is a reduction in pressure. The amount of variation from normal pressure is dependent upon the velocity of the pressure wave and the decrease in velocity of the water during the time required for the pressure wave to travel the entire length of the pipe and return. The applicable formula is as follows:

$$(3) \qquad h=\frac{vV}{g}=\frac{v}{g}\left(\frac{4660}{\sqrt{1+\frac{0.3d}{Et}}}\right)=\frac{145v}{\sqrt{1+\frac{0.3d}{Et}}}$$

in which

h=variation in pressure from normal in feet of water;
g=acceleration due to gravity (32.2 f. p. s. p. s. at sea level);
v=decrease in velocity of the water during the time required for the pressure wave to travel the length of the pipe and return, f. p. s;
V=velocity of the pressure wave, f. p. s;
E=modulus of elasticity of the pipe material in million p. s. i. (approximately 30 for steel, 15 for cast iron, 3.5 for asbestos-cement);
d=internal diameter of the pipe, inches;
t=thickness of the pipe wall, inches.

Theoretically, the value of "h" is not affected by the intensity of the normal pressure. Practically, in an open system as in the case of stopping a pump, the forward flow of water would continue for a longer period of time if the normal pressure were low than if it were high. This prolongation of the forward flow might decrease the amount of extinguished velocity, "v", and thus decrease the intensity of the water hammer, particularly in short force mains. Each case should be considered individually and if the total pressure, working pressure plus water hammer, would exceed the safe working pressure of the pipe, appropriate means of reducing the water hammer should be provided. Such devices as air chambers or electrically operated slow-closing gate valves are suggested for consideration.

1-09 HYDRAULICS DESIGN OF INVERTED SIPHONS. The design of inverted siphons requires special care to secure velocities that would prevent clogging due to sedimentation. To accomplish this the pipe should be as small as the available head permits except that pipe smaller than 6-inch is not recommended. Inasmuch as the siphon must be of sufficient size to discharge the extreme peak flow, better velocities for the normal range of flows often could be obtained by using two small pipes instead of one large pipe. This would require an entrance box equipped with a diversion gate for the periodic alternation of pipes in service and with an overflow weir arranged so that, when the flow exceeds the capacity of one pipe, the excess could overflow to the other pipe. However, conditions might be such that two pipes in lieu of one would not be advantageous or necessary. Each case should be analyzed individually. Figure 5 would be of assistance in making such analysis.

1-10 STRUCTURAL DESIGN OF SEWERS. The following criteria for the structural design of sewers are based on the assumption that the sewers will be buried in trenches entirely below natural ground surface, that the sides of the trench will be virtually vertical below the top of the pipe and will have no flatter slopes than one horizontal to two vertical above the top of the pipe, and that the trench width at the top of the pipe will be relatively narrow. (OCE guide specifications limit the trench width to outside diameter plus 16 inches maximum.) The cases where sanitary sewers would be laid in fills that have not become thoroughly compacted or with the top of the pipe projecting above ground surface are too rare to warrant a discussion, in this part of the manual, of the numerous variables affecting the loads transmitted to the sewers in such cases. The theory of loads on projecting conduits is discussed in Iowa State College Bulletin 112, The Supporting Strength of Rigid Pipe Culverts.

a. Loads on Sewers. There are three kinds of external loads to which a sewer laid in a trench might be subjected, namely, loads due to trench-filling materials, to uniformly distributed super-loads and to concentrated super-loads. Formula 4 and figure 6 are for computing loads due to trench-filling materials. The weight per cubic foot of various materials may be taken as 120 pounds for mixed sand and gravel, 110 pounds for saturated top soil (loam and silt), 120 pounds for ordinary damp clay, and 130 pounds for saturated clay. The probability of the backfill material becoming saturated with water before becoming thoroughly settled and stabilized, which might occur in areas subject to flooding, should be considered in the load computations. An examination of formula 4 will show the importance of the trench being as narrow as practicable at and below the top of the pipe. Formula 5 and table II are for computing the load that would be transmitted to the sewer from a uniformly distributed super-load, such as stockpile materials or loose fill above natural ground surface. Formula 6 and table III are for computing the load that would be transmitted to the sewer from a concentrated super-load, such as that of a truck wheel. It will be noted from table III that the effect of a concentrated load diminishes rapidly as the amount of cover over the sewer increases; also, that the percentage of load transmitted to each foot of pipe length decreases somewhat as the pipe length increases. The tests and theories explained in Iowa State College Bulletin Number 96, Theory of External Loads on Closed Conduits in the Light of the Latest Experiments, which has been reproduced in the Proceedings of the Highway Research Board, Volume 9, 1929, and other publications, are the basis of the aforementioned formulas and tables which are as follows:

(4) $L_t = C_t W_t B_t^2$ ..... for loads due to trench filling;
(5) $L_u = C_u W_u B_t$ ..... for uniformly distributed super-loads;
(6) $L_c = I C_c W_c$ ..... for concentrated super-loads;

in which

L_t, L_u, L_c = Loads in pounds per linear foot transmitted to the pipe from trench-filling materials, from uniformly distributed super-loads, and from concentrated super-loads, respectively;
W_t, W_u, W_c = Weight in pounds of trench-filling material per cubic foot, uniformly distributed super-load per square foot, and total concentrated super-load, respectively;
C_t, C_u, C_c = Calculation coefficient taken from figure 6, table II and table III, respectively;
B_t = Width of trench at top of pipe, feet;
I = Impact coefficient (1.0 for static loads; variable for wheel loads depending upon speed and surface conditions—1.25 is considered safe when surface is paved with concrete).

(*Note.* In the usual form in which formula 6 is expressed, pipe length appears as a divisor on the right-hand side of the equation. This division has been made in establishing the values of C_c in table III, which accounts for pipe length not appearing in formula 6 as given above).

Table II. Coefficient C_u in formula 5

Ratio of height above pipe, at which super-load is applied, to width of trench, H/B_t	Sand and gravel	Saturated topsoil	Ordinary damp clay	Saturated clay
1.0	0. 72	0. 75	0. 77	0. 80
1.5	. 61	. 64	. 67	. 72
2.0	. 52	. 55	. 59	. 64
2.5	. 44	. 48	. 52	. 57
3.0	. 37	. 41	. 45	. 51
4.0	. 27	. 31	. 35	. 41
5.0	. 19	. 23	. 27	. 33
6.0	. 14	. 17	. 20	. 26
8.0	. 07	. 09	. 12	. 17
10.0	. 04	. 05	. 07	. 11

Table III. Coefficient C_e in formula 6

Height above pipe at which super-load is applied (ft.)	Outside diameter of pipe—feet (interpolate for actual O. D.)							
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
2.5-foot pipe lengths:								
1	0. 114	0. 199	0. 264	0. 299	0. 320	0. 332	0. 339	0. 344
2	. 045	. 088	. 129	. 156	. 180	. 199	. 212	. 222
3	. 023	. 045	. 067	. 086	. 102	. 117	. 131	. 140
4	. 014	. 027	. 040	. 052	. 064	. 074	. 084	. 092
5	. 009	. 017	. 026	. 036	. 043	. 050	. 057	. 064
6	. 006	. 012	. 018	. 025	. 030	. 037	. 042	. 046
7	-------	-------	. 014	. 019	. 023	. 027	. 032	. 035
8	-------	-------	-------	. 013	. 017	. 021	. 024	. 027
9	-------	-------	-------	-------	. 013	. 017	. 019	. 022
3-foot pipe lengths:								
1	. 098	. 175	. 231	. 258	. 276	. 287	. 294	. 298
2	. 041	. 080	. 114	. 142	. 165	. 182	. 196	. 206
3	. 022	. 043	. 063	. 081	. 097	. 111	. 124	. 134
4	. 013	. 025	. 038	. 050	. 062	. 072	. 081	. 089
5	. 009	. 017	. 026	. 034	. 014	. 049	. 056	. 063
6	. 006	. 012	. 018	. 024	. 030	. 036	. 041	. 044
7	-------	-------	. 014	. 018	. 022	. 027	. 031	. 035
8	-------	-------	-------	. 014	. 017	. 021	. 024	. 028
9	-------	-------	-------	-------	. 014	. 017	. 020	. 022
4-foot pipe lengths:								
1	. 075	. 135	. 175	. 200	. 215	. 224	. 229	. 232
2	. 035	. 067	. 096	. 120	. 140	. 155	. 167	. 175
3	. 019	. 039	. 057	. 073	. 087	. 101	. 112	. 121
4	. 012	. 025	. 036	. 048	. 059	. 068	. 076	. 084
5	. 008	. 016	. 025	. 033	. 040	. 047	. 054	. 060
6	. 006	. 012	. 018	. 024	. 030	. 035	. 040	. 045
7	-------	-------	. 014	. 018	. 022	. 026	. 030	. 035
8	-------	-------	-------	. 014	. 017	. 021	. 024	. 027
9	-------	-------	-------	-------	. 014	. 016	. 020	. 022

Figure 7 is for convenience in determining loads on sewers under average conditions. If the actual conditions differ materially from the assumed conditions on which these curves are based, the loads should be computed for the actual conditions. It will be noted that the solid lines in figure 7 indicate dead loads on sewers at various depths in trenches having a width 16 inches greater than the outside diameter of the pipe and backfilled with ordinary clay weighing 120 pounds per cubic foot. The broken lines indicate dead loads combined with a live load of 20,000 pounds (wheel load and impact). Three-foot pipe lengths were used in computing the effect of live load per linear foot of pipe. It will also be noted that in using these curves interpolation will be required to determine the loads corresponding to actual outside diameters of various sizes and classes of pipe. This can be done with reasonable accuracy.

b. Supporting Strength of Pipe Sewers. The supporting strength of a pipe sewer depends primarily upon the strength of the pipe itself and the manner in which it is laid in the trench. A factor of safety of about 1.5 should be used in design to provide for uncertainties. Figure 8 indicates various methods of laying pipe and their comparative load supporting ratios. Pipe laid in first-class bedding, illustrated in figure 8*b*, would support approximately 25 percent more load than if laid in ordinary bedding as illustrated in figure 8*a*. First-class bedding is the type specified in OCE Guide Specifications CE 500 and 600.01. The other types are suggested for use where conditions require additional reinforcement. The strength of the pipe is usually determined by either of two test methods, the three-edge-bearing method or the sand-bearing method,

the three-edge-bearing method being much the simpler and the only method specified in Federal specifications. The test strength of pipe determined by the sand-bearing method would be about the same as the supporting strength if laid in ordinary bedding and about 1.5 times the test strength determined by the three-edge-bearing method. It will be noted that, if the three-edge-bearing test strength is used in design, the two values of 1.5 would cancel, further consideration of safety factor then being unnecessary. Therefore, in design, the safe working load would be determined by multiplying the applicable load-supporting ratio indicated in figure 8 by the three-edge-bearing strength specified in Federal or other acceptable specifications.

1-11 PIPE MATERIALS. *a. Sanitary Sewers.* Clay sewer pipe may be used in all sizes that are readily available. Bituminized fiber sewer pipe of the 6-inch and 8-inch sizes may be used except in house connections to boiler blow-down tanks and laundries. Concrete pipe and asbestos-cement pipe may be used except as follows: where local experience indicates that they are not suitable; where alkali or acid of a type that would gradually destroy the pipe is present in the soil; where the sewer is to receive acid waste that would not be sufficiently diluted with alkaline sewage to prevent corrosion; where conditions, such as high sulphate content, high temperature, and low velocity of the sewage, would be conducive to the formation of hydrogen sulphide. A study should be made therefore to determine whether concrete or asbestos-cement pipe would be suitable and contract specifications should be so written as to permit the use of all the suitable types of materials. Where pressure pipe is required, as in force mains or inverted siphons, the pipe may be cast iron, steel or asbestos-cement pressure pipe. Pipe of any material should conform to the requirements of current OCE guide specifications.

b. Industrial-Waste Sewers. Vitrified clay pipe conforming to Federal Specification SS-P-361 normally should be specified for industrial-waste sewers. Conditions would seldom exist at military installations requiring the discharge of acid waste in such concentrations that vitrified clay pipe would not be satisfactory. Where it is known that such conditions would occur frequently, special acid-resistant pipe should be specified. As the missions of or processes in military installations are subject to change, pipe made of material that is subject to attack by acids should not be included in the specifications.

1-12 SEWER PIPE JOINTS. *a. Sanitary Sewers.* The joints of nonpressure bell-and-spigot sewer pipe normally should be made with hot poured bituminous material, poured in place or precast as rings inside the bells and as collars on the spigots. This type of joint is advantageous in the reduction of infiltration and of the entrance of roots into the pipe. Portland cement mortar and certain cold-applied bituminous jointing compounds are satisfactory materials for sewer joints if the annular space is properly filled entirely around the pipe. The difficulty with these materials is that the lower part of the joint would be more difficult to fill and defects would be more difficult to detect. It is primarily for this reason that hot poured bituminous joints are preferred in bell-and-spigot pipe. However, cold-applied bituminous material should be included in project specifications in accordance with current OCE guide specifications. Cement mortar or cold-applied compound would be required for the mortised or tongue-and-groove type of concrete pipe. Also, cement joints should be used in house connections to boiler blow-down tanks and laundries.

b. Industrial-Waste Sewers. The joints of industrial waste sewers which carry wastes in the concentrations normally occurring at military installations should be filled with hot-poured or cold-applied bituminous materials used in sanitary sewers. When it is known that these wastes would be exceptionally high in acid or alkaline content or other deleterious material, it may be necessary to specify some other jointing material that would be especially suitable for the purpose. This would have to be determined for the particular requirement.

1-13 MANHOLES. Manholes should conform to the general dimensions, materials, methods of construction, and safety features indicated on and specified in current OCE standard drawings and specifications. The foundations should be of plain concrete except where the ground is unstable and reinforced concrete is necessary. The invert channels should be such as to avoid obstruction to flow as much as possible and may be formed in the concrete, built up with brick and mortar, or by laying half tile or pipe through the manhole, the top half of the pipe being later broken out. Manholes which exceed 12 feet in depth from top of cover to invert of main sewer should be constructed with a vertical wall for the entire

height at one point in the circumference and steps or ladder rungs should be built into this vertical section. Steps or rungs should not be installed in manholes which do not exceed 12 feet in depth. Access to such manholes normally will be by means of a lightweight portable ladder. Where special designs require that manholes be constructed of poured-in-place concrete, prefabricated metal ladders of suitable design should be specified in lieu of embedded steps or rungs.

1-14 PRELIMINARY DRAWINGS AND DESIGN ANALYSIS. In conformity with the requirements of Orders and Regulations, paragraph 4106.13, or other current instructions, preliminary drawings and design analyses for all new sewer systems or additions to existing sewers should be forwarded to the designated reviewing authority sufficiently in advance of the preparation of project drawings to permit beneficial review and the issuance of instructions. The design analysis should indicate the data outlined in paragraph 1-07*c*.

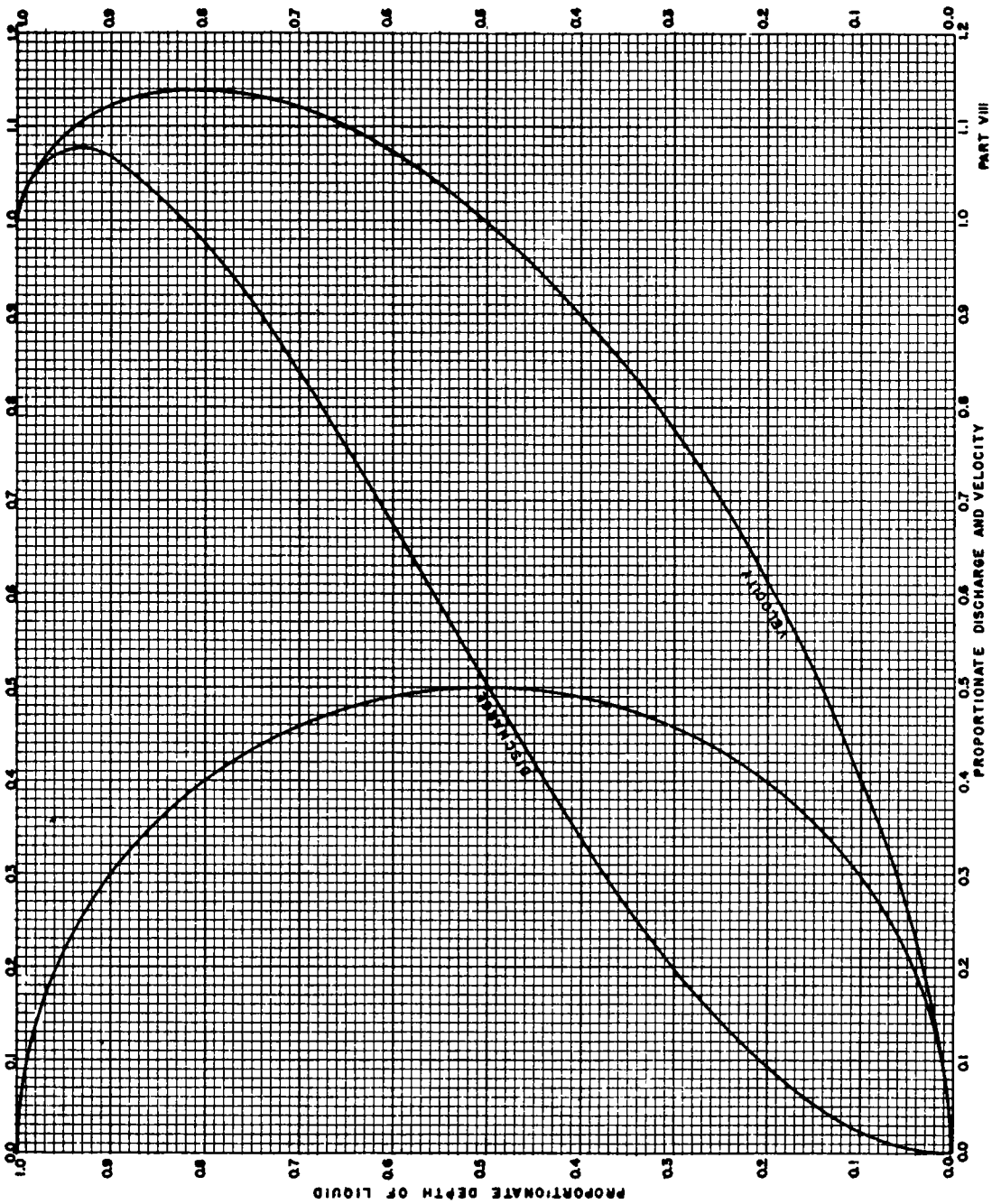
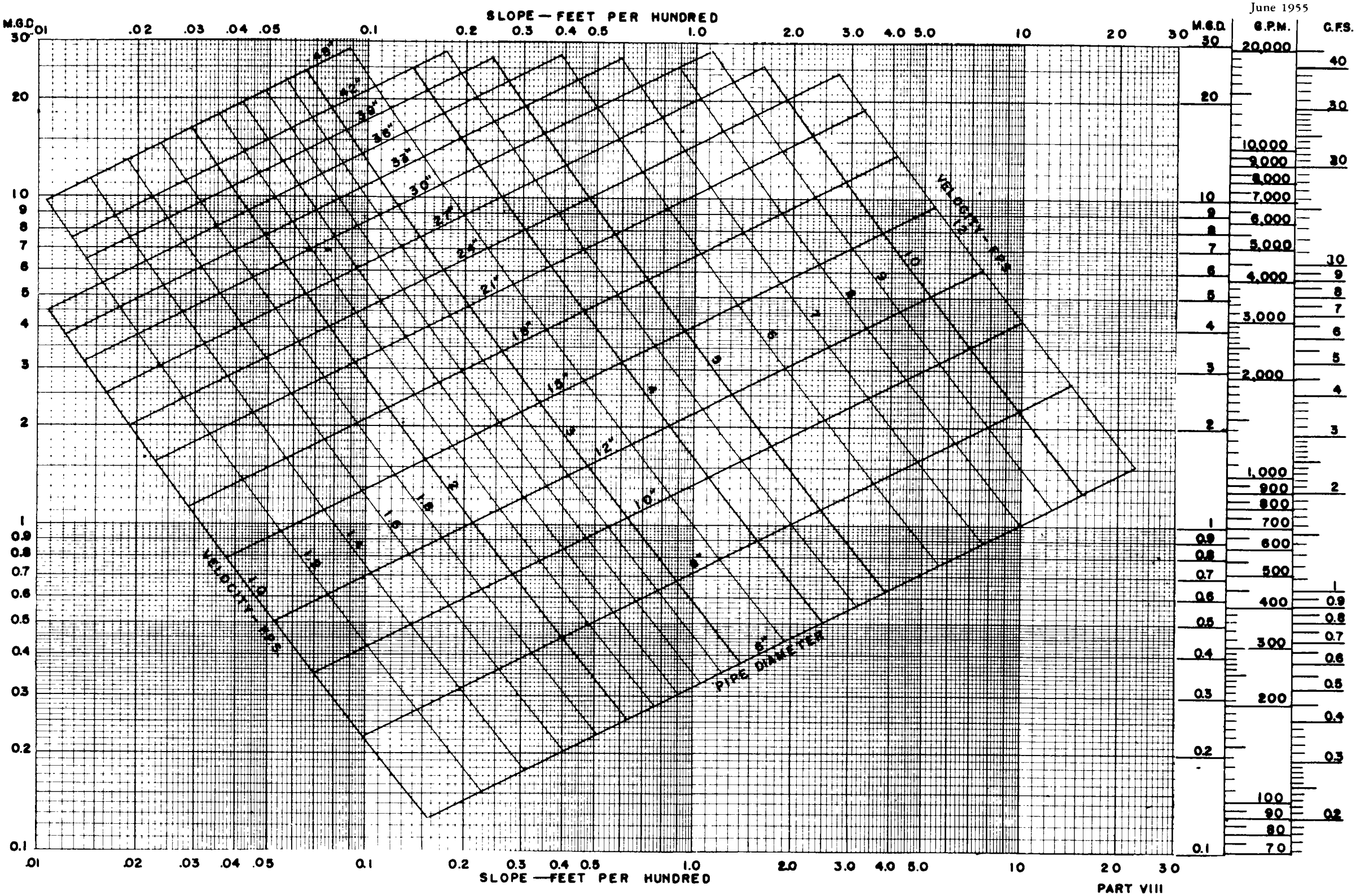

PROPORTIONATE DEPTH OF LIQUID
PROPORTIONATE DISCHARGE AND VELOCITY
PART VIII
CHAPTER 1
PROPORTIONATE FLOW CHART
BY MANNING'S FORMULA

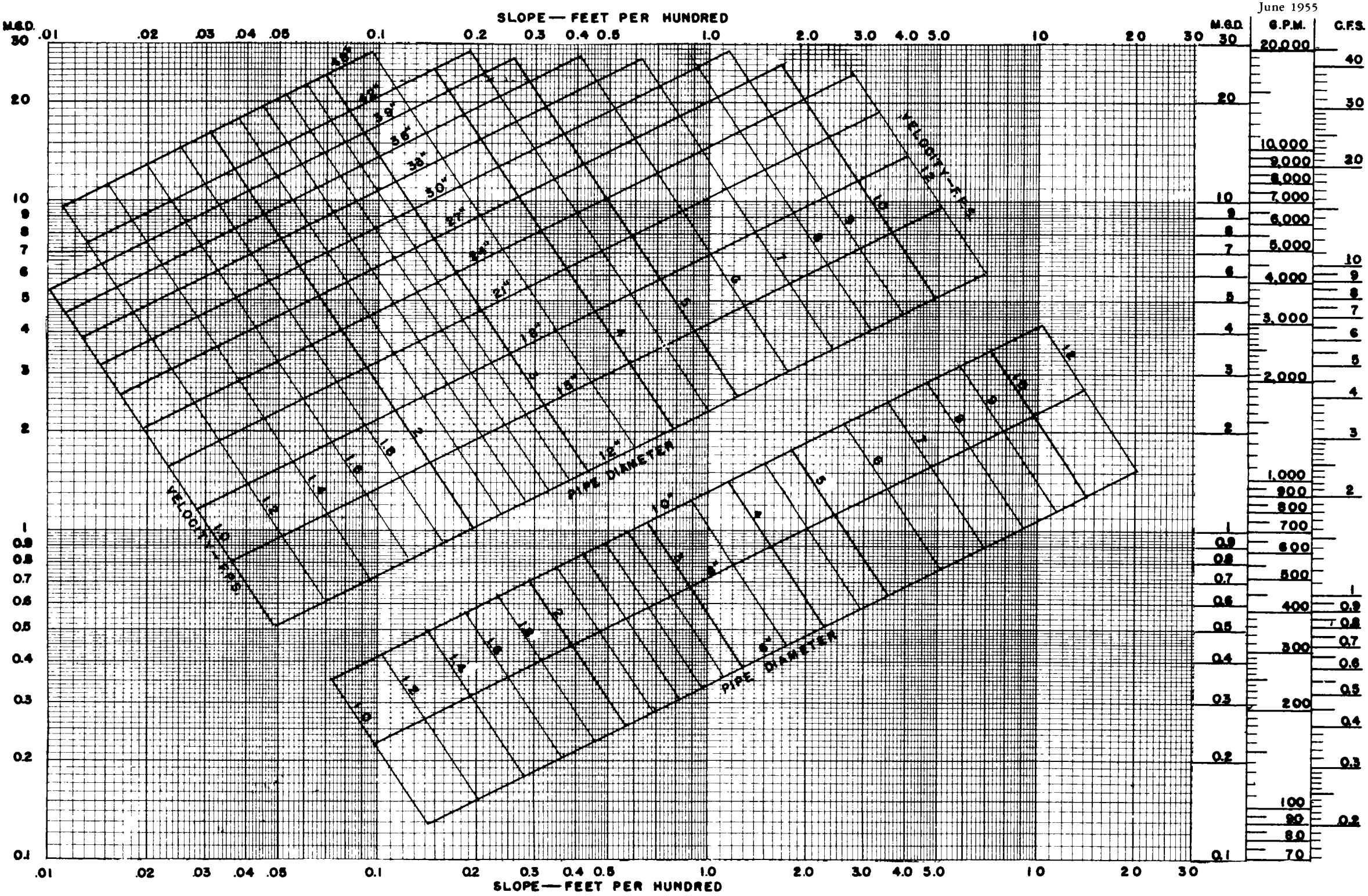
FIGURE 4.



PIPE FLOW CHART
KUTTER'S FORMULA (N=.013)

FIGURE 2

356931 O—55 (Face p 12) No 1

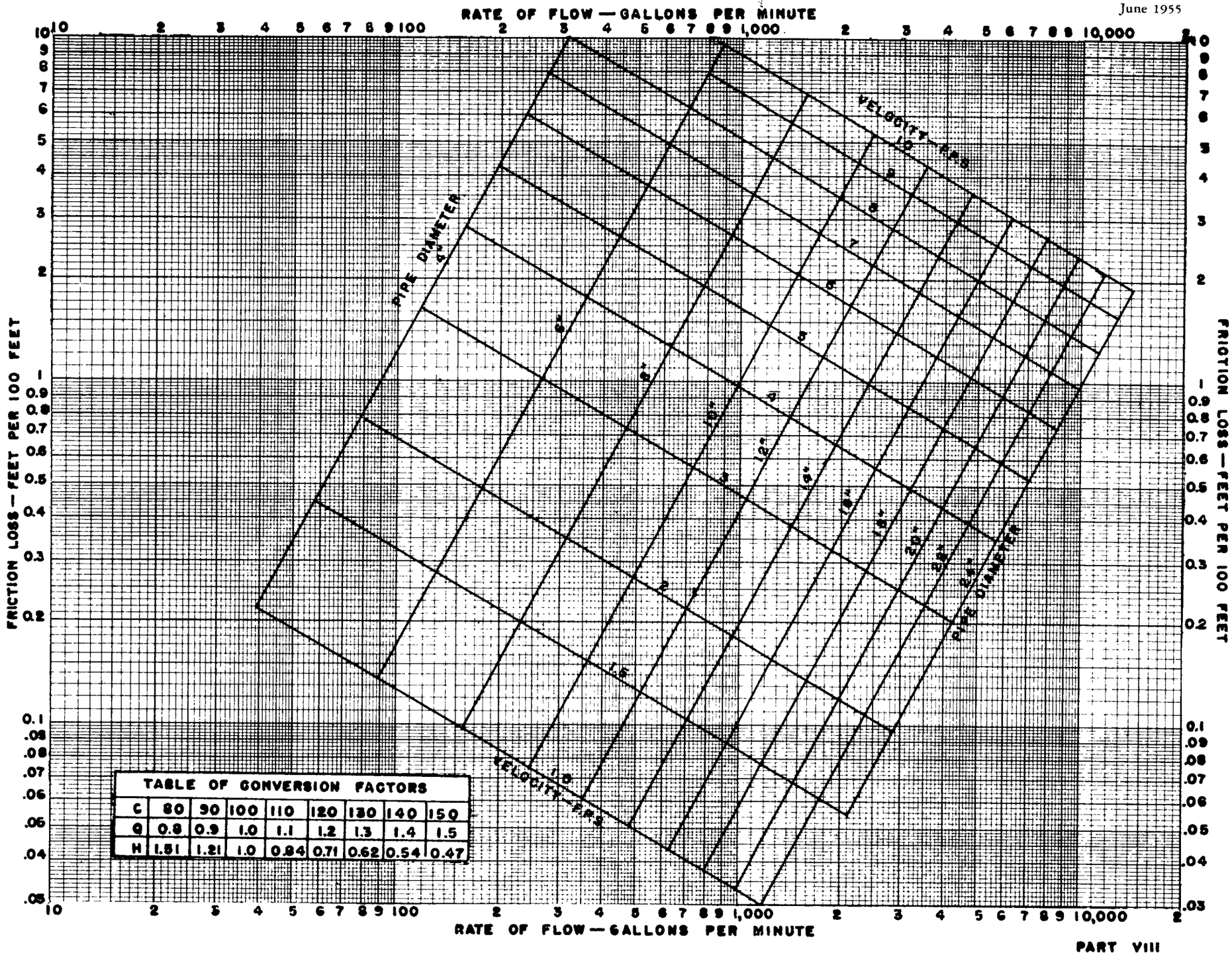


PIPE FLOW CHART

MANNING'S FORMULA (N = .013 FOR 12" PIPE AND LARGER) (N = .014 FOR 10" PIPE AND SMALLER)

PART VIII
CHAPTER 1

FIGURE 3



PART VIII
CHAPTER 1

PIPE FLOW CHART

HAZEN AND WILLIAMS FORMULA (C=100)

FIGURE 5

356931 O—55 (Face p. 12) No 4

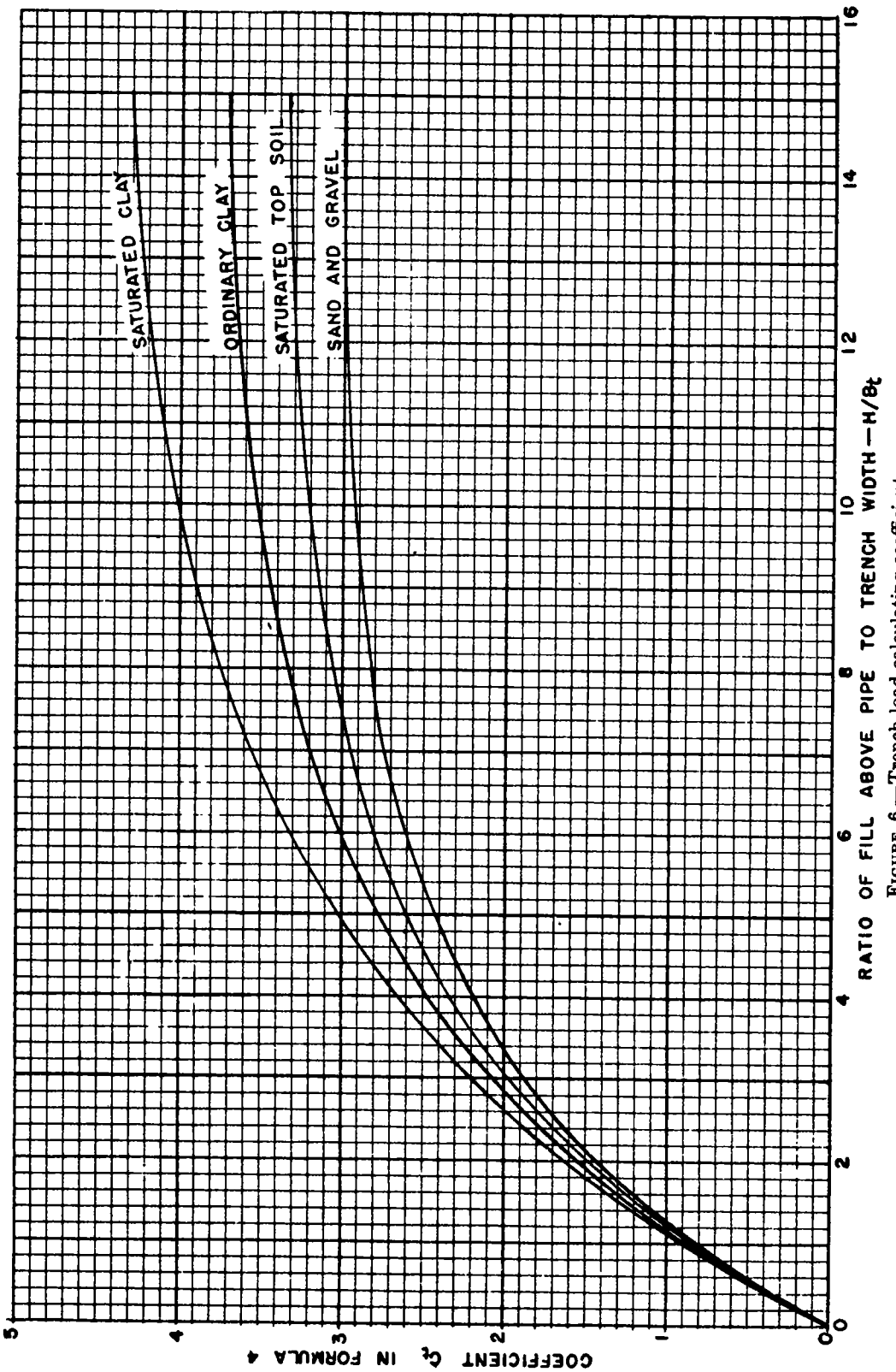


FIGURE 6.—Trench load calculating coefficients.

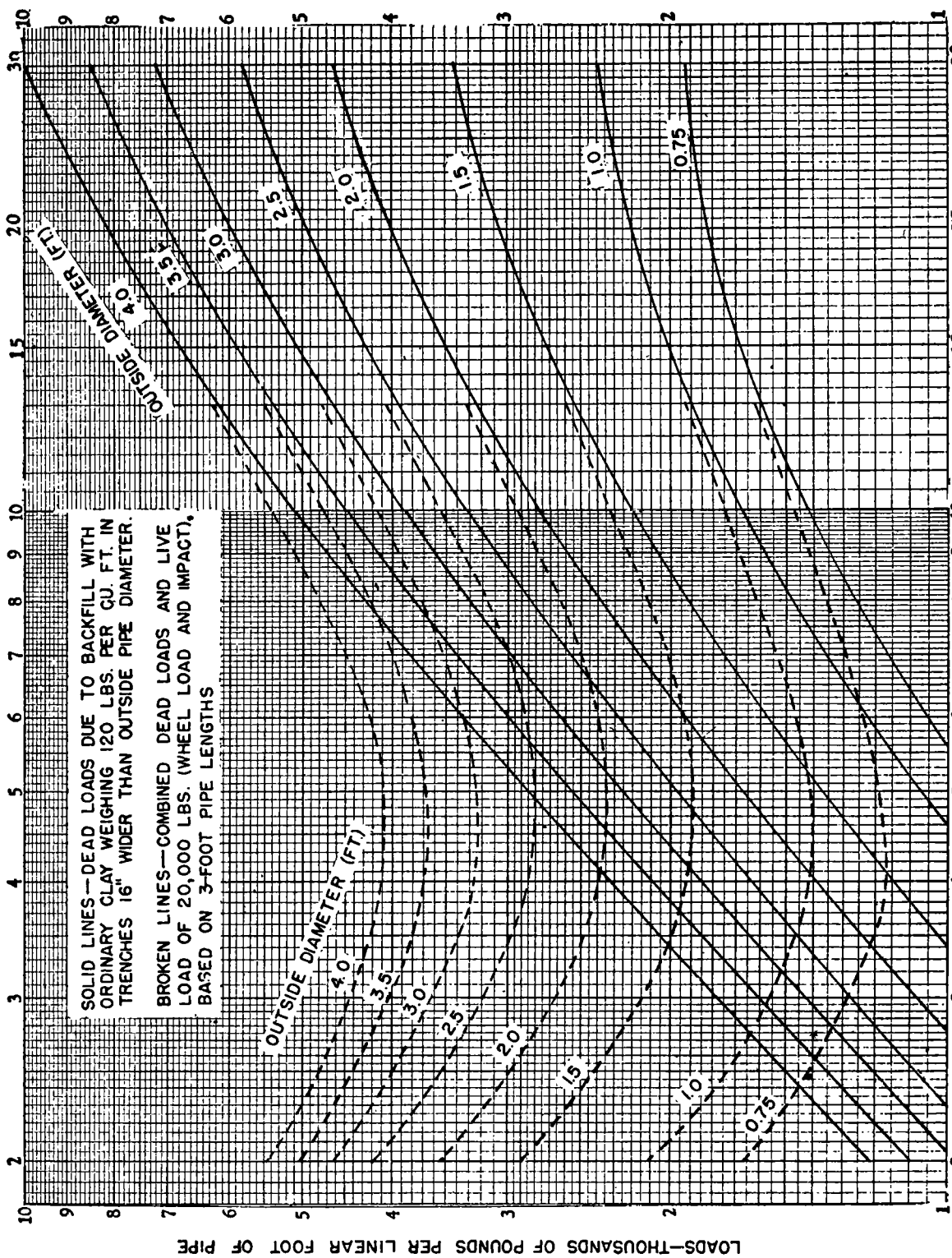


FIGURE 7.—Loads on sewers in trenches.

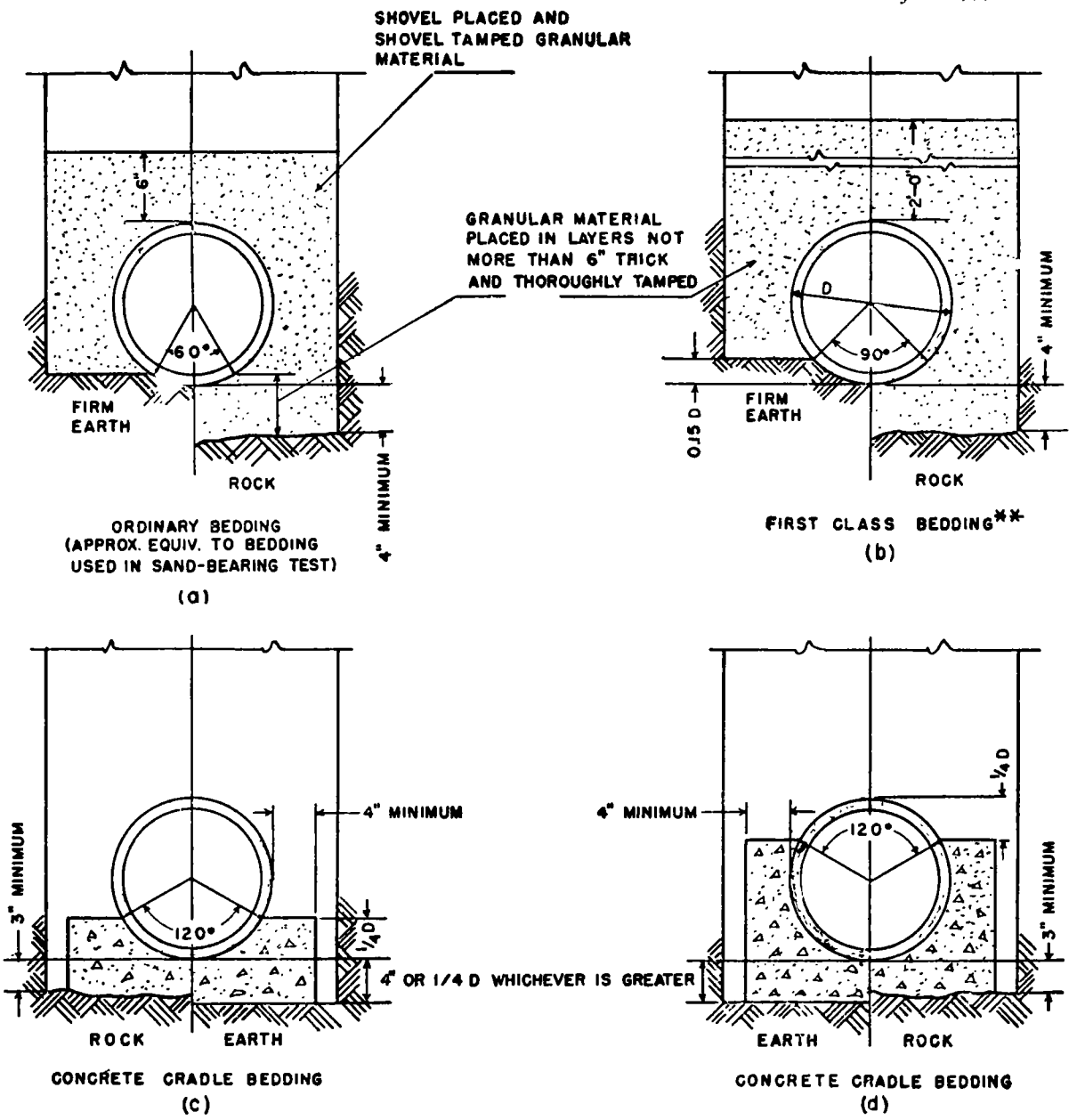


FIGURE	TYPE OF BEDDING	LOAD SUPPORTING RATIO*
(a)	ORDINARY	1.0
(b)	FIRST CLASS	1.25
(c)	CONCRETE CRADLE	1.5
(d)	CONCRETE CRADLE	2.0

*NOTE: THESE RATIOS ARE RELATIVE VALUES AND SHOULD NOT BE CONFUSED WITH FACTOR OF SAFETY (SEE TEXT)

**AS SPECIFIED IN O.C.E. GUIDE SPECS. 500 AND 600.01

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FIGURE 8.—Diagrams showing types of pipe bedding.

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SEWAGE AND WASTE DISPOSAL

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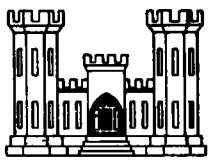

ARMY SERVICE FORCES
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

CHAPTER 3

SEWAGE TREATMENT PLANTS

3-01 GENERAL

3-02 SITE SELECTION FOR SEWAGE TREATMENT PLANTS

3-03 DEGREE OF TREATMENT
- a. Primary Treatment
- b. Secondary Treatment

3-04 ELEMENTS OF A PLANT PROVIDING PRIMARY TREATMENT ONLY

3-05 ELEMENTS OF A PLANT PROVIDING SECONDARY TREATMENT
- a. Standard or Low Capacity Trickling Filters
- b. High Capacity Trickling Filters
- c. Activated Sludge
- d. Intermittent Sand Filters
- e. Combined Processes

3-06 ARRANGEMENT OF UNITS

3-07 CAPACITY FACTOR

3-08 SEWAGE CHARACTERISTICS

3-09 SEWAGE FLOWS AND HYDRAULIC DESIGN
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- b. Average 16-Hour Sewage Flow
- c. Maximum 4-Hour Sewage Flow
- d. Minimum 4-Hour Sewage Flow
- e. Extreme Peak Sewage Flows

3-10 SCREENS

3-11 GRIT CHAMBERS

3-12 MEASURING DEVICES

3-13 PRIMARY SETTLING TANKS
- a. Detention Period
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SEWAGE AND WASTE DISPOSAL

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SEWAGE TREATMENT PLANTS

3-01 GENERAL. The basic design data contained herein applies to the planning of sewage treatment plants of all sizes. Designs should be simplified as much as possible and preference should be given to types of treatment which require the minimum amount of skill and technical training of the operating personnel that are commensurate with the required degree of treatment. It is anticipated that sewage treatment plants will be capable of treating the normal laundry wastes together with the sanitary sewage Plants for the pre-treatment of laundry wastes should be considered only at locations where existing treatment works are overloaded and where the pre-treatment of the laundry wastes will eliminate the necessity for enlarging the sewage treatment plants. At certain Ordnance plants, Chemical Warfare plants, and repair bases, there may be unusual industrial wastes which require special treatment. Design data for such treatment cannot be generalized and each case will require individual consideration. In the design of additions to existing treatment plants, the design data contained herein may be modified if dependable data relating to the performance of the existing plant indicates the advisability.

3-02 SITE SELECTION FOR SEWAGE TREATMENT PLANTS. Sites for sewage treatment plants should be carefully selected. The topography and location of the receiving stream will usually determine the location. Plants should be located as far as practicable, preferably one-half mile or more, from dwellings, shops, offices and traveled ways, and consideration should be given to the direction of prevailing winds. Plants should be located where they will not interfere with military operations and should be at a safe distance from rifle and artillery ranges. If possible, sites should be located above high water, but flood protection should be provided if required. Sufficient space should be available for a convenient arrangement of plant structures and for possible future extensions to the plant.

3-03 DEGREE OF TREATMENT. The State Sanitary Engineer or the Director of the State Department of Health should be consulted regarding the disposal of the sewage from Army projects and, if practicable, the design of a treatment plant should meet the requirements of the health authorities. The degree of treatment required will depend upon the amount of diluting water available in the receiving stream during periods of minimum flow, the condition of the stream as regards pollution and the use of the stream below the proposed point of discharge. Consideration should be given also to local practice with regard to the degree of treatment being provided by existing plants and the anticipated period of occupancy of the project.

a. Primary Treatment. Where the effluent from the sewage treatment plant is to be discharged into a relatively large stream with a flow sufficient to provide a minimum dilution of about four (4) c.f.s. of stream flow per 1,000 population, primary settling, sludge disposal and chlorination will usually be sufficient. This partial degree of treatment may also be suitable in cases where the effluent is to be discharged into

tidal waters, or finally disposed of by irrigation on land. The biochemical oxygen demand removed by primary treatment will usually be in the range of from 30 to 40 percent of the total contained in the raw sewage.

b. Secondary Treatment. Secondary treatment should be provided only to the extent necessary for the prevention of stream pollution or of a nuisance. It should be noted that, insofar as the treatment plant surroundings are concerned, there are often more objectionable features in secondary treatment plants (filter flies, for instance) than in primary treatment plants. The degree of treatment produced by a given type of plant or process will vary according to the applied loading of organic matter and to its condition. The size of the various units should be designed accordingly to meet the requirements. Where more than partial but less than complete treatment is required, high capacity filters can be used to good advantage. This intermediate treatment can also be obtained by chemical precipitation in primary settling tanks, but it is not recommended for general use at Army camps and should be confined to the treatment of industrial waste. Treatment by the activated sludge process, standard rate trickling filters, or sand filters, will provide complete treatment if properly designed and loaded. The term "complete treatment" is often incorrectly and indiscriminately used in reference to any form of secondary treatment regardless of the type of the loading. The treatment should not be referred to as complete unless it removes at least 85% of the biochemical oxygen demand.

3-04 ELEMENTS OF A PLANT PROVIDING PRIMARY TREATMENT ONLY. A primary treatment plant normally will be provided with screens, grit chambers, measuring devices, primary settling tanks, sludge disposal facilities, chlorination facilities, plant sewers, and laboratory and control building. Screens remove large suspended and floating matter, such as sticks, rags and miscellaneous materials that would clog pumps or cause excessive scum. Grit chambers remove sand and similar heavy gritty materials that would injure pumps or clog sludge pumps. Measuring devices are for the purpose of measuring the sewage flows and the amount of sludge gas produced. Sludge may also be measured in large plants. Such measurements provide valuable information to the operator and lead to obtaining better effluents. The plant sewers comprise all the pipe and open channel connections between the various plant elements, recirculating piping and by-pass lines. Chlorination facilities are for the purpose of sterilizing the plant effluent and for odor control. The laboratory and control building is the central building housing the pumps, equipment controls, plant laboratory and operating records.

The settling tanks and sludge disposal facilities are the principal elements in primary treatment plants. The settling tanks remove a large proportion of the settleable solids through quiescent settling and thus reduce the organic content of the liquid. The solid matter or sludge removed is at first unstable, large in quantity and high in water content. Before it can be finally disposed of it must be stabilized. This is usually accomplished through the action of anaerobic bacteria in digestion tanks. After the sludge has been thoroughly digested it is withdrawn to drying beds, where it is removed and discharged as convenient. Sludge pumps are usually necessary for the transfer of sludge.

3-05 ELEMENTS OF A PLANT PROVIDING SECONDARY TREATMENT. Plants providing secondary treatment require the elements of a primary treatment plant and means for the further treatment of the primary settling tank effluent by biological processes. Final settling tanks following the biological treatment are also usually required. In these biological processes, organic matter remaining in the sewage after primary treatment is stabilized through the action of oxidizing bacteria. This may be accomplished by standard trickling filters, high capacity trickling filters, the activated sludge process, intermittent sand filters, or combined processes.

a. Standard or Low Capacity Trickling Filters. These are beds of crushed rock or slag of relatively large size. The sewage trickles in a thin film over the stones which are coated with an organic film containing the aerobic oxidizing bacteria.

b. High Capacity Trickling Filters. The most important differences between these and the standard filters are the greater dosing rate and the provision for recirculating filtered effluent back through the filter. Some filters may have provision for forcing air through them. These filters depend more upon coagulation of colloidal sewage solids for their efficiency than do standard filters.

c. Activated Sludge. In the activated sludge process settled sewage is passed through aeration tanks where it is brought into contact with previously developed activated sludge. Activated sludge is created by aerating with compressed air blown into it or by mechanical agitation or by a combination of these methods. This sludge, containing aerobic bacteria which feed upon the organic matter, assimilates some of the organic matter and constantly increases in volume. The activated sludge is settled out in the final settling tank, a portion of it being returned to the aeration tank with the incoming settled sewage and a portion discharged into the digester.

d. Intermittent Sand Filters. These are beds of specially selected sand about three feet thick. The Sewage is applied uniformly over the entire surface to a depth of three or four inches. As it trickles through the sand, fine suspended solids are filtered out and dissolved organic matter is also removed through the action of bacteria living in a gelatinous growth on the surface of the sand. Intermittent sand filters usually produce as high degree of treatment as can be obtained by biological processes, but are not often economical for large installations due to high maintenance cost.

e. Combined Processes. Combinations of the foregoing biological processes have been successful in a few Army sewage treatment plants. The number of such cases has been relatively few and definite design criteria have not been established. Proposed designs utilizing combined processes should be referred to the Office of the Chief of Engineers for approval prior to installation.

3-06 ARRANGEMENT OF UNITS. Plants serving populations greater than 5,000 should be flexible enough to permit operation and treatment with any individual plant unit out of service. This can be accomplished by providing the required capacity for primary settling tanks, filters, final settling tanks and other plant elements in at least two units each and arranging the piping so that any individual unit can be taken out of service. The arrangement of plant units should be such as to permit future

enlargement of the plant capacity at minimum cost and minimum interference with plant operation.

3-07 CAPACITY FACTOR. The initial construction of sewage treatment plants should be based on the authorized military and civilian tributary population, increased by the capacity factors indicated in Table I.

TABLE I - CAPACITY FACTORS

AUTHORIZED PROJECT POPULATION	CAPACITY FACTORS
5,000 and less	1.50
10,000	1.25
20,000	1.15
30,000	1.10
40.000	1.05
50,000 and over	1.00

The capacity factor for populations intermediate between those indicated should be determined by straight line interpolation. The capacity factor is applied by multiplying the authorized military and civilian tributary population by the proper capacity factor stated in Table I. This gives the design population and all elements should be based on the design population. The capacity factor is to provide for reasonable increases in population, uncertaintities as to actual quantities and characteristics, and unusual peak flows, the magnitude of which cannot be accurately estimated in advance.

3-08 SEWAGE CHARACTERISTICS. Data on sewage characteristics at Army Projects indicate larger per capita quantities of suspended solids, larger amounts of gases and slightly larger quantities of B.O.D. than is normally found in domestic sewage. The sewage reaching the treatment plant will usually be relatively fresh and have good settling qualities. The settled sewage will be readily treatable by biological processes. The design of sewage treatment plants should be based on the sewage characteristics indicated in Table II, except in the special cases indicated in paragraph 3-01.

TABLE II - SEWAGE CHARACTERISTICS

ITEM	RESIDENT PERSONNEL POUNDS PER CAPITA FOR 24 HOURS	NON-RESIDENT PERSONNEL POUNDS PER CAPITA FOR 8-HOUR SHIFT
Suspended Solids	0.27	0.13
B.O.D. (5-Day)	0.20	0.10
Ether-Soluble Matter	0.09	0.05

The sewage characteristics in pounds per capita will remain constant regardless of rates of flow and of total gallons per capita per day. Provision for additional capacity in the biological processes for reasonable population increases is made by applying the capacity factors outlined in paragraph 3-07.

3-09 SEWAGE FLOWS AND HYDRAULIC DESIGN. The design of the various elements of a sewage treatment plant should be normally based on the average 24-hour rate of flow. The hydraulics of conduits and distributor mechanism should be designed to permit passage of an extreme peak rate of flow of three times the average daily rate of flow. This may be somewhat higher than the peak flow for which the outfall sewer is designed as indicated in paragraph 3-05, Chapter 1, Part VIII. Experience has shown, however, that such peaks do occur occasionally and may be discharged by the sewer when flowing under a slight surcharge. At Army projects the rates of sewage flow vary widely throughout the day. Figure 1 indicates typical hourly variations and was prepared from the flow data at several Army camps. The information indicated by Figure 1 can be used to advantage in analyzing the hydraulics for various flow rates.

a. Average 24-Hour Sewage Flow. The average daily sewage flow to be used for the design of sewage treatment plants will be determined by multiplying the total tributary population, increased by the proper capacity factor, as set out in paragraph 3-07, by the per capita rates of flow indicated in Table III.

TABLE III - TABLE OF PER CAPITA SEWAGE FLOW

Type of Unit	Gallons per Capita Per Day			
	Permanent Posts	Mibiliza-tion Type	T. of O. Type	Field Training Camps
Airfields, Camps, Cantonments and Troop Facilities	100	70	50	35
Hospital Units	100	100	85	70
Plant, Port and Storage Projects	30 per 8-hour shift 100 for resident personnel			

Additional allowances should be included for ground water infiltration if provision has been made for infiltration in the design of the sewers. The sewage flow at Plant, Port and Storage Projects should be computed for the eight-hour shift when the greatest number of employees are engaged and should be computed at a rate of flow of 90 gallons per capita per day, although the total flow will be only 30 gallons per capita per day.

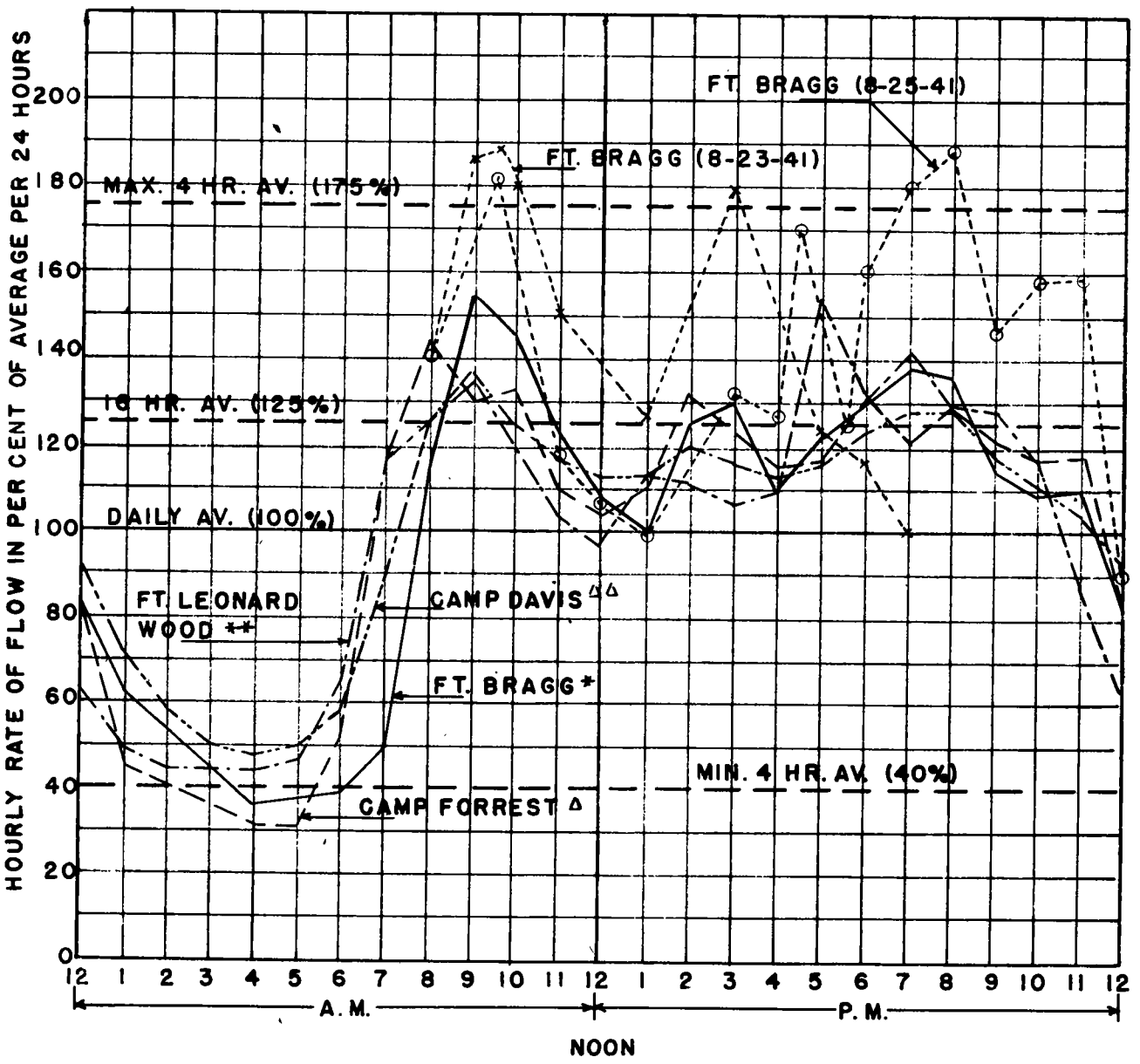
b. Average 16-hour Sewage Flow. The 16-hour average rate of flow will be 125 per cent of the average rate for 24 hours.

c. Maximum 4-Hour Sewage Flow. The maximum 4-hour average rate of flow will be 175 per cent of the average rate for 24 hours.

d. Minimum 4-Hour Sewage Flow. The minimum 4-hour average rate of flow will be 40 per cent of the average rate for 24 hours.

e. Extreme Peak Sewage Flows. Occasional extreme peak rates will reach 300 per cent of the average rate for 24 hours.

HOURLY SEWAGE FLOW VARIATIONS FOR ARMY CAMPS



** AVERAGE OF 7 DAYS 9-14-41 TO 9-20-41.

ΔΔ AVERAGE OF 95 DAYS 6-13-41 TO 9-15-41.

* AVERAGE OF 6 DAYS SELECTED FROM MONTHLY RECORD OF AUG., 1941.

Δ AVERAGE OF 7 DAYS 7-24-41 TO 7-30-41.

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CHAPTER 3

FIG. 1

3-10 SCREENS. Screens will, in general, be hand-cleaned bar screens. Mechanical cleaning devices normally should not be installed at camps smaller than Division size. All screens should have a submerged area of at least twice the area of the incoming sewer. If mechanical means for comminuting the solid matter are employed, the equipment should consist of one such device and a by-pass bar screen. The clear spacing between bars should be as follows:

Hand cleaned	1" to 1½"
Mechanically cleaned	5/8" to 1"

3-11 GRIT CHAMBERS. Grit chambers, where provided, should be designed for a controlled velocity of one foot per second with a detention period of from 30 to 45 seconds. The principles of design of grit chambers will be found in standard textbooks. In general, grit chambers will be hand-cleaned with disposal of grit by burying.

3-12 MEASURING DEVICES. Devices for measuring sewage flows should be installed in all plants of the types referred to in paragraphs 3-04 and 3-05 and for measuring sludge gas from separate digesters. For plants serving a population of 2,000 or less, recording and totalizing equipment will not be required. For plants serving a population greater than 2,000, equipment for indicating, recording and totalizing flow should be provided. For measuring gas flows in the smaller plants, orifices with U-tube indicators will usually be satisfactory. For the larger plants, commercial gas meters should be used. Venturi meters, weirs, and Parshall flumes have been found satisfactory for the measurement of sewage, the Parshall flume being generally preferable for Army projects. Measuring devices should be designed with a view toward obtaining their maximum accuracy of measurements throughout the expected range of flows. The principles of design are covered in standard textbooks. If sewage is pumped into the treatment works, it should be measured ahead of the pumping station, if practicable, in order to record the hourly variations in the rate of flow. In plants requiring the recirculation of sewage it is also desirable to provide suitable meters with means for indicating the rates of recirculation.

3-13 PRIMARY SETTLING TANKS. Primary settling tanks will normally be the flat bottom type, either rectangular or circular, with mechanical sludge moving equipment. Hopper bottom tanks, if used, should be confined to small installations. Imhoff tanks, which combine primary settling and sludge digestion in the same structure, are discussed separately in paragraph 3-20. The design of primary settling tanks should conform to the following.

a. Detention Period. Primary settling tanks, except for Plant, Port and Storage Projects, should have sufficient volumetric capacity to provide a detention period based upon average daily rate of flow through the tanks including recirculation, as follows:

In activated sludge plants	1.5 hours
In all other types of plants	2.5 hours

For Plant, Port and Storage Projects, where the contributing population is largely non-resident, a detention period of 2 hours should be provided on the basis of the average hourly rate for the 8-hour period when the maximum personnel will be contributing.

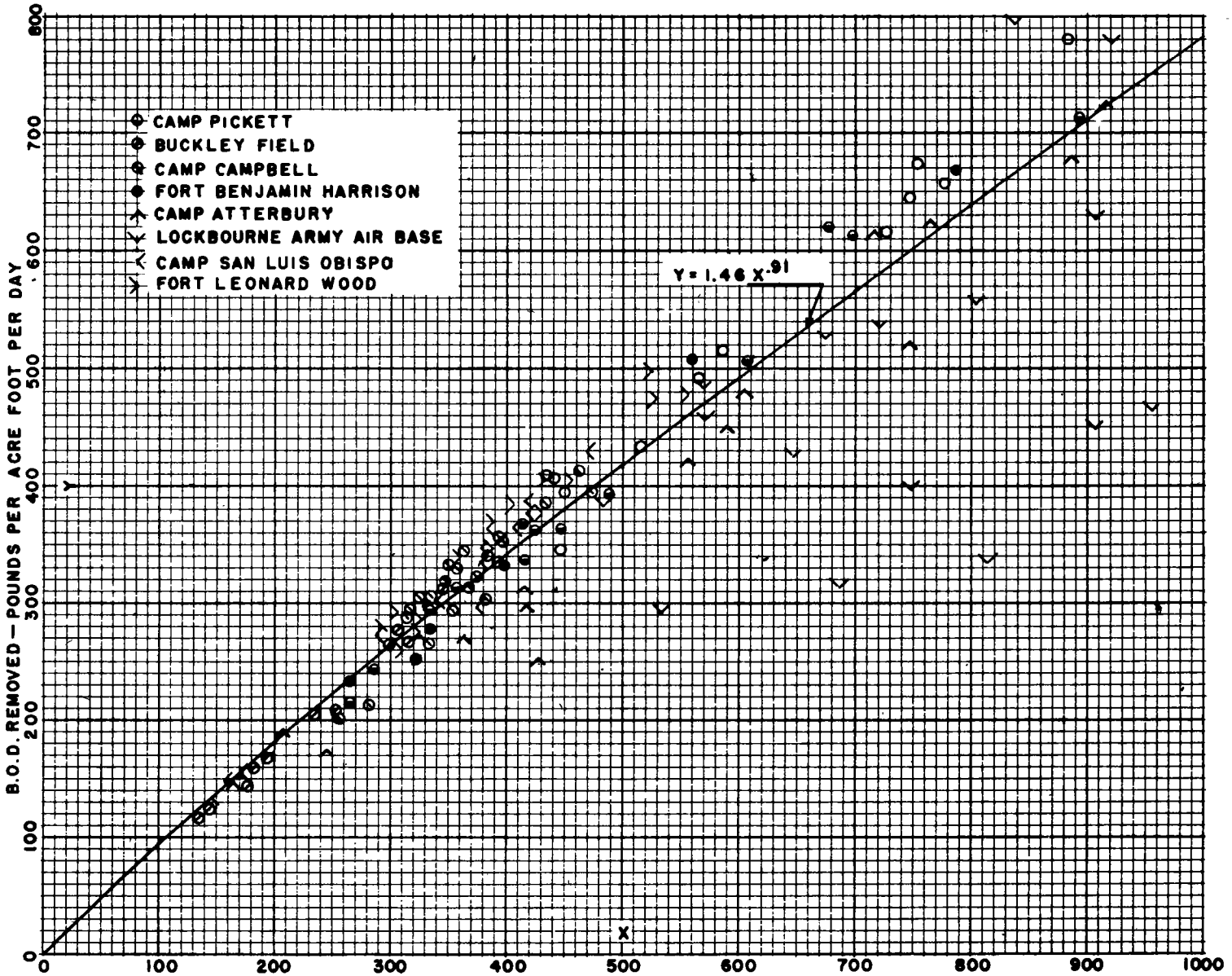
b. Design Features. Inlet and outlet channels should be designed so as to maintain a minimum velocity of 2 feet per second at average rate of flow and all corners should be filleted to prevent the collection of solids. The inlet to rectangular tanks should be such as to distribute the sewage uniformly over the entire width of the tank. For this purpose, partially submerged, rectangular ports are effective. Overflow weirs should be adjustable for accurate leveling. Scum troughs, with the crest about one inch above maximum water surface elevation, should be provided in all rectangular primary settling tanks. Circular tanks should be provided with scum baffles ahead of the overflow weirs and with suitable means for collecting the scum. The side water depth should preferably not exceed 10 feet. Sludge hoppers should have minimum side slopes of 1½ vertical to 1 horizontal. Visual sludge wells, into which sludge is withdrawn from the sludge hoppers and from which the sludge is pumped, are considered preferable to direct pump connections with the hoppers. The withdrawal pipes should operate under at least a three-foot static head and be equipped with quick closing valves.

3-14 TRICKLING FILTERS. The design of trickling filters should be based on the following:

a. Determination of Applied B.O.D. In determining the amount of B.O.D. applied to trickling filters, the amount of B.O.D. in the raw sewage may be assumed to be reduced by 35 percent by prior settling in primary settling tanks.

b. Standard Rate Trickling Filters. Standard or low capacity trickling filters when followed by final settling tanks are assumed to provide complete treatment. Under a loading of 600 pounds of applied B.O.D. per day per acre foot, filters with depths not greater than 6 feet may be expected to maintain a minimum overall plant reduction of 85 per cent of the B.O.D. and an average reduction of about 88 per cent. Higher percentages of B.O.D. removal can be obtained with lower loadings. Figure 2, Standard Rate Trickling Filter Performance Curve, indicates removal of B.O.D. in pounds per day per acre foot of filter media under various loadings. The curve represents monthly averages of data from numerous Army sewage treatment plants of the standard rate trickling filter type of various sizes and in various parts of the United States.

c. High Capacity Trickling Filters. High capacity trickling filters are assumed to provide an intermediate degree of treatment. An overall B.O.D. reduction ranging from 75% to 85% may be expected in plants of this type with filters not deeper than 6 feet under a loading of 3,000 pounds of B.O.D. per day per acre foot and with recirculation at approximately 1½ times the average daily rate of sewage flow. Higher percentages of reduction may be obtained under lighter loadings and with higher rates of recirculation, but the cost of construction and operation will usually be increased thereby to such extent that there would be no cost advantage over the more dependable standard rate filter. Where it is determined that the use of high capacity filters will result in economies, it is suggested that the design data set forth herein be strictly conformed to and that the manufacturer's recommendations on the required equipment and processes be followed. This will make it possible to fix responsibilities and require guarantees covered by performance bonds. The use of such processes should provide for competitive bidding on equipment.



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STANDARD RATE TRICKLING FILTER PERFORMANC CURVE
FIG. 2

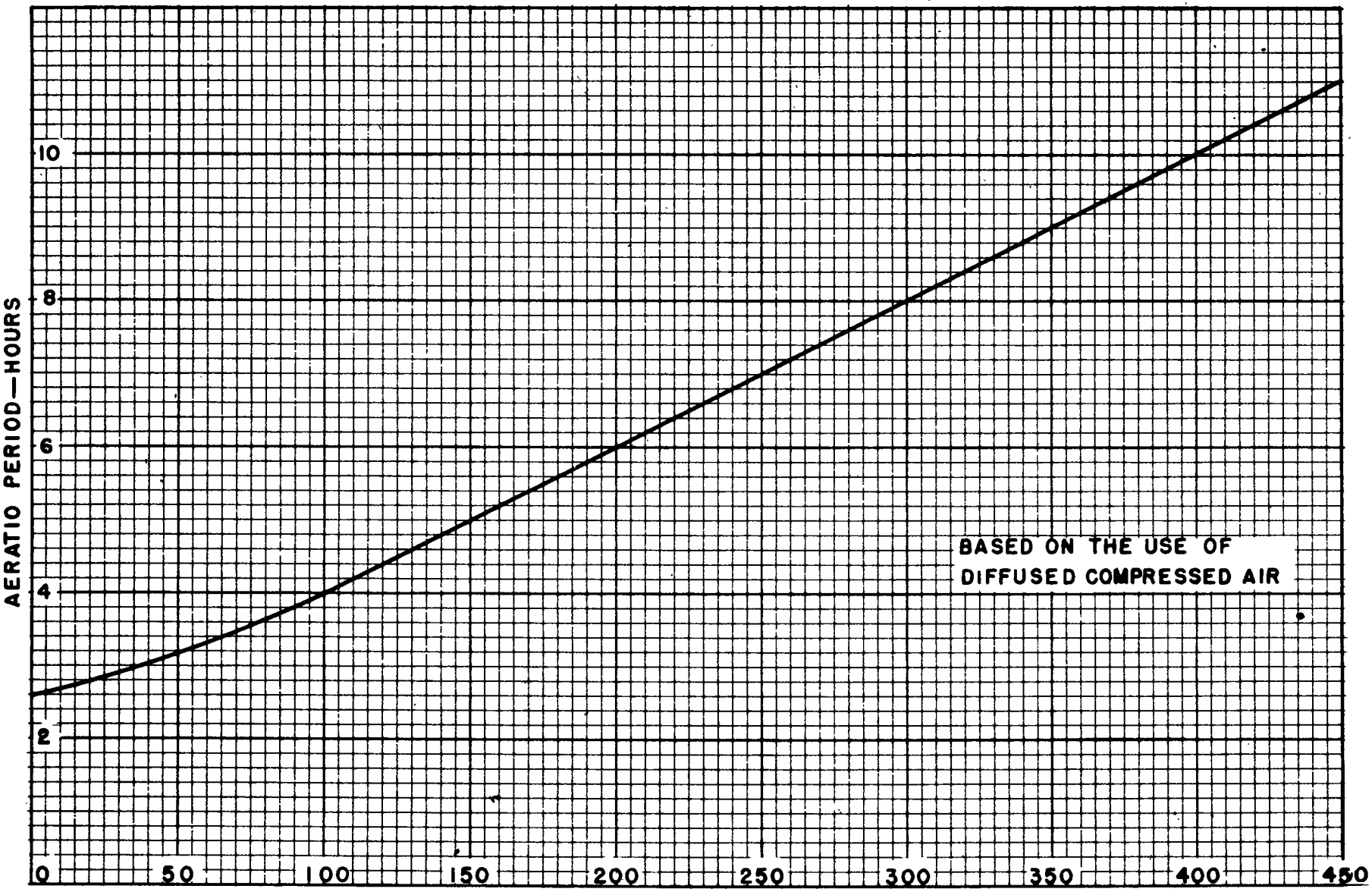
d. Underdrains. All filters should be designed with an underdrainage system that will adequately provide for ventilation as well as for the discharge of the effluent. Self spacing filter blocks manufactured especially for trickling filters are preferable to other types of underdrains. Vents through the filter wall or vent stacks of sewer pipe along the inside periphery of the wall and extending vertically from the drainage system to the surface of the filter, should be provided at a spacing of about 20 feet. In standard rate filters, means should be provided for closing the underdrainage discharge lines so that the filters can be flooded for fly control.

3-15 ACTIVATED SLUDGE. Designs for the activated sludge process as the principal biological treatment in a sewage treatment plant should be based on the use of compressed air diffusers. Mechanical aeration, which depends upon entrainment and surface absorption with agitation, has not proved entirely satisfactory for activated sludge in Army installations. Mechanical aerators, used in auxiliary treatment combined with other methods of biological treatment, have given satisfaction in some installations and may be used for such purposes.

a. Aeration Tanks. Aeration tanks for activated sludge plants using diffused air, should have volume for a displacement period as determined by the use of Figure 3 and computed for the average daily rate of sewage flow to which is added an allowance of 25 per cent for return sludge. Figure 3 indicates the required aeration time based on parts per million 5 day B.O.D. in the raw sewage. The number of parts per million will be determined from the total pounds of B.O.D. and the total flow entering the primary settling tank daily. The water depth may be from 10 feet in small tanks to 15 feet in large tanks, preferably about 12 feet as an average. The side walls should be of such shape as to aid in the spiral action of the sewage and the tank bottom should slope along the longitudinal axis to a sump. For correct cross flow conditions it is recommended that the width be 16'-8" in tanks of 10-foot side water depth, 30'-0" in tanks of 15-foot side water depth, and as determined by direct interpolation between these widths in tanks of intermediate side water depths. The tank inlet port should be near the side along which the diffusers are placed.

b. Qunatity of Air. The equipment for supplying air through the diffusers should have capacity for 600 cubic feet of air per pound of B.O.D. in the raw sewage on a daily basis. At least 3 cubic feet of air per minute per linear foot of tank for its entire length will be required in order that a minimum cross velocity of 2 feet per second may be maintained. It is desirable to distribute the greater portion of the air along the first third of the tank length. The number and spacing of diffuser tubes or the total area of diffuser plates will depend upon the required amount of air and the rates of distribution. The maximum spacing for diffuser tubes should be 2 feet.

c. Blowers. The air blowers for aeration tanks can be either the centrifugal type or the positive displacement type. Each has its peculiar advantages and disadvantages. Accurate determination of the operating pressure is of prime importance in the selection of a blower, particularly in the case of centrifugal blowers. The location and type of control valves are also of major importance in view of the fact that throttling affects different types of blowers in different ways. The design should provide for operating flexibility and stand-by service. Blower manufacturers should be consulted regarding specific needs. In order that responsibil-



AERATION REQUIRMENTS CURVE FOR ACTIVATED SLUDGE

FIG. 3

ity for correct correlation and proper operation may be fixed, it is desirable that all the aerating equipment be furnished through one manufacturer.

d. Air Mains. The air mains should be designed so that, regardless of lengths, the pressure loss will not be greater than 1 oz. per square inch from one end to the other in order that uniform distribution through each square foot of diffuser surface may be obtained. Mains connected to a manifold should be provided with an orifice, a slope gauge and a blast or butterfly valve. Means should be provided for indicating and integrating total air flow.

e. Return Sludge. Sludge pumps should be provided in duplicate for returning sludge to the aeration tanks and to the primary settling tanks and should have combined capacity for approximately fifty (50) percent of the design sewage flow. A sludge division box and suitable means for measuring the return sludge should be provided.

f. Flow Channels. All sewage flow channels should be designed for a minimum velocity of 2 feet per second at average flow. Dead ends should be avoided and corners should be filleted so as to prevent the collection of solids. Aeration facilities in flow channels are sometimes advisable.

3-16 FINAL SETTLING TANKS. The design of final settling tanks should be based on the following:

a. Volume. Final settling tanks for all types of treatment requiring final settling have sufficient volume to provide a detention period of two and one-half (2½) hours based on the average daily rate of sewage flow through the tanks, including recirculation. The recirculation of sludge or sewage drawn from the inlet end of rectangular tanks or from the center of circular tanks does not materially affect the detention period and should not be considered in computing the tank volume.

b. Design Features. Final settling tanks should be provided with overflow weirs equivalent in length to at least one foot for each 5,000 gallons of sewage flow per day for activated sludge plants and for each 10,000 gallons in all other types of plants. The surface area of the tanks should be not less than one square foot for each 800 gallons of sewage flow through the tank per day. Facilities should be provided for pumping sludge from final settling tanks to the inlet of the primary settling tanks and to the digester, also to the aeration tanks of activated sludge plants. Normally, scum collecting facilities are omitted. In other respects, final settling tanks are practically the same as primary settling tanks.

3-17 INTERMITTENT SAND FILTERS. The use of intermittent sand filters should, in general, be confined to small installations requiring a high degree of secondary treatment and to plants having other means of secondary treatment, but requiring additional treatment of the effluent. When sand filters are used they should be designed, as to area, so that the maximum loading, expressed in gallons of sewage per acre per day for the effective size of sand indicated in millimeters, will be as follows:

Septic tank effluent: 0.2 mm, 40,000; 0.3 mm, 60,000; 0.4 mm, 80,000.
Fresh settled sewage: 0.2 mm. 75,000; 0.3 mm, 100,000; 0.4 mm, 125,000.
Final settling tank effluent following trickling filters or their equivalent: 0.2 mm, 225,000; 0.3 mm, 250,000; 0.4 mm, 275,000

The sand should have a uniformity coefficient that does not exceed 5. The sand bed should be about three feet deep and underdrains should be provided on about 30 foot centers. The minimum number of beds should

be three and preferably more. Distributor pipes or troughs should be such that the sewage will be distributed uniformly over the entire bed. Application of the sewage to the beds at a rate of approximately 0.1 gallon per square foot per minute is recommended. Alternating siphons, operating from a common dosing tank and arranged so as to dose the beds in rotation, are satisfactory means for dosing the beds.

3-18 SLUDGE DISPOSAL. In general, the sludge resulting from sewage sedimentation should be disposed of by digestion and air drying. Mechanical dewatering and incineration are not considered economically justifiable except in special cases of industrial waste treatment where the sludge may contain sufficient toxic materials to prevent satisfactory digestion. Air drying of digested sludge should be provided by specially constructed open sludge drying beds or by the preparation of undrained drying areas.

3-19 SLUDGE DIGESTION TANKS. The required digestor capacity should be provided in two or more tanks unless this would result in impracticably small tanks. The tanks should preferably be arranged for two stage digestion. This, in addition to having other advantages, will minimize the possibility of partially digested sludge being drawn to the drying beds. The minimum side water depth should be 18 feet and preferably 21 feet. In general, the diameter should not exceed 60 feet. The design in other respects should conform to the following:

a. Capacities. Volumetric capacity in digestion tanks should be provided for as indicated in Table IV.

TABLE IV - SLUDGE DIGESTER CAPACITIES

Type of Sewage Treatment	Digestion Tank Capacity Cubic Feet per Capita	
	Heated Tanks	Unheated Tanks
Plain Sedimentation (No recirculated flow.)	2.0	3.0
Plain Sedimentation with Chemical Precipitation	3.0	4.5
Intermittent Sand Filters	2.0	3.0
Activated Sludge	4.0	6.0
All other types of secondary treatment	3.0	4.5

b. Heating. Normally, digesters should be provided with facilities for heating the sludge. In two-stage digestion, when the primary digester is heated, the heating facilities may be omitted from the secondary digester if properly insulated or if in a climate where insulation is not necessary. Under these conditions the secondary digester can be considered as heated and the capacity can be computed accordingly. Effective insulation can be obtained by providing a closed air space between the

digester wall and an outer brick shell or by earth embankment. The determination of whether or not insulation is required and of the type to be provided should be based upon local conditions. Under favorable climatic conditions, unheated digesters may give satisfactory results if extra capacity is provided as indicated in Table IV. Generally, however, heated digesters will be more satisfactory and will, except in small plants, be less costly to construct.

c. Disposal of Supernatant Liquor. Piping arrangement should be provided for discharging supernatant liquor from the sludge digestion tanks into the influent ahead of the sedimentation tanks and into the sludge drying beds. When compressed air is available, as in activated sludge plants it is desirable to aerate the supernatant liquor prior to returning it to the system. A tank for this purpose should provide a detention period of one hour based on one per cent of the average daily sewage flow.

d. Piping. The piping system should provide for simplicity in normal operation and for a reasonable amount of flexibility. Unnecessarily complicated designs for remote eventualities should be avoided. The sludge lines should be arranged for the input, withdrawal, transfer and recirculation of sludge. The supernatant lines should provide for the selection of supernatant liquor from the clear stratum as it may vary in elevation. The discharge point of the sludge input line and the point of supernatant withdrawal, should be sufficiently far apart to prevent mixture. Piping should be provided for the collection and withdrawal of gas with adequate flame protection.

e. Covers. Floating covers for digesters have many advantages over fixed covers and are desirable under all conditions. When fixed cover digesters are used, adequate means should be provided for the automatic and simultaneous refilling of the tank with either gas or liquid when liquid contents are being withdrawn. This is to prevent the admission of air and the creation of an explosive mixture which could be ignited spontaneously or in other accidental manners.

3-20 IMHOFF TANKS. Imhoff tanks, combining primary settling tanks and sludge digesters into common structures, are suitable for use at Army projects under favorable conditions. The cost of Imhoff tanks will be probably less than the cost of primary settling tanks and separate digesters in small plants for populations of about 3,000 or less. In larger plants the relative cost will usually be higher. The design should conform to the following:

a. Settling Compartments. The flowing through chambers or settling compartments should have the same displacement volume as specified hereinbefore for primary settling tanks. The entire cross-sectional area should be used in computing the volume. Velocities should not exceed 15 inches per minute at peak flow. The side walls of the V-section of the chamber and the tops of all submerged cross-sections, upon which solids may settle, should have minimum slopes of one and one-half (1½) vertical to one (1) horizontal. The slot at the bottom of the V-section should be about 8 inches wide. Overflow weirs should be provided as in primary settling tanks. When two or more flowing through chambers are provided, they should be interconnected by submerged pipes near the inlets and the outlets so as to minimize the diving of liquid in the event of unequal distribution of either the inflow or the effluent.

b. Sludge Compartments. Sludge compartments of Imhoff tanks should have the same per capita volume as specified for unheated separate sludge digestion tanks. The volume should be computed from a line 18 inches below the slot of the settling compartment. Suitable deflectors should be provided under the slot for preventing the passage of gas and sludge particles from the sludge compartment into the settling compartment. The open area of the liquid surface outside the settling compartment should be at least 20 per cent of the total area so as to provide free venting of the gases. The bottom of the sludge compartment should slope approximately in the ratio of one vertical to five horizontal.

3-21 SLUDGE DRYING BEDS. The design should normally provide open sludge drying beds with underdrains. The surface area of such beds should be one square foot per capita, except in projects where the population is composed largely of shift workers, in which case one-half square foot per capita should be provided for the non-resident personnel. Underdrains should be spaced on approximately 15 foot centers and the bottom of the beds should slope toward the underdrains. A layer of gravel, broken stone, slag or other similar material should cover the underdrains about one foot and extend over the entire bed. The finer material should be placed at the top. Above the layer of gravel, a 6-inch layer of coarse sand should be placed and the surface leveled. Splash plates should be provided so as to avoid disturbing the sand when the beds are being filled with sludge. In permanent installations, the outside walls and partitions should be of masonry construction. For the larger beds, it is desirable to provide concrete runways and creosoted wooden stop gates for the entrance of trucks.

If the natural soil is sufficiently pervious to absorb the liquid and there is no danger of polluting an underground water supply, the underdrains and layer of gravel may be omitted. The required area will depend upon local conditions, but under average conditions, three square feet per capita will be required. Beds without underdrains should be prepared by building small earthen dykes around leveled areas.

3-22 CHLORINATION. There appears to be an impression among the general public and to some extent among engineers and sewage treatment plant operators that chlorination will remove all the health hazards from sewage. There is a potential danger in this sense of false security, which sometimes leads to actual contamination. Although chlorine is an effective germicide when in actual contact, there is always the possibility that the organisms inside the solid matter may not come in contact with the chlorine. The design of the various plant elements should, therefore, be such that the need for chlorinating will be reduced to a minimum.

a. Points of Application. Chlorination facilities should be provided only to the extent necessary to safeguard health and to prevent a nuisance. If conditions are such that through failure of power or equipment there is a possibility of contaminating a water supply with raw sewage, capacity should be provided for chlorinating at a rate of 200 pounds per million gallons at the 4-hour peak rate of sewage flow. In other cases where chlorination is required, the facilities should provide for a rate of 125 pounds per million gallons at the 4-hour peak rate of flow. The equipment should be the solution type and points of application should be as follows: ahead of primary settling tanks; ahead of trickling filters; ahead of final settling tanks; following final settling tanks;

in wet wells or pumping stations from which the discharge of overflow could at times by-pass all other points of chlorination and contaminate a water supply.

b. Chlorine Contact Tank. When chlorination of the final effluent is required, a contact tank following the application of the chlorine should be provided to permit the chlorine to act on the organic matter in the effluent. Contact time of fifteen minutes displacement at the average 4-hour peak rate of flow should be provided in a baffled tank unless there is sufficient length of outlet sewer to provide for this detention. When the wet well of a pumping station is used as a point of application, it should, if possible, have storage capacity for 15 minutes or longer.

3-23 DEWATERING DRAINS. All tanks in a sewage treatment plant, including chlorine contact tanks, should be provided with drains or pump connections to permit dewatering. Sludge pumps can usually be utilized for this purpose and the piping arrangement should permit the tank contents to be returned ahead of the primary settling tanks.

3-24 SEPTIC TANKS. Septic tanks may be used to serve small or scattered installations where the effluent can be disposed of by subsoil irrigation, leaching wells or underground filters. In general, this method of treatment should be limited to installations where the total contributing population does not exceed 500.

a. Design of Septic Tanks. Septic tanks should be constructed of reinforced concrete and should have sufficient capacity to provide approximately 24 hours detention at the average rate of sewage flow. From 15 to 25 percent should be added to the required volume for sludge space, with the greater space being provided for the smaller tanks. The length of the tank should be not less than two nor more than three times the width and the liquid depth should be not less than 4 feet for the smaller tanks and 4½ to 6 feet for the larger tanks. Tanks of less than 500 gallons capacity are of questionable value and should not be used. Manholes should be provided over both inlet and outlet pipes and over the low point in the tank bottom.

b. Dosing Tanks. Dosing tanks with automatic sewage siphons should be provided for all septic tanks handling the sewage from 20 or more persons where the effluent is disposed of in tile fields or subsurface filters. They are not necessary where the effluent is discharged into leaching trenches or leaching wells. Dosing tanks should be designed to discharge a volume equal to about 80 per cent of the volumetric capacity of the disposal lines comprising the tile field or filters. The dosing tanks can usually be constructed the same width and as parts of the septic tanks. The high water level should be not less than 3 inches below the level of the sewage in the septic tank.

3-25 SUBSURFACE IRRIGATION. Subsurface irrigation can be used as a means for disposing of the effluent from septic tanks, where the soil and site conditions are suitable. It should never be used, however, in the vicinity of shallow water wells or springs or where the pollution of the ground water is objectionable and is possible.

a. Tile Fields. In tile fields the sewage is applied to the upper layers of pervious soil by means of open joint agricultural tile, of 4-inch or 6-inch diameter. The tile should be laid in trenches about 18 inches wide and preferably not over 2 feet deep. The tile should be completely surrounded with crushed stone or gravel the full width of the trench and

about 12 inches deep, the invert of the tile being about 6 inches above the bottom of the trench. The upper half of each tile joint should be covered with tar paper to prevent the entrance of sand or gravel. The tile lines should be spaced from 5 to 10 feet apart, depending on the soil absorption, and the laterals should not greatly exceed 100 feet in length. The grade of the laterals should be about 0.3 per cent when dosing tanks are used and 0.5 per cent when not used and equal distribution of the sewage should be obtained in all the tile lines.

b. Leaching Wells. Leaching wells may be used in connection with septic tank installations where the absorptive quality of the upper soil of the topography does not permit the economic use of a tile field, but where the absorption of the subsoil is sufficiently great to permit the disposal of settled sewage. The wells should be lined with field stones, rubble or masonry blocks provided with lateral openings, laid without mortar below the high water elevation. Surface drainage should be away from the wells. The distance between wells should be not less than twice their diameters. The wells should be interconnected with sewer pipe.

c. Soil Absorption Test. In order to determine the suitability of any area for subsoil effluent disposal, test holes approximately one foot square should be dug to the proposed depth of the tile or leaching trench at several points and be filled with water to a depth of about one foot. After this water has seeped away and while the bottom of the hole is still wet, it should be filled with water to a depth of six inches and the average time required for the water level to drop one inch should be noted. The amount of tile lines or area of leaching trench or leaching well required to dispose of the effluent may be computed from the data contained in Table V.

TABLE V - TABLE FOR DETERMINATION OF SOIL ABSORBTIVITY

Time in Minutes Required for Water to Fall 1 Inch in Test Hole	ABSORPTION IN GALLONS PER DAY	
	Per sq. ft. of Trench Bottom in Tile Trench	Per sq. ft. of Percolation Area in Leaching Wells
1	4.0	5.3
2	3.2	4.3
5	2.4	3.2
10	1.7	2.3
30	0.8	1.1
60	0.6	0.8

3-26 SUBSURFACE SAND FILTERS. Subsurface sand filters may be used in connection with septic tank installations where conditions are unfavorable to the use of either tile fields or leaching wells for the disposal of the tank effluent. The filters may be constructed as individual trenches or in the form of rectangular beds. In either case they consist of distribution tile, filter medium, effluent collecting tile and effluent discharge line. A bed of not less than 30 inches of clean, medium sized sand should separate the distribution and effluent lines in addition to the gravel surrounding these lines. Distributor lines should be laid level and collector lines at approximately 0.3 per cent grade. Subsurface sand filters should be designed on the basis of one gallon per square foot of filter surface per day and dosing chambers will be required.

3-27 OPERATING INSTRUCTIONS. Detailed instructions, including appropriate sketches, explanatory of the operation of the various items of equipment and plant units, should be provided. Five copies of these instructions should be furnished for distribution to the plant operator, the Post Engineer, the District Engineer, the Division Engineer and the Office of the Chief of Engineers. General supervision of operation by the Designing or other Sanitary Engineer, or a Chemist especially experienced in the operation of a plant of the type to be constructed, is desirable for a period of at least three months, in order to provide satisfactory operation during the transition period from construction to operation. Formal monthly reports as prescribed in TM 5-665, Operation of Sewerage and Sewage Treatment Facilities at Fixed Army Installations, should be prepared, showing records of adjustments, corrections and operating results during the starting period.

3-28 MANUFACTURER'S GUARANTEE AND SERVICE INSPECTION AND TEST. The specifications for the major items of equipment should require the equipment manufacturer to guarantee the equipment against defective materials and workmanship for a period of one year and to furnish the services of a factory representative experienced in the erection of equipment, to supervise the installation and test the operation of the equipment, units furnished by his company. In case of any difficulty with operation, the factory representative should make additional visits as may be required to correct the operating difficulties.

3-29 SEWAGE TREATMENT PLANT LABORATORY. Each plant should be provided with a laboratory equipped with furniture and equipment with which routine tests can be made as prescribed in TM 5-665, Operation of Sewerage and Sewage Treatment Facilities at Fixed Army Installations. Classification of Army Sewage Treatment Plants by type and size is given in Appendix "A" attached hereto. Appendix "B" is a list of Recommended Laboratory Furniture, and Appendix "C" is a Schedule of Recommended Laboratory Equipment for plants of various types. A list of Recommended Laboratory Chemicals and Reagents for Plant Laboratories is given in Appendix "D", and Appendix "E" is a suggested list of Tools for Plant Maintenance.

3-30 DESIGN ANALYSIS. A preliminary flow chart setting forth the tentative design factors will be submitted in accordance with the provisions of paragraph 740.09-a (6), Orders and Regulations. A design analysis, required by paragraph 740.09-a, Orders and Regulations, Corps of Engineers, will be prepared to accompany all plans and specifications for sewage treatment plants. The design analysis will set forth the design population, the basis for the selection of the degree of treatment to be provided, and the basis of design for each unit of the treatment plant and will be accompanied by a final flow chart.

APPENDIX "A"

CLASSIFICATION OF SEWAGE TREATMENT PLANTS

FOR

SCHEDULING LABORATORY FURNITURE AND EQUIPMENT

Plant Type	Classification per 1,000 population capacity			
	38 & over	12-38	6-12	1.5-6
Secondary Treatment with Separate Sludge Digesters	A	A	B	C
Primary Tanks and Separate Digesters Primary Treatment Only	A	B	C	C
Imhoff Tanks with Trickling Filter or Slow Sand Filter	B	B	C	D
Imhoff Tanks Only	-	C	D	D

APPENDIX "B"

RECOMMENDED LABORATORY FURNITURE FOR ARMY SEWAGE TREATMENT PLANTS

For Type "A" Plants	Items 1, 2, 3, and 4
For Type "B" and "C" Plants	Items 2, 3, and 5
For Type "D" Plants	No furniture

Item 1: One (1) Industrial Chemistry Laboratory Table 72" long, 48" wide, 36" high, equipped with 4 cupboards; not less than 20 drawers; a bottle rack 68" long, 10" wide, and 18" high; a lead-lined or stone trough 66" long, 6" wide, and 3" to 6" deep; a stone sink 20" long, 12" wide and 12" deep; three (3) straight-way water cocks; one bib water cock; one set of sink fittings; and two (2) double gas cocks. The table top should be carbonized birch 1-5/8" thick and scored to drain to the drain trough. The bottle-rack should be carbonized. Except as otherwise noted, the table should be oak with natural finish and should be equivalent to the units designated by catalog numbers, as follows:

E. H. Sheldon & Co., Muskegon, Michigan, No. 11268
W. W. Kimball Co., Chicago, Illinois, No. 502
Hamilton Mfg. Co., Two Rivers, Wisconsin, No. L-512

Item 2: One (1) Balance Shelf, 3' long x 2' wide, oak construction except for 1-5/8" thick birch, black carbonized top, equipped with drawer 21" wide, 15" deep, 3-3/4" high. Shelf to be similar to the following except as to drawer and size:

E. H. Sheldon & Co.	No. 12520
W. W. Kimball Co.	No. 682
Hamilton Mfg. Co.	No. L-1174

Item 3: One (1) Oak Supply Case with natural finish, 48" wide, 15" deep, 80" high, upper section glazed, 44" wide, 60" high, with 3 adjustable shelves, cupboard section 44" wide, 12" deep, 13" high, equivalent to the following:

E. H. Sheldon & Co.	No. 41040
W. W. Kimball Co.	No. 9562

Item 4: One (1) Lower Section Cupboard Unit 37-5/8" long x 24" wide x 36" high, containing 1 double cupboard 34" wide, 28-1/4" high x 20-5/8" deep, with 1 stone sink 14-1/4" long x 10" wide x 8" deep with 1 set of drain fittings, 1 cold water pantry cock and 1 double electric receptacle for 110 V A.C., table top to be scored to drain to sink. The unit should be oak with natural finish, except the table top which should be 1-5/8" carbonized birch.

Item 5: One (1) Chemistry Laboratory Table, 60" to 96" long, 36" high, 30" wide, similar in all respects to Item 1, except size and except that the table should be constructed for installation against wall with cupboards on one side only.

APPENDIX "C"

RECOMMENDED LABORATORY EQUIPMENT FOR ARMY SEWAGE TREATMENT PLANTS

QUANTITY			UNIT	DESCRIPTION	CATALOG NUMBERS		
Type of Plant					E. H. Sargent Co.	Central Scientific Co.	Fisher Scientific Co.
A & B	C	D					
1	1		ea	Balance, Analytical, Student Model, Chain Type, with Notched Beam	S-2675	1010	---
1	1		ea	Balance, Harvard Trip, Agate Bearings, 10 gm Beam, grad. to 1/10 gram	S-3215	3470	2-035
1	1		set	Balance Weights, for Chain Type, Analytical Balance, 1 gm to 100 gm, Gold Plated, no fractional, w/case	S-4045	----	2-215
1	1		set	Balance Weights, for Harvard Trip Balance, metric, 1 gm to 100 gm	S-4285	9140	2-300
1	1		ea	Bath, Water, 4 Hole, for Gas Heat	S-84355	19840	15-495
2			ea	Beakers, Griffin, Low Form, Pyrex, 2000 ml	S-4675	14265	2-540
2	2		ea	" " " " " 1000 ml	"	"	"
2			ea	" " " " " 600 ml	"	"	"
4	6		ea	" " " " " 400 ml	"	"	"
4	6		ea	" " " " " 250 ml	"	"	"
2			ea	" " " " " 50 ml	"	"	"
72	24		ea	Bottles, B.O.D., Glass Stoppered, U.S.P.	S-83805	29000	---
6	4		ea	Bottles, Dropping, Barnes, 30 ml	S-8725	10535	2-960
12	6		ea	Bottles, Narrow Mouth, Mushroom Glass Stoppered, Flint Glass, 32 oz.	S-8345	10430	2-915
6	3		ea	16 oz.	"	"	"
12	6		ea	8 oz.	"	"	"
36	36	24	ea	4 oz.	"	"	"
6	3		ea	Bottles, Narrow Mouth, Green Glass, for Cork Stoppers, 5 gal.	S-8435	10310	2-885
2	1		ea	Bottles, Washing, Pyrex, 1,000 ml	S-9365	10710	3-395
1	1		ea	Brush, Flask, for 500 ml Flask	S-9965	10985	3-570
1	1		ea	" , Test Tube, Medium	S-9995	10972	3-590
2	1		ea	Burettes, Geissler, Exax Blue Line, 50 ml	S-10635	15926	---
2	1		ea	Burners, Mixed Gas, Tirrill Type	S-12265	11026A	3-960
2	1		ea	Clamps, Burette, Spring Closing, Rubber Covered jaws	S-19045	12120	5-770

APPENDIX "C" (Continued)

QUANTITY			UNIT	DESCRIPTION	CATALOG NUMBER		
Type of Plant					W. H. SARGENT & CO.	CENTRAL SCIENTIFIC CO.	FISHER SCIENTIFIC CO.
A & B	C	D					
6	4		ea	Clamps, Pinch, Flat Jaws, for 3/8 inch Tubing	S-19495	12186	5-850
1	1		Bag/100	Corks, XXX Quality, Assorted Sizes, Nos. 6 to 15	S-23055	----	7-785
1	1		Set/6	Cork Borer, Brass, 5 mm to 11 mm, approx.	S-23175	12460B	7-845
12	6		ea	Crucibles, Coors, Porcelain, Wide Form, 30ml	S-23665	18540	7-995
12	6		ea	" , Filtering, Gooch, Coors, Porcelain, 25 ml	S-24315	18565	8-195
2	2		ea	Crucible Holder, Walter, for 25 ml Gooch Filtering Crucible	S-24475	18110	8-285
				Cylinders, Graduated (See Graduated Cylinders)			
1	1		ea	Dessicator, Schiebler, Plain, 250 mm without Plate	S-25005	14560	8-595
1	1		ea	Desicator, Plate, Porcelain, 8-Hole, for 250 mm Schiebler Dessicator	S-25185	18605	8-635
6			ea	Dishes, Evaporating, Porcelain, Coors, 150ml approx.	S-25505	18575	8-690
2	1		ea	Files, Triangular, Tapered, 4 inch	S-32235	88325	9-725
12	6		Pkg/100	Filter Paper, White, 9 cm	S-32915	13255	9-795
2			Pkg/100	" " " 12.5 cm	"	"	"
1	1		ea	Filter Pump, Richards, Brass, 3/8 inch I P Thread Connection	S-33575	---	9-965
6	3		ea	Flask, Erlenmyer, Pyrex, Narrow Mouth, 500ml	S-34105	14905	10-040
6	3		ea	" " " " " 250ml	"	"	---
2	1	1	ea	Flask, Filtering, Side Tube, Resistant Glass 500 ml	S-34375	14985	10-175
2	1		ea	Flask, Volumetric, Unstoppered, 1000 ml	S-34815	16220	10-200
1	1		ea	" " " 500 ml	"	"	"
2	1		ea	" " " 250 ml	"	"	"
4	2		ea	" " " 200 ml	"	"	"
2	1		ea	" " " 100 ml	"	"	"
1	1		ea	" " , Large Mouth, for D.O. 200 ml	S-34995	16295	10-240

APPENDIX "C" (Continued)

QUANTITY			UNIT	DESCRIPTION	CATALOG NUMBERS		
Type of Plant					E. H. Sargent & Co.	Central Scientific Co.	Fisher Scientific Co.
A & B	C	D					
2	2		ea	Funnels, Analytical, Bunsen, 75 mm	S-35315	15050	10-325
2	2		ea	" " , Short Stem, 150 mm	S-35305	15070	10-320
1			ea	* " , Buechner, Porcelain, for 9 cm Filter Paper	S-35555	18590	10-355
1	1		ea	Furnace, Muffle, Electric, Hoskins, 110-Volt Size 202, Including Rheostat	S-36855	13675	10-510
2	1		ea	Gauze, Wire, Chromel, 16 Mesh, 4" x 4"	S-85315	19960	15-585
4	2		ea	Graduated Cylinders, Read Up and Down, 1000 ml	S-24685	16105	2-555
1	1		ea	" " " " " " , 500 ml	"	"	"
1	1		ea	" " " " " " , 250 ml	"	"	"
2	2		ea	" " " " " " , 100 ml	"	"	"
1	1		ea	" " " " " " , Low Form, 100 nl	S-24765	16110	---
				Hydrogen Ion Indicator (See pH Indicator)			
3	3	2	ea	Imhoff Cone, Settling, Sewage	S-84125	29015	15-440
1	1		ea	Incubater, 20° C, Mechanical Cooling, Frigidaire Type or Eimer & Amend Water Bath Type			
8	6	3	ea	Kettle, Milk, Ivory Enameled, Seamless, 4 qt. Capacity, (for sample storage)			
1	1		ea	Mortar, Porcelain, Shallow, Pour Out Form, w/Pestle, 100 mm	S-62235	17381	12-960
1	1		ea	Oven, Electric, Single Wall, 140° C, 700 W., 100 V.	S-64055	95000A	13-265
	1	1	ea	pH Color Comparator, LaMotte or Hellige w/Bromthymol, Blue Standards	S-41725	21500	----
	1		100 ml	pH Indicator Solution, Cresol Red, LaMotte or Hellige	S-41745	21562	5-985-A
			ea	pH Meter, Electrometric, Industrial Type, Class Electrodes, Beckman Model M or equal	S-30060	21070	----
	1		ea	pH Standards, LaMotte or Hellige, Cresol Red,	S-41735	21550	----
6	4		ea	Pipettes, Measuring, Mohr, 10 ml, Graduated to 1/10 ml	S-69555	16320	13-665

* For Activated Sludge

APPENDIX "C" (Continued)

QUANTITY			UNIT	DESCRIPTION	CATALOG NUMBERS		
Type of Plant					E. H. Sargent & Co.	Central Scientific Co.	Fisher Scientific Co.
A & B	C	D					
2	1		ea	Pipettes, Volumetric, Transfer, 100 ml	S-69505	16340	13-650
2	1		ea	" " " 50 ml	"	"	"
2	1		ea	" " " 25 ml	"	"	"
2	1		ea	" " " 10 ml	"	"	"
2	1		ea	" " " 5 ml	"	"	"
2	2		ea	" " " 1 ml	"	"	"
1	1		ea	Plate, Color Reaction, Porcelain, Approx. 90 mm x 110 mm	S-70025	18600	13-745
				Pump, Filter (See Filter Pump)			
1	1		ea	Refrigerator, Mechanical, Sealed Type Mechanism, 6 cu. ft.			
2	1		ea	Rings, Iron, w/Clamp, 4 in.	S-73045	18005	14050
2	1		ea	" " " 3 in.	"	"	"
1	1		ea	Spatula, Stainless Steel, 4 in. Blade	S-75245	18755	14-365
1	1		ea	Spoon, Horn, 150 mm	S-75175	18775	14-425
1	1		ea	Still, Water, Stokes, Gas, 1/2 Gal. per Hour	S-27645	12808	9-055
1	1		lb	Stirring Rod, Glass, 6 mm	S-40075	14050	11-375
				Stoppers, Cork (See Corks)			
3	2		lb	Stoppers, Rubber, Solid, Assorted Sizes (Specify)	S-73305	18150	14-130
1	1		ea	Support, Funnel, 4 Place, w/Clamp	S-78815	19035	14-740
4	2		ea	" , Iron, Rectangular, Approx. 6" x 9" Base, 24" Rod	S-78305	19070	14-670
2	1		ea	Thermometers, -10° C. to 110° C.	S-80005	19240	14-985
1	1		ea	" 0° C. to 250° C.	"	"	"
2	1	1	ea	10° F. to 220° F.	S-80015	19280	14-990
2	1		ea	Tongs, Crucible, Nickel Plated, 9½ inches	S-82205	19625	15-185
1	1			" " " 14 inches	S-82215	---	---
2	1		ea	Triangles, Round Wire, Nichrome, 2 inches	S-82445	19705	15-255
2			ea	Tubes, T, Glass, 5/16" O.D.	S-82725	15650	15-325
3	1		lb	Tubing, Glass, Assorted, 5 mm to 10 mm (Specify)	S-40135	14076	11-350
20	10		Ft	Tubing, Rubber, Pure Gum, 1/4" diam, 1/16" wall	S-73505	18270	14-150
10	10		Ft	Tubing, Rubber, Pure Gum, 3/8" diam, 1/16 wall	"	"	"
10	10		Ft	Tubing, Rubber, Vacuum, 1/4" Diam	S-73535	18204	14-175
6			ea	Watch Glass, Plain, Ground, Annealed, 115 mm	S-83605	15850	2-610

APPENDIX "D"

RECOMMENDED LABORATORY CHEMICALS FOR ARMY SEWAGE TREATMENT PLANTS

QUANTITY			ITEM
Type of Plant			
A & B	C	D	
1 lb.	1 lb.		Acetic Acid - Glacial
½ lb.	½ lb.		Asbestos, Medium Fiber, Acid Washed
5 lbs.	5 lbs.		Calcium Chloride, Anhydrous
Ampules			* Calcium Hypochlorite
¼ lb.	¼ lb.		Chloroform - U S P
5 lbs.			Copper Sulphast - Crystals, Technical
5 lbs			Ferric Chloride, C.P., Lump
6 lbs.			Hydrochloric Acid
5 lbs	5 lbs		Manganous Sulphate, C. P.
100 ml			Methyl Orange, Indicator
1 oz.	1 oz.		Methylene Blue, U.S.P.
		1 Pt.	Methylene Blue Solution
100 Grams			Orthotolidine
100 ml			Phenolphthalein Indicator
5 lbs	5 lbs		Potassium Bichromate, Technical
1 oz.	1 oz.		Potassium Biniodate, C. P.
1 lb.	1 lb.		Potassium Iodide, C. P.
¼ lb.	¼ lb.		Potato Starch
100 Grams	100 Grams		** Sodium Azide
1 lb.	1 lb.		Sodium Bicarbonate
1 lb.			Sodium Carbonate, Anhydrous, C. P.
5 lbs.	5 lbs.		Sodium Hyclorozide, Pellets, U. S. P.
1 lb.	1 lb.		Sodium Thiosulphate, Crystals
1 lb.	1 lb.		Sulfamic Acid, C. P.
18 lbs.	9 lbs.		Sulphuric Acid, C. P.
18 lbs.	9 lbs.		" " Technical

* Obtain in Field

** For Secondary Treatment Plants Only

APPENDIX "E"

TOOL LIST FOR ARMY SEWAGE TREATMENT PLANTS

Minimum Requirements for Class A, B & C Plants.

QUANTITY	DESCRIPTION	*CATALOG NUMBER	
1	Chisel, Cold, 1/2"	200 ZAO	or equal
1	" " 1", Extra Long	205 ZAO	" "
2	File, 10" Mill, Bastard	3 ZA3	" "
1	Hacksaw	1027 ZA1	" "
12	Hacksaw Blades	1412 FLZAO	" "
1	Hammer, Ball Peen #2	252 ZAO	" "
1	" , Blacksmith, 201/2 lb.	0272 ZAO	" "
1	" , Claw #1	211 ZAO	" "
1	Pliers, Combination, 8"	26 GZA1	" "
1	Saw, Hand, 26", 8 Point	80 ZA2-08	" "
1	Screw Driver, 6"	26 ZAO	" "
1	Vise, Combination Jaw and Pipe, Swivel Base	A204½ ZA2	" "
1	Wrecking Bar 24"	95 ZAO	" "
1	Wrench, Cresent, Adjustable, 10"	710 ZA1	" "
1	Wrench, Open Double End, Set of 9, 1/4" to 1"	P725 ZAO	" "
1	Wrench, Pipe, 8"	254 ZAO	" "
1	Wrench, Pipe, 12"	2512 ZAO	" "
2	" " 18"	2518 ZAO	" "
1	" " 24"	2524 ZAO	" "
1	" , Socket, Hex, Set of 10 and Handle, 7/16" to 1"	P21 ZAO	" "

* H. Cannon Co., Cat. #166, Chicago, Ill.

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ENGINEERING MANUAL

MILITARY CONSTRUCTION

PART VIII

CHAP. 4

FEBRUARY 1948

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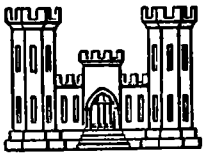
SEWAGE AND WASTE DISPOSAL

INCINERATION



DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

Chapter 4

INCINERATION

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Part VIII

SEWAGE AND WASTE DISPOSAL

Chapter 4

INCINERATION

4–01 GENERAL INSTRUCTIONS. The instructions and information contained in this chapter relate to the disposal of combustible waste materials and garbage by incineration. The design of Army incinerators should normally be based on the use of natural draft. However, in the design of wet garbage incinerators of 10 tons per day capacity or larger, auxiliary forced draft facilities are desirable and may result in economies. Under some conditions, for instance when the incinerator is unavoidably located where a natural draft chimney would create a hazard to airplanes, forced draft will be required.

4–02 SELECTION OF SITES. Sites for incinerators should be selected for convenience with respect to the housing area to be served and for accessibility from the existing road net. The length of average one-way haul, in general, should not be more than 3 miles. Where additional roads are necessary, they should be over the most direct practicable route to the site. In all cases, travel on and across primary roads should be held to a minimum. It is desirable that the site be at least 1,000 feet from inhabited buildings and located so that the prevailing winds will not be from the incinerator toward building areas. Drainage conditions should be adequate for run-off and to accommodate drains from the incinerator plant to the sanitary sewers.

4–03 DEFINITIONS. Definitions of terms in their particular application to the purposes of this chapter are as follows:

a. Incinerator. A special type of structure for the reduction of refuse to inert gases and solids by burning.

b. Furnance. That part of the incinerator in which combustion takes place, including the ignition chamber, mixing chamber, combustion chamber, and charging hood if provided.

c. Arch. The arched ceiling of the furnace over the ignition, mixing, and combustion chambers.

d. Grate. The cast iron grate on which the dry material is burned.

e. Hearth. An inclined floor on which the wet material is dried and burned. It may be constructed of firebrick or of cast iron grate bars.

f. Effective Grate Area. The grate area plus the effective area of the hearth in terms of grate area. (See par. 4–07*c*.)

g. Ignition Chamber. The space between the grate and the arch and between the hearth and the arch.

h. Mixing Chamber. The chamber adjacent to the ignition chamber where the gases mix before passing to the combustion chamber. This is often called the down pass.

i. Bridge Wall. The wall at the end of the grate or hearth between the ignition chamber and the mixing chamber.

j. Combustion Chamber. The final chamber of the furnace where combusiton of the gases is completed.

k. Target Wall. The wall between the mixing chamber and the combustion chamber.

l. Flue. The horizontal connection between the combustion chamber and the stack.

m. Damper. The vertical movable refractory slab in the flue for draft control.

n. Damper Box. The box over the damper for housing it in its open position.

o. Charging Hood. A structure directly over the ignition chamber provided with a door, through which the furnace is charged with refuse.

p. Charging Throat. An extension from an opening in the arch to the charging floor, through which the furnace is charged with refuse.

4–04 TYPES OF INCINERATORS. Three types of incinerators are considered in this section: Type I—garbage and rubbish incinerators; type II—wet garbage incinerators; and type III—rubbish incinerators. Standard designs have been prepared for types I and II, drawings for which are listed in appendix B. Type I of these standard designs is a general purpose incinerator and is the most suitable for the present-day needs at a majority of Army installations. It will burn refuse consisting of all rubbish or, by proper control of the damper, a mixture of 65 percent rubbish and 35 percent garbage by weight. Type II will burn a mixture of 65 percent wet garbage by weight and 35 percent rubbish without the use of auxiliary fuel. However, this type is not designed to withstand the high heat release which would result from burning refuse containing a high percentage of rubbish and should not be constructed except when the conditions are definitely unsuited to the use of type I. Type III should be used only when the refuse contains less than 15 percent moisture and, as a special design would be required, should be used only when economy will result in its use over that of type I.

4–05 INCINERATOR CAPACITIES. Requirements should be based on the expected waste from the particular post. At an average troop cantonment, the per capita waste will approximate 1.5 pounds of rubbish, 0.50 pound of nonedible garbage (citrus peels, coffee grounds, etc.) and 2.0 pounds of edible garbage per day. Quantity determinations, however, should be based on an actual survey whenever practicable. Capacity should be provided for 25 percent excess over the average hourly needs in order to make allowance for irregularity in the delivery of refuse to the incinerator. For example, if 4 tons are to be burned in 8 hours, the incinerator should have a capacity of 1,250 pounds per hour. Capacity factor for troop expansion should not be used as the incinerator can be operated 16 hours per day if necessary, 8 hours remaining for cooling and cleaning. Little or no economy will result in designing special incinerators of sizes intermediate between the sizes indicated on the standard O. C. E. designs listed in appendix B.

4–06 ABBREVIATIONS. Abbreviations of terms used in the formulas in this chapter are indicated below:

T_a	Atmospheric temperature in ° F. (absolute).
T_s	Average stack gas temperature in ° F. (absolute).
H	Stack height above the grate (feet).
A	Average inside cross-sectional stack area (square feet).
B	Barometric pressure (pounds per square inch).
D	Static stack draft (inches of water).
V	Gas velocity (feet per second).
W	Weight of gas including excess air (pounds per second).
L	Stack height above flue plus length of flue (feet).
P	Inside stack perimeter (feet).

4–07 BASIC DESIGN REQUIREMENTS. The incinerator should be designed for the severest conditions which may reasonably be expected. For instance, a type I incinerator may be required to burn refuse consisting of all dry material and no garbage. The design, therefore, insofar as it

involves heat release, gas quantities, velocities, etc., should be based on burning only dry materials. A drying hearth should be provided for the occasions when wet materials are to be burned. The design should conform to the following basic requirements:

a. Total Furnace Volume. Such that the heat release per cubic foot of furnace volume will not exceed 18,000 B. t. u. per hour.

b. Hearth Area. Approximately equal to the grate area for types I and II incinerators. (Not required in type III.)

c. Effective Grate Area. For types I and III incinerators—0.022 square foot for each pound of refuse per hour; and for type II—0.04 square foot for each pound of refuse per hour. In determining effective grate area, the hearth may be considered to be 60 percent effective if made of firebrick and 80 percent if made of grate bars.

d. Gas Velocity. A maximum of 15 feet per second through the combustion chamber and a maximum of 35 feet per second through the mixing chamber, flue, and stack.

e. Combustion Chamber Volume. At least 30 cubic feet per pound of gas produced per second, including excess air required for cooling purposes.

f. Combustion Chamber Temperature. Sufficient for complete combustion but not to exceed 1,600° F. (2,059° F. absolute). This can be controlled by use of the damper and by the introduction of excess air.

g. Combustion Time. A minimum of 1.5 seconds, total time required for the gases to pass through the furnace.

h. Stack Height. Sufficient to provide the necessary draft and determined by the formula:

$$H = \frac{D}{0.52\ B\left(\frac{1}{T_a} - \frac{1}{T_s}\right)}$$

i. Draft. Sufficient to discharge the gases of combustion and required excess air. The total draft requirements should be determined in accordance with the following allowances for losses expressed in inches of water:

Velocity head: $\frac{0.119\ BV^2}{14.7\ T_s}$

Friction loss through the stack and flue: $1.1 \times 10^{-6} T_s W^2\ LP \div A^3$

Loss through each 90° turn in the gas passage: computed as a stack or conduit, the length of which is 12 times the square root of the area of the opening.

Loss through grate: varies according to type of grate, quantity, and type of refuse burned, quantity of air and attention given to stoking. Under average conditions this loss may be considered to be 0.25 in types I and III incinerators and 0.15 in type II when the furnace is operating at rated capacity.

4–08 FORCED DRAFT INCINERATORS. The design of a forced draft incinerator with respect to heat release, temperature, effective grate area, combustion chamber volume, velocities, etc., will be the same as for a natural draft incinerator except that the draft requirements used in the stack design need not include allowance for loss through the grates, and the cast iron grate area may be reduced by 40 percent after the area has been determined as if for a natural draft incinerator.

4–09 PRELIMINARY DESIGN. A preliminary design should be made first and then checked and adjusted to assure compliance with the basic design requirements set out in paragraph 4–07. For this purpose table I, Preliminary Design Factors, will be found convenient. The design of an incinerator is illustrated in appendix A.

TABLE I.—*Preliminary design factors*

	Type of incinerator		
	I	II	III
Effective grate area per pound of refuse per hour (sq. ft)	0. 022	0. 04	0. 022
Ratio of hearth area to grate area	1.	1.	0.
Effectiveness of hearth area in terms of grate area:			
Firebrick hearths	60%	60%	--------
C. I. grate bars	80%	80%	--------
Horizontal cross-sectional area of mixing chamber in terms of effective grate area	25%	20%	25%
Horizontal cross-sectional area of combustion chamber in terms of effective grate area	60%	30%	60%
Cross-sectional area of flue in terms of effective grate area	25%	10%	25%
Cross-sectional area of stack in terms of effective grate area	22%	10%	22%
Ratio of height of arch above grate to width of furnace not to exceed	1	1	1

4–10 STRUCTURAL DETAILS. The structural design and the specifications relating to materials and to construction should provide for sturdy construction of all parts of the incinerator. In this respect the effects of expansion and contraction due to high temperature change should be carefully considered. The type of construction should, in general, be as indicated on the standard drawings and in the guide specifications listed in appendix B. Special consideration should be given to various features in the design as outlined below.

a. Furnace. The furnace should be constructed with an inner and outer shell. The walls of the inner shell and the arch should be approximately 9 inches thick and constructed of fire-clay brick conforming to Federal Specification No. HH–B–671, High Heat Duty, or constructed of refractory plastic material having equivalent qualities. Firebrick should be laid in high-temperature, air-setting, bonding cement. The arch should be covered with a 2½-inch layer of insulating material. The side walls of the outer shell should be 8-inch common brick walls securely braced to prevent settling and crackling. The bracing should consist of upright corner angles and intermediate upright channel buck stays, tied with rods and horizontal steel angles. The tie rods should be entirely outside the inner shell and should not be in contact with the refractory material at any point. The top, forming a part of the outer shell, should be reinforced concrete. If the top is not needed as a floor or as a roof for protection against the weather, it may be omitted and the arch covered with a 4-inch layer of common brick on top of the insulating brick. There should be no physical connection between the inner shell and the outer shell except the skewbacks of the arches, where the outer shell should be properly braced to take the arch thrust, and except around openings. The inner and outer shells should be separated by suitable insulating material or air space. The bridge wall and target wall should be 13½ inches thick in incinerators of 1,000 pounds per hour capacity or larger and 9 inches thick in smaller sizes.

b. Stack. The stack should be constructed with an inner shell of fire-clay brick for the entire height and an outer shell of common brick. The outer shell should be separated by a 2-inch air space from the inner shell and should have no physical contact with it at any point. The stack may be square or circular; however, the cross-sectional area should be the same for either shape.

c. Damper. The damper should be a movable vertical slab constructed of refractory material, steel shapes and tie rods. It should be located in the flue and should fit freely in guide grooves. Suitable means, such as a chain hoist or cables, pulleys, and counterweights, should be provided for raising and lowering the damper. A damper box should be provided for housing the damper in its open position.

d. Furnace Doors. The size, type, and location of the furnace doors should be determined with a view toward convenience of incinerator operation. The following comments relate to the

doors of incinerators of 1,000 pounds per hour capacity or larger: Types I and II incinerators require means of charging the drying hearth with wet material. This can be accomplished through a charging throat extending from the furnace arch to the operating floor above. A removable lid should be provided for the charging throat. The charging of the grate with dry material is best accomplished through a guillotine type of door. In a type I incinerator this door should be in the side of a hood which extends above the operating floor and is directly above the grate. In type III the charging door should be in the end of the furnace just above the grate. Types I and II should be provided with a guillotine firing door in the side wall immediately above the grate. In type III the firing door may be a cast iron hinged furnace door. The guillotine doors and the lid on the charging throat should be constructed of refractory material. Cast iron furnace doors approximately 18 by 24 inches should be installed in the side wall of the furnace just above and opposite the drying hearth and at the firing floor level opposite the mixing chamber, the combustion chamber, and the ash pit. The charging hood, the charging throat, and all openings should be adequately lined with refractory material.

e. Grate. The grate should be cast iron. The total area of the openings should be such that the loss of draft through the grate and refuse will not exceed the allowances indicated in paragraph 4–07*i*.

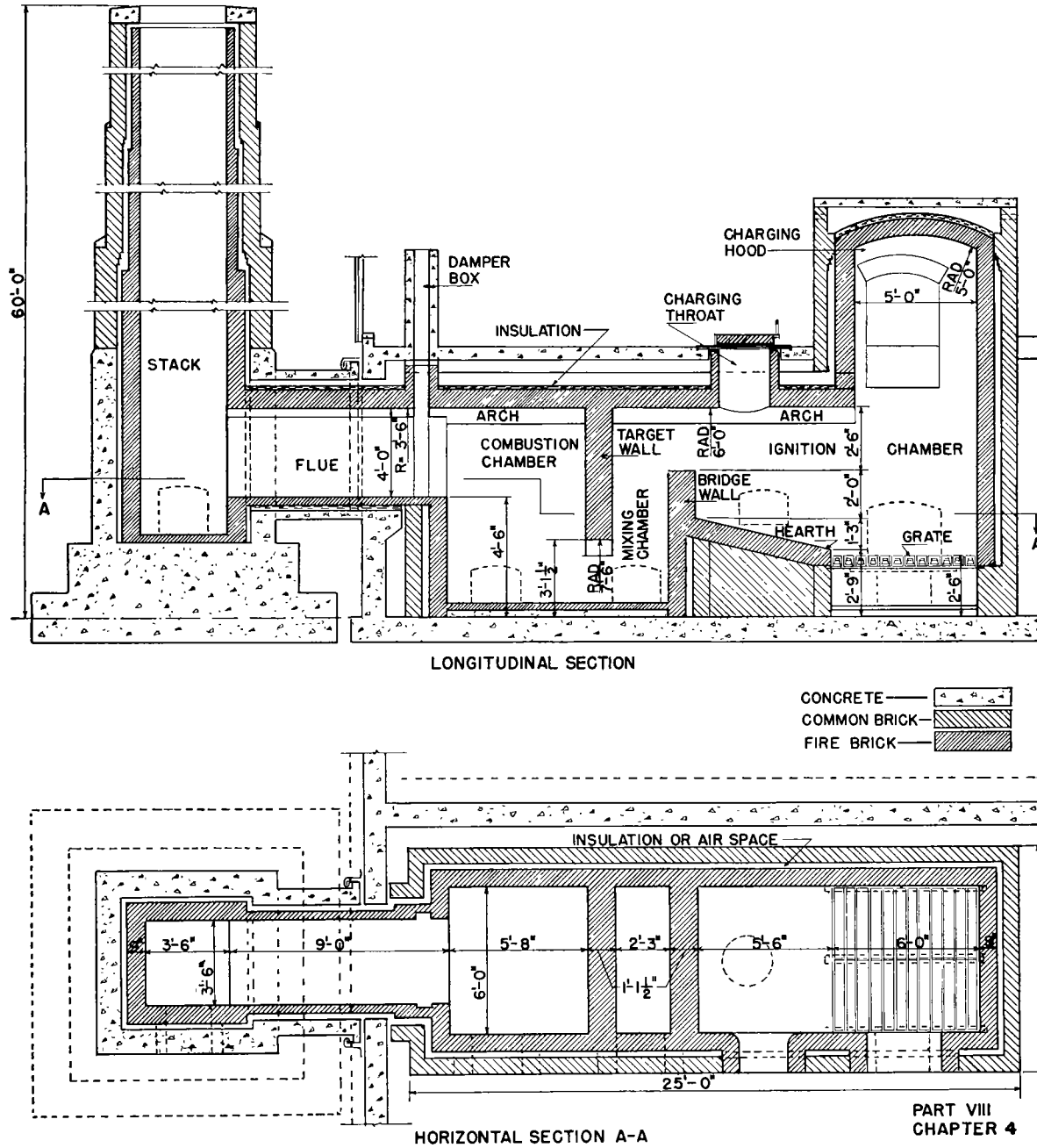
f. Incinerator Layout. Facilities should be carefully planned for the ready discharge of the refuse from delivery trucks directly on the charging floor or on a platform where it will be readily accessible for charging into the furnace. Space should be provided on the charging floor for storing refuse when the rate of delivery exceeds the furnace capacity for burning. Floor drains with removable, cast iron, slotted drain covers should be provided on both the charging floor and the firing floor.

g. Pyrometer. For purposes of controlling the temperature within safe limits for the refractory material, the combustion chamber should be provided with an indicating-recording pyrometer.

h. Draft Gage. A draft gage of the inclined tube type which will indicate the draft in the combustion chamber in inches of water is desirable.

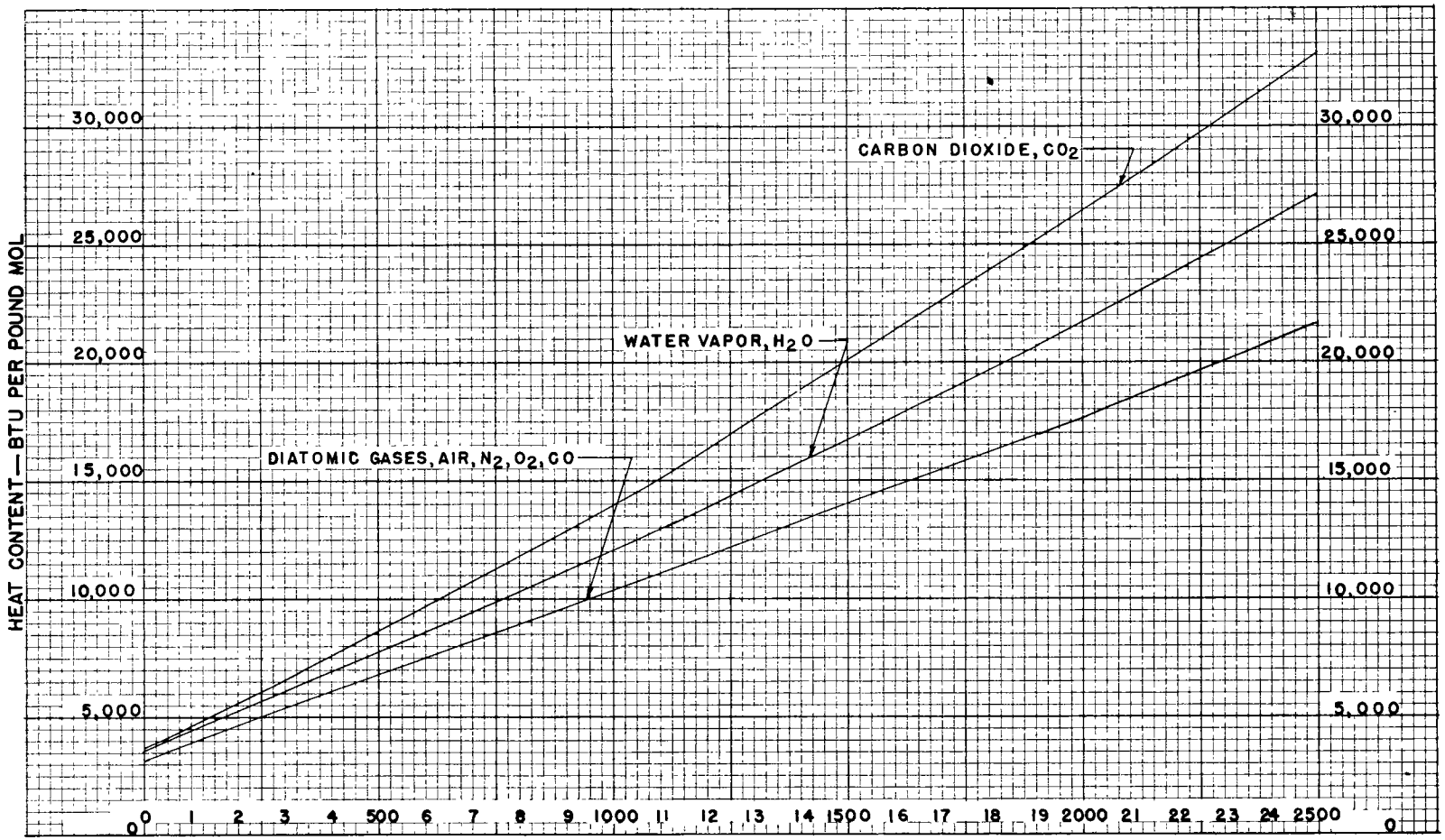
4–11 CAN WASHING EQUIPMENT. Garbage cans, when emptied at the incinerator, should be soaked in hot water, then sprayed with hot water inside and outside. Water may be heated for this purpose by means of a hot water pipe located in the combustion chamber and connected to a hot water storage tank of required capacity.

4–12 DESIGN ANALYSIS. A design analysis as required by Orders and Regulations will accompany all requests for authority to construct incinerators and all incinerator plans and specifications, other than standard plans and specifications. The analysis will indicate the type of material to be incinerated and, as outlined in paragraph 4–05, the basis upon which the capacity requirements were established.



INCINERATOR FURNACE AND STACK

Figure 1.



PART VIII
CHAPTER 4

CHART OF HEAT CONTENT OF GASES
(CONSTANT PRESSURE)

Figure 2.

APPENDIX A

ILLUSTRATIVE DESIGN

PROBLEM. Design a natural draft incinerator for burning an average of 2,000 pounds of mixed refuse per hour consisting of 35 percent nonedible garbage containing 50 percent water, and 65 percent rubbish containing 10 percent water and 15 percent solid inerts; atomspheric temperature, 60° F. (519° F. absolute); combustion chamber temperature, 1,600° F. (2,059° F. absolute); average stack temperature, 1,500° F. (1,959° F. absolute). The chemical analysis of 1 pound of the refuse on a *moisture free and solid inerts free basis* is assumed to be as follows: Carbon, 0.47 pound; hydrogen, 0.07 pound; nitrogen, 0.04 pound; oxygen, 0.42 pound.

PRELIMINARY DESIGN. A type I incinerator should be used to provide the required service. Using the preliminary design factors in table I and the capacity requirements set out in paragraph 4–05, the preliminary design is as follows:

Design capacity	$2{,}000 \times 1.25$	2,500 lb. per hour
Effective grate area	$2{,}500 \times 0.022$	55.0 sq. ft.
C. I. grate area (assumed)		36 sq. ft.
Hearth area (firebrick)	$\frac{(55.0-36)}{0.6}$	31.7 sq. ft.
Inside width of furnace (assumed)		6 ft.
Height of furnace arch above C. I. grate		6 ft.
Horizontal cross-sectional area of mixing chamber	55.0×0.25	13.75 sq. ft.
Horizontal cross-sectional area of combustion chamber	55.0×0.6	33.0 sq. ft.
Stack cross-sectional area	55.0×0.22	12.10 sq. ft.
Flue cross-sectional area	55.0×0.25	13.75 sq. ft.

To provide the above areas, the dimensions will be:

Length of C. I. grate	6 ft. 0 in.
Length of hearth	5 ft. 6 in.
Length of mixing chamber	2 ft. 3 in.
Length of combustion chamber	5 ft. 8 in.
Width of flue	3 ft. 6 in.
Height of flue to crown of arch	4 ft. 0 in.
Size of stack	3 ft. 6 in. square.

The above dimensions are the dimensions shown on Drawing No. 414:43–369, parts of which are reproduced in figure 1.

CHECK OF DESIGN. To assure conformance with the basic requirements of paragraph 4–07, a check involving heat release, heat balance, quantities of gases, velocities, draft, etc., should now be made of the preliminary design. The areas, volume, and dimensions shown on Drawing No. 414:43–369 and figure 1 are used in this check. The specific heats, heats of vaporization, and molecular weights of the various substances are taken from standard handbooks. The heat absorbed by various gases as the temperature rises over a specified range can be ascertained by use of figure 2, Chart of Heat Content of Gases. The following illustrates the method of checking the design.

The oxygen requirements for complete combustion of 1 pound of moisture-free and solid inerts free material of the stated chemical analysis are:

For burning carbon to CO_2	$0.47\times32\div12$	1.25 lb.
For burning hydrogen to H_2O	$0.07\times16\div2$	.56 lb.
		1.81 lb.
Less oxygen in refuse		.42 lb.
Oxygen to be supplied by air		1.39 lb.

The air required to furnish the above amount of oxygen is 1.39 divided by 0.23 or 6.06 pounds (oxygen in air is 23 percent by weight). The nitrogen in this quantity of air amounts to 6.06×0.77 or 4.67 pounds. Therefore, the products of combustion of 1 pound of moisture-free and solid inerts free refuse will be:

H_2O	$0.07\times18\div2$	0.63 lb.
CO_2	$0.47\times44\div12$	1.72 lb.
N_2	$0.04+4.67$	4.71 lb.
Total weight of gases		7.06 lb.

For conditions of burning all rubbish without wet garbage, the severest conditions under which the furnace will be required to operate insofar as heat release is involved, the products of combustion of 1 pound of refuse, taking into consideration the content of 10 percent water and 15 percent solid inerts (0.75 lb. on a moisture-free, solid inerts free basis), will be:

H_2O	$0.10+0.63\times0.75$	0.57 lb.
CO_2	1.72×0.75	1.29 lb.
N_2	4.71×0.75	3.53 lb.
Total weight of gases as products of combustion		5.39 lb.

The heat of combustion of 1 pound of moisture-free and solid inerts free refuse (using Dulong's formula for the determination of calorific values) will be $14,500\times0.47+62,000$ $(0.07-0.42\div8)$ equal to 7,900 B. t. u. The heat of combustion of 1 pound of the refuse, taking moisture and inert solids into consideration, will be $7,900\times0.75$ or 5,925 B. t. u. A portion of this heat of combustion will be lost through radiation and solid inerts, a portion will be absorbed in heating and evaporating water, and a portion (the larger portion) will be absorbed in heating the gases. In figure 2, which may be used in the determination of the heat absorbed by various gases, the difference between B. t. u. (British thermal units) per Mol (defined as m pounds where m denotes molecular weight) at two temperatures in question is the heat absorbed by the gas as its temperature rises from the lower to the higher value. B. t. u. per Mol divided by the molecular weight (not atomic weight) gives B. t. u. per pound. It should be noted that, for instance, the chart is graduated in degrees Fahrenheit, zero on the scale being 32° below the freezing temperature of water and not absolute zero which is used in most heat formulas. The heat lost or absorbed will be as indicated in the following heat balance:

Evaporating water from 60° F	0.57×1122	640 B. t. u.
Heating water vapor from 212° F. to 1,600° F. (weight multiplied by the difference in heat content per Mol at the two temperatures divided by molecular weight)	$0.57\times12,300\div18$	390 B. t. u.
Heating CO_2 from 60° F. to 1,600° F	$1.24\times17,100\div44$	502 B. t. u.

Heating N_2 from 60° F. to 1,600° F	3.53×11,200÷28	1,412 B. t. u.
Radiation through furnace walls, assuming a loss of 1,000 B. t. u. per sq. ft. per hour and a total radiating surface of 350 sq. ft	350×1,000÷2,500	140 B. t. u.
Heating 300 gallons of water per hour from 60° F. to 180° F. for can washing	300×8.33×120÷2,500	120 B. t. u.
Loss through solid inerts (assuming a specific heat of 0.20 and a temperature of 600° F	0.15×0.20×(600−60)	16 B. t. u.
Subtotal		3,220 B. t. u.
Balance to be absorbed by excess air (5,925−3,220)		2,705 B. t. u.
Total heat of combustion (as above)		5,925 B. t. u.

The excess air that will be required to absorb 2,705 B. t. u. so that the combustion chamber temperature will not exceed 1,600° F. (see fig. 2 for heat absorbed between 60° F. and 1,600° F.) will be 2,705×28.9÷11,200, which is equal to 6.95 pounds.

Therefore the total weight of gases per pound of refuse burned (the products of combustion plus the excess air used for controlling maximum temperature of the combustion chamber) will be 5.39+6.95 which is equal to 12.34 pounds. As this gas has a molecular weight which is practically the same as air, it will be considered air from this point on. The volume of 1 pound of air at 60° F. (519° F. absolute) and 14.7 pounds per square inch barometric pressure is approximately 13.1 cubic feet. Using the foregoing computations, formulas, quantities, temperatures, etc., the following determinations are made:

Total weight of gas produced per second	12.34×2,500÷3,600	8.57 lb.
Total volume of gas passing through the combustion chamber	8.57×13.1×2,059°÷519°	445 c. f. s.
Velocity through combustion chamber	445÷(5.67 ft.×6 ft.)	13.1 f. s.
Velocity through flue	445÷(3.5 ft.×4 ft.)	31.8 f. s.
Velocity through mixing chamber	445÷(2.25 ft.×6 ft.)	33.0 f. s.
Average volume of gas passing through the stack	8.57×13.1×1,959°÷519°	423 c. f. s.
Velocity through stack	423÷(3.5 ft.×3.5 ft.)	34.6 f. s.
Heat release per hour per cubic foot of furnace volume	5,925×2,500÷930	15,925 B. t. u.
Combustion time (total furnace volume excluding charging hood divided by volume of gas produced per second	720÷445	1.62 sec.
Combustion chamber volume per pound of gas produced per second	5 ft. 8 in.×6 ft.×7 ft. 11 in.÷8.57	31.1 cu. ft.
Draft loss in stack and flue (L=51.5 ft.+9 ft.=60.5 ft.)	$1.1\times10^{-6}\times1,959\times8.57^2\times60.5\times14\div12.25^3$	0.073 in.

Velocity head	$0.119\times34.6^2\times14.7\div(14.7\times1,959)$	0.073 in.
Loss through five turns through openings which have an average area of 14 sq. ft. and an average perimeter of 16 ft. taken as a stack whose height is $5\times12\sqrt{14}$ or 224 ft	$1.1\times10^{-6}\times2,059\times8.57^2\times224\times16\div14^3$	0.216 in.
Loss through grate (assumed)		0.250 in.
Total draft requirements	$0.073+0.073+0.216+0.250$	0.612 in.
Required stack heights	$\frac{0.612}{0.52\times14.7\left(\frac{1}{519}-\frac{1}{1,959}\right)}$	56.5 ft.

which is 1 foot less than the height above grate shown in fig. 1.

From the above analysis the design complies with the basic requirements set out in paragraph 4–07.

APPENDIX B

STANDARD PLANS AND SPECIFICATIONS

The following standard plans and specifications are available for the construction of incinerators when authorized:

Type I. Rubbish and Garbage Incinerators:

Incinerator, 2,500 pounds per hour capacity:

414: 43–368 (formerly 672–310).
414: 43–369 (formerly 672–311).
414: 43–370 (formerly 672–312).
414: 43–371 (formerly 672–313).
414: 43–372 (formerly 672–414).

Incinerators, 1,250 pounds per hour capacity:

414: 43–375.
414: 43–376.
414: 43–377.
414: 43–378.
414: 43–379.

Type II. Wet Garbage Incinerators:

3 tons in 8 hours capacity—natural draft:

414: 43–227.
414: 43–227.1 (700–4437).
414: 43–227.2.

5 tons in 8 hours capacity—natural draft:

414: 43–320.
414: 43–321.
414: 43–322.
414: 43–323.
414: 43–324.
414: 43–325.
414: 43–326.
414: 43–327.
414: 43–328 (700–4443).
414: 43–329.

10 tons in 8 hours capacity—forced draft:

414: 43–330.
414: 43–331.
414: 43–332.
414: 43–333.
414: 43–334.
414: 43–335.
414: 43–336.
414: 43–337 (700–4449).
414: 43–338 (700–4450).

Specifications for the incinerators listed above are covered in Guide Specification CE–601.

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ENGINEERING MANUAL
FOR WAR DEPARTMENT CONSTRUCTION

PART VIII
CHAP. 5
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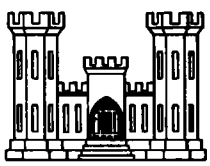
SEWAGE AND WASTE DISPOSAL

SANITARY FILL



ARMY SERVICE FORCES
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

CHAPTER 5
SANITARY FILL

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PART VIII

SEWAGE AND WASTE DISPOSAL

CHAPTER 5

SANITARY FILL

5-01 SCOPE. The disposal of garbage, rubbish and other wastes of like nature, by the sanitary fill method, does not require engineering design and construction in their usual sense. Advice to the using agency regarding the use of the method or its practicability at the particular project under consideration as an alternative to constructing incinerators may be an engineering function. The instructions given in this chapter are to serve as a guide in performing this function. The decision should be based on current established policy, economy and conditions affecting sanitation.

5-02 GENERAL. The use of sanitary fill should be confined to localities where frost will not extend below a depth of two feet and where percolation or run-off from the fill will not endanger a water supply. It probably will be preferable to incinerators for summer camps or other training camps which are occupied only periodically. It may also be a valuable means for reclaiming waste land. Normally, sanitary fill will be more economical than incinerators. On the other hand, incinerators destroy the waste and remove the possibilities of unsanitary conditions. A comparative cost analysis, based on the life period of equipment and structures, should be made. When sanitary fill is employed, it must be accomplished in such manner as to seal the contents effectually and to prevent a nuisance from rodents and objectionable odors. It is an acceptable method of waste disposal when properly operated under proper conditions. Figure 1 is a graphic sketch illustrating sanitary fill.

5-03 SELECTION OF SITE FOR SANITARY FILL. The selection of a site for a sanitary fill should take into consideration the following:

a. Type of Soil. The soil should be free from large boulders, should be a type that can be readily excavated and restored as fill covering by standard type of equipment, and should be of a loose nature that is not conducive to the formation of tunnels by burrowing rodents.

b. Area. The total area required for the sanitary fill will depend upon the population to be served and the various types of refuse. It is estimated that disposal can be made of 12 tons of mixed garbage and rubbish per day for one year on an area of one acre filled to a depth of six feet. At an average troop cantonment, the per capita daily waste will approximate 1.5 pounds of rubbish, 0.50 pound of non-edible garbage (citrous peels, coffee grounds, etc.) and 2.0 pounds of edible garbage. Consideration should be given to the possibility of moving the fill successively to several small areas if one large area is not available.

c. Drainage Conditions. The location of the fill should be such that the run off can be disposed of without polluting surface or subsurface water supplies or preventing access to the fill at all times. The top coverage of the fill should be graded to a slope of approximately one per cent, preferably away from open fill, to effect adequate drainage and to provide a means of access for trucks. Occasional grading may be necessary to maintain a satisfactory surface condition.

d. Length of Average Haul. The sanitary fill should be located conveniently with respect to the housing areas in order to avoid long hauls.

In general, the average one-way haul of all garbage and refuse should not exceed three miles.

e. Availability of Access Roads. Existing roads, except primary roads, should be used as access roads to the sanitary fill wherever possible. Where additional roads are necessary they should be over the most direct route to the site.

f. Minimum Use of Primary Roads. The site should be selected so that travel on primary roads is not necessary and crossings of primary roads is held to a minimum.

g. Proximity of Inhabited Buildings. It is desirable that the site be at least 750 feet from inhabited buildings.

h. Direction of Prevailing Winds. The site should preferably be such that prevailing winds are away from habitations, other things being equal.

5-04 METHOD OF MAKING THE FILL. The first trench to be dug for the sanitary fill will normally be thirty to seventy inches in depth in order that material therefrom may be used to build a ramp from which trucks will discharge their loads. The depth of the second and following trenches need be only sufficient to supply adequate coverage of the top surface and slope of the sanitary fill as prescribed below.

a. Compaction. One of the most important conditions to be maintained relative to the newly dumped refuse is that it shall be confined to the least practicable area and be thoroughly compacted. This can be accomplished by pushing or dragging the refuse into the main pile and by frequently driving the tractor into the pile or by dropping the drag-line bucket therein. This method of compaction should be resorted to frequently during the day so that, as a result, the completed fill will be in successive, well compacted layers. This compaction will not only result in confining the waste to the least practicable space but should provide satisfactory support for the final earth cover over which trucks will operate in making subsequent fill.

b. Coverage. The top coverage of the fill should never be less than eighteen inches of compact soil and preferably should be twenty-four inches in thickness. The thickness of the coverage on the outside slope should not be less than 12 inches. The top and side cover should be placed within twenty-four hours after the refuse has been deposited. It is not necessary to seal off the end of the fill each day but it should be sealed off at least twice a week. This seal completes the cell which acts as a fire break in case refuse and garbage in any one cell should become ignited.

5-05 EQUIPMENT. The following equipment or its equivalent is necessary for the maintenance of a sanitary fill.

a. For Camps of Less Than 10,000 Population. One track-laying tractor equipped with bull clam shovel of one cubic yard capacity.

b. For Camps of 10,000 to 40,000 Population. One track-laying power shovel with at least a thirty-four foot boom and with 1/2 cubic yard or larger dragline bucket or one track-laying tractor equipped with a 2-yard bull-clam shovel.

c. For Camps of 40,000 Population and Greater. One 3/4 cubic yard track laying power shovel with a forty-foot boom and a 3/4 cubic yard dragline bucket, and one 30-60 horsepower crawler tractor equipped with bulldozer.

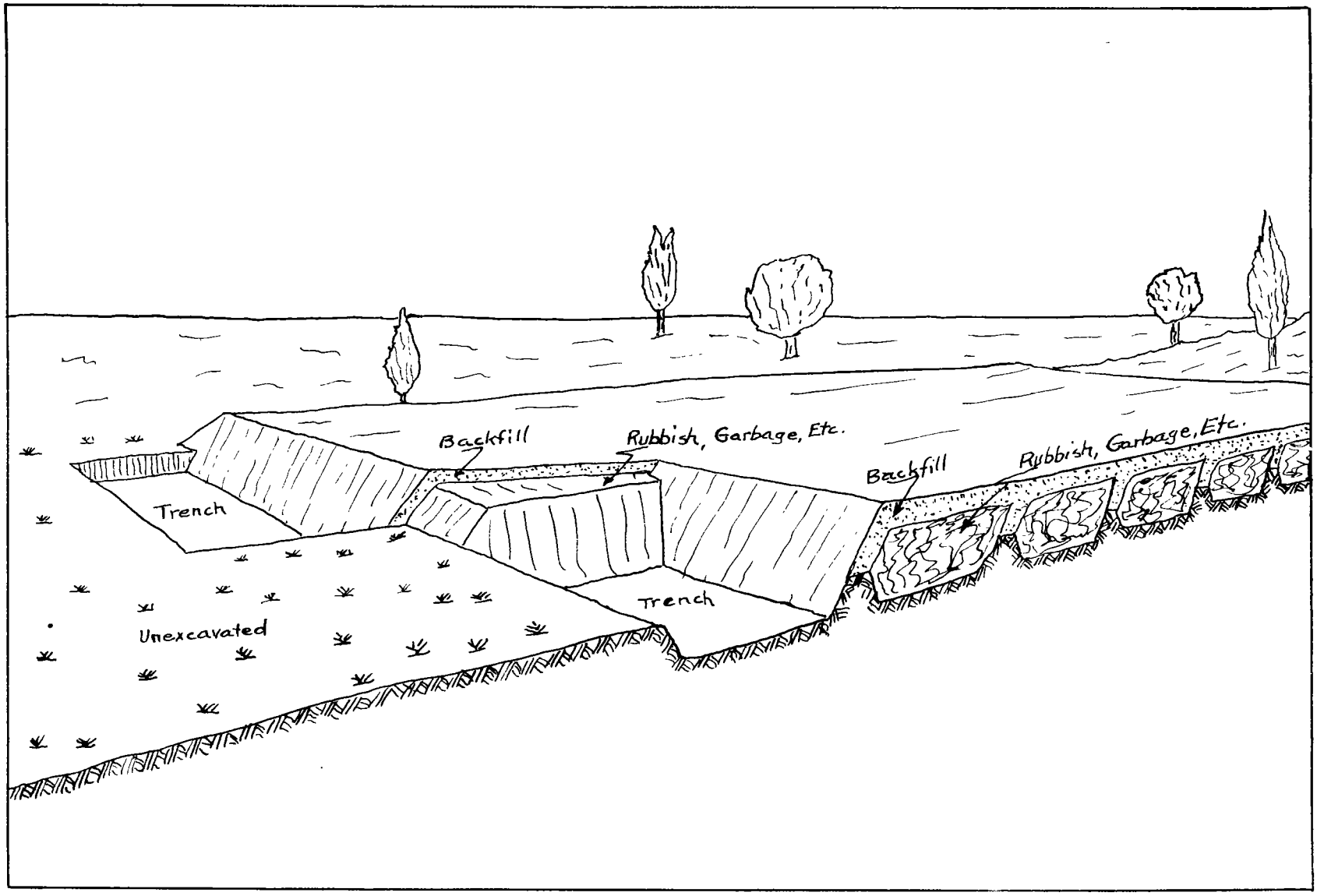

ILLUSTRATION OF SANITARY FILL

FIG. 1

PART VIII
CHAPTER 5

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ENGINEERING MANUAL
MILITARY CONSTRUCTION

PART IX
CHAP. I

SEPTEMBER 1948

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FUEL DISTRIBUTION AND STORAGE

GAS DISTRIBUTION



DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

Chapter 1

GAS DISTRIBUTION

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Part IX

FUEL DISTRIBUTION AND STORAGE

Chapter 1

GAS DISTRIBUTION

1–01 SCOPE. The instructions and information contained in this chapter relate to pipe systems, including pressure regulators, valves, meters, and other necessary appurtenances, for the transportation of fuel gas, natural and manufactured, from the point of delivery by the gas supplier to the points of connection with building piping which ordinarily terminates 5 feet outside the buildings. The purpose is to furnish a guide for use in designing new gas distribution systems, in checking the adequacy of designs which may be furnished by the gas supplier, and in analyzing existing systems to determine their adequacy for supplying the demands of proposed additions.

1–02 LINE PRESSURE. Gas lines are usually designated as low pressure, intermediate pressure, medium pressure, or high pressure. Distinguishing limits are not well-standardized, but vary in different localities. For purposes of this manual, pressure is defined as low if less than 1½ pounds per square inch, high if above 50 pounds per square inch, and medium if between these limits, without differentiating between intermediate and medium.

a. Low-pressure lines. In low-pressure lines, gas is usually distributed at pressures of 3 to 8 ounces per square inch. Individual building regulators are often omitted when this type of system is used. The omission of building regulators can, however, be the source of serious trouble if the line pressures are subject to appreciable fluctuation. Leakage in a low-pressure system will normally be less than in medium-pressure systems, but the construction cost will be considerably higher because of the necessity for larger pipe. Low-pressure systems are not recommended for general use at Army installations if medium pressures are available.

b. Medium-pressure lines. For permanent construction, design pressures for a distribution system should not exceed 25 pounds per square inch gage and, for purposes of providing a reasonable capacity margin for increased demand, should preferably not exceed 20 pounds per square inch. In temporary construction, the design pressures for a distribution system may be higher than for permanent construction, but under no conditions should the pressure exceed 50 pounds per square inch.

c. High-pressure lines. The principal function of high-pressure gas lines is cross-country transmission. When necessary, they may be used at Army installations to connect the distribution system with the gas company's transmission line, but should not be used in the distribution system itself. The location of high-pressure lines should be carefully planned with a view toward minimizing danger of line breakage and danger of fire in case of breakage.

1–03 SYSTEM LAY-OUTS. Gas distribution systems should be carefully planned with due consideration for economy, safety, and uniformity of pressure. The lines should be well-looped within the main area and in all outlying areas whenever practicable and economically feasible to do so. It is not always practicable to loop a supply line to an outlying area back into the main system, but in such cases the objectionable effects of dead ends can often be relieved to some extent by looping such line around the area it serves back into itself. At large posts, for purposes of adequacy and uniformiy of pressure, it will usually be advantageous to extend the high-pressure line to provide two or more tie-ins with the distributing lines.

a. Pipe-line locations. Gas lines should never be installed under a building. They should not be laid in the same trench with other utilities. The purpose of this precaution is to minimize the possibility of leaking gas following along or collecting in other conduits and creating an explosion hazard. For the same reason, gas lines should be above other utilities wherever they cross, if practicable. Gas lines should not be laid under paved streets or in locations subject to heavy traffic, so far as is practicable to avoid. Whenever it is necessary to locate gas lines in such locations, the lines should be protected by suitable casing or by installing at such depth as may be necessary to relieve sufficiently the stress from superimposed loads.

b. Drips. Drips should be installed at all low points in lines transmitting manufactured gas. In lines transmitting natural gas, drips should be installed at the low points immediately following reduction from high pressure to medium pressure and at occasional low points throughout the system to provide for blowing out the lines.

c. Grading of pipe lines. Gas mains should be at such depth as will provide at least 2 feet of cover over the top of the pipe. Where manufactured gas is used, the lines should be uniformly graded to drain to low points to guard against the occurrence of pockets where condensate could restrict the flow of gas. Lines transmitting natural gas need not be graded, but may follow the contour of the ground surface.

d. Valves. Valves should be installed in the system and so located that interruptions to service can be confined to reasonably small areas in case of line breaks or other causes. In locating the valves, consideration should also be given to the matter of adequately purging the lines of air, particularly in complicated, looped systems. As the purpose of a valve in a gas distribution system is to shut off positively rather than to throttle the flow and as a small amount of trash in the seat of a gate can prevent effective stoppage of flow when the valve is closed, plug valves are preferable to gate valves.

e. Pressure regulators. Pressure regulators are necessary at all points where equipment or design requires reduction in or regulation of pressure. Building regulators are usually included in the building plumbing and not in the gas distribution system. All regulator stations in the distribution system should be provided with a bypass and valves, arranged so that the regulator could be taken out of service for repairs.

f. Central regulating and metering station. A central regulating and metering station is generally provided by the gas company and is usually located near the entrance to the reservation. When provided by the Government, all necessary equipment should comply with the requirements of the gas company. The housing should be of fire-resistant construction and adequate provision should be made for ventilation. A valve should be installed in the main supply line, approximately 100 feet ahead of the station.

1–04 WARNING AGENT. A suitable malodorant should be injected into natural gas for the purpose of detecting leaks. Unless the gas in the supply line has already been odorized by the gas company, it will be necessary to provide the necessary facilities for the purpose. A storage tank and means for injecting the odorizing agent at a rate that is proportional to the rate of gas flow, as determined by pressure drop across an orifice, will be required. The point of injection should be on the down-stream side of the central regulating and metering station. Dependable recommendations can usually be obtained from gas companies as to type and required quantity of malodorant to use and as to injecting equipment.

1–05 SERVICE LINES. Service lines should be at least 18 inches below ground surface and deeper as required or suitably encased if subject to traffic loads. If practicable, the lines should be graded to drain to the mains. The size of pipe should be sufficient to supply the demand without excessive pressure drop and should not be less than 1 inch for medium pressure nor less than 1¼ inches for low pressure. Each line should be provided with a shut-off plug valve, con-

veniently located outside the traffic and protected with a valve box. Connections are usually made to the top of cast-iron pipe through street T's with end of run plugged. The purpose of using a street T in preference to a street L is to provide a means for stopping the flow of gas by inserting a temporary stopper of rubber or other material into the connection while working on the service line. Similar fittings for welding are used with steel pipe.

1–06 PIPE MATERIALS. Cast-iron pipe and steel pipe are both used extensively in gas-distribution systems. Each material has advantages and disadvantages as compared with the other. Steel pipe would probably be less expensive if protection against corrosion is not required. Either material may be used.

a. Pipe joints. There are three types of joints which may be used for steel pipe in conformity with current guide specifications, namely: welded, Dresser coupled; and threaded, in order of preference. Welded joints, if properly made, will usually result in less leakage and less maintenance difficulties than threaded joints. Dresser couplings are acceptable, but, normally, are more expensive than welded joints in the larger pipe sizes. Where Dresser couplings are used, the tendency for the line to blow apart at bends in the pipe should be studied, particularly in the larger lines that are subject to relatively high internal pressure, and concrete anchors should be installed if necessary. In permanent installations, threaded joints should not be used in pipe sizes larger than 3-inch and preferably not in sizes larger than 2-inch, because of leakage difficulties.

Joints for cast-iron pipe should, for general purpose, be of mechanical type. A number of pipe manufactureres have developed satisfactory mechanical joints for their pipe. Plain end cast-iron pipe with Dresser couplings is also used. In view of the difficulty in making and maintaining joints gas-tight with lead, bell-and-spigot pipe should not be used ordinarily. It may be advantageous to use bell-and-spigot pipe for minor extensions to existing systems in which bell-and-spigot pipe was previously used, for purposes of utilizing stock on hand, or for similar purposes.

b. Protection against corrosion. Ferrous materials are subject to electro-chemical corrosion in the ground. The rate of corrosion depends upon a number of factors, such as moisture, salts, and electrical resistivity, and would be approximately the same for cast iron, wrought iron, or steel, if subjected to the same conditions. Usually, the rate decreases as the time of exposure increases, probably as the result of an insulating effect of the products of corrosion. Therefore, the length of life of ferrous pipe is largely dependent upon wall thickness. Obviously, bare cast-iron pipe could be used successfully in many soils where protection would be essential to steel pipe of thinner walls. In very highly corrosive soils, any ferrous pipe should be adequately protected. The subject of soil corrosion, including determinative field tests, is extensively treated in National Bureau of Standards Circular C450, Underground Corrosion, which is obtainable from the Superintendent of Documents, Washington, D. C. Steel pipe should be protected if the soil is appreciably corrosive, but protection is expensive and should not be required where it is not needed. It may be needed in some parts of a large distribution system and not needed in other parts of the same system. In each case, a determination should be made as to where it is and is not needed. For extensions to an existing system, local experience is the most accurate guide. In new systems of appreciable size, a survey should be made, using methods suggested in Circular C450 referred to above.

(1) *Coating and wrapping.* Where this type of protection is required, the pipe should be primed and coated with a suitable bituminous material and wrapped with an inorganic fabric impregnated with bituminous material. The purposes of the coating are exclusion of moisture and insulation against the flow of low potential electric currents. To accomplish these purposes, it appears that $\frac{3}{32}$ of an inch should be the minimum thickness of the coating and that the material should be such that it can be applied without leaving pinholes and will not check or crack with aging. The principal purpose of the wrapping is to protect the coating against mechanical scoring which could result in the concentration of electric current at the points of defect. At present, coal-tar enamel is considered the best bituminous material for the coating. No standard specifica-

tion for asphalt that would be entirely satisfactory has been developed by the industry and this material should not be used until a satisfactory specification is available. The current issue of Guide Specification CE–900, relating to gas distribution systems, should be followed.

(2) *Cathodic protection.* Cathodic protection of either bare pipe or coated pipe may be used as an alternate for coating and wrapping on a competitive bid basis where its suitability for a particular system has been determined. Methods have not been sufficiently standardized in this type of protection for inclusion in this manual or in a guide specification at this time. However, there are engineering firms who specialize in this field and who might be consulted. If cathodic protection is permitted in project specifications, a guarantee of satisfactory performance should be required.

1–07 DESIGN. The design of a gas-distribution system should be based on a demand that is equivalent to the full connected appliance load without consideration of any diversity factor. The actual consumption may never be equal to the full connected load, but such diversity factor as may exist at an Army post will not be as large as in a civilian community and would serve as a margin of safety if not included in the design. In the various gas flow formulas, demand is expressed in cubic feet per hour. Because of the variability of the volume of gas with changes in pressure and temperature, reference to definite bases of pressure and temperature is necessary in expressing quantities volumetrically. It is also essential that the stated characteristics of the gas, the computations of the connected appliance loads and the flow formulas used in the design of the pipe system, all be on the same basis.

a. Flow formulas. For the solution of gas flow problems involving pressures less than 1½ pounds per square inch gage, the following formula, generally referred to as the low-pressure formula, is commonly used:

$$(1)\quad Q=\frac{C\,(P_1-P_2)^{1/2}D^{5/2}}{(G\,L)^{1/2}}$$

Where—

Q=flow in cubic feet per hour;
D=internal diameter of pipe, inches, actual;
P_1=pressure, inches of water (gage), at point 1;
P_2=pressure, inches of water (gage), at point 2;
G=specific gravity of the gas (air=1.0);
L=length of pipe, yards, between points 1 and 2;
C=a constant, given as 1,000 by Molesworth and as 1,350 by Pole. For reasonably smooth pipe and under usual conditions, the American Gas Journal has recommended values of C varying with pipe diameter as follows:

Nominal pipe Diameter	C
¾″ and 1″	1,000
1¼″ and 1½″	1,100
2″	1,200
3″	1,300
4″ and larger	1,350

When the gas pressure is 1½ pounds per square inch gage or higher, the effects of changes in volume of gas because of changes in pressure become appreciable and the flow formulas are more complicated than for low-pressure systems. The general equation for the flow of gas through pipe lines under pressure of 1½ pounds per square inch gage or higher is—

$$(2)\quad Q=\frac{K\,T_0\,(P_1^2-P_2^2)^{1/2}\,D^{5/2}}{P_0\,(G\,T\,L\,F)^{1/2}}$$

Where—

Q=volume, cubic feet of gas per hour at pressure and temperature bases of P_0 and T_0;
T_0=temperature basis defining a cubic foot of gas, degrees F. absolute;
P_0=pressure basis defining a cubic foot of gas, pounds per square inch absolute;
K=constant, 1.6156;
P_1=pressure, pounds per square inch absolute, at point 1;
P_2=pressure, pounds per square inch absolute, at point 2;
D=internal diameter of pipe, inches, actual;
G=specific gravity of the gas (air=1.0);
T=temperature of the flowing gas, degrees F. absolute;
L=length of pipe, miles, between points 1 and 2;
F=coefficient of friction.

There are a number of empirical formulas employing the above-stated general equation, among which are the Weymouth, Pittsburgh, Cox, California, Towl, Oliphant, and others. All of these formulas are basically the same, the differences being in the value of the friction coefficient. In some of the formulas the friction coefficient is constant and in others it varies as a function of the pipe diameter. Tests on flow of natural gas through high pressure transmission lines were conducted jointly by the Bureau of Mines, the State of Oklahoma, and the American Gas Association. A report on these tests, including a comparison of metered flows with values that would be derived by use of the various formulas and including a theoretical development of the general equation, was prepared by Mr. T. W. Johnson and Mr. W. B. Berwald, of the Bureau of Mines, and is published under the title, "Flow of Natural Gas Through High-Pressure Transmission Lines," by the American Gas Association, 420 Lexington Avenue, New York. The tests indicated that the Weymouth formula is generally the most accurate for computing flows in 6-inch pipe and larger. For 4-inch pipe, or smaller, the Pittsburgh formula and the Cox formula appear to be the most applicable. The Weymouth and Pittsburgh formulas, as applicable to the size of pipe, are recommended for use in the design of gas distribution systems for Army projects.

By substituting certain empirically derived values for the friction coefficient in the general equation and by changing L from miles to hundreds of feet the Weymouth formula and the Pittsburgh formula are obtained in their general forms as follows:

(3) Weymouth formula $$Q=\frac{131.24\ T_0\ (P_1^2-P_2^2)^{1/2}\ D^{8/3}}{P_0\ (GTL)^{1/2}}$$

(4) Pittsburgh formula $$Q=\frac{172.34\ T_0\ (P_1^2-P_2^2)^{1/2}\ D^{5/2}}{P_0\ (GTL)^{1/2}}$$

By further substitution of 519.6° absolute (60° F.) for both T_0 and T, 14.7 p. s. i. absolute for P_0, and 0.6 for G and by introducing another factor, M, for purposes hereafter explained, the two formulas, under these assumed conditions, reduce to simplified forms as follows:

(5) Weymouth formula $$Q=\frac{262.7\ M\ (P_1^2-P_2^2)^{1/2}\ D^{8/3}}{L^{1/2}}$$

(6) Pittsburgh formula $$Q=\frac{345\ M\ (P_1^2-P_2^2)^{1/2}\ D^{5/2}}{L^{1/2}}$$

The factor M has been introduced into equations (5) and (6) as a multiplier for use in the event that any of the actual conditions or conditions under which the connected appliance loads were computed differ from the assumed conditions stated. The numerical value of M would remain constant throughout the design of a particular distribution system and obviously would be unity

if the actual conditions are the same as the conditions assumed for the equations. The determination of M is explained in appendix A.

b. Graphic solution. The solution of gas flow problems by the formulas is somewhat complicated because of the fractional powers involved and the use of logarithms or a log-log slide rule is necessary when solving by the formulas. By the use of properly prepared charts, however, the solutions can be simplified greatly and performed with an accuracy comparable to that obtained with a log-log slide rule and with less chance of large error because of misplacement of decimal points. The accompanying charts, figure 1, "Pipe Flow Chart for Low Pressure Gas Systems," and figure 2, "Pipe Flow Chart for Medium and High Pressure Gas Systems," may be used for this purpose. Figure 1 is for use only when the pressure is less than 1½ pounds per square inch gage and is based on the low-pressure formula, equation (1), with the specific gravity assumed to be 0.6. If the actual specific gravity is different from 0.6, the specific gravity lines should be used in conformity with directions given on the chart. Figure 2 is for use when the pressure is 1½ pounds per square inch gage or higher and is based on the Weymouth formula, equation (5), for 6-inch pipe and larger and on the Pittsburgh formula, equation (6), for pipe smaller than 6-inch. If conditions are different from the assumed conditions on which equations (5) and (6) were based, that is, if M is not unity, the correction multiplier lines should be used according to directions given on the chart. Figure 1 gives the differences in pressure in inches of water gage and figure 2 gives the differences in the squares of the absolute pressures, corresponding to various quantities of gas flowing through 100 feet of pipe of various sizes. The charts are for quantities of gas and pressure drops that would usually obtain in Army camps. If the values of Q or of P_1-P_2 or $P_1^2-P_2^2$ per 100 feet of pipe are beyond the chart limits, they may be brought within the limits by a shift of decimal points, bearing in mind that shifting the decimal point one place in the value of Q will, for correct answer, require shifting the decimal point two places in the opposite direction in the value of P_1-P_2 as given by figure 1, or in the value of $P_1^2-P_2^2$ as given by figure 2.

c. Equivalent quantities. One of the premises in the derivation of the above-quoted formulas was that there would be no change in the quantity of gas flowing between points 1 and 2. Strict compliance with this premise would require the computation of pressure drop in each section of pipe between points of draw-off in the system. The work entailed in such procedure would be enormous in most cases. When the draw-offs between two points under consideration are equal in quantity and equally spaced, an equivalent quantity of gas can be determined, which would produce the same pressure drop between the two points as would be produced by the actual flowing quantities with the draw-offs taken into consideration. The equivalent quantity, Q_e, is equal to Q_u plus FQ_c, where Q_u is that portion of gas entering the section that is not drawn off between the two points under consideration but flows beyond point 2, Q_c is the sum of the quantities drawn off between points 1 and 2, and F is a factor taken from table I. The table gives F for various numbers of draw-offs, N, and various ratios of Q_u to Q_c. In preparing this table, it was assumed that the draw-offs would be equidistantly spaced and would be of equal quantities. These conditions seldom actually exist; however, slight variations from these conditions will not affect the results appreciably, and the table can be used with sufficient accuracy for all practical purposes. The tabulations in table I are given to the nearest two decimal places. From inspection of the table, it will be observed that as the values of N and Q_u/Q_c increase, the decrease in the values of F is very slight. Therefore, N may be considered as 10, where it actually exceeds 10 and Q_u/Q_c may be considered to be 4 where its actual value exceeds 4, without introducing appreciable error.

TABLE I.—*F, for various values of Q_u/Q_c and N*

N	Q_u/Q_c				
	0	1	2	3	4
1	1.00	1.00	1.00	1.00	1.00
2	.79	.77	.76	.76	.76
3	.72	.69	.68	.68	.67
4	.68	.65	.64	.64	.63
5	.66	.62	.61	.61	.61
6	.65	.61	.60	.59	.59
7	.64	.60	.59	.58	.58
8	.63	.59	.58	.57	.57
9	.63	.58	.57	.57	.56
10	.62	.58	.57	.56	.56

d. Illustrative design. In designing a gas-distribution system, a line diagram of the entire system, drawn to scale and showing all the connected appliance loads, should be prepared. The sizes of pipe should be assumed and the pressure drops computed. Such changes in sizes as appear necessary to assure adequacy and economy of design should then be made. Figure 3, a line diagram showing pipe sizes and connected loads, is used to illustrate design procedure. It will be noted in this case that the portion of the system under consideration forms a loop between point B and point E. The quantity of gas entering the loop at point B is divided, a portion flowing into line BC and a portion flowing into line BC'. The portions flowing into these lines are assumed and sizes of the various lines are assumed. The pressure drop for each line in the loop is computed and corrections are made in the assumptions until the total of the pressure drops going clockwise around the loop to point E equals the total of the pressure drops going counterclockwise, with a reasonable pressure remaining. In the illustration, the flows have been balanced. All pertinent data have been tabulated in table II, computation table, which is self-explanatory from the various column headings. The quantity entering the 6-inch line AB is 151,000 cfh. None of the gas is consumed between points A and B and therefore the equivalent flowing quantity is 151,000 cfh. Referring to the chart, figure 2, the value of $P_1^2—P_2^2$ per 100 feet of pipe is obtained as 23.00. Multiplying this value by the length of line in hundreds of feet gives 115.0 for the total value of the difference in squares of the absolute pressures at points A and B. The quantity entering line BC is 69,000 cfh, 14,000 cfh (Q_c) being drawn off between B and C and 55,000 cfh (Q_u) flowing beyond point C. The ratio of Q_u to Q_c is approximately 4. The number of draw-off points along line BC is 4. Referring to table I, the value of F is found to be 0.63 for this number of draw-off points and this ratio of Q_u to Q_c. Multiplying 14,000 by the value 0.63 gives 8,800, which, added to 55,000, gives 63,800 as the equivalent flowing quantity (Q_e) in line BC. For more precise design, the pressure drop should be computed at the fourth draw-off point in line BC and again at C. In this case, however, as Q_u and Q_e do not differ greatly and as the distance from the fourth draw-off point to C is not great, the final results would not be appreciably different and the error is on the safe side. The equivalent quantities in all lines in the loop are similarly determined. Also the values of the differences in the squares of the absolute pressures per 100 feet and for the total length of line are found as before. The sum of the differences between the squares of the absolute pressures is found to be 573.8 going clockwise around the loop and 575.1 going counterclockwise, indicating a proper balance. The absolute pressure at point A is 34.70 pounds per square inch, the square of which is 1,204.09. Extracting the square root of the difference between 1,204.09 and 115.0 gives 33.0 as the absolute pressure at point B. The absolute pressures at all points are similarly determined. By deducting from the absolute pressures the value of normal atmospheric pressure, 14.7 pounds per

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square inch absolute in this case, the gage pressures are obtained and entered on the line diagram as indicated.

TABLE II.—*Computations for illustrative design*

1	2	3	4	5	6	7	8	9	10	11
Line	Length (100 feet)	Nominal size (inches)	Quantity entering line	Quantity consumed (Q_c)	Quantity forward (Q_f)	Equivalent flowing quantity (Q_e)	$P_1^2-P_2^2$ per 100 feet	$P_1^2-P_2^2$ for the length of line (2) x (8)	P_1 (p. s. i. *Abs.*)	P_2 (p. s. i. *Abs.*)
AB	5. 0	6	151, 000	00	151, 000	151, 000	23. 00	115. 0	34. 70	33. 00
BC	11. 3	4	69, 000	14, 000	55, 000	63, 800	32. 20	363. 9	33. 00	26. 93
CD	10. 1	4	46, 000	7, 000	39, 000	43, 060	15. 00	151. 5	26. 93	23. 94
DE	14. 6	4	27, 000	11, 000	16, 000	22, 380	4. 00	58. 4	23. 94	22. 70
								573. 8		
BC'	24. 7	4	71, 000	42, 000	29, 000	53, 800	22. 80	563. 2	33. 00	22. 94
C'E	11. 3	4	15, 000	9, 000	6, 000	11, 400	1. 05	11. 9	22. 94	22. 67
								575. 1		

1–08 ANALYSIS OF EXISTING SYSTEMS. Before making any major additions or extensions to an existing gas distribution system, and analysis should be made to determine the residual pressures under conditions of consumption equivalent to the full existing and proposed connected appliance loads. The principles outlined under "DESIGN" should be followed in making the analysis. Figure 4, Analysis of Existing Gas Distribution System, is a reproduction, with minor modifications, of an analysis made in one of the district engineer offices for determining the changes required in an existing system in converting from temporary to permanent type of construction. The analysis indicated that additional pressure would be required to supply the ultimate demand. This could be supplied in three ways. The most desirable of these possibilities would be to move the regulator from point *A* to point *B* and distribute the gas from that point at an initial pressure of 15 pounds per square inch. The second possibility would be to boost the pressure at point *A* to 25 pounds per square inch. These two possibilities obviously would depend upon the pressure available in the gas company's line. The third possibility, and the one upon which the pressures indicated in figure 4 were computed, would be to install an auxiliary 6-inch line between points *A* and *B*.

1–09 PLANS AND DESIGN DATA. The plans and design data should be prepared and forwarded to the Office of the Chief of Engineers in conformity with applicable requirements of Orders and Regulations.

a. Plans. The plans should include a lay-out drawing showing the entire distribution system and detail drawings of such scale as may be necessary to show clearly the location of gas mains, service connections, valves, regulators, and other fittings.

b. Design analysis. The design analysis should be in diagram form drawn to scale and showing all connected loads, flowing quantities, pressures, and the location of regulators. Notes should be included on the diagram to indicate the specific gravity of the gas, the calorific value of the gas in B. t. u. per cubic foot, the base pressure and base temperature at which a cubic foot of gas is defined, the flowing temperature, the normal atmospheric pressure and such other information as may be pertinent.

APPENDIX A

FACTOR M IN EQUATIONS 5 AND 6

The factor M in equations (5) and (6) of the text is made up of one or more multipliers as applicable for the correction of the formula to suit conditions differing from those on which the formulas were based and may be expressed in the form of the equation: $M=m_1\times m_2\times m_3\times m_4$. The values of the various multipliers, m_1, m_2, m_3, and m_4, can be taken from or determined as indicated in tables III to VI.

TABLE III.—*Pressure-base multipliers*

$$m_1=\frac{14.7}{\text{new } P_0}$$

New P_0	Multiplier m_1	New P_0	Multiplier m_1
12. 0	1. 225	14. 0	1. 050
12. 5	1. 176	14. 4	1. 021
13. 0	1. 131	14. 6	1. 007
13. 5	1. 089	14. 7	1. 000

TABLE IV.—*Temperature-base multipliers*

$$m_2=\frac{459.6+\text{new base temp. (°F.)}}{519.6}$$

New base temperature °F.	Multiplier m_2	New base temperature °F.	Multiplier m_2	New base temperature °F.	Multiplier m_2
45	0. 971	65	1. 010	85	1. 048
50	. 981	70	1. 019	90	1. 058
55	. 991	75	1. 029	95	1. 067
60	1. 000	80	1. 039	100	1. 077

TABLE V.—*Specific gravity multipliers*

$$m_3=\left(\frac{0\ 6}{\text{actual } G}\right)^{1/2}$$

Specific gravity	0.00	0.02	0.04	0.06	0.08
0. 5	1. 095	1. 074	1. 054	1. 035	1. 017
. 6	1. 000	. 984	. 968	. 954	. 939
. 7	. 926	. 913	. 901	. 889	. 877
. 8	. 866	. 855	. 845	. 835	. 826
. 9	. 817	. 808	. 799	. 791	. 783
1. 0	. 775	. 767	. 760	. 752	. 745

TABLE VI.—*Flowing temperature multipliers*

$$m_4=\left(\frac{519.6}{459.6+\text{new flowing temp. °F.}}\right)^{1/2}$$

New flowing temperature °F.	Multiplier m_4	New flowing temperature °F.	Multiplier m_4	New flowing temperature °F.	Multiplier m_4
20	1. 041	50	1. 010	80	0. 981
30	1. 030	60	1. 000	90	. 972
40	1. 020	70	. 991	100	. 962

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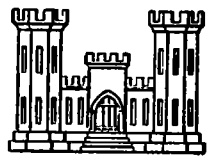
FUEL DISTRIBUTION AND STORAGE

ENGINE FUEL AND ENGINE OIL SUPPLY



WAR DEPARTMENT
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

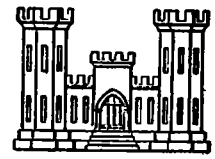
U S Army

AD INTERIM ENGINEERING MANUAL
FOR WAR DEPARTMENT CONSTRUCTION

PART IX
CHAP. 2
JULY 1947

FUEL DISTRIBUTION AND STORAGE

ENGINE FUEL AND ENGINE OIL SUPPLY



WAR DEPARTMENT
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

Chapter 2

ENGINE FUEL AND ENGINE OIL SUPPLY

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2–11 CRITERIA FOR DESIGN
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b. Fill couplings
c. Fill lines
d. Storage tanks
e. Tank vents
f. Tank clean-out and gaging
g. Suction lines
h. Pumps
i. Delivery lines
j. Station house
k. Electrical controls

Part IX

FUEL DISTRIBUTION AND STORAGE

Chapter 2

ENGINE FUEL AND ENGINE OIL SUPPLY

GENERAL CONSIDERATIONS

2–01 SCOPE. The information and instructions contained in this chapter cover the major requirements in the design of vehicular and aircraft engine fuel and engine oil storage and dispensing systems for all services. Plans for engine fuel and engine oil storage and dispensing systems should be developed concurrently with those for roads, railways, runways, aprons, and other facilities which they serve. The instructions are for general guidance and standardization to provide a uniform design policy so far as practicable. Deviation from the standards may be necessary in certain special cases; however, such deviations should be presented to the Office, Chief of Engineers, for approval. Established and accepted engineering practice will be followed in the absence of specific instructions for special conditions, problems, and details.

2–02 CHARACTERISTICS AFFECTING THE STORAGE AND HANDLING OF ENGINE FUELS AND ENGINE OILS. The design of an engine fuel dispensing system differs from ordinary hydraulic design due to the characteristics of the fluid. With regard to the principal fuels, the characteristics which are important in this connection are as follows:

a. Gasoline. Gasoline must be tightly confined (low pressure storage) or kept at a relatively low constant temperature (underground storage at atmospheric pressure) to minimize loss by evaporation. The Reid vapor pressure of gasoline is a measure of its volatility. This pressure is expressed in pounds per square inch and measures the approximate absolute vapor pressure at 100° Fahrenheit. The Reid vapor pressure bears no direct relation to octane rating. The vapor pressure of automotive gasoline is generally higher than that of aviation gasoline, making the former slightly less stable and somewhat harder to handle.

The inflammability of gasoline requires that every precaution be taken to prevent leakage or spillage, accumulation of vapors in pits or inclosed rooms, and to keep sparks of any kind, whether open fires, sparks from electric wires or fixtures, or static discharges from the area where gasoline vapors may be present. Vapors from storage tanks should be vented sufficiently high and dispersed to the atmosphere where there is no opportunity for ignition.

The fact that gasoline is a good solvent of greases affects the design of lubricants for, and the lubrication of, pump shafts and valves. Natural rubber and several synthetic rubbers cannot be used in hoses and seals for gasoline, as these materials rapidly lose desirable properties in the presence of gasoline. Certain inhibitors used in gasoline are affected by alkaline materials. The low viscosity of gasoline requires that special attention be given to the details of pump shaft seals and to the tightness of joints generally. Viscosity affects the head loss in pipe lines which is less than that of water. (See table 1 hereafter.)

Gasoline expands and contracts markedly. Under ordinary temperature ranges an allowance of about 3 percent should be made for expansion in containers. Pipe and hoses full of gasoline will burst from expansion unless provision for relief of the pressure is made. The pressures in a dis-

pensing stand mount very rapidly on a hot day unless relieved. *Gasoline vapor is heavier than air.* It will therefore flow into pits and low areas of floors, and accumulate in such places where it forms an explosive hazard. Gasoline vapors are dangerous to breathe if inhaled for more than a short time. The vapors cause dizziness, nausea, and headache and large amounts act as an anesthetic.

The specific gravity, viscosity, and, particularly, the Reid vapor pressure are the principal qualities which affect the pumping of gasoline. The octane rating has no bearing on "pumpability." The Reid vapor pressure is important in affecting the possible suction lift, which decreases with the increasing vapor pressure, thus resulting in the tendency to vapor lock the pump. Pumping of gasoline is not noticeably affected by changes of viscosity within ordinary temperature ranges.

b. Jet type fuel. Differences between aviation gasoline and jet type fuel as to volatility, inflammability, viscosity, expansion, and vapor weight are not sufficient to require a change in the facilities used in the storage and distribution of aviation gasoline when their use for jet type fuel is contemplated. *Fuel approved for use in jet type propelled aircraft is a special fuel and must not be confused with kerosene.* Valve and shaft packing, lubricants, and pipe compounds will not be more adversely affected by jet type fuel than by aviation gasoline. The affinity of existing jet type fuel for water and its tendency to emulsify is not greater than gasoline. The penetrating effect of jet type fuel tends to loosen scale and other deposits in pipe lines and tanks.

Those parts of existing systems to be used for jet type fuel storage should be completely isolated from other fuel storage. Valves should not be relied upon for separation of pipe lines. *Isolation should be accomplished by the use of blind flanges or by removal of pipe sections.*

c. Diesel oil. Diesel oil at normal temperatures is stable and the amount of evaporation at normal temperatures is negligible. The inflammability of diesel oil requires that precautions should be taken to prevent leakage, spillage, and the creation of fire hazards. The same precautions should be taken to relieve expansion pressures as are taken for gasoline. The action of diesel oil on lubricants, rubber, and pump seals is not as rapid as that of gasoline, but the action exists, and materials capable of resisting this action should be used on all parts of the system in contact with the diesel oil. The viscosity of the diesel oil normally used in high-speed automotive type engines is slightly higher than water at summer temperatures.

d. Lubricating oils. Lubricating oils are stable and loss by evaporation is inconsequential. Lubricating oils are difficult to ignite. Most lubricating oils become very viscous in cold climates. It may be necessary to install heating coils in the storage tanks located in latitudes above 31° N. in order to render the oils pumpable. Lubricating oil lends itself favorably to pumping by gear or double helix positive displacement pumps. Lube oils should be stored at constant temperature in underground tanks.

2–03 SELECTION OF MATERIALS AND EQUIPMENT. Because of the inherent qualities of gasoline, jet type fuel, diesel oil, and lubricating oil, all of the materials and equipment comprising the dispensing systems should be especially designed for particular use with these fuels. Selection of suitable pumps, valves, gaskets, hose, fittings, explosion-proof electrical equipment, etc., is deemed essential in order to insure safe and efficient operation of the systems.

2–04 FIRE PROTECTION AND SAFETY REQUIREMENTS. Systems designed in accordance with details of this chapter should meet all current instructions of the Office, Chief of Engineers, pertaining to safety. The following manuals and publications should be helpful in designing the systems: "Containers for Flammable Liquids," "National Electric Code," and "Suggested Fire Prevention Ordinance," published by the National Board of Fire Underwriters; "The Accident

Prevention and Fire Protection Manuals," published by the American Petroleum Institute; and "Safety Requirements," published by the Office, Chief of Engineers.

a. Electrical equipment. All electrical equipment in storage and dispensing areas where hazardous accumulations of inflammable vapors may exist under normal operating conditions should be suitable for use in class I, division 1, group D locations as defined in the National Electrical Code. The entire system should be designed with the object of preventing hazards arising from any possible source of ignition. The system should be thoroughly grounded in accordance with the requirements set forth in Article 250, National Electrical Code. Where a railroad spur is required, the section of the track assigned to the tank cars should be insulated from the main line in order to ground the spur without interfering with the railroad signal system and to protect the unloading track from stray electric currents.

b. Heating. Space heating by open flame heaters or open electrical elements should not be permitted in any type of building utilized in connection with the storage and dispensing of liquid fuels and lubricants.

c. Fire protection equipment. Normally, fire protection for storage and dispensing facilities consists of a sufficient number of fire hydrants located in the vicinity of these facilities and an ample supply of water at adequate pressure. Any special fire extinguishing equipment deemed necessary should be available as portable apparatus.

2–05 SEPARATION OF DIFFERENT GRADES OF FUEL. Separate storage and dispensing facilities should be provided for each grade of fuel handled. *Interconnections between any grade or type of system either on the filling or dispensing side should not be permitted.* Contamination by mixing different grades of fuel may result in irreparable damage to aircraft engines or other high compression engines. Storage systems should be operated on the basis of zero contamination.

AIRCRAFT ENGINE FUEL AND ENGINE OIL SYSTEMS

2–06 TYPES OF DISPENSING SYSTEMS. The Army Air Forces have used two types of storage and dispensing systems for aviation engine fuel; that is, the hydraulic displacement type and the mechanical (pumping) type. Unless the construction directive specifically states the type of systems to be installed, the choice should depend on the availability of the supply of power, either water or electricity, and the comparative costs of the two types of systems, together with due consideration being given to the limits of pump suction lift at locations 2,000 feet or more above mean sea level. All grades of engine fuel and engine oil stored in tanks should be buried underground. Exceptions to this policy shall be specifically authorized by the Office, Chief of Engineers.

a. Hydraulic displacement system. The design and operation of a hydraulic displacement fueling system is based in the difference between the specific gravities of gasoline and water and the immiscibility of the liquids. Gasoline (or jet type fuel) being the lighter of the two fluids floats on the top of the water and is practically immiscible with water. Hence, water under pressure introduced into the bottom of a storage tank filled with gasoline (or jet type fuel) will float either fuel out of the tank through a delivery line connected to the top of the tank. Conversely, when the water pressure on the tank is relieved, gasoline added to the tank through the fill line will force water out of the tank into a drain.

The top of each storage tank should be at a depth of 5 feet below grade to provide a static head of gasoline on the fill line of sufficient height to force water out of the top of the tank during filling operations. The water connection to the tank should extend to within 6 inches of the tank bottom in order to introduce the water at the bottom and thus minimize any turbulence which might result in the temporary mixing of gasoline and water. The flow of water to the tank should be controlled by a remote control 3-port, 2-way valve. When in the fueling position, this valve should allow

water under pressure (normally 35 p. s. i.) from the field water supply system to enter the tank through the water connection, thus forcing gasoline out of the tank through the delivery line to the fuel dispensing outlets. In the non-fueling position the remote control valve should allow water forced out of the tank (by the filling operation, by expansion of the tank contents due to temperature changes, or to relieve the static pressure when no gasoline is being withdrawn) to be spilled from one port of the valve into the drain leading away from the water control pit by an individual sewer, a storm sewer, or an open ditch. *The drain line should never be connected to a sanitary sewer.* Where two or more tanks are connected to one remote control valve, a manually operated 3-port, 2-way water control valve, and a gate valve should be installed in the branch line to each tank in order to control the supply of water to the tank or tanks actually being used. The manually operated 3-port valves should allow any tank or tanks to be filled while gasoline is being dispensed from any other tank or tanks. The remote control valve should be controlled by an operating and emergency switch from each dispensing outlet.

The high and low limits of the gasoline level in any tank should be controlled by float-operated shut-off valves, one located at the fill connection to the tank and the other at the delivery connection. The floats operating the valves should be designed to float in water and sink in gasoline. The float operating the valve in the fill connection should sink and close the valve when the gasoline displaces the water in the tank to a predetermined level, which is normally 9 inches above the tank bottom. The float controlling the valve in the delivery line should rise and shut off the supply of gasoline to the delivery line when the water has displaced the gasoline in the tank to a predetermined level, which is normally 9 inches below the top of the tank. In the event that the float on either of the shut-off valves fails, the valves should stay closed until the defective float is repaired. The delivery float valve must be reset manually before operations can continue. An additional safeguard to prevent water from being delivered to the dispensing outlets in the event that the delivery float valve fails should be provided in the form of a gasoline-water separator. The system must be so arranged as to eliminate the possibility of gasoline being siphoned out of the storage tanks into the water system.

b. Mechanical (pumping) system. Water is not introduced into the storage tanks of a mechanical system as is done in the hydraulic displacement system. Storage tanks need not be buried as deep as those for the hydraulic displacement system, unless the terrain warrants such a condition to fill the tanks by gravity, since it is unnecessary to provide a static head to force water out of the tanks.

The fill line should enter the top of the tank and extend to within 6 inches from the tank bottom and terminate with an anti-splash deflector, thus minimizing any turbulence which might result in the temporary mixing of the bottom sediment and water. The suction line should be located at opposite end of the tank from the fill line. The suction line should extend to within 6 inches of the tank bottom. A baffle plate should be set under the end of the suction pipe to prevent water or sediment that is below its level from being "sucked" up by the pump. Foot valves should not be installed in the end of the suction pipe as they are difficult to reach in case they need repairs.

Either a deep well turbine or a self-priming centrifugal pump should be installed at grade as the unit for delivering gasoline to the dispensing outlets. Setting the pumps in deep pits should be avoided if possible. However, if pumps are unavoidably located in pits, in order not to extend the suction lift of the centrifugal pumps over 12 feet vertically, the pits should be well ventilated to remove hazardous vapors that may accumulate. If a deep-well type pump is installed, the pump suction may be bell-mouth in shape and installed about 6 inches above the tank bottom and over the baffle plate. The deep well pump should be provided with a separate return line into the tank which will allow about 2 percent of the pump capacity to be circulated, and thus prevent

the pump and pump bearings from overheating, should the pump be allowed to run when the discharge is closed. If a self-priming pump is installed, a check valve should be installed as close to the tank connection of the suction line as possible, in order to hold the pump prime. The horizontal run of the suction line between the tank connection and the pump should not exceed 50 feet and should be sloped up toward the pump.

Water invariably collects in storage tanks, either by condensation of moisture in the air within the tanks due to temperature changes or as introduced from tank cars or tank trucks during filling operations. It is essential that a safeguard in the form of a gasoline-water separator be provided in the delivery line, in order that water, which may be picked up by the pumps, be eliminated before discharging through the dispensing outlets.

2–07 GENERAL CONSIDERATIONS. Lay-outs for separate grades of engine fuels showing the general tank and piping arrangements for the hydraulic displacement and mechanical (pumping) systems are shown on figures 1 and 2, respectively.

a. Engine fuel system. Aircraft engine fuel systems should be located on the airfield where refueling trucks have access to the apron for servicing aircraft. An unrestricted amount of underground storage may be located in one area. Storage and truck fill facilities should be located in the same area, preferably adjacent to a road having minimum vehicular traffic.

The bulk of aviation gasoline required at airfields will be 100-octane rating or of a higher grade. Each grade of gasoline should be stored and dispensed as a separate individual system.

Jet type fuel can be stored in either the mechanical or the hydraulic displacement systems. The specific gravity of jet type fuel is greater than that of regular type aviation fuel. The difference in specific gravity, however, will not appreciably increase the power requirements of the dispensing systems for jet type fuels. Caution must be exercised to insure that the operating valves and floats are properly adjusted when jet type fuel is handled in the hydraulic displacement system. *Aviation gasoline and jet type fuel are different types of fuel, and mixtures of the two fuels are not suitable for either jet or internal combustion engines of aircraft. Therefore they must be kept strictly separate.*

b. Engine oil system. Wherever installation of engine oil underground storage and dispensing systems are authorized, the systems should be located in the same vicinity as the engine fuel systems in order to locate all combustible liquids in one restricted area.

Lubricating oils for aircraft engines will be the grade specified by engine manufacturers. Separate storage and dispensing facilities should be provided for each grade of lubricating oil handled. Where lubricating oil is provided, a storage tank for used oil should be installed adjacent to the oil storage tanks. A drain should be provided in the oil house which will allow used oil to drain by gravity into the storage tank. The installation should permit used oil to be pumped from this storage tank through a pipe line to a fill coupling where it may be dispensed into a tank car or tank truck for removal from the airfield.

Where diesel oil is required in large quantities, the storage tank may be placed underground adjacent to the lubricating oil tanks.

2–08 CRITERIA FOR DESIGN. A general description of the component parts of the engine fuel and engine oil storage systems, utilizing the hydraulic displacement and mechanical types of dispensing systems follows:

a. Distance criteria. A minimum clear distance of 100 feet should be established between all airfield structures, buildings, or facilities, not an intergral part of or appurtenant to aircraft engine fuel and engine oil storage or dispensing system operations, and the nearest group of truck fill stands, underground storage tanks, fueling outlets, or tank car, or tank truck unloading points.

b. Unloading facilities. Where a railroad spur or siding is required, the section of the track

assigned to the unloading of tank cars should not, as a rule, exceed 500 feet in useful length. This length of track should be ample to provide for simultaneous unloading of 10 tank cars. This length may be decreased by about 40 feet for each car less than the 10 cars required. Where delivery by commercial tank truck is contemplated, turn-outs should be provided at the unloading area.

The unloading facilities for the engine oil storage system served by the same railroad spur as the engine fuel storage system should be located at the dead end of the spur since unloading oil will be much slower than unloading gasoline. Thus the oil tank cars will be "spotted" beyond the gasoline area which will not tie up the facilities for gasoline unloading. Where delivery by commercial tank truck is contemplated, turn-outs should be provided at unloading areas.

c. Fill couplings. The number of fill couplings to be provided for a specific installation depends on the amount of storage installed. Separate fill couplings should be provided for each grade of engine fuel or engine oil. Not more than one fill coupling should be provided for each 25,000 gallons of storage. Not more than a total of 10 fill couplings should be installed at one tank car unloading track. Fill couplings should be spaced 40 feet apart at the railroad siding. Where storage tanks are filled from tank trucks, fill couplings should be installed at locations to enable tank trucks to unload simultaneously at suitable turn-out areas.

Standard above ground fill couplings (not swivel head couplings) should be used. Swivel head couplings are conducive to leaving fill hoses attached when not in use. Unloading hose should be detached from the coupling and stored on racks protected from the weather when not in use. The fill couplings for the different grades of fuel should have distinctive markings.

d. Fill lines. Gravity fill lines to underground storage tanks should be laid level with no pockets or on a uniform grade sloping toward the tanks so that they will drain dry. Where two or more tanks are manifolded to one fill line, a valve should be provided on the branch line to each tank in order to control the filling of the tanks.

Coarse-mesh strainers should be installed in a concrete pit in the fill line to prevent foreign materials (sometimes present in tank cars) from entering the tanks. Block valves should be installed on each side of the strainer when the fill lines do not drain dry in order to avoid spilling fuel in the pit when the strainer baskets are removed for cleaning.

e. Storage tanks. Where a hydraulic displacement system is to be installed, standard 25,000-gallon horizontal pressure type tanks or any other pressure type tanks suitable for underground installation should be used, provided that the capacity of any one tank does not exceed 50,000-gallon capacity.

Tanks for mechanical systems are required to withstand only nominal internal pressures. The tanks, therefore, may be of lighter plate, if properly stiffened with struts, than in the case of tanks for the hydraulic displacement systems. Tanks for storing engine fuel in the mechanical systems should be standard 25,000-gallon horizontal flat end tanks. Tanks for storing engine oil should be standard 12,000-gallon horizontal flat end tanks, since the requirements for engine oils are usually small in comparison with engine fuel.

f. Tank vents. Underground tanks of mechanical systems should be equipped with screened atmospheric vents inasmuch as the temperature of the tanks' contents should normally remain fairly constant and vapor losses due to "breathing" should be negligible. A separate vent should be provided for each tank for the reason that manifolding of vents introduces the danger of overflowing one grade of engine fuel or engine oil into a tank containing another grade. The height of the vent openings should be at least 10 feet above the ground, or higher if deemed necessary to prevent the possibility of accidently igniting the vapors from the tank. Vents should be located about 100 feet from foreign sources of ignition and not less than 20 feet from the opening of any pit that personnel can enter. The vent connection to the tank should not extend into the tank more than 1 inch. Tank vents are not required on storage tanks in the hydraulic displacement system.

g. Tank clean-out and gaging. Tank clean-outs should be provided on all storage tanks to allow for the periodic removal of sediment and water which invariably collects on the bottom of the tanks after a period of use. The clean-out pipe for an underground tank should be of sufficient length to reach within a few inches of the tank bottom and should be of ample diameter to allow insertion of a sludge pump suction hose. Tank gaging on hydraulic displacement storage tanks should be made from a separate opening on the top of the tanks. Gaging in the mechanical system may be made through the clean-out opening. Gaging should be confined to the stick method type.

h. Water control pit. The water control pit in the hydraulic displacement system should contain the following equipment in the main water supply line in the pit: a manually operated shut-off valve; a basket type strainer; a shock arrestor to absorb the hydraulic shock incident to the sudden closing of a valve in the line; a pressure regulating valve to reduce the incoming water pressure to approximately 35 pounds per square inch or other normal operating pressure for the system; one or more solenoid-controlled, pilot operated by hydraulic pressure, water control valve or valves (the number of valves depending on the demands of the system); and a header from which branch lines extend to each tank. Each branch line should contain a manually operated, 3-port, 2-way water control valve; a manually operated shut-off valve; and a pressure relief valve to prevent excessive pressures from being transmitted to the tank. A lay-out showing the arrangement of the equipment is shown on figure 3.

i. Suction lines. Suction lines should be laid either level without pockets or on a uniform grade sloping up toward the pumps. A horizontal swing check valve with a composition disc should be installed in the suction line as close to the tank as is practicable in order to hold the pump prime.

The total static suction lift from the bottom of the suction intake to the center line of the pump should not exceed 12 feet vertically in addition to a horizontal run of the suction line from any underground tank to the pump of not more than 50 feet, proper allowance being made for the pump capacity and pipe friction losses in the selection of the size of the suction line. Floating suctions should not be installed in tanks, as it is difficult to observe their performance and condition.

Where two or more tanks are connected to the same pump, a valve is required in the suction line to each tank in order to eliminate the possibility of air entering the suction line from an empty tank when the pump is drawing fuel from an adjacent tank, and thus destroying the pump prime. Each valve should be located so that when closed a minimum length of "dead" line will be under less than atmospheric pressure when pumping from an adjacent tank. Gasoline in the "dead" ends tends to vaporize, thus causing vapor lock and other pumping irregularities. Suction lines should be short and direct as possible and should not contain high points in which vapor may accumulate.

j. Pumps. Pumps for handling gasoline are designed for that specific purpose and therefore may be radically different from water pumps. Consideration must be given to all factors affecting the successful operation of the pumps in selection of the type to be installed for a specific use.

Pumps for dispensing engine fuel from underground tanks should be either the self-priming centrifugal or deep well turbine types. Plain centrifugal pumps should not be used for unloading tank cars (where gravity filling is not possible) due to the possibility of drawing air through the suction line when the level of the gasoline in the tank car approaches the bottom, thus vapor locking the pump. Experience has proven that even though a considerable volume of gasoline may remain in the tank car, the pump will draw air through the vortex formed at the suction connection of the car and will often become vapor locked due to the accumulation of this air in the high point of the pump casing and in the eye of the impeller. Air elimination should be provided at any pump where vapor locking may occur. Wherever possible, pumps should be installed at grade rather than in pits where explosive vapors might collect. Pumps installed at grade

should be top manifolded in the suction and discharge lines, using "square" piping connections, in order to provide maximum piping flexibility. The maximum suction lift for the self-priming centrifugal type pump should not exceed 12 feet. The deep well turbine type pump should be installed over the tank at grade. Where pumps are unavoidably located in pits, due to the design of the installation, positive ventilation of the pits must be provided. Control equipment, for pumps located in pits, should be mounted above grade level, and all such equipment should be explosion-proof carrying the "Underwriters' Label." Pumps should be driven by electric motors of explosion-proof type.

Existing dispensing pumps normally have a range from 150 to 300 gallons per minute, since truck fill stands have a nominal delivery capacity of 150 gallons per minute per outlet. Pump capacities which are multiples of this figure should provide the most economical design. However, this should not be construed as a restriction on the size of pumps, since pumps of greater capacity might prove to be more practical for a specific installation.

Pumps for handling engine oils should be of the positive displacement gear or double helix type and should be able to operate at 125 pounds per square inch. The pumps should be vertically mounted and installed directly in the engine oil tank and driven by a vertical motor similar to the deep well pump installation for engine fuel. This will eliminate the use of the existing basement type pumphouse.

k. Delivery lines. Delivery lines from pumps to dispensing outlets should be laid either level or on a uniform grade sloping down from the pump. Where it is necessary to lay pipe lines under paving, the top of the pipe should be a minimum of 2 feet below the bottom of the paving slab. Sleeves of concrete or vitrified clay pipe two sizes larger than the pipe they protect should be installed around all pipe lines under pavement to provide for withdrawal of the pipe for repairs.

A check valve (unless the pump is equipped with a built-in check valve) and a manually operated shut-off valve should be installed in the discharge line from each pump to prevent back flow when the pump is under repair or inspection, and to avoid starting the pump under load.

A pressure relief and necessary pipe should be installed around each dispensing pump to provide for line volume expansion. The pipe should connect the discharge line from the pump, beyond the downstream side of the check valve and shut-off valve, to a tank.

l. Gasoline-water separators. Gasoline-water separators should be installed in the delivery lines of the hydraulic displacement and mechanical engine fuel systems. Gasoline-water separators should be installed for the purpose of preventing water from being delivered through the dispensing outlets. Normally, the rated capacity of the gasoline-water separators should be 300 gallons per minute. The separators should not be operated beyond their rated capacity. The number of gasoline-water separators required is proportional to the rated capacity of the pumps or the fueling outlets, whichever is greater.

m. Dispensing outlets. Dispensing of engine fuel should be through truck fill stands or fueling outlets in the vicinity of the apron. Separate outlets should be provided for each type and grade of engine fuel. Fueling outlets should be installed only where specifically authorized.

In general, the number of truck fill stands required for any grade of engine fuel should be based on the following criteria: one truck fill stand for storage up to 50,000 gallons; two truck fill stands for storage from 50,000 to 100,000 gallons; three truck fill stands for storage from 100,000 to 150,000 gallons; and four truck fill stands for storage over 150,000 gallons.

Where the total authorized storage is divided into two or more groups, the truck fill stands should be prorated in order to provide dispensing outlets for each group. Double outlet truck fill stands composed of two single outlet truck fill stands should be accessible from both sides in order to allow simultaneous loading of the tank trucks.

Dispensing of engine oil should be through truck fill outlets, normally provided on the outside wall of the engine oil utility house. One dispensing outlet is sufficient for each grade of engine oil storage since the requirements should be small in comparison with engine fuel.

n. Pump house. Pumps dispensing engine fuel should be located at or near grade and protected from the weather by an open-sided shelter. However, when it is deemed necessary to protect the pumps from adverse weather conditions, they may be placed in a pump house. The pump house should be well ventilated to expel the gasoline vapors. Where pumps are set in the open, an attendant's shelter may be provided for keeping records, storing tools, etc.

A utility house should be provided at the engine oil storage for keeping records, tools, etc. A drained oil sump should be provided on the floor level and should drain dry by gravity to the drained oil tank.

o. Electrical control system. The electrical controls for all types of dispensing systems should be explosion-proof type as defined by the National Electrical Code, class I, division I, group D, Hazardous locations.

In the mechanical system where dispensing is through truck fill stands only, the pump motor should be energized by a magnetic switch located near the pump. A start-stop push button switch controlling the operation of the pump should be located at each truck fill stand. An emergency shut-off switch should be located at each truck fill stand to shut down the entire system. A suggested electrical lay-out for dispensing engine fuel through truck fill stands by the mechanical system is shown on figure 4.

Where a battery of pumps dispenses to truck fill stands and fueling outlets at the apron area, pumping should be remotely controlled by start-stop push button switches. A pressure actuated switch located beyond the pressure regulating valve, controls the operation of additional pumps automatically to maintain the pressure in the gasoline header within a predetermined range. Emergency shut-off switches should also be installed at each fueling outlet. A suggested electrical lay-out for dispensing engine fuel through truck fill stands and fueling outlets by the mechanical system is shown on figure 5.

In the hydraulic displacement system start-stop switches will be located at each fueling outlet and truck fill stand. The start-stop switch, by remote control, actuates the solenoid-operated, pilot-controlled, 3-port diaphragm valve which permits the pressure of the water supply to be applied to the tank, thus forcing the fuel through the delivery lines to the fueling points. Emergency shut-off switches should be provided at all dispensing outlets as in the case of the mechanical system. A suggested electrical lay-out for dispensing engine fuel by the hydraulic displacement system is shown on figures 6 and 7.

VEHICULAR ENGINE FUEL SYSTEM

2–09 TYPE OF DISPENSING SYSTEM. In general, the vehicular engine fuel system is similar to a mechanical system for aircraft engine fuel but has smaller pumps and uses different dispensing facilities. Storage and dispensing facilities for handling vehicular engine fuel should be confined to the service station type of system. A standard service station pump unit combining the dispensing, metering, and pumping facilities should be provided in a single unit.

Where it is necessary to install intermediate storage and dispensing facilities at the railroad siding, the installation should conform to the requirements for an aircraft engine fuel mechanical system. The installation of gasoline-water separators is unnecessary in a vehicular engine fuel system.

2–10 GENERAL CONSIDERATIONS. *a. Motor pool system.* Various organizations within an installation should have their own central motor pool area. Where more than one grade of

engine fuel is required, separate storage and dispensing facilities should be provided for each grade of engine fuel handled. One noncomputing commercial type dispensing pump should be provided for each 50 fuel-consuming vehicles assigned in each motor pool area. The total amount of storage in each motor pool area should be approximately twice the capacity of all the fuel tanks of the vehicles assigned to each area.

Generally, two tanks of 5,000-gallon capacity each are sufficient for storing regular gasoline in a motor pool area. However, if the requirements are greater, a 12,000-gallon tank together with a 5,000-gallon tank may be used. The number of tanks installed should be kept at a minimum.

The method of commercial delivery of gasoline to the installation must be determined in advance in order to provide adequate unloading facilities. If gasoline is to be delivered by tank car, intermediate storage may be provided dependent upon local conditions. If intermediate storage is necessary, not less than one 12,000-gallon tank should be provided in order that the contents of a tank car, which are approximately 10,000 gallons, may be unloaded. Truck fill stands should be provided at the intermediate storage for loading tank trucks which in turn should unload into storage tanks in the motor pool areas. If delivery by commercial tank trucks is contemplated, unloading of gasoline should be made directly into storage tanks in the motor pool area.

b. Commissary service station. A commissary service station should be provided for each 500 fuel-consuming vehicles in an installation. Two computing commercial type dispensing pumps should be provided for each of the regular and premium grades of gasoline. Each grade of gasoline should be stored in 5,000-gallon tanks.

2–11 CRITERIA FOR DESIGN. A general description of the component parts of the vehicular engine fuel storage and dispensing system follows:

a. Unloading facilities. Unloading facilities should be similar to those described in paragraph 2–08*b*.

b. Fill couplings. Fill couplings for intermediate storage located at the railroad siding should be installed as described in paragraph 2–08*c*. Flush type fill boxes may be installed in lieu of aboveground fill couplings at the tank truck unloading area for motor pool and commissary service stations.

c. Fill lines. Fill lines should be installed as described in paragraph 2–08*d*.

d. Storage tanks. Tanks for storing vehicular engine fuel are required to withstand only nominal internal pressures. Normally, the tanks should be 5,000-gallon capacity horizontal flat-end tanks. Storage tanks of 12,000-gallon capacity may be used where requirements demand larger storage.

e. Tank vents. Tank vents should be installed as described in paragraph 2–08*g*.

f. Tank clean-out and gaging. Tank clean-out and gaging for underground storage tanks should meet the requirements as described in paragraph 2–08*h*.

g. Suction lines. Suction lines should be installed as described in paragraph 2–08*i*.

h. Pumps. Where intermediate storage is provided, pumps should be installed as described in paragraph 2–08*j*. Pumps for dispensing gasoline at motor pool areas and at commissary service stations should be a commercial type dispensing unit. The pump should have a capacity of approximately 12 gallons per minute and be equipped with an explosion-proof motor.

i. Delivery lines. Where intermediate storage is provided, delivery lines should be installed as described in paragraph 2–08*k*.

j. Station house. Where necessary a station house may be installed in the motor pool area as an attendant's shelter house and for keeping records, storing tools, etc.

k. Electrical controls. The electrical controls should be explosion-proof type as defined by the National Electrical Code, class I, division 1, group D, Hazardous Locations.

Where intermediate storage is provided, electrical controls should be installed for pumping through truck fill stands as described in paragraph 2–08*o*.

TABLE 1.—*Gasoline flow, 70° A. P. I. gasoline at 60° F.*

[Friction head loss per foot of pipe in pounds per square inch]

Flow (gallons per minute)	Nominal diameter pipe—Inches							
	1″	1¼″	1½″	2″	3″	4″	6″	8″
10	0. 0215	0. 0056	0. 0028	0. 00082				
20	. 080	. 021	. 0105	. 003	0. 00044			
40	. 290	. 074	. 036	. 0105	. 0016	0. 0004		
60	. 620	. 1575	. 076	. 022	. 0034	. 0009		
80	1. 275	. 270	. 130	. 0375	. 0056	. 0015		
100		. 410	. 200	. 057	. 0085	. 00225		
150		. 850	. 410	. 122	. 0180	. 0047	. 00066	
200			. 720	. 210	. 0315	. 0081	. 00114	
300				. 430	. 066	. 0175	. 00236	0. 00062
400					. 112	. 0298	. 0041	. 00105
500						. 0450	. 0062	. 0016
600						. 0630	. 0085	. 00222
700							. 0118	. 0029
800							. 0150	. 00382
900							. 0185	. 00475
1,000								. 00575

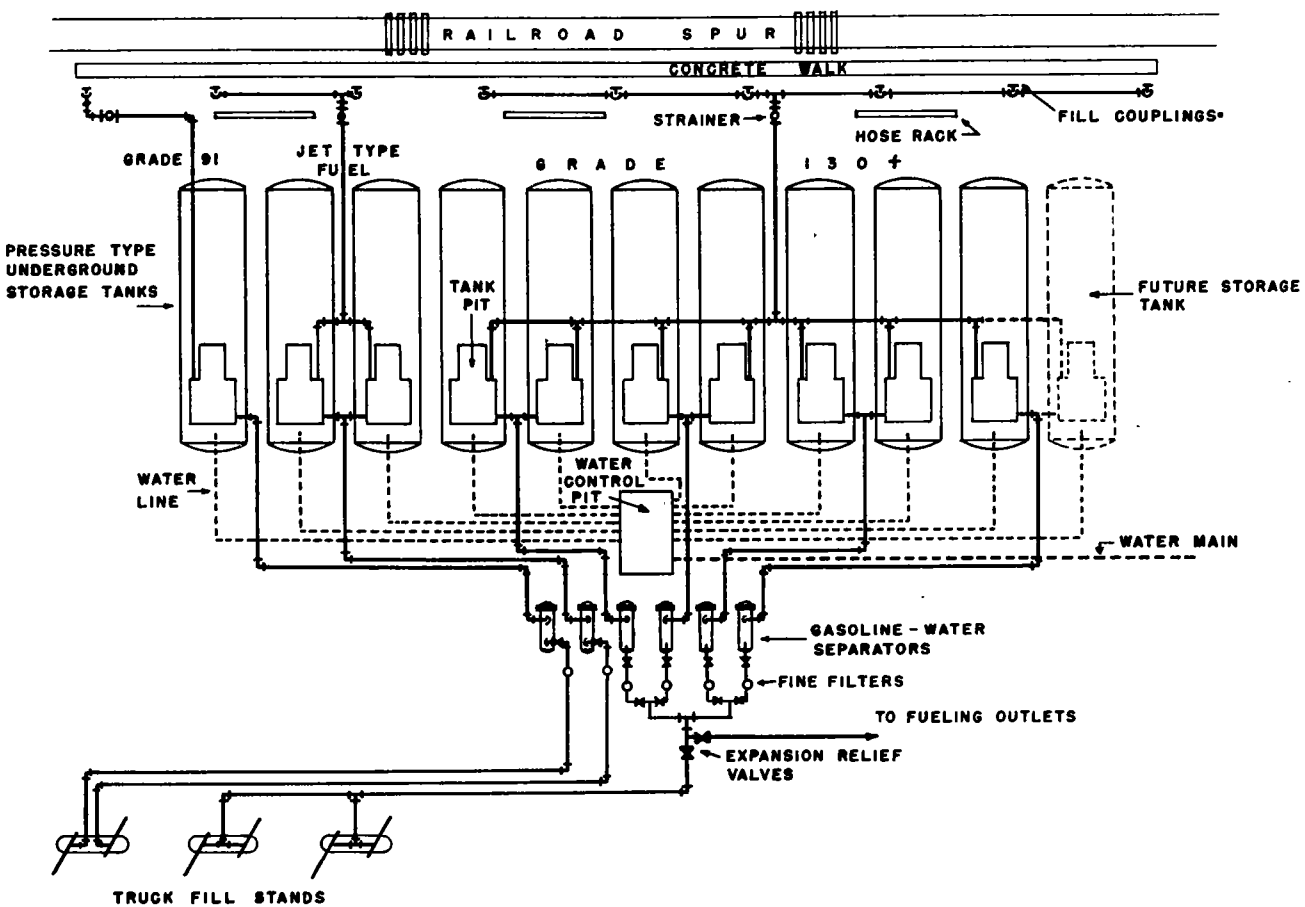
Equivalent lengths of straight pipe

Fittings	1″	1¼″	1½″	2″	3″	4″	6″	8″
45° Bend	1. 3	1. 7	2. 0	2. 5	3. 8	5	7. 5	10
90° Bend	2. 7	3. 5	4. 3	5. 5	8. 0	11	16. 0	20

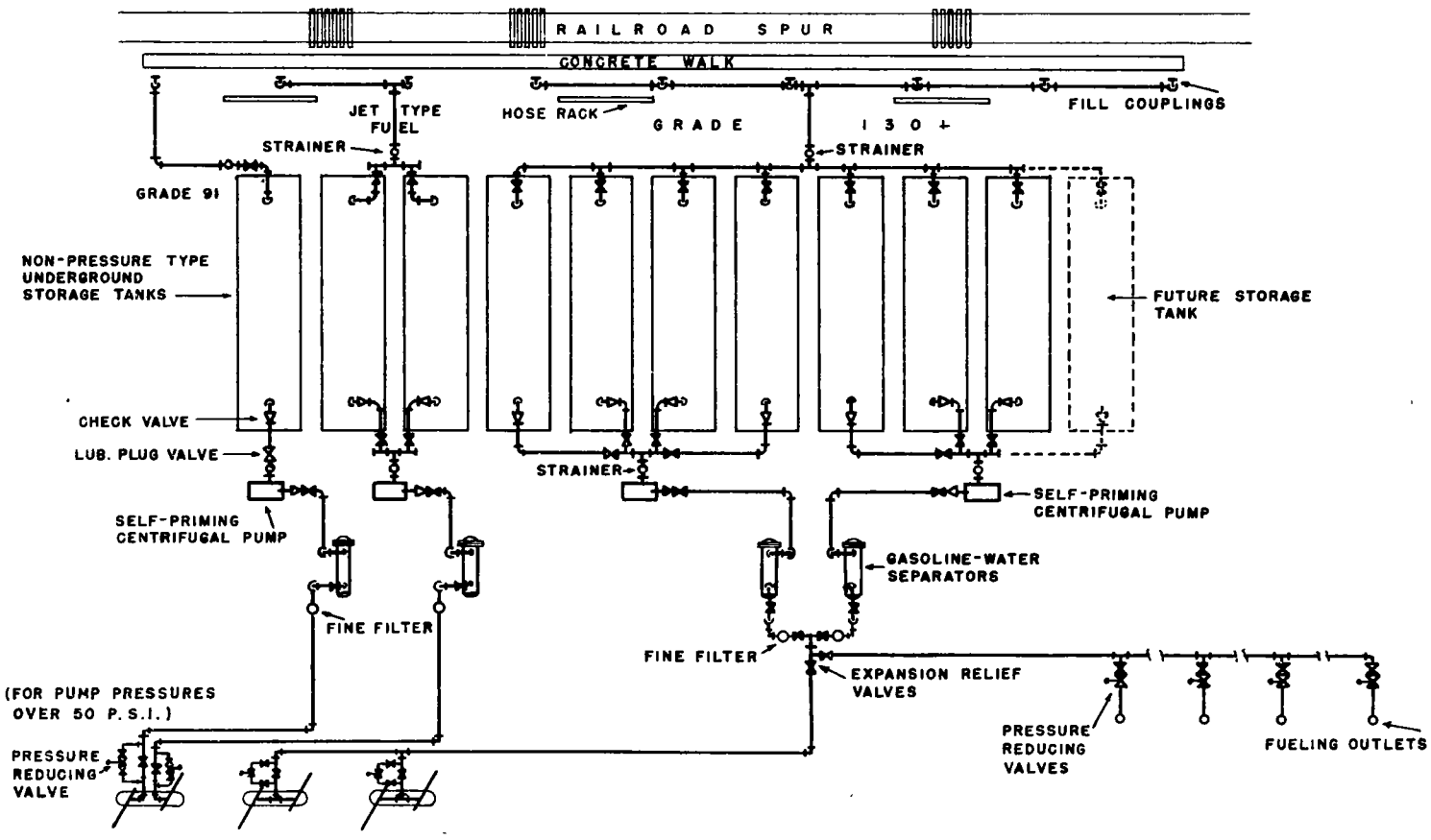
TABLE 2.—(*Based on AN–P–32, Army-Navy aeronautical specification fuel; grade K, aircraft engine; temperature at 60° F; density, 51.5 pounds per cubic foot*)

[Friction head loss per foot of pipe in pounds per square inch]

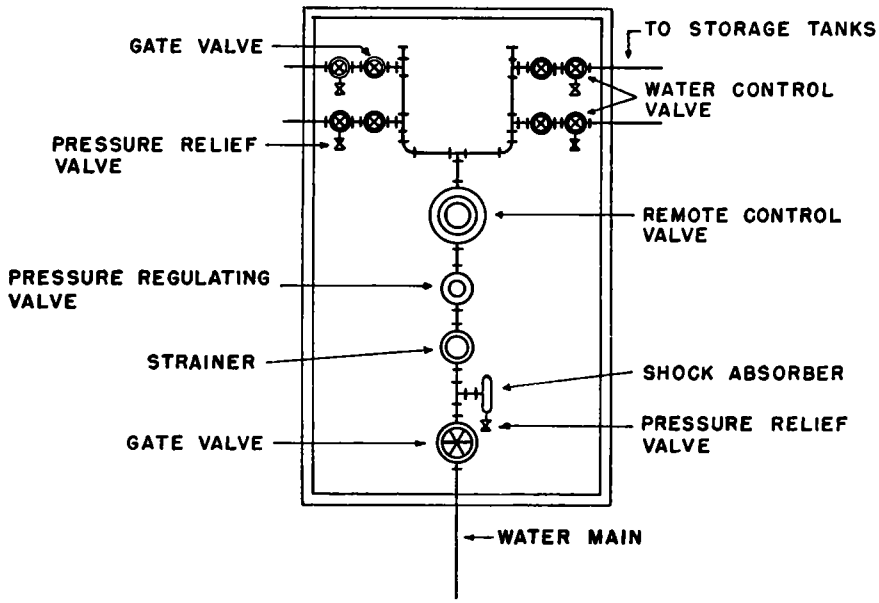
Flow (Gallons per minute)	Internal diameter pipe—inches				
	2″	3″	4″	6″	8″
100	0. 076	0. 0122	0. 0027		
200		. 0425	. 00925	. 0013	
300		. 085	. 0195	. 0026	0. 0007
400			. 034	. 0044	. 0012
500			. 0525	. 00675	. 0018
600			. 0725	. 00920	. 00245
700			. 0925	. 0125	. 0033
800				. 016	. 00425
900					. 00525
1,000					. 00625



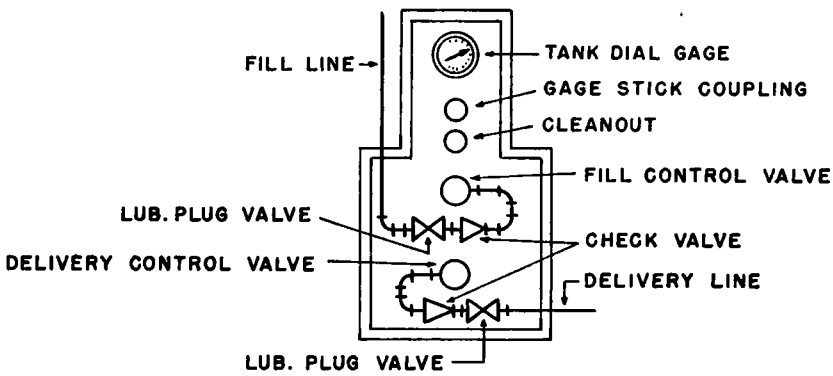
A.A.F. LIQUID FUELS
HYDRAULIC DISPLACEMENT SYSTEM
TYPICAL LAYOUT



A.A.F. LIQUID FUELS
MECHANICAL SYSTEM
TYPICAL LAYOUT



WATER CONTROL PIT

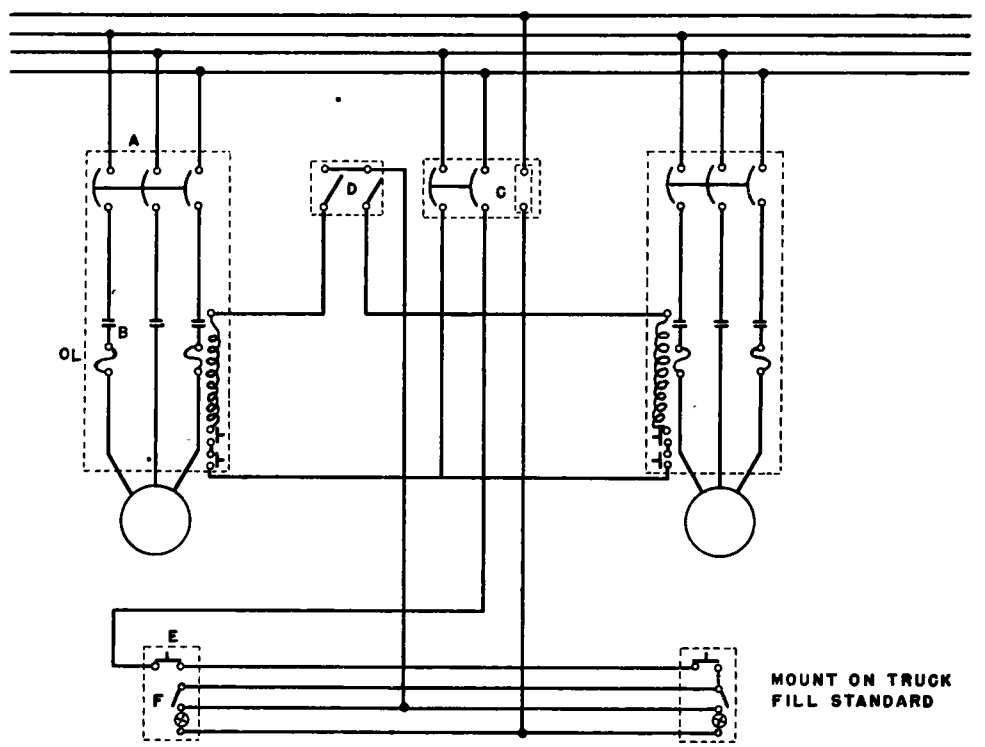


TANK PIT

A.A.F. LIQUID FUELS

HYDRAULIC DISPLACEMENT SYSTEM

DIAGRAMMATIC LAYOUT OF TANK PIT & WATER CONTROL PIT



A CIRCUIT BREAKER } MAY BE COMBINED
B MOTOR CONTROLLER } IN ONE ENCLOSURE
C 15A., 115/230V., SP SN CIRCUIT BREAKER FOR CONTROL CIRCUIT
D 2-10A., 250V., SP SWITCHES (SELECTOR SWITCHES)
E 1-10A., 250V., SP SWITCH (EMERGENCY-NORMALLY CLOSED)
F 1-10A., 250V., SP SWITCH WITH PILOT LIGHT
OL OVERLOAD PROTECTION

NOTE: ALL ELECTRICAL FITTINGS & APPARATUS TO BE EXPLOSION-PROOF.

A.A.F. LIQUID FUELS

MECHANICAL SYSTEM
DISPENSING TO TRUCK FILL STANDS
ELECTRICAL LAYOUT

ENGINEERING MANUAL - PART IX - CHAPTER 2 - JULY 1947 FIGURE 4

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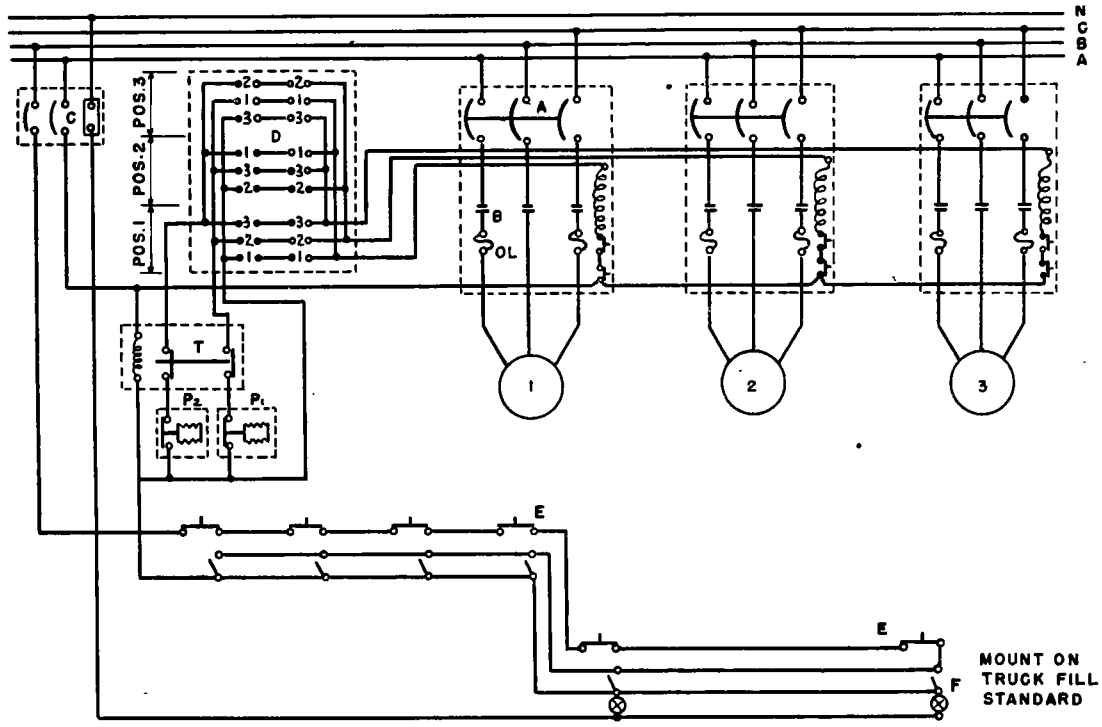


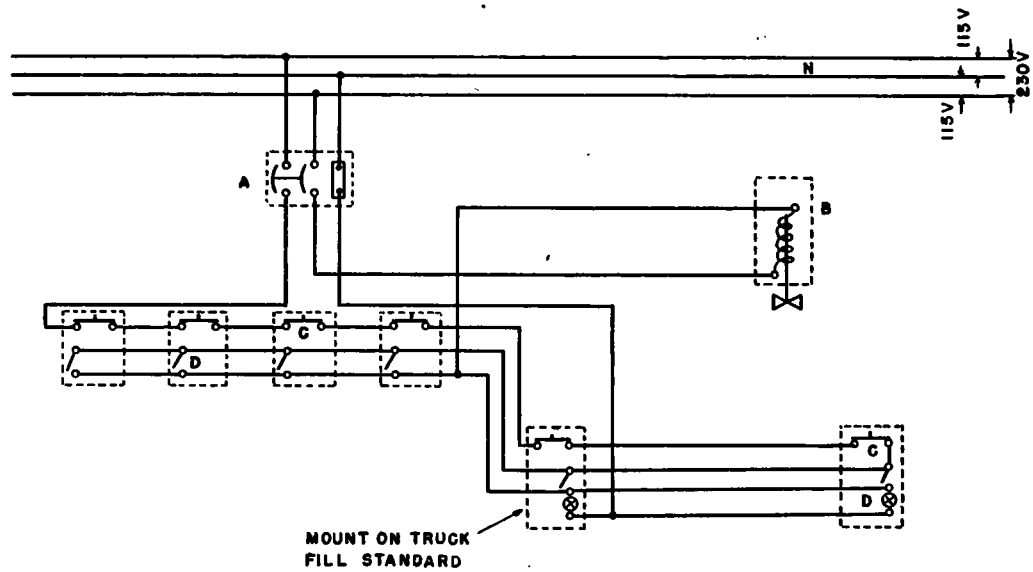
A CIRCUIT BREAKER } MAY BE COMBINED
B MOTOR CONTROLLER } IN ONE ENCLOSURE
C 15A., 115/230V., 2P SN CIRCUIT BREAKER (FOR CONTROL CIRCUIT AND LIGHTS IF NECESSARY)
D 3 POLE - 3 POSITION SELECTOR SWITCH
E 1 - 10A., 250V., SP SWITCH (EMERGENCY - NORMALLY CLOSED
F 1 - 10A., 250V., SP SWITCH FOR NORMAL OPERATION (PROVIDE PILOT LIGHT AT TRUCK FILL STANDS ONLY)
OL OVERLOAD PROTECTION
P PRESSURE SWITCH IN GASOLINE HEADER
T TIME DELAY RELAY. CONTACTS CLOSE 30 SECONDS AFTER COIL IS ENERGIZED.

NOTE: ALL ELECTRICAL FITTINGS & APPARATUS TO BE EXPLOSION-PROOF.

A.A.F. LIQUID FUELS

MECHANICAL SYSTEM
DISPENSING TO TRUCK FILL STANDS & FUELING OUTLETS
ELECTRICAL LAYOUT

ENGINEERING MANUAL - PART IX - CHAPTER 2 - JULY 1947 FIGURE 5



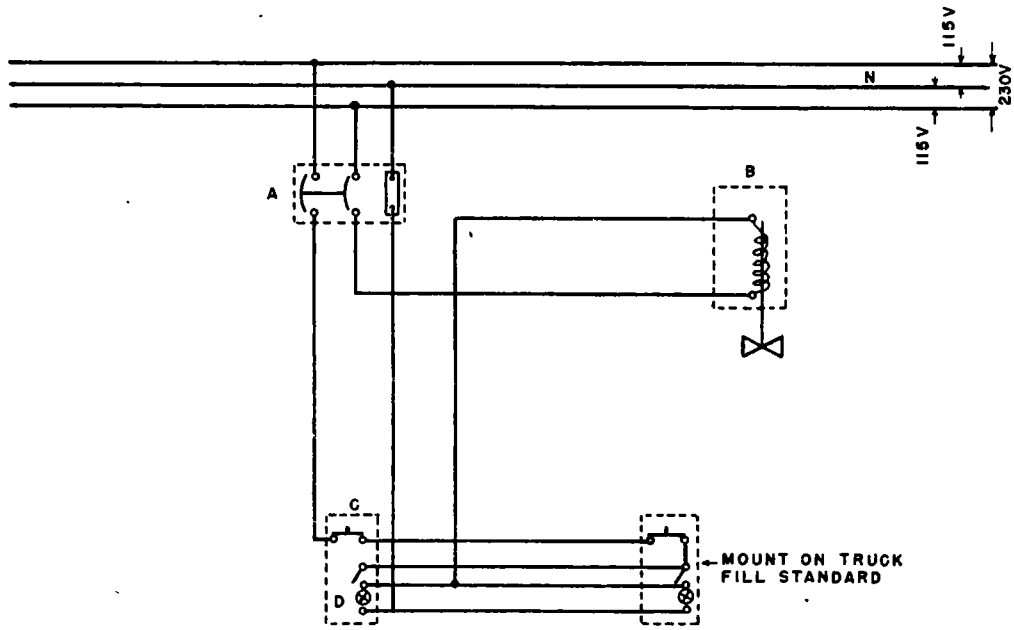
A 15A., 115/230 V., 2P SN CIRCUIT BREAKER FOR CONTROL CIRCUIT
B SOLENOID OPERATED VALVE (230 V)
C 1-10A., 250V., SP SWITCH (EMERGENCY-NORMALLY CLOSED)
D 1-10A., 250V., SP SWITCH FOR NORMAL OPERATION (PROVIDE PILOT LIGHT AT TRUCK FILL STANDS ONLY)

NOTE: ALL ELECTRICAL FITTINGS & APPARATUS TO BE EXPLOSION-PROOF.

A.A.F. LIQUID FUELS

HYDRAULIC DISPLACEMENT SYSTEM
DISPENSING TO TRUCK FILL STANDS & FUELING OUTLETS
ELECTRICAL LAYOUT

ENGINEERING MANUAL - PART IX - CHAPTER 2 - JULY 1947 FIGURE 6



A 15A., 115/230V., 2P SN CIRCUIT BREAKER FOR CONTROL CIRCUIT
B SOLENOID OPERATED VALVE (230 V)
C 1-10A., 250V., SP SWITCH (EMERGENCY-NORMALLY CLOSED)
D 1-10A., 250V., SP SWITCH WITH PILOT FOR NORMAL OPERATION

NOTE: ALL ELECTRICAL FITTINGS & APPARATUS TO BE EXPLOSION-PROOF.

A.A.F. LIQUID FUELS
HYDRAULIC DISPLACEMENT SYSTEM
DISPENSING TO TRUCK FILL STANDS
ELECTRICAL LAYOUT

ENGINEERING MANUAL - PART IX - CHAPTER 2 - JULY 1947 FIGURE 7

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ENGINEERING MANUAL
FOR WAR DEPARTMENT CONSTRUCTION

PART IX
CHAP. 3
DECEMBER 1946

Housing and Home Finance Agency
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FUEL DISTRIBUTION AND STORAGE

COAL STORAGE



WAR DEPARTMENT
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

Chapter 3

COAL STORAGE

3–01 SCOPE OF THESE INSTRUCTIONS.
3–02 QUANTITY TO BE STORED.
3–03 LOCATION.
3–04 STORAGE AT BOILER PLANTS.
3–05 FACILITIES:
a. Railroad spur.
b. Roads and driveways.
c. Storage area.
d. Mechanical equipment.

Part IX

Chapter 3

COAL STORAGE

3–01 SCOPE OF THESE INSTRUCTIONS. These instructions cover major requirements for the design of coal storage facilities. Plans for coal storage should be developed concurrently with those for roads and railroads and the facilities which they serve.

3–02 QUANTITY TO BE STORED. Normally 50 percent of the annual coal consumption will be stored. The capacity of boiler house bunkers and bins which hold a two or more weeks' supply for the units served will be included in this amount. In troop housing facilities the annual consumption is determined by the quantity indicated on the accompanying chart (fig. 2), which is based on the number of degree days per year. The number of degree days in a single day is the minus difference in the number of degrees F. between the mean temperature for that day and 65°. In other establishments where heating or steam power is required, the coal demands should be arrived at by definite analysis and history records.

3–03 LOCATION. The storage should be located where railroad and road service can be made available, consideration being given to a balanced economy between construction and operational costs. In troop housing establishments the site is normally in the vicinity of the warehouse area; in other establishments, in the vicinity of facilities using the greater amount of coal. Where possible, coal should be stored on the prevailing leeward side of any buildings, and preferably at a minimum distance of 500 feet.

3–04 STORAGE AT BOILER PLANTS. In postwar construction, where direct delivery will prove economical, coal should be delivered by car to boiler houses. The coal storage should be in the immediate vicinity. The storage may be confined by a masonry wall at least as high as coal is stored, where conditions justify such precautions to prevent nuisance from dust and to present a less unsightly appearance. Planning of the storage facility should be based on mechanical handling of coal from car through storage to the boilers in an efficient manner consistent with the size and type of boiler installation.

3–05 FACILITIES. Facilities will consist of the following:

a. Railroad spur. Where the location of the storage area is not adjacent to an existing track, storage should be on both sides of the spur. Where the storage area is alongside an existing track, the amount of approach track and cross road construction will determine whether storage should be on one or both sides. In figure 1, lay-out A will be economical for storage under 8,000 tons; lay-out C, if terrain and space permit, between 8,000 and 10,000 tons; and lay-out B, above 10,000 tons. The track should extend one or two car lengths beyond the storage area. The grade of that portion on which cars will stand should not exceed 0.4 percent.

b. Roads and driveways. Roads and driveways leading to and surrounding the storage area shall be of a type similar to that used for comparable traffic requirements on either primary or secondary roads constructed elsewhere within the establishment.

c. Storage area. The length of the storage area will be determined by a capacity of 10.5 tons per lineal foot if stored on one side, and 21 tons if stored on both sides. The operational and storage areas should be provided with flexible or nonflexible pavement adequate to support 9,000-pound wheel loads and should have an impervious wearing course. The wearing course should be stable enough to prevent materials composing it from working loose under action of the elements and equipment operation. Flexible-type pavements should consist of an adequate base course with a bituminous wearing surface not less than 1½ inches thick. Nonflexible pavement should consist of an adequate thickness of portland cement concrete. The surface of the area should be at base of rail elevation along the track, and slope away from the track to provide positive drainage.

d. Mechanical equipment. The mechanical handling equipment will consist of car unloaders, stacking conveyors, and truck loaders. The equipment should be arranged and operated substantially as indicated in figure 1. Type and quantity of equipment will conform with TM5-675.

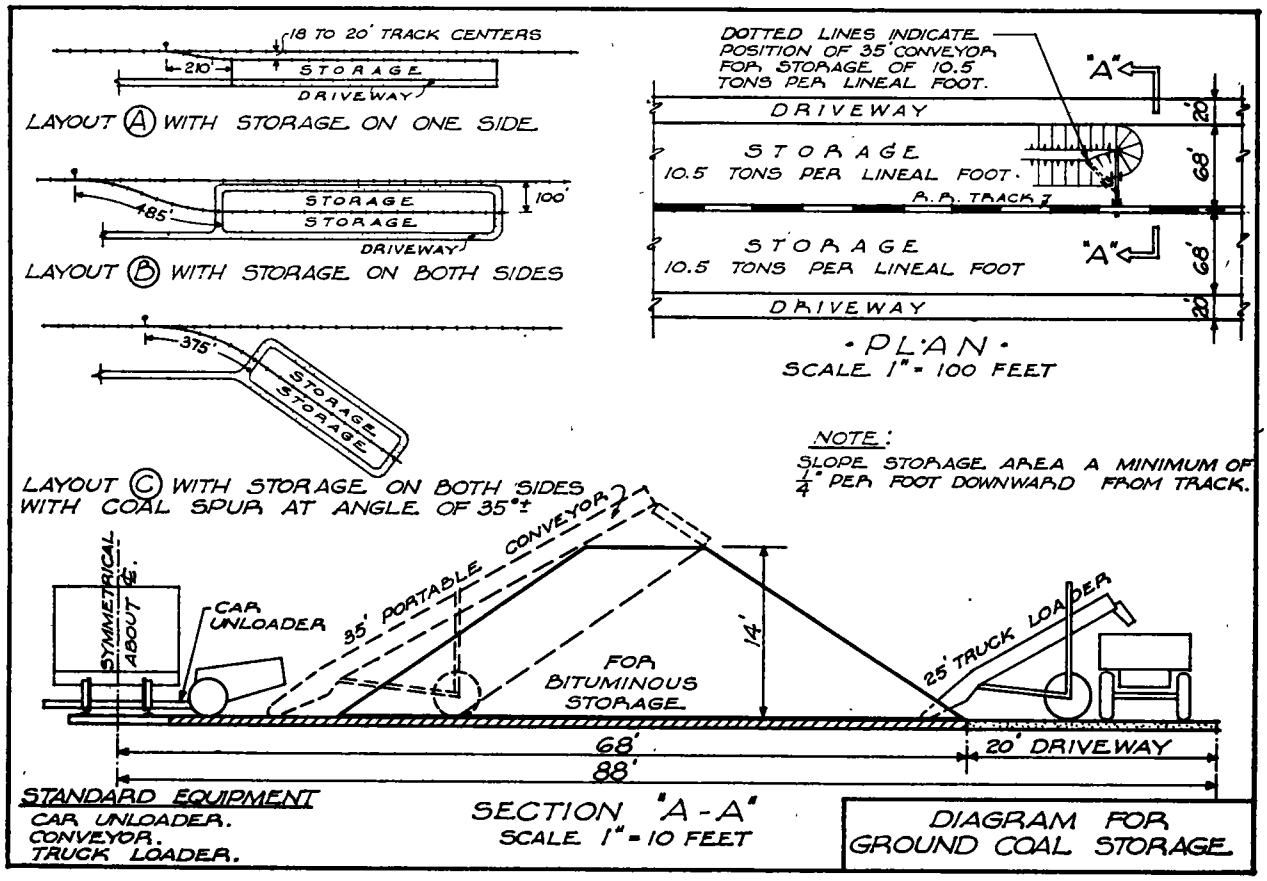

FIGURE 1.—Engineering Manual, Part IX, Chapter 3.

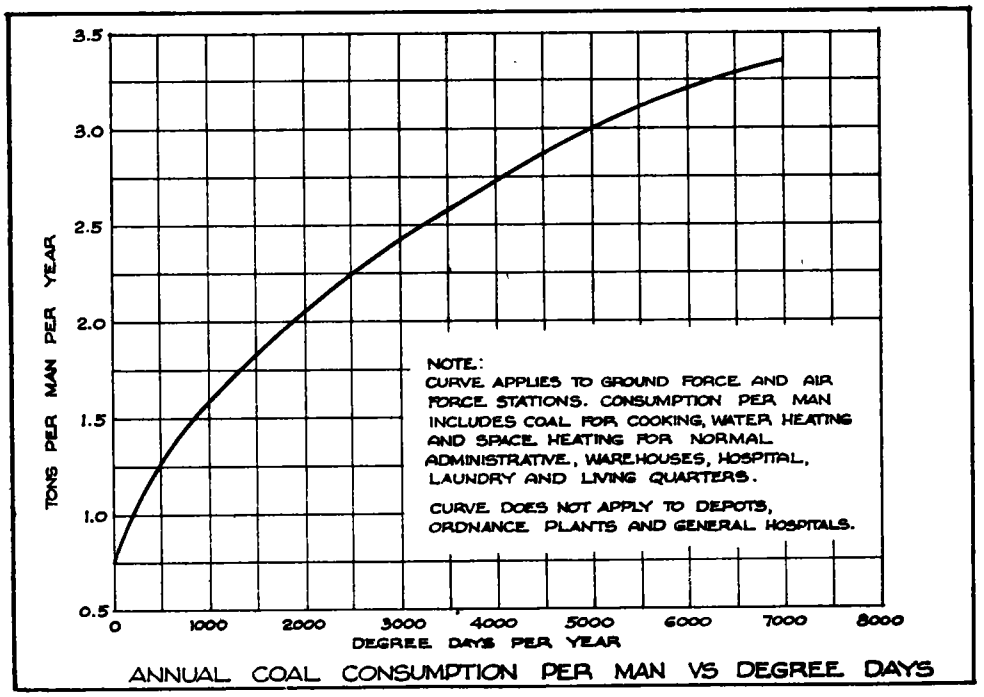

FIGURE 2.—Engineering Manual, Part IX, Chapter 3.

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AD INTERIM
ENGINEERING MANUAL
FOR WAR DEPARTMENT CONSTRUCTION

PART X
CHAP. 1
MAY 1947

Housing and Home Finance Agency
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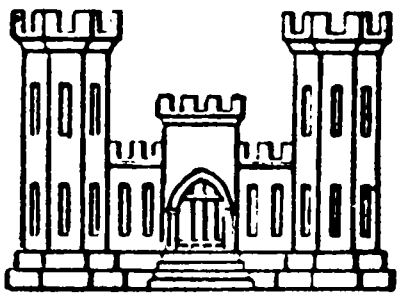
TRANSPORTATION FACILITIES

ROADS, WALKS & OPEN STORAGE AREAS



WAR DEPARTMENT
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

Chapter 1

ROADS, WALKS AND OPEN STORAGE AREAS

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Part X
TRANSPORTATION FACILITIES

Chapter 1
ROADS, WALKS AND OPEN STORAGE AREAS

1–01 GENERAL. These instructions are published for guidance in the design and construction of highways, open storage areas, and sidewalks at all types of installations under the control and supervision of the War Department. Good and sound engineering practice will be followed in regard to special conditions and problems and to items not covered by these instructions. It is the responsibility of the Corps of Engineers to select construction types which will comply with the stated functional requirements of the using service.

1–02 DEFINITIONS. Definitions of general terms used in this chapter are as follows:

a. Highway. Highway is a general term applicable to both road and street.

b. Street. Street is the term applied to highways within built-over areas.

c. Road. Road is a term applied to highways outside of built-over areas.

d. Access highways. Access highways are roads and streets providing access to Army Installations or closure roads required to facilitate travel around these installations, and to provide highway connections shut off from general public use. Access roads are usually not within the reservation limits of the Army installation and their construction and maintenance are usually the responsibility of state, county, or other public authorities.

e. Project highways. Project highways include all streets and roads within the site limits of Army installations which are constructed and maintained by the Government. All project streets or roads are classified in accordance with their relative importance to the installation as a whole and with respect to the character of traffic using them.

They are subdivided into three general classifications as regards to their relative importance, and four general classifications as to character of traffic using them in accordance with the following subparagraphs.

f. Primary highways. Primary highways, designated by the letter "P," include all project streets or roads which serve as the main distributing arteries for all traffic originating within or without an installation and which provide access to, through, and between the various functional areas. Primary highways are designed and planned to accommodate the largest and heaviest vehicle that may be required to operate within the reservation.

g. Secondary highways. Secondary highways, designated by the letter "S," include all project streets or roads which supplement the primary highway system by providing access to, between, and within the various functional areas. Secondary highways are usually planned and designed to accommodate a reasonable volume of the comparatively lighter weight vehicles with an occasional passage of the maximum size vehicles.

h. Tertiary highways. Tertiary highways, designated by the letter "T," include all project streets or roads which provide access from other streets or roads to individual units or facilities of a functional area.

i. Class AA highways. Class AA highways, designated by the symbol "CL–AA," comprise those project streets and roads which are designed and planned for traffic consisting of a comparatively large volume of both wheeled and track-laying vehicles, such as heavy duty trucks, tractor-trailer combinations, tanks, tank destroyers, self-propelled artillery vehicles (full track) etc., or material handling equipment, such as crawler or wheel type cranes, fork-lift trucks and small wheeled trailers equipped with either hard rubber or steel treads. The large loads imposed per unit area of contact surface and torsional

stresses imposed from turning of these vehicles require special consideration as to pavement types and design.

j. Class A highways. Class A highways, designated by the symbol "CL–A," comprise project roads and streets designed and planned as heavy duty routes for traffic containing a large and uniform percentage of military and commercial vehicles of either the wheeled or combined wheel and track-laying type. On the average, 95 percent of these vehicles should have wheel loads equal to or less than the design wheel load of 12,000 pounds. The wheel loads of the remainder may range between 12,000 and 15,000 pounds.

k. Class B highways. Class B highways, designated by the symbol "CL–B," comprise roads and streets designed and planned as medium traffic routes for traffic containing a large and fairly uniform percentage of military and commercial vehicles principally of the wheeled type, providing 95 percent of such vehicles have wheel loads equal to or less than design wheel load of 9,000 pounds. The wheel loads of the remainder may range between 9,000 and 12,000 pounds.

l. Class C highways. Class C highways, designated by the symbol "CL–C," comprise project streets or roads which are designed and planned as routes for traffic consisting principally of passenger cars and light trucks, 2½ tons or less, with an occasional vehicle having a wheel load equal but not exceeding 9,000 pounds. The proportion of heavier trucks shall not exceed 5 percent of the average daily traffic.

Note. All project streets or roads are designated by a combination of a letter and symbol. The combination of letter and symbol results in a system of designating project highway classification which is simple and which indicates readily the relative service provided with respect to importance and character of traffic served. Thus a classification of "P CL–A" indicates a street or road which is of primary importance with relation to the project as a whole and is designed as heavy-duty route for traffic containing a high percentage of vehicles having maximum wheel loads approaching 12,000 pounds.

m. Undivided highway. Undivided highway is a roadway having no natural or structural barrier constructed thereon separating traffic moving in opposite directions.

n. Divided highway. Divided highway is a two directional roadway having either a natural or constructed barrier separating the lines of traffic moving in opposite direction.

o. Open storage areas. Open storage areas consist of designated areas planned and designed either for the storage, servicing, and parking of organizational vehicles, or for the parking of vehicles of visitors, civilian employees, and attached personnel, or for the reception, classification, and storage of supplies, new and salvage materials and equipment pending assignment for use or distribution, or for salvaging, processing, or repairing of equipment.

p. Walks. Walks are graded strips adequately surfaced for all weather use of pedestrians betweeen buildings and facilities of the built-over areas.

q. Built-over areas. Built-over areas consist of those areas within the site limits which contain an aggregation of buildings, reasonably closely spaced, and arranged for housing, warehousing and storage, plant or depot purposes. The street or road system serving built-over areas are such that intersections of streets occur at intervals one-fourth mile or less apart.

r. Other areas. Other areas are all areas within the site limits but outside built-over areas and designated for training, maneuver, ammunition storage or other incidental purposes.

s. Street or road right-of-ways. Street or road right-of-ways are strips of land dedicated and reserved for vehicular and pedestrian traffic.

t. Roadway. Roadway is that portion of the right-of-way included within the construction limits of the grading, drainage, and surface course improvements and appurtenant structures.

u. Roadbed. Roadbed is that portion of the roadway occupied by traffic lanes, parking lanes and shoulders, gutters, and curbs. Roadbeds are divided vertically into two general parts: the natural foundation and the road structure. The natural foundation is the nonmanipulated natural ground upon which the road structure is placed and supported. The road structure may be made up of one or several parts, named from the natrual foundation upward as follows: embankment, subgrade, base course and pavement.

v. Subgrade. Subgrade applies to the natural soil in place or to fill material upon which a base or pavement is constructed.

w. Compacted subgrade. Compacted subgrade applies to the upper part of the subgrade which is compacted to a density greater than the underlying portion of the subgrade to provide increased stability.

x. Base. Base applies to the course or combined courses of specially selected soils, aggregates, or treated soils placed on the subgrade beneath the pavement.

y. Pavement. The term "pavement" is defined as a surface of a prepared or manufactured product superimposed upon the base or subgrade as a weather and abrasive resisting structural medium.

z. Shoulders. Shoulder is defined as that portion of the roadbed between the edges of the traffic lane or parking lane and the top of ditch slope or fill slope.

aa. Traffic lane. Traffic lane is that strip of roadbed intended to accommodate the forward movement of a single line of vehicles.

ab. Parking lane. Parking lane is a lane separate and distinct from a traffic lane, intended for the parking of vehicles. The width of the parking lane depends upon the proposed method of parking and the character of traffic. The parking lanes shown on figure No. 3 are for parking of vehicles parallel with the line of traffic.

ac. Bridge. Bridge is defined as a structure which provides a waterway or other opening under a highway and which has a clear span of 20 feet or more between the inside faces of the end supports, measured normal to the face of supports, or a multiple span structure of which the sum of the individual clear spans plus the total width of the intermediate supports is in excess of 20 feet. Bridges 100 feet or less in length between outside supports or abutments are classed as "Short Bridges." Bridges in excess of 100 feet between abutments are classed as "Long Bridges."

ad. Culvert. Culvert is any structure, not classified as a bridge, which provides a waterway or other opening under a highway.

1–03 SUBMISSION OF DESIGN DATA. In accordance with provisions of Orders and Regulations, plans and specifications covering construction of highways, walks, open storage areas, and drainage facilities should be accompanied by design analysis including all necessary soil survey data, field and laboratory investigations and tests made thereon, affecting the proposed or ultimate design.

ACCESS HIGHWAYS

1–04 GENERAL. Provision for permanent access highways and readjustments of the adjacent public highway system to serve Army installations is covered in current instructions of the Chief of Engineers. Where access roads are not within the site limits of Army installations, their design and construction are normally the responsibility of the state, county, or other public authorities. Where such access highways are to be constructed upon rights-of-way obtained by the Government and the construction thereof is to be financed by War Department funds, such access highways will be designed and constructed in accordance with the criteria established hereafter for project highways.

Prompt maximum usage of access highways for the transportation of construction materials will reflect savings in time and cost of construction. An early survey should be made to determine needed repairs and construction of the existing highway system. Every effort should be exerted to see that the responsible authorities perform the necessary repair and construction work prior to the receipt of bids covering work to be performed within the installation. Improvement of access highways adjacent to active projects should be performed in advance of work on the project in order to minimize interference with the hauling of construction materials to be used in the project.

PROJECT HIGHWAYS

1–05 GENERAL. The criteria and standards set forth herein are established to guide in constructing roads and streets of new installations, for reconversion of roads and streets of temporary installations to permanent use, and for constructing new highways at existing permanent installations.

Many military facilities constructed for World War II will be retained for postwar and peacetime use. Construction in part will consist of converting these existing temporary facilities for permanent occupation. Extensive planning studies will be undertaken to arrive at economical and efficient lay-outs for permanent occupation, resulting in the adoption of a master plan which will govern and will provide for the orderly comprehensive development of the installation. Existing roads and streets at temporary installations, satisfactory in alinement and grade with remaining useful pavement life, may be retained temporarily pending the availability of necessary construction funds. Careful and proper planning in connection with reconversion of temporary installation to permanent use will permit necessary road and street reconstruction to be accomplished by sections, areas, or by stage construction. Accurate and reasonable evaluation of existing highway facilities will determine the suitability of their retention. Such evaluations will provide data and information helpful in the selecting and designing suitable types for permanent pavements.

Where construction consists of an extension of existing facilities, permanent in nature, the type of base and surface course may conform to type used in the original project providing performance under traffic has been satisfactory and the type is justified for the volume and character of traffic to be encountered. Radical changes in type of surfacing which will necessitate costly maintenance equipment or maintenance methods not applicable for use in existing highways should be avoided so far as possible.

1–06 DETERMINATION OF TYPES. In establishing types of construction, consideration should be given to soil conditions, volume and character of traffic using the highways under normal project functioning, the ultimate cost of transportation service, the anticipated life expectancy of the existing or contemplated project and the suitability of the construction for the season of the year in which the work must be performed. The type of construction should be the cheapest consistent with the requirement of present and anticipated traffic and local conditions.

a. Soil conditions. Design and construction of the roadway require a knowledge of topographic features and of the soils involved. Experience shows that many failures or incipient failures in paved surfaces have been due to settlement, poor drainage, and other unstable conditions of the roadbed that modern construction methods could have prevented. The care and slight additional cost necessary for adequate earth work are well justified by the superior service the pavement will render. Construction operations necessary in preparing the grade are practically the same for all classes. Grading operations must be carefully planned and executed. Information for use in planning grading operations, the preparation of plans, and estimating construction costs is obtained by means of location and soil surveys. Location surveys shall be made in accordance with standard practice. Soil surveys consist of determining the soil profile, selecting samples of the soil in the profile for the determination of the physical properties of the soils and the mapping of the profile. These determinations serve as a guide in the selection of materials for embankments and in the design and construction of subgrades and base courses. Soil investigations shall be made in accordance with chapter 2, part XII of this manual. Soils will be classified in accordance with Casagrande Soil Classification, figure No. 1. The soil classification scheme shown in the table is arranged for the practical use of evaluating soils for subgrade and base course purposes.

b. Volume and character of traffic. Selection of construction type and the subsequent design thereof requires a knowledge of the volume and character of traffic. The volume and character of traffic determine the width of the roadway required. The weight and frequency of wheel loads form the basis for an economical structural design.

Volume and character of traffic upon project highways are related to size, type, and mission of the installation. Size of installation is stated in terms of either troop strength, housing units, hospital beds, plant capacity, square feet of storage, etc., or combinations thereof which together with the mission and type of installation provide an index as to the volume and character of traffic using highways under normal project functioning. The type and mission of the installation provide information as to its functional requirement indicating the character and size of vehicles required for satisfactory project opera-

tion. Types of vehicles and frequency of use establish the traffic classifications in which the various highways fall.

The system of highway classification outlined and defined heretofore is believed sufficiently broad for the classifying of all roads and streets within an installation regardless of type and mission. Classification reflecting character of traffic is based upon the characteristics of existing civilian and military vehicles. The characteristics and design policies of military motor vehicles are given in Bulletin AR 850–15 and listed and depicted in Technical Manual TM 9–2800. For information relative to military vehicles attached to organizational units of the Army see latest tables of organization. The majority of these military vehicles conform in design and characteristics to those in civilian use on public highways. However, numerous military vehicles have over-all dimensions and weight distribution such that the resulting axle load and overall dimension exceed limits adopted and used in the design of public highways. Public highways are usually designed to accommodate traffic composed chiefly of wheeled vehicles equipped with pneumatic tires. Military vehicles include not only wheeled vehicles, but also combined wheel and track vehicles and full-tracked vehicles. Tracked vehicles are not equipped with pneumatic tires. Special consideration must be given in the selection and subsequent design of pavements subjected to tracked vehicles and greater axle loadings of military vehicles.

Each project will require careful consideration as to volume and character of traffic required on the individual roads or streets to obtain an efficient and economical highway system. The road designer should work in close cooperation with site planner to develop a highway system adequate for project functioning.

c. Cost of transportation service. The efficient management of a highway system requires, among other things, that the surfaces provided for the use of the traffic be of such types and designs that highway transportation can be conducted at the lowest possible cost when both cost of the construction and the cost of vehicle operation are given consideration. In arriving at the estimated cost of transportation services, consideration should be given to every type of construction that is suitable for the location and service required. Physical characteristics of pavement wear, smoothness, resiliency, and rate and manner of wear enter into the cost of transportation service and are included in proper cost comparison. Possible future maintenance and replacement cost are also included in proper cost comparison. The availability and costs of materials are usually the largest factors influencing cost of transportation service. Undeveloped sources of local materials should not be considered unless it is established that the materials are of acceptable quality and can be made available in ample quantities at reasonable costs.

d. Anticipated life expectancy. The life expectancy of pavement types selected should be comparable to life expectancy of the facilities served. In selection of roadway types consideration should be given to the life expectancy of the project served. Life expectancy of project highways within permanent and established posts should be based on 25 years occupancy. (See WD memo 100–46, 4 March 1946) Temporary type projects should use less costly structures and roadway types than established posts or permanent projects.

e. Construction season. In the selection of types, consideration should be given to the season of the year in which the work must be performed. An exigency may arise where consistruction must be carried on under adverse conditions which may affect the selection of construction types. Certain types of bases and surface course require prolonged curing periods after construction prior to their use by traffic, whereas other types require little or no curing periods prior to use. In those areas where low temperatures prevail for extended periods, the necessary protective measures that must be taken with certain types affect the ultimate cost of the highway and may affect its ultimate strength and durability. All factors must be considered, the cheapest type consistent with services required should be selected. Stage construction may be advisable. An adequate base type of construction can be selected that is suitable for construction under adverse weather conditions expected. Such base courses may be used temporarily and the final pavement course constructed when more favorable weather conditions prevail. This is particularly true where construction must be carried out during wet weather seasons and unfavorable

soil conditions. Base courses constructed under these conditions attain thorough compaction under traffic and may permit a reduction in thickness of pavement courses.

GEOMETRIC DESIGN

1–07 GENERAL. Geometric design of project roads and streets deals with the dimensions of the visible features of a road or street, such as the alinement, sight distances, widths, slopes, and grades, as distinguished from structural design which deals with the thickness, composition of materials, and load carrying capacity. Geometric design standards set forth in the subsequent paragraphs are applicable to road and street construction within permanent Army installations and have been related to the road classifications given in paragraph 1–02 of this chapter. Consideration has also been given to the difference in character, degree, extent, and types of improvements between areas within Army installations as defined under paragraphs 1–02 *n* and 1–02 *o* of this part. The terms, "roads" and "streets", are referred to to effectuate the differences in design policy between "other" and "built over" areas.

It is realized that available finances may not permit the construction of project roads and streets initially to the standards set forth herein. It is urged, however, that when economy is necessary, it be practiced on some feature of highway design other than the geometric features. The roadway section can always be improved and widened at reasonable costs. The paving surface can be widened and strengthened at any future date when finances will permit. But the geometric features of alinement, grade, and sight distances when once molded into the landscape and tied down with pavement surfaces, right-of-ways, and other adjacent properties, are most difficult and expensive to correct. The geometric standards set forth herein have been established on a generous factor of safety and adequacy and should be the criterion to which road and street construction, whether stage or final, is ultimately planned and constructed.

1–08 ROADWAY WIDTH. The primary object of a road or street is to furnish access by ingress and egress to the abutting property and to provide an adequate traffic-way for pedestrian and vehicles in the interchange of the installations traffic. All other purposes are secondary. The locations of utilities of every description above or below ground should be subordinated to the requirements of traffic. So far as practicable service facilities should not be placed beneath the travel portion of the pavement.

The greatest factor influencing roadway widths is usually that required for vehicular traffic movement. The roadbed may be limited to the necessary traffic lanes only, or to a combination of traffic lanes and shoulders or a combination of traffic and parking lanes, depending upon service requirements. The number of traffic lanes of an individual road or street is dependent upon the relative function the road or street bears to the highway net as a whole and the functions required of the facilities located on abutting property.

Studies relating to traffic flow and road and street capacities have been made by numerous and different traffic and highway engineers. These studies provide information relative to the practicable working carrying capacities of highways as affected by design features, motor vehicle characteristics, traffic regulations, and driver's reaction. The practical working capacity of a highway is a relative value based on the number of vehicles that a highway can carry without restricting the speed or movements of vehicles more than the driver can reasonably be expected to tolerate. In other words, the practical carrying capacity of a highway is reached on a facility carrying an uninterrupted flow of traffic when a higher volume would cause the drivers to be unreasonably restricted.

These studies also revealed the importance of the time interval of one hour. Such studies indicated that if a highway facility is to be so designed that traffic will be properly served, consideration must be given to the brief but frequently repeated rush hours. It was concluded from information available, that it would be desirable to design a highway facility to accommodate the thirtieth highest hourly volume of a year. The thirtieth highest hourly volume is the hourly volume on a given roadway that is

exceeded by 29 hourly volumes during the given year. This is based on observations which indicated that when the volume of the thirtieth highest hour of the year was expressed as a percentage of the average 24-hour traffic volume of the year this percentage relation was for all practical purposes relatively constant, even though the annual volume for other years changed substantially. This percentage relation is shown in top graph of figure No. 2. This consistency held for lightly and heavily traveled roads or streets regardless of the many other factors operating to influence traffic.

Similar data are not available relative to traffic flow and capacities of streets and roads subject to military traffic only. Therefore, the results of the studies made on public roads and streets have been used to establish tentatively criteria for the design of project roads and streets.

a. Traffic capacity—design basis. The practical working capacities of 2-, 3-, and 4-traffic lane streets within "built-over areas" are tentatively established as 800, 1,400, and 2,800 vehicles per hour respectively, and for roads in "other areas" as 600, 1,100, and 2,200 vehicles per hour respectively. In establishing the above capacities, consideration has been given to the minimum design requirements set forth hereinafter, the greater proportion of trucks and military vehicles likely to be present on these roads or streets, the characteristics of the military vehicles, and the probability of more effective enforcement of traffic regulations on these roads and streets. It should be further appreciated that roads and streets designed for the above capacities are capable of accommodating a larger volume of traffic for a comparatively short period of time. The actual maximum carrying capacities of such roads and streets are at least twice that of practical capacities. Maximum possible capacities are reached only under the most ideal road conditions with all vehicles moving at approximately the same speed, maintaining safe following distances and not passing vehicles ahead. These maximum possible capacities may be approached during road movement of a well trained motorized military unit under adequate police control. However, the average driver will not tolerate such conditions, except for short intervals of time. Since project roads and streets are subject to all types of traffic under varying conditions, these capacities should be established on the basis of practical working capacities rather than maximum possible capacities.

b. Hourly volume—design basis. The above practical working capacities refer to hourly volumes. The design of roads and streets within Army installations should be based on that required to accommodate the thirtieth highest hourly density of some selected year.

c. Traffic estimates. An estimate of the anticipated volume of traffic on each road or street should be made. These estimates of traffic should be based so far as practicable upon traffic data available for the installation under consideration or similar installations. Consideration should also be given to the traffic volumes apt to be generated by the population and mission of the installation under consideration. At permanent installations, the probable traffic of a future year should be chosen in preference to existing traffic volumes in order to avoid congestion and obsolescence in a relatively short time.

Figure No. 2 contains graphs showing the relation between various hourly volumes during the year and annual 24-hour traffic volumes, the percentage relation between the maximum and tenth highest hourly volumes with the thirtieth highest hourly volumes and the percentage relation of the various hourly traffic volumes with the annual 24-hour traffic volume. These graphs are based upon actual capacity studies made on public roads and streets. These graphs furnish basic relations necessary for projecting known traffic volumes to design volume capacities and should be used wherever other traffic data are not available.

1–09 WIDTH OF TRAFFIC LANES. The width of a traffic lane is dependent upon the width and operational characteristics of the vehicles using roads and streets under consideration and the vehicle speeds such roads and streets are designed to accommodate. In general, no road or street should be provided with less than two traffic lanes. Exception may be made for light traffic density roads or streets as described under paragraph 1–13 of this chapter.

The characteristics of vehicles using roads and streets within Army installations are such that the width of pavement allowed for moving vehicles should be multiples of the traffic lane widths given in the following rable:

Table 1. Minimum traffic lane widths.

Road or street classification	Traffic density		Traffic lane width (feet)
	Hourly (30th highest) vehicles	Average daily (annual) vehicles	
Cl–AA roads	Over 8	Over 50	12′
Cl–AA streets	Over 8	Over 50	12′
Cl–A and Cl–B roads	Over 8	Over 50	11′
Cl–A and Cl–B streets	Over 8	Over 50	10′
Cl–C roads	8 to 50	50 to 330	9′
Cl–C roads	Over 50	Over 330	10′
Cl–C streets	8 to 50	50 to 330	8′
Cl–C streets	Over 50	Over 330	10′

Traffic lane widths given in the above table are based on assumed design speeds of 30 miles per hour or less for streets and in excess of 30 miles per hour for roads. Roads will be provided with adequate shoulders as called for under paragraph 1–10 of this chapter. See paragraph 1–12 of this chapter for criteria establishing pavement widths for streets. No portion of a paved gutter should be considered as a portion of any traffic lane.

1–10 SHOULDERS. Shoulders should be provided on all roads constructed in conformity with typical Road Type Cross Section of figure No. 3. They are necessary for safe operations and for developing the full capacity of traffic lanes. Shoulders of roads in Army installations should, in so far as economically practicable, be of the widths as specified in the following table:

Table 2. Minimum shoulder widths.

Road class	Traffic density		Width of shoulder feet	Remarks
	Hourly (30th highest) vehicles	Daily (average annual) vehicles		
Cl–AA	Over 8	Over 50	10	
Cl–A or Cl–B	8 to 50	50 to 330	8	
Cl–A or Cl–B	Over 50	Over 330	10	See note *a*
Cl–C	8 to 300	50 to 2000	6	
Cl–C	Over 300	Over 2000	8	See note *a*
All classes except Cl–AA	Less than 8	Less than 50	4	

Note a. Where divided highways are provided, the width of shoulder may be reduced to six feet.

The lateral clearance between any vertical obstruction, one foot or more in height required for drainage, bank control or traffic protection, and the edge of a traffic lane should not be less than that specified in table 2 above, except as noted hereafter.

Shoulders shall be continuous throughout except across "long bridges." See section 1–21 of this chapter for minimum roadway widths of "long bridges." In rough topography, it will be permissible to narrow shoulders to a minimum of 4 feet at points where extremely heavy grading must be made, providing full width shoulders are made available at other locations. Sections of narrow shoulders should be limited in length so that stopping at these sections is not encouraged. Transitions between sections of narrow and full width shoulders should be made in long flowing curves.

Shoulders should provide adequate support for all standing or disabled vehicles. The greater the traffic density, the more likelihood there is of the shoulder being put to emergency use and the more desirable it is that its construction be such that it is usable under all weather conditions. The shoulders of all primary and secondary roads within troop training and storage projects likely to have hourly traffic volumes exceeding 15 vehicles per hour (100 vehicles per day) should be constructed for use under

all weather conditions. The shoulders of roads of other type installations where the hourly traffic volumes equal or exceed 50 vehicles per hour (330 vehicles per day) should be constructed for use under most weather conditions.

Soil conditions may require that shoulders be surfaced or existing soil material be stabilized for use under unfavorable weather conditions. Materials specified in section 1–32*a* of this chapter are suitable for all weather shoulders.

Surfaces of all shoulders should be, as far as feasible and practicable, dustless and should contrast in texture and color with adjacent traffic lanes. This can be accomplished by treating the surfaces with bituminous or commercial materials, by sodding or seeding. Turf can be developed and maintained in shoulders constructed of aggregate materials, supplied with required plant nutrients, capable of supporting highway loads. For additional information see Part XIV of the Engineering Manual. Shoulders should be constructed and maintained flush with the edge of pavement (traffic lanes), so that vehicles traveling at design speeds may leave the pavements (traffic lanes) without danger of the driver losing control.

1–11 PARKING LANES. Most typical lay-outs prepared for various type installations and shown in part II of this manual, provide off-street car parking facilities at theaters, chapels, post exchanges, industrial buildings and similar places of public assembly. Separate facilities for the repair, storage, and parking of organization vehicles at or near troop housing areas are also shown. Provision for these off-street facilities reduces to a minimum the necessity of parking lanes along streets of Army installations. Where mass on-street parking is required, it should be, so far as practicable, limited to streets of the secondary and tertiary classification. However, on-street parking may, in some instances, be required along a primary street. As an illustration of the latter, take the case of the main circulating thoroughfare street within an area designated principally for family and bachlors' housing of officers, enlisted men, and civilians, installation of parking lanes along these streets may be required.

The width of parking lane depends upon the method of parking and character of traffic. In the interest of economy and convenience to traffic, the method should be confined to parallel parking. For parallel parking of passenger vehicles, a width of 8 feet is considered adequate. This width is adequate for parallel parking of most trucks. Where the gutter is of type of construction adequate to support and permit cars to stand with one wheel in it, the gutter may be considered as a portion of the parking lane. Parking lanes may be provided on both sides or limited to one side of a street only, depending upon parking requirements.

Parking lanes will usually conform in pavement type to that of the adjacent traffic lanes. However, where funds are limited, construction types specified for shoulders under paragraph 1–10 may be used as a temporary expedient. These temporary shoulders should be replaced as construction funds become available.

1–12 MINIMUM STREET WIDTHS. The following criteria shall be used in establishing pavement widths of streets within built-over areas of all Army installations except as noted hereafter. General application of this criteria as they relate to any 2-lane, 2-directional street is shown on figure No. 16.

a. Streets with parking. The minimum pavement width of an undivided street upon which mass on-street parking (parallel) is to be permitted should be equal to the combined width of all required traffic and parking lanes.

The minimum pavement width of a traffic-way of a divided street upon which mass on-street parking is to be permitted should be equal to the combined width of all traffic lanes and one parking lane. However, mass on-street parking should normally be avoided along the traffic-ways of divided streets, as they are primarily designed and intended as freeways for fast moving vehicles. In no event, should a parking lane be provided adjacent to the medial strip of a divided street.

b. Streets without parking. There are many streets within Army installations upon which mass on-street parking will be prohibited due to presence of adequate off-street parking facilities. However,

sufficient space must be allowed along some of these streets to care for the occasional disabled vehicles or other vehicle stopped temporarily to load or unload passenger or materials, without interfering unduly with the free movement of traffic or creating a hazardous traffic condition. This is particularly important on 2-lane, 2-directional streets. Similar provisions are not usually required along trafficways of divided streets or along 3- or more lane undivided streets. In the former case ample facilities are provided elsewhere, whereas in the latter case, the temporarily standing vehicle can be accommodated safely in one lane leaving the remaining lanes for the passage of through traffic without too much restriction.

Therefore, the width of each traffic lane of all primary 2-lane, 2-directional streets of Army installations, except cemeteries along which mass on-street parking (parallel) is to be prohibited, should be 3 feet greater in lane width than given in table 2 section 1–09 for the various street classifications and traffic densities shown. Traffic lanes of secondary and tertiary 2-lane, 2-directional streets within Army installations, except hospitals and cemeteries, should be similarly increased in width where volume of traffic equals or exceeds 25 vehicles per hour (30th highest hour). In making application of this criteria, no portion of a paved gutter shall normally be considered as a part of a traffic lane.

c. Pavement widths at bus stops. The traffic lane should be increased at bus stops over the widths specified in paragraph *b* above. Sufficient width lane or paved area shall be provided at these points to permit any commercial or private buses to stand clear of the normal traffic lane when loading or unloading passengers. Length shall be adequate to accommodate a single or group of vehicles. Such areas should only be provided at regularly designated bus stops on primary and secondary roads, where volume of traffic exceeds 25 vehicles per hour.

d. Hospital streets. The criteria given under section 1–09 and section 1–12 above, except as hereafter noted, shall not be used in establishing width of traffic lanes or pavement widths of streets within hospitals. The width of traffic lane of any street at hospitals shall not be less than 10 feet regardless of traffic density. A 2-lane, 2-directional street will usually suffice for the normal installation. Pavement widths of primary streets for hospitals will conform to criteria given in section 1–12 *b* above. Off-street parking facilities will be provided at hospitals for mass parking, thus permitting the paved widths of all secondary and tertiary streets at hospitals to be limited to 20 feet in width. Furthermore, the volume of traffic using these streets will not, in the normal size installations, exceed 25 vehicles per hour (30th highest hour). Furthermore, traffic volumes in excess of the above occur so seldom or are of such short duration that the inconvenience caused traffic at such times can be disregarded. The width of fire lanes, or lanes for maintenance equipment at hospitals shall not exceed 10 feet and shall be so constructed as to cause the minimum interference to the crossing of wheel chairs and handicapped individuals.

e. Cemetery streets and roads. The criteria given in section 1–09 for Class C highways shall be used in establishing traffic lane widths of cemetery highways. Cemetery highways may be constructed in conformity with either the typical street or road cross section of figure No. 3. Pavement widths of streets should not be determined in accordance with criteria given in section 1–12. Pavement and overall roadway widths of cemetery highways will conform to that specified in planning or construction directives. Pavement widths of roads and streets for normal size installations are shown on figure No. 17.

1–13 SINGLE TRAFFIC LANE ROADS. There are many roads and streets within Army installations, particularly those falling in the tertiary classification, where volume of traffic will not warrant more than one traffic lane. On such roads and streets single traffic lanes should be provided if traffic density does not exceed 8 vehicles per hour. In such cases, shoulders of adequate width or turnouts at frequent intervals should be provided for use in occasional passing or meeting vehicles.

1–14 THREE LANE ROADS. Practical working capacities are given for 3-traffic lane highways. The construction of 3-traffic lane highways is not recommended for streets within Army installations. The construction of 3-traffic lane roads in "other areas" should only be considered where it is possible to provide passing sight distances on almost all sections of the road.

1-15 DIVIDED HIGHWAYS. Where traffic counts justify four or more traffic lanes and the highways are planned and designed for relatively high speeds, consideration may be given to the construction of divided highways where practicable. Statistics indicate fewer accidents per million miles of travel on four-lane divided highways than on four-lane undivided highways. The additional expenditure required for divided highway construction may be justified on the basis of safety and convenience to travel and the greater traffic density such roads will accommodate.

However, prior approval should be secured from OCE for the construction of divided highways. Recommendations for such installations should be accompanied by plan showing location and cross section of the proposed construction, the estimated additional cost, a statement outlining traffic and other conditions warranting the improvement, and the identity of individuals or agencies concurring in recommendations.

When so provided, divided highways should be considered in the nature of express highways on which the convenience of access traffic should be subordinated to the requirements of through traffic. Openings in the median strip permitting left turns should be limited so far as practicable. Indeed, the desirability of permitting an opening across the median strip for every cross road may be questioned. It may be desirable and economical to reduce such crossings to a minimum by providing service road connections between the provided openings.

Divided highways provide for vehicles moving in opposite directions to be separated by a median strip. The width of median strip provided on divided highways is a most important factor in reducing conflicts between through, crossing, and turning traffic at intersections at grade and should be given special attention, particularly if crossings are numerous.

The width of median strips at grade intersections of road and streets at Army installations should be as follows:

Table 3.

Location	Width in feet	
	Minimum	Desirable
Other areas	18	40
Built-over areas	10	30

The width of median strips at points other than crossings should not be less than 10 feet.

The above minimum median width of 18 feet combined with compromised length of opening of 57 feet will provide protection for all passenger cars and most light weight trucks crossing and turning left to the opened area, but vehicles that turn left onto the divided highway must begin the turn in the face of the opposing cross-road traffic before reaching a protected position in the median area. The above stated desirable median width of 30 feet when combined with a length of opening of 80 feet will provide practically the same protection for single unit vehicles whose overall length does not exceed 30 feet and have short turning radius. The above stated desirable width of 40 feet when combined with length of openings of 70 feet through the median strip will provide protection for all single unit vehicles whose overall length is 40 feet or less, crossing, turning left, or making U-turns. Single unit vehicles in excess of 40 feet in length and combined vehicles in excess of 35 feet in length will in making U-turns be required to go around the block for left turning or make use of any available shoulder or parking lane.

Narrower widths of median strips than specified above in combination with proper lengths of openings may be utilized to provide full protection for all vehicles making left turns only, but will not provide protection for cross traffic in median openings. The use of the extremely long openings required thereby is not recommended in view of conflict that will occur between pedestrian and vehicular traffic. To permit vegetative growth, median strips, at points other than crossings, should never be less than 10 or 12 feet wide.

1-16 CROSS SECTION. The cross section deals with the transverse profile of the right-of-way. Care must be exercised in designing the cross section to adequately care for the various related and associated functions the highway is to provide.

a. Cross section—Undivided highways. Typical cross sections for undivided highways are shown on figure No. 3. The type of cross section for streets within "built-over areas" should conform in general to standard section designated "Street Type." This section is designed to carry all vehicular traffic, permit where necessary the parking of vehicles and conduct all drainage water from the street area and from the adjacent property to inlets of an underground drainage system. This obviates the necessity for undersirable and unsightly drainage ditches within these closely built-up areas and permits with minimum of interference, servicing the adjacent facilities and properties.

The type of cross section for roads within "other areas" should conform to standard section designated "Road Type." This section is designed to carry all vehicular traffic and provides shoulders adequate in width and of sufficient carrying capacity to support standing or disabled vehicles clear of the road.

The cross section of a road or street consists of independent units, the design of each being developed in harmony with the other parts, but on the basis of the particular function of the part. These typical sections show all elements that must be considered in developing the design. Certain parts shown on these sketches may be omitted permanently and construction of others deferred temporarily due to lack of construction funds. However, no part should be omitted permanently or construction deferred until consideration has been given to the need of that part for the particular road or street in question.

Thus, if lack of current construction funds precludes the construction of curbs, gutters, inlets and underground facilities on a street located within built-over areas, a system of roadside gutters, ditches, and culverts may be provided as a temporary drainage expedient pending further fund appropriations. However, the design of the cross section to be currently constructed should be developed so that when the ultimately desired section is built, such that reconstruction can be done at minimum expense with least disturbances to the other permanent parts of the cross section.

b. Cross section—divided highway. Divided highways need not be of uniform cross section. Median strips may vary in width, the trafficways may be at different levels and super-elevation may be separately effected in each trafficway. The high point of the crown may be at the center of each trafficway where drainage in the median area is provided.

The design of the cross section for a divided highway will be dependent upon the nature of the terrain and local conditions. Through level and rolling terrain, the trafficways may be at approximately the same elevation, providing ample provision is made for surface drainage of the interior portion of the trafficways and the median strip either by means of a ditch in the center of the median strip or gutters adjacent to the edge of the pavements common to the median strip.

On level rolling terrain, it may be desirable to maintain the center of the median strip as the highest point in the roadway, especially where the median strip is less than 18 feet in width. Surface drainage in this instance should be provided in the conventional manner by roadside ditches or curbs and gutters at the outer edges of the pavements. In regions where snow prevails, this method of design should be discouraged as the snow collecting in the median strip (either by usual snowfall, drifting, or by storage of snow removed from the pavements) will upon melting result in moisture soaking and reducing bearing value of base courses under the pavement or cause water to flow transversely across the pavement. Such water upon freezing creates a hazard to vehicular traffic.

Through sloping or sidehill terrain, the trafficways may be constructed some distance apart and at different elevations. Drainage of interior surfaces of the trafficways should be accomplished by provision of adequate drainage facilities located in the median strip. Care should be taken in not having too great a difference in roadway elevations, otherwise the cross slopes required within the median strip may be so steep as to present a hazard to traffic unless some means of protection is made available.

c. Slopes. In general, slopes should be as flat as feasible and rounded to the extent practicable within grading limits. Fill slopes up to 6 feet in height should not be greater than 1 on 4 and above

6 feet not greater than 1 on 2 if possible. Back slope in excavation of 1 on 2 except in solid rock cuts is desirable. Ditch slopes in excavation should not be steeper than 1 on 4. Roadside slopes of both cut and fill should be rounded to provide a smooth transition from roadway into the surrounding terrain. Sterotype and too regular rounding of slopes should be avoided.

Control slopes indicated above and shown on cross sections of figure No. 3 are the preferred rates of slope desired from a traffic safety standpoint and ease of maintenance. These slopes may be modified where deemed desirable and practicable for landscape requirements, conforming with existing or contemplated improvement adjacent to streets, restoration of vegetation, reduction of soil erosion and drainage. Slopes in many existing Mobilization and T/O camps are steeper than those specified herein due to anticipated life of these camps and in part to bar indiscriminate crossing of ditch lines by inexperienced drivers. Where conditions of these slopes establish that these steeper slopes are satisfactory, slopes may be modified accordingly where desirable to avoid disturbances of existing utilities and to accomplish reductions in construction costs.

d. Crown or cross slope of roadway. The roadbed should be provided with cross slope or crown for drainage. The rate of crown or cross slope for the roadbed should be the minimum consistent for acceptable drainage based upon the type of surfaces provided and longitudinal grades. The equivalent rates of cross slopes should be followed so far as practicable for unsymmetrical cross sections. The rate of crown should not exceed ¾ inch per foot for natural soil, clay sand, or gravel surfaces, ¼ inch per foot for bituminous surfaced areas, and ⅛ inch per foot for portland cement concrete surfaces.

e. Curbs and gutters—street section. Curbs, combination curbs and gutters, or shallow paved gutters will be required to control drainage along streets constructed to conform to cross section designated "Street Type" of figure No. 3. Curbs should be provided adjacent to sidewalks and along raised median strips of divided highways. Paved gutters only may be used along streets where there are no paralleling sidewalks. Curbs should be 6 to 8 inches in height with the faces nearly vertical. Curbs of this height are not absolute barriers but effectively control almost all vehicles under ordinary circumstances as they are mounted only with some difficulty. Gutters should be of sufficient width to care for and direct storm water to appropriate inlets. The width of paved gutter should not be considered as a portion of the traffic lane.

f. Curbs and gutters—road section. The use of curbs along roads constructed to conform to cross section designated "Road Type" should be avoided except where necessary to control drainage. Curbs and gutters may be required on steep grades to prevent erosion of shoulders and fill slopes. Where curbs are used, they should be located outside the edges of traffic lanes and should be low and flat with the incline on traffic side not steeper than 45° so that vehicles may mount them without difficulty. Suitable inlets with pipe outlets or paved gutters extending across the shoulders and down the fill slopes, should be provided to prevent erosion. Special care should be given in the design of these paved gutters so that when in place they are not hazardous to traffic using the shoulders.

g. Drainage. The nature and extent of the drainage facilities that must be provided will vary with the type of soil on which the highway is built, the precipitation in the area where the highway lies and the topography. Erosion problems vary with the same conditions. For discussion as to methods and design for roadway drainage see chapter 4, part XIII of this manual.

1-17 ALINEMENT. Typical lay-outs for various types of military installations are included in part II of this manual. These lay-outs provide schematic systems of roads and streets that are governed by facilities served. However, the exact applications of these typical lay-outs to proposed installations are problems of engineering economics governed principally by topography of site and other conditions.

a. Horizontal curves. In general, it is desirable to have a straight tangent between termini of a road or street. The nature and character of terrain, limitation as to grades, present use or development contemplated of the land in the immediate vicinity of the highway and other conditions, precludes this in many instances at Army installations requiring changes in alinement of individual roads and streets.

Where changes in alinement are necessary, horizontal curves should be used wherever practicable, to connect the two tangents. In all cases consideration should be given to the use of the flattest curvature practicable under existing conditions. Maximum curvature should be in accordance with the following table:

Table 4.

Assumed design speed (mph)	Degree of curve	
	Desirable Maximum	Absolute Maximum
30	20	25
40	11	14
50	7	9
60	5	6
70	3	4

The absolute maximum curvature is based upon a practical maximum superelevation and a safe value for side friction factor of 0.16 for speeds up to 60 mph. and 0.14 for a speed of 70 mph. The desirable maximum curvature is based upon the same friction factor but approximately half the maximum superelevation. Figure No. 4 provides recommended design data relative to the rate of superelevation, the minimum length of transition and the additional widening of two lane pavements deemed desirable on horizontal curves for design speeds 30, 40, 50, 60, and 70 miles per hour.

b. Superelevation—undivided highways. Curves 1°30′ and sharper should be superelevated in accordance with the table of figure No. 4. The superelevation values are based on the assumption that all centrifugal force resulting from a speed of three-fourths of the design speed is counteracted by the effects of superelevation up to a maximum practicable limit of 0.10. Figure No. 5 provides data relative to method of attaining superelevation on horizontal curves by rotation of the normal cross section (tangent) about the inside pavement edge of the curve. The outer half of the pavement should be warped from the crowned section at a point on the tangent to a level section at the T.S. so that the difference in slope between outer edge of pavement profile and the centerline profile is not greater than 1 in 400. Transition from a level section at the T.S. to the point of full superelevation in the curve should be on a smooth uniform grade line. This should be accomplished in such manner that the difference in slope between longitudinal profiles (outer edge of pavement—centerline profile) will not be greater than 1 in 200. Vertical curves should be used at points of longitudinal profile grade changes to round off angular breaks.

c. Superelevation—divided highways. Figure No. 5 shows a method of attaining superelevation where trafficways separated by a median strip are at approximately the same elevation. This is accomplished by establishing the profile grades at the edges of the respective pavements adjacent to the median strip and rotating the pavements upward or downward about these edges, dependent on direction of horizontal curves. Curbs should be constructed at edges of pavements adjacent to median strip, with ample provision for draining the outer pavement.

Where pavements are separated by wide median strips, 30 feet or over, or are at different elevations, superelevation may be separately effected in each trafficway. The method of superelevation should be similar to that shown for undivided highways of figure 5.

d. Spirals. Transitional spirals serve two purposes, (1) affecting gradual changes from crowned or level sections to the maximum superelevated section, and (2) permitting a driver of a vehicle to stay within his traffic lane while traversing the curve at the uniform speed for which the curve was designed. The minimum length of spiral should preferably permit complete transition in superelevation. Figure No. 4 provides the minimum lengths of transitional spirals required on horizontal curves for stated design speeds. These spirals are of sufficient length to meet the expressed speed requirements and permit a smooth gradual transition from tangent alinement to full superelevation of the curve. Minimum transi-

tional spirals should be, wherever practicable, incorporated on 2°15′ or sharper curves in accordance with values given in this table.

e. Widening. When a vehicle travels on a curve at a speed greater than that at which the centrifugal force is counteracted by the superelevation, the rear wheels assume a position farther out in order to provide the "slip angle" (angle between car axis and direction of travel, or tangent, at rear axle center) necessary to develop the required friction. Where speed is increased causing the rear wheels to track outside the front wheels, widening of traffic lane will be required. Widening also is required, for added safety, partly because drivers do not drive as close to the far edge of opposing traffic lanes on curves as on tangents, and partly because increased clearance is needed where sight is restricted. Figure No. 4 provides the total widening, in feet, recommended for two-lane pavements. This is the widening normally required for off-tracking and may not provide increased clearance where sight is restricted. The increased sight distance might better be provided by removing obstacles to view, outside of roadway limits. Figure No. 6 shows the relation that an obstruction to view, located on the inside of certain degree curves, has to sight distance along the centerline of the curve. The clear-sight distances along the centerline of horizontal curves should be equal, wherever practicable, to the non-passing sight distance given in table 4, paragraph 1–20*a*. The additional width should be added to the inside of the curve, starting with zero widening at the T.S., attaining the maximum at the S.C. as recommended for the curvature and design speed shown in figure No. 4 and diminishing from the maximum as the C.S. to zero at the S.T. as shown on lay-out sketch on figure No. 5.

1–18 INTERSECTIONS AT GRADE. Substantially all streets within Army installations will intersect at grade. The intersection area is a part of the intersecting highways and should be designed to adequately accommodate all anticipated turning and crossing movements. Figure No. 7 provides design data for obtaining the minimum paved areas required for turning movements of single-unit vehicles. Figure No. 8 gives the recommended minimum radii of curbs required at street intersections to provide the minimum paved areas obtained by lay-out method shown in figure No. 7. The design data have been developed from the dimensions of military and civilian vehicles considering the mechanical limitations of vehicles and the driving characteristics of average operators. The majority of single-unit vehicles can negotiate these curves in making right turns without infringing upon the path of oncoming traffic in the left lane of the intersecting street.

1–19 GRADES. The designing of longitudinal grades involves the consideration of the characteristics of traffic and of certain physical factors associated with the site, such as drainage, access to adjacent property, appearances and safety. The following table gives the desirable and absolute maximum rate of gradients for roads and streets located within Army installations:

Table 5.

Road class	Desirable Maximum	Absolute Maximum*
Class AA Highways	3%	5%
Class A Highways	4%	7%
Class B Highways	5%	8%
Class C Highways	6%	10%

*If abnormal conditions require gradients in excess of these, report conditions and recommendations for prior approval of O.C.E.

Maximum curvature, table 4, paragraph 1–17*a* and maximum gradient, table 5, paragraph 1–19, particularly on primary and secondary roads, should not coincide. The above maximum gradients are established on the basis of operating characteristics of military vehicles and with the view of facilitating

movement of traffic. Grades below the maximum rate should be fixed with a view to keeping the excavation costs as low as possible, after due consideration of the drainage, safety and aesthetic features of the site.

Minimum grades are determined by hydraulic conditions rather than vehicular traffic. The "built-over areas" where curbs and gutters are to be installed, minimum grades of 0.3 percent should be used to insure drainage, with a greater slope employed where practicable.

At points of longitudinal grade changes, vertical curves should be introduced to improve riding qualities and provide maximum vertical sight distances. Any vertical curve on a highway should be as long as possible, incorporating appearance, economical construction and safety. Its minimum length should be based on sight distance requirements. Parabolic curves (see fig. 9), owing to their easement qualities and adaptability to the method of offsets, should be used for vertical curves. Since the curvature of the parabolic curve varies slightly from point to point, the sight distance will do likewise and will be most restricted across the summit. Therefore, control of sight distances at summits will satisfy all other positions of a vehicle. Vertical curves on summits should, in every case, have sufficient length to permit the operator of a vehicle to take appropriate action in case of emergency stopping or passing. Figure No. 10 provides design data showing the relation between sight distances, length of vertical curves and the algebraic differences in gradients in accordance with the tables given under paragraph 1–20.

1–20 SIGHT DISTANCES. While it is desirable to construct project highways on which adequate sight distances for safe passing are available at all locations, the limitations of topography and right-of-way make it economically inadvisable to do so. When sight distance sufficient for passing cannot be obtained, the sight distance should in no case be less than the nonpassing minimum given in table 6 below, and preferably should be increased above the nonpassing minimum as much as is economically feasible. Where funds are limited, consideration should be given to making necessary expenditures by providing safe passing sections at frequent intervals instead of increasing sight distances at all critical points above the minimum given in table 6 below. Sight distances on project roads within "other areas" should be designed to provide the minimum nonpassing sight distance given in table 6 below based on a design speed of 60 miles per hour on flat terrain, 50 miles per hour on rolling terrain and 40 miles per hour on mountainous terrain. Sight distances for project streets in "built-over areas" should be designed to provide, wherever practicable, the minimum nonpassing sight distance given in table 6 for a design speed of 30 mph. Where horizontal curves occur over summits, the vertical sight distance should exceed the horizontal sight distance.

Sight distances should be recorded on the plans for the construction and improvement of roads and streets of Army installations. For two- and three-lane highways, the location of safe passing sections should also be recorded.

a. Nonpassing. The nonpassing sight distance is the longest distance in which a driver, whose eyes are assumed to be 4.5 feet above the pavement surface can see the top of an object 4 inches high on the road and is the length of road required for the driver of a vehicle traveling at the design speed to bring his vehicle to a stop before reaching a stationary object in the same lane. The minimum nonpassing sight distance on highways within Army installations should be at least equal to the distances shown for the various assumed design speeds of the following table:

Table 6.

Assumed design speed of highway (mph)	Minimum nonpassing sight distance (feet)
30	200
40	275
50	350
60	475
70	600

b. Passing. The passing-sight distance is the longest distance in which a driver whose eyes are assumed to be 4.5 feet above the pavement surface can see the top of an object 4.5 feet high on the road and is the length of road that must visibly be free of oncoming vehicles in order that the driver of a vehicle traveling at the design speed can pass a slower moving vehicle. The passing-sight distance for highways in Army installations should, so far as economically practicable, be in accordance with the recommended distances given in the following table:

Table 7.

Assumed design speed of highway (mph)	Minimum passing sight distance	
	Desirable feet	Absolute feet
30	600	500
40	1,100	900
50	1,600	1,400
60	2,300	2,100
70	3,200	2,900

1-21 HORIZONTAL AND VERTICAL CLEARANCE FOR BRIDGES. On "long bridges" the horizontal clearance between roadway curbs (width of roadway) should be six feet greater than the total width of approaching traffic lanes. On "short bridges" the horizontal clearance between roadway curbs (width of roadway) should be equal to the total width of the approaching highway, including all traffic lanes, parking lanes, and effective width of shoulders. The distance from the face of roadway curb to the face of handrail or any other structural member should be one foot or more. Sidewalks or safety walks should be included on all structures wherever pedestrian traffic justifies. The clear height of all structures should be at least 14 feet over the entire width of traffic lanes and at least 12½ feet over the effective shoulder width.

1-22 HORIZONTAL CLEARANCES FOR CULVERTS. The clear width of roadbed at culverts should be sufficient to carry traffic lanes, median strips, sidewalks, shoulders, or parking lanes without reduction and, as necessary, for the continued slope outside the shoulders.

1-23 GUARD POSTS AND GUARD RAIL. There will be many sections of roads and streets within Army installations where guard posts or guard rail will be required for the protection and guidance of traffic. Guard rail should be placed on all sections of roads and streets where a vehicle operated with ordinary care might, if it left the roadway, be damaged and result in injury to the occupant. Guard posts should be placed on sections of roads and streets where drivers may be confused as to direction of road and where driving off the roadway is prohibited. Driving off the roadways at these points may not be particularly hazardous to either vehicles or their occupants.

It is impracticable to formulate rules applicable for all conditions likely to be encountered. The following general regulations are given for the purpose of obtaining reasonable uniformity of guard post and guard rail installations at Army projects.

Except as stated below, guard post and guard rail will not normally be required on sections of highways constructed with comparatively flat embankment slopes, where the height of roadway above natural ground surface is 6 feet or less.

Wherever a highway will be flooded at high water stages and the fill is 2 feet or more in height, guard posts should be installed on both sides at uniformly spaced intervals. The distance between posts should not exceed 50 feet. These guard posts should be marked to indicate the approximate depth of water over pavement surface in order that the operator of a vehicle can take the necessary and appropriate action required.

Sections of highways on tangents or curves of 5° or less, where the height of roadway above natural ground at the toe of fill is 6 feet or more but not in excess of 10 feet should be protected by guard posts installed at regularly spaced intervals. Spacing between posts should not exceed 50 feet. The natural ground at the toe of the fill should not be inundated. Similar sections of highways on curves in excess of 5° should be likewise protected if the height of fill is 4 feet or more but not in excess of 6 feet. Guard rail should be used in lieu of posts at all points where the toe of fill may be inundated 2 feet or more.

Short sections of guard rail should be installed on approaches to bridges which have roadway widths narrower than approach roadways. These sections should be spread or flared out, particularly on the side of approaching traffic from end of the bridge handrail to the shoulder edges of the roadway to increase visibility and avoid possibility of head-on collision with bridge rail.

Narrow shoulders or berms, curbs, deep ditches close to pavements, inadequate superelevation of the pavement, side hill locations, kind and type of pavement as well as other conditions or combinations of these items are factors that may necessitate modifications from these general regulations. Guard posts and guard rails should be set near the shoulder line. All posts and rails will be painted for visibility. Reflector buttons should be set in the posts, particularly on side of the approaching traffic, for better night visibility. One or more panels of end sections of guard rail should be spread or flared outward for increased visibility and to avoid possibility of striking end anchors or head-on collisions with the rail.

1–24 MARKING AND POSTING OF ROADS AND STREETS. It is essential that the road user be amply warned as to the restrictions and hazards present in the highway. It is customary to provide markers and directional signs for the guidance of traffic. These warnings and directions consist of pavement markings and shoulder signs or a combination of both. Provision for necessary pavement marking and posting of signs is covered in TM 5–624—Roads, Runways and Miscellaneous Pavement. All sight distances should be recorded in plans covering reconstruction and new construction for assistance in the proper marking and posting of project roads.

STRUCTURAL DESIGN

1–25 GENERAL. The required load-carrying capacity of the highway is the prime factor influencing structural design of the highway structure. The highway classifications given under subparagraphs 1–02 *f*, *g*, *h*, and *i* delineate, in general, the differences in load-carrying capacities required of project highways within Army installations.

There are two general types of roadway pavement, namely, the rigid and flexible types. Rigid type pavements include portland cement concrete pavement with or without reinforcement and portland cement concrete base with or without reinforcement having a bituminous or brick wearing course. Flexible type pavements consist of a well-compacted subgrade or base course on which is placed a bituminous surface course or a suitable surface course composed of selected soils and aggregate. The load-carrying capacity of a highway is dependent upon the design and construction of the elements of the road structure, i.e., the foundation, subgrade, base, pavement, and drainage facilities. The design and construction operations of some of these elements are practically the same for both pavement types and are discussed in general under appropriate headings. The design and construction operations of the elements which differ are discussed under separate headings for the appropriate "Flexible Type" and "Rigid Type Pavement."

1–26 COMPACTION CONTROL TESTS. The stability of embankments, subgrades, and base courses is dependent upon the degree of density at which the soils comprising these elements are compacted. The density to which soils are to be compacted in highway embankments, subgrades and base courses shall be determined, so far as practicable, by the American Association of State Highway Officials

(AASHO) Method T-99-38 as modified by the Corps of Engineers. Modifications made by Corps of Engineers include changing the weight of the tamper from 5½ pounds to 10 pounds, dropping the tamper from a distance of 18 inches above the sample instead of 12 inches, compacting the samples in five equal layers (approximately 1 inch each) instead of three equal layers, using 55 blows per layer in a 6-inch mold and using aggregate particles up to ¾ inch size. All material larger than ¾ inch should be removed and replaced with an equal amount of material between No. 4 sieve and the ¾-inch screen.

Control tests other than described above may be required for certain types of soils. The Modified AASHO Method should not be used if the soil contains particles which are readily broken under the blow of the tamper unless the field method of compaction will produce a similar rupture of particles. The unit weight of certain types of sands and gravels as obtained by the Modified AASHO Method is often not representative of the unit weight that can be obtained by field methods, hence the Modified AASHO Method may not be applicable. Density tests in these cases should be made under other modifications of the AASHO Method, such as tamping with other type or weight of hammer, by static pressure or vibration (alone or in combination). The method of control adopted should produce the maximum unit weight that can be obtained by the field compaction equipment to be used in construction.

1-27 COMPACTION PROCEDURE. Specifications should stipulate the compaction to be obtained in construction as a degree of the maximum density obtained in the laboratory compaction test. It is recognized, however, that the degree of compaction obtained by the laboratory test cannot always be obtained practicably in construction. The degree of compaction stipulated in the specifications should be based on the maximum density that can be economically and practicably obtained with modern compaction equipment consistent with the efficiency of the item under consideration as it relates to the completed highway structure. A study of physical properties of the soils to be compacted, based upon the experienced judgment of the designer or engineer, should permit the insertion of a percentage of the maximum compaction obtained by laboratory methods which are practicable of attainment by field forces with modern compaction equipment. Studies of physical characteristics of soils should furnish information on moisture control procedures, thickness of lift, equipment type, weight, and number of passes required to secure the desired density.

1-28 FOUNDATIONS. The entire roadway should be cleared and grubbed in accordance with the requirements of standard specifications. Embankments should be placed on sound foundations as nearly level as possible. If foundation conditions for embankments are found to be unstable or are apt to become unstable, suitable corrective measures should be included in construction plans and specifications. Foundations should be stripped of all topsoil and sod which would be objectionable as a foundation under a fill or as subgrade material when incorporated in a fill. The soil survey data should be studied for evidence of the presence of any inclined planes, of bodies of soft or saturated material and of water in the form of springs and seepages. Wherever practicable, the removal and replacement of material of low bearing value with suitable material should be made. The cost of removal and replacement should be compared with the cost of alternate methods, such as trestling the area or obtaining stability through supercharged fills and drainage. Good and sound engineering practices should be followed in these cases. Wherever practicable, slip planes should be graded out to a substantial bench before embankments are placed. Springs or seepage water should be collected and drained from soils upon which embankments are to be placed, in a manner so thorough that saturation of the soil is improbable.

1-29 EMBANKMENT. Stability of an embankment is dependent upon the character of material employed and in the case of fine graded soils upon its moisture content and the densities at which such materials are placed. Success in embankment construction is dependent upon careful selection, placing, and compaction of soil materials. An effort should be made to arrange construction procedures so that the better soils will be in the top of the finished grade. The most suitable soils should be selected for topping of embankments unless construction limitations made such selection uneconomical. Distribution

of soil materials which produce the best and most economical soil structure requires close cooperation between designing, construction, and inspection forces.

Embankment compaction should insure required stability, consistent with costs, for the purposes for which the embankment is required. Method of compaction should be based on the character of the material, amount of moisture normally present in the excavated material and percentages of compaction required. For general requirements each layer of an embankment should be compacted to 90 percent of maximum density obtained at optimum moisture content as determined by Modified A.A.S.H.O. Method described under 1–26 of this chapter.

1–30 SUBGRADE. The subgrade structure on which the base and pavement courses are to be placed is most important. Subgrade preparation involves the processes of improving the stability of the soils of the immediate zone underlying the base or surface courses and preventing occurrences of undesirable conditions within this zone as well as the proper shaping of the surface of the subgrade to proper elevation and contour for receiving the subsequent base and surface courses. Laboratory tests should be conducted on soil samples taken from the subgrade to determine the physical and behavior characteristics of the subgrade soils. These characteristics indicate the most suitable type of treatment required. The basic idea is to build the most stable subgrade practicable which will be least affected from moisture and temperature changes and protect it by adequate drainage.

Adverse soils such as adobe and certain clays which exhibit large changes in volume of varying water content, encountered at subgrade level in cuts, should be removed and replaced with suitable material. The depth to which such adverse soils should be removed or covered is dependent upon the kind of soil and drainage conditions and should be determined by the experienced judgment of the designer or engineer on the basis of service records, traffic to be served and costs involved. Wherever a portion of the excavated material is of a sandy or granitic nature, such select material should be conserved and utilized, if practicable, for subgrade purposes.

Markedly adverse soils should be removed and replaced by suitable material. In some instances adverse soils may be economically improved by blending and mixing materials with these soils whereby the physical and behavior characteristics of the composite material becomes suitable for subgrade purposes. Methods and design procedure outlined under chapter 5, part XII, are applicable. However, subgrade stabilization should not be attempted unless the costs reflect corresponding savings in base, pavement, or drainage construction.

Compaction, in general, improves the stability of the subgrade soils and provides a uniform foundation for base and pavement courses. Most subgrade soils when compacted at optimum moisture and density offer the greatest resistance to change. Therefore, except in areas where the soil is clay or has expansive characteristics, the entire subgrade area should be scarified, moistened if necessary, to approximately optimum moisture content and compacted by suitable means to a minimum of 95 percent of maximum density as determined by the Modified A.A.S.H.O. Method or other suitable compaction test methods. The minimum depth of compacted subgrade under the base or pavement should be not less than 6 inches.

FLEXIBLE TYPE PAVEMENTS

1–31 GENERAL. The California Bearing Ratio (CBR) Method should be used for evaluating subgrade and base course materials and for determining the required thickness of base and pavement for flexible type pavements. The CBR method of design and tests are described and explained under chapter 2, part XII. Testing of both subgrade and base course materials used in the construction of highways and storage area should conform to criteria given therein. However, the required thickness of base and pavement for highways and storage areas should be determined from the load curves given in figure 11 of this chapter.

1–32 BASE COURSES UNDER FLEXIBLE PAVEMENTS. A base course is required under flexible pavements where the subgrade does not provide sufficient support for the traffic loads. Base courses act as a stress distributing medium to insure that the stresses imposed by standing or moving wheels will not exceed the strength of the subgrade. They should have sufficient structural stability, toughness, and thickness to withstand the complex stresses produced by standing or moving wheel loads and to distribute adequately the wheel load pressures to the subgrade. Base courses should be sufficiently resistant to vertical pressures produced by wheel loads to prevent consolidation within themselves that would result in distortions of the bituminous surface. They should be resistant to volume changes or softening due to climatic variations and moisture variations.

a. Base course materials and compaction. Base courses may consist of natural materials such as selected soils, gravels, sands, limerock, shell, caliche, etc., used singly or in combination or processed materials such as crushed stone, crushed and graded gravel, slag and crushed limerock. The latter materials usually have the higher bearing ratios. Where natural or processed materials of satisfactory CBR are not economically obtainable, available materials may sometimes be stabilized to produce satisfactory results in accordance with the design and construction criteria covering soil stabilization given in chapter 5, part XII, of this manual. The composite and resulting material should provide a base course material having a satisfactory CBR.

Thorough compaction of base course layer is highly important to develop the maximum stability of which the material is capable. All base course layers should be compacted to the maximum density possible. Base course should be constructed in layers no thicker than can be properly compacted, but in no event in excess of 6 inches. Thickness of layer will depend upon type of material and method of compaction used. Tests as described in paragraph 1–26 shall be used to control compaction during construction. Where Modified A.A.S.H.O. Method of testing compaction is suitable for the materials used, base course should be compacted to 95 percent of maximum density at optimum moisture content.

b. Materials in top of base course. Experience has shown that under highways it is desirable to have a high bearing ratio material directly beneath bituminous pavements to resist the high stresses produced in this zone by the wheels of using traffic. The required bearing value of the material used in the top layer depends upon the type and thickness of pavement, the magnitude of wheel loads, and the type of tire equipment. The minimum CBR of the upper base material should be 80 or more for a minimum compacted depth of 6 inches beneath the pavement of Class AA and Class A highways. It is preferable that the CBR of the upper base material be 80 beneath the pavements of Class B and C highways, particularly within "Build-Over Areas." However, where 80 CBR material is not economically or readily available, materials having minimum CBR value of 50 may be used, providing pavement thickness equals or exceeds the minimum set forth in Table 8 of paragraph 1–33*c*.

c. Design of base courses over soils affected by frost. The design and construction of base courses under flexible pavements of highways and open storage areas within permanent installations over potentially frost-action subgrade soils should conform to the principles of design and construction outlined under chapter 4, part XII, Airfield Pavement Design.

1–33 FLEXIBLE PAVEMENTS. The types of bituminous pavements are given in chapter 2, part XII of the Engineering Manual. The terms, tests, materials, and design criteria given therein relating to bituminous pavement construction are applicable to bituminous pavements used for highway purposes.

a. Bituminous pavement types—permanent construction. Hot-mix bituminous concrete, cold-laid bituminous concrete when composed of asphalt, liquifier and well-graded aggregates, and rock asphalt mixtures and penetration macadam provide high-type pavements. The above types are preferable for paving streets within permanent installations. While sheet asphalt, stone-filled sheet asphalt, and some sand asphalts provide comparatively high-type pavements, their use is not considered satisfactory for paving Class AA and Class A highways of military installations due to character and type of traffic

using them. These latter types are satisfactory for paving Class B and C highways where traffic is well distributed over the entire paved area. For other limitations as to their use see chapter 2, part XII, of this manual.

Past experience has indicated that most suitable of the above types for paving Class AA highways, particularly for heavy duty tank roads, is hot-mix bituminous concrete. Care, however, must be taken in its design and construction to secure a pavement capable of resisting the shearing stresses imposed by track laying vehicles. High-quality aggregate mixed with a low penetration asphalt, preferably 50 to 60 penetration and in no case in excess of 60 to 70 penetration grade in cold regions, should be used. The maximum size aggregate in the surface course should not exceed ¾ inch. Well graded aggregates conforming to graduations given in figure 20, appendix "B," chapter 2, part XII, of this manual, have proven satisfactory for surface courses on highways subjected to medium tanks equipped with all steel treads. The material passing the No. 200 mesh sieve should be higher than used in paving Class A, B, or C highways. The higher the coarse aggregate content of the paving mixture, the lower the No. 200 mesh material should be and vise versa. Pavement thickness of this composition should not be less than 4 inches and should be laid in two equal courses. Where the pavement thickness exceeds 4 inches, a binder course may be employed, providing the wearing course is not less than 2½ inches in thickness. These pavements should be laid on an adequate thickness of flexible base course composed of crushed aggregate having a CBR of 80 or more. It is preferable that the base course be waterbound.

The maintenance cost on tank highways for all types of pavements will be comparatively high. On bituminous types of the composition given above, it is necessary to maintain at all times a mat two or more inches in thickness above the base course. This requires supplemental courses of bituminous concrete to be added as the surface wears. If this is not done, the resulting thin layer of bituminous concrete may be torn loose from the base course by the lugs of the tank treads.

b. Bituminous pavement types—temporary construction. Cold-mix bituminous types of compositions other than described in *a* above, some sand asphalts, road mixes, and bituminous surface treatments provide medium or low-type pavements. These are usually less costly to construct and provide satisfactory pavements for temporary and light duty roads. These types are not satisfactory, however, for paving highways subjected to tank traffic. These types may be used as the first step in stage construction of permanent roads and streets where the latter are planned to be supplemented by additional layer or layers of plant type surfaces as traffic warrants. The type selected should be consistent with the character of traffic to be served. Maintenance costs are usually high. Bituminous surface treatments are usually of short life.

c. Bituminous pavement thickness. Bituminous pavements should be designed using a surface course or surface and binder course of sufficient thickness and quality to prevent displacement and shear when subjected to the design wheel load. In determining whether a pavement should consist of a surface course for its full depth or a combination of binder and surface courses, consideration should be given to the total thickness of pavement required, the economic use of materials, the design requirements of the foundation and surface courses, stage development and job conditions. The curves of figure 11 provide for minimum pavement thickness of from 2 to 4 inches depending on wheel loads. The table below gives the minimum recommended pavement thickness in inches for the various highway classes.

Table 8.

Highway Class	Minimum total pavement thickness inches	Minimum binder course thickness inches	Minimum surface course thickness inches
Class AA	4 * 4	 2	4 * 2
Class A	3	1½	1½
Class B	2½ **	1½	1
Class C	2		2

*—For recommended pavement thickness of Class AA roads designed to accommodate traffic from tanks equipped with steel treads, see paragraph 1–33e.

**—May be composed of surface course mixtures for the entire depth.

Where a bituminous macadam surface is employed, the minimum thickness of wearing course should not be less than 2½ inches regardless of highway class.

Pavements with total thickness less than that given in table 8 may be used in the first stage of permanent highway construction and may be used for paving Class A, B, and C highways within temporary installations. However, in these cases, the total compacted thickness of pavement composed of plant or road mixes should be not less than 1½ inches. The total thickness of pavement and base courses of highways within temporary installations should be equivalent to the combined thickness required by curves of figure 11. Where stage construction is employed, the combined thickness of pavement and base courses of the successive stages may be less than required by curves of figure 11. However, the combined thickness of pavement and base courses of permanent highways when ultimately completed should equal or exceed the thickness obtained from the design curves of figure 11.

Bituminous surface treatments vary in thickness from a light skin coat to maximum of approximately ¾ inch. Where such treatments are used for paving highways of temporary installation, the combined thickness of pavement and base course should be equal to that required by design curves of figure 11.

RIGID TYPE PAVEMENTS

1–34 DESIGN BASIS. The thickness of concrete pavement slabs for roads, streets, and open storage areas should be determined in accordance with empirical design curves given in figure 12. Concrete slab thickness is expressed in terms of the three principal factors: wheel load, subgrade modulus, and concrete flexural strength. The design curves of figure 12 have been determined by empirical means on the basis of past and existing highway practices, investigations conducted on both highway and airfield pavements, and guided by consideration of Westergaard analysis for load stresses.

a. Wheel loads. Investigation made by Westergaard and others developed the fact that the critical load stress in a concrete pavement is primarily a function of the wheel load and not a function of the gross weight of the vehicle or axle spacing, when axle spacing is in excess of 3 feet. The design curves of figure 12 are based on these findings. These curves give pavement thickness adequate for weight distribution of the conventional motor vehicle. The wheel loads given on figure 12 represent static weights of the loaded wheel. These static wheel loads represent the specific wheel load apt to predominate and prevail for the type and character of traffic delineated for the various highway classifications of paragraphs 1–02 *f*, *g*, *h*, and *i* of this chapter. Pavements designed in accordance with the criteria given herein should have adequate structural life to support the less frequent heavier wheel loads.

Consideration has been given in developing these curves to the additional impact or dynamic forces created by the wheel of a moving vehicle over a pavement surface. Impact factors used in such determinations are shown graphically in figure 13. The wheel loads shown on figure 12 multiplied by the

impact factor given for the respective wheel load obtained from figure 13 gives the total load reaction on which the respective load curves are based. Thus for the 9,000-pound wheel load, the curve is based on a total static and impact loading of 12,000 pounds, as shown in the example of figure 13.

b. Subgrade modulus. The subgrade modulus "k" in figure 12 should be based upon the modulus of subgrade soil reaction obtained by the field bearing test. The evaluation of subgrade reaction and subgrade test results should be made upon sufficient subgrade areas in accordance with the procedure stated in chapter 3, part XII, to establish a basis of design. A conservative value of "k" should be selected for the basis of design. Subgrade areas tested which indicate values below the value selected for design purposes should be strengthened. Uniform "k" value throughout is the ideal sought, however, this may be impossible to obtain and adjustment in slab thickness may be necessary. Slab thickness is not sensitive to small changes in "k," therefore, a relative value should be established rather than an absolute value for design purposes. A "k" value in excess of 300 should not be selected for design basis of concrete pavements for highways regardless of the result of field bearing test performed on the subgrade.

c. Concrete flexural strength. Concrete quality as reflected in these curves is on the basis of the flexural or so-called "modulus of rupture" strength of 28-day old concrete. The flexural strength of concrete should be determined in accordance with A.S.T.M. Designation C 78–44. Flexural strength values so determined or established by specifications should be used to enter the design curve of figure 12 to obtain the thickness of pavement slab required for the predetermined design wheel load and subgrade modulus. The thickness of slab so obtained has been predicated on the basis that load stresses imposed by the wheel load will not exceed the safe working stress of concrete of normal properties having the flexural strength obtained by 28-day old beam tests.

The engineer is cautioned that, where the conditions do not insure concrete of normal properties, the design should be modified accordingly. It must be recognized that the most ideal conditions rarely obtain and that full consideration should be given to the probable influence of such factors discussed below. The thickness of the slab should be made greater than that indicated by the design curves when:

There is less than normal predicated strength gain for the concrete after the age of 28 days as is the case of some cements and aggregates.

There is probable retrogression in concrete strength due to weathering or other causes.

Available information concerning concrete made of similar materials indicates unusual brittleness or high modulus of elasticity without corresponding high flexural strength.

Aggregate or concrete is expected to have high moisture absorption and shrinkage that will develop large curling or tensile stresses.

The engineer should explore all possible sources of information consistent with job conditions and perform such tests as are feasible to obtain facts and data useful in evaluating the effect of these variables as related to the concrete for the job at hand.

1–35 BASE COURSES UNDER CONCRETE PAVEMENTS. Base courses may be required under concrete pavements for the purpose of either producing a uniform bearing surface for the pavement slab; for replacing soft, highly compressible or expansive soils; for insuring stability in areas subject to detrimental weakening of the subgrade by frost action; to aid in the reinforcement of joints; or to produce a suitable surface for operating construction equipment during adverse weather conditions.

Laboratory tests performed on soil samples taken from the subgrade will provide information regarding the physical and behavior characteristics of the subgrade soils. If conditions indicate that a base course is desirable, a thorough study should be made of topography, soil formations, drainage and climatic conditions, and of any similar construction within the locality and an investigation made as to the possible sources, quantities and characteristics of suitable and available base course materials. This information will provide a guide as to the minimum depth and requirements of the base course for the anticipated highway loadings. The combined thickness of pavement and base courses over soils subject to detrimental weakening from frost action should be based upon a reduced modulus of soil reaction as provided

under chapter 4, part XII, of this manual. In no case should a base thickness of less than 6 inches be used over subgrade soils subject to detrimental weakening from frost action.

a. Materials. Base course material should be of a character that will not appreciably suffer loss of bearing power from exposure to moisture and should preferably be freely draining. The base course may consist of a stabilized subgrade or an imported base material. A wide variety of natural, processed, and stabilized materials may be used similar to that indicated for use for flexible pavement base courses. The base course material, in general, should be well graded, high stability material with a low percentage of fines. Where crushed aggregates are used, the upper layer or lift should be relatively fine crushed material.

b. Compaction. Base course for concrete pavements should be constructed in layers or lifts thoroughly compacted to produce a structure of low compressibility in accordance with the criteria established for base courses under flexible pavements.

1–36 NON-REINFORCED CONCRETE PAVEMENTS. Concrete pavement slabs may be uniform in cross sectional thickness or thickened at the free edges.

Slabs uniform in cross sectional depth should be equal to the "slab thickness" obtained from the empirical design curves of figure 12. Where the thickness from the design curves indicates a fractional value greater than one-third inch, the next full inch thickness should be used. The minimum thickness of a concrete slab of uniform cross section should not be less than 6 inches for any design wheel load. Edge and interior thickness of thickened edge pavement slabs shall be determined from the design curves of figure 12 in accordance with the following:

The interior thickness of thickened edge pavements shall be equal to approximately 85 percent of the uniform thickness obtained from the empirical curves, figure 12, for the design load, subgrade modulus, and flexural strength. The edge thickness at free edges should be approximately 1½ times greater than the interior thickness so obtained. The edge thickening should decrease uniformly to the interior edge thickness over a distance of from 2 to 4 feet from the edge. Thus, in the case of the design example shown on figure 12, if thickened-edge section is desired, the interior thickness will be 85 percent of 9 inches, or 7.6 inches, and the edges thickened to 1½ times 7.6 inches, or 11.4 inches. A 11″-7.5″-11″ section fulfills these requirements and will be equal in load carrying capacity to the 9″ uniform slab. In no event should a thickened edge pavement be less than 8″-5″-8″ in section.

1–37 REINFORCED CONCRETE PAVEMENTS. Highway pavement slabs may be at the option of the designer, reinforced with wire mesh or hot rolled steel bars arranged in square or rectangular grid. The sole function of steel distributed throughout a pavement slab is to hold together the fractured faces of the slabs after cracks have formed. This will aid in load transmission at these points and also prevent the infiltration of objectionable matter into the cracks. Joint spacings of reinforced concrete pavements should be in excess of that required for crack control of non-reinforced concrete slabs in order that the distributed steel may perform a useful purpose.

a. Pavement thickness. Thickness of reinforced concrete slabs for highway purposes shall be determined in accordance with criteria given in paragraph 1–36 *a* above from load curves of figure 12. There will be no reduction in slab thickness over the values so obtained by reason of the inclusion of distributed steel.

b. Reinforcement steel. The amount of steel required in each direction, transversely and longitudinally, should be determined in accordance with the "subgrade drag" theory which involves assumption of the coefficient of subgrade friction and selection of an allowable unit tensile stress in the steel. Reinforcement requirements shall be determined in accordance with the following formula:

$$A_s = \frac{wcL}{2f_s}$$

in which—

A_s=effective cross-sectional area of steel in square inches per foot length or width of section

L=distance in feet between free joints (spacing of free transverse joints when computing longitudinal steel or spacing of free longitudinal joints when computing transverse steel.)

w=weight of slab in pounds per square foot

c=coefficient of subgrade friction

f_s=allowable unit stress in the reinforcement in pounds per square inch.

Values of the coefficient of subgrade friction vary from less than 1.0 to a maximum of about 2.5 depending upon the amount of slab movement and character of subgrade. A value of c=1.5 is generally used for average subgrade conditions.

Free joint is a joint wherein no provision is made for unrestrained opening or closing of the joint when adjoining slabs contract or expand. Expansion and contraction joints, whether doweled or not doweled as described herein, are free joints.

1–38 JOINTS AND JOINT SPACING. Joints are constructed in pavements to permit contraction and expansion of concrete under the action of temperature and moisture changes and so far as possible to control cracking resulting from uneven support of the subgrade or base. Joints are also required as a construction expedient to separate strips, or sections, of concrete pavement poured at different times. There are three general types of joints: weakened plane (contraction) or dummy type, construction, and expansion. Some variations in the design and uses of these joints are provided. They are illustrated in figures 14 and 15 and discussed under the following headings for the respective joint types.

a. Weakened plane joints. Weakened plane joints (commonly referred to as contraction or dummy joints) are installed to control contraction warping and to limit curling or warping stresses induced by temperature and moisture changes in the pavement. Some relief from expansion force is afforded by this type of joint since initial shrinkage of the concrete which usually breaks the pavement at the groove, or the weakened plane, opens the joint slightly and thus provides space for subsequent expansion. Bituminous filler in the grooves at the top of the joint excludes infiltration of surface water and solid substances into the joint spaces and at the same time provides a cushion along the top edges of adjoining slabs and prevents excessive pressure when the slabs expand and curl downward at the joint.

Transverse dummy joints should be placed at intervals of from 12½ to 25 feet across each paving lane of non-reinforced concrete pavement slab to control cracking. The dummy groove should extend one-fourth the depth of the slab. Each joint must be straight and continuous from edge to edge of the paving lane. Joints of adjacent lanes should coincide at the edge common to both and be straight and continuous from edge to edge of the pavement slab. Experience has shown that the maximum length of slab between transverse joints that will effectively control cracking depends on the temperature coefficient of the aggregates used in the concrete. The spacings given in the following table are believed sufficient to effect control of transverse cracking apt to occur in concrete slabs composed of the various types of concrete aggregates listed therein:

Table 9.

Aggregate	Transverse joint spacing
Granite	20—25
Limestone and dolomite	20—25
Flinty material and quartzite	15—20
Slag	12½—15

The spacings given above are usually sufficient under ordinary conditions of subgrade and climate. However, consideration should be given to experience encountered with local materials.

Transverse dummy joints will be used to control contraction warping and to limit curling or warping stresses in reinforced concrete pavements. These joints should conform to types shown on figure 15, designated contraction or dummy groove joint. The contraction joint is a variation of the dummy groove or weakened plane joint with the addition of dowl bars for load transfer. The spacing between transverse contraction joints should not exceed three times the joint spacing specified for the various concrete aggregates given in table 9. Steel reinforcing shall be carried continuously between contraction joints, but not through and across such joints. The dummy joints of figure 15 are formed grooves, the depth being governed by the depth the mesh reinforcing is below the concrete surface. Mesh reinforcing should be carried through and across these latter type joints. The omission, installation, and spacing of these latter type joints are optional with the designer.

Longitudinal dummy groove joints may be employed to mark the edge of each traffic or parking lane of the highway. The width of any division between longitudinal dummy joints should not exceed 16 feet. Dowels or tie bars will not be required across dummy joints of non-reinforced concrete pavements except as noted below. Tie bars consisting of ½-inch round, deformed steel bars 2 feet 6 inches in length, spaced 2 feet 6 inches apart, will be required across dummy joints of lanes adjacent to the free edge of any major paved area.

b. Construction joints. Longitudinal construction joints should be installed along the centerline of 2 and 4 lane concrete undivided highways and may be used to mark the edges of other traffic lanes. The distance apart of longitudinal joints is dependent upon the size of the paving equipment (often determined by the width of the finishing machine). These interior longitudinal construction joints may be either doweled, keyed, or provided with tie bars in accordance with the designs shown in figures 14 and 15. Tie bars provided across longitudinal construction joints should be similar in size and spacing indicated above for "Weakened Plane Joints." Longitudinal construction joints installed at the junction of a pavement slab and a combination curb and gutter should be provided with tie bars similar in size and spacing as called for above under "Weakened Plane Joints."

Transverse construction joints should be installed at the end of each day's pouring or at other points within a paving strip where the placing of concrete is discontinued a sufficient time for the concrete to set. All transverse construction joints will be of the doweled type, and so far as practicable will be located in place of other regularly spaced transverse joints (dummy or expansion type). The extreme edges and ends of all paved surfaces that are likely to be extended should be formed in a manner for regular construction joint installation of a type used in the body of the pavement.

c. Expansion joints. Expansion joints consisting of approved preformed bituminous filler or wood should be installed to surround, or to separate from the new pavement, all structures and features which project through, into, or against the pavement. The thickness of the filler and the manner of its installation will depend upon the particular case. Usually ¾-inch thickness is sufficient. The width, length, and position of each joint should be sufficient to form a complete, uniform separation between the pavement and the structure concerned. For strips of pavement or extensive paved areas which intersect or are connected in such a manner that expansion of the concrete would be expected to cause serious distortion, buckling, or displacement of some part of the pavement, provision should be made for an adequate expansion joint to be installed at or near each intersection.

Expansion joints shall be placed at regular intervals, approximately 180 to 405 feet apart, transversely across the roadway pavement slabs. Paved areas, such as in open storage areas having areal dimensions in excess of 180 feet in any direction, should be provided with longitudinal and transverse expansion joints spaced at intervals of approximately 90 to 200 feet apart.

d. Use of dowels. The important function of dowels or any other load transfer device in concrete pavements is to maintain the alinement of adjacent slabs and strengthen the free edges by providing load transfer between the free edges. Experience has shown that the conventional steel dowels as well as some of the proprietary devices are effective in maintaining slab alinement. The efficiency of these

devices in transfer of load thereby minimizing concrete stresses is questionable. Under certain conditions the device may result in increased concrete stress. But, regardless of its predicated effect in ultimate load capacity of the pavements, dowels will be required at all transverse expansion joints and all transverse construction joints of both non-reinforced and reinforced concrete pavements. Dowels will be required at all transverse contraction joints in reinforced concrete pavements. Dowels or tie bars may be used at the option of the designer in the longitudinal construction joints instead of formed-key joints.

Three quarter-inch round, smooth bars, not less than 16 inches in length spaced 12 inches apart should be used as dowels in transverse and longitudinal joints of slabs 8 inches or less in thickness and 1 inch-round, smooth bars, 16 inches in length, spaced 12 inches apart as dowels in pavement slabs exceeding 8 inches in thickness. All dowels should be straight, smooth, and free from burr at the ends and should be painted and greased thoroughly before being installed in the pavement. Dowels used at expansion ends should be capped at one end permitting further penetration of the dowels in the concrete when the joints close.

SIDEWALKS

1–39 MINIMUM REQUIREMENTS. Minimum sidewalk construction should be included as part of the original construction program. See part II, Planning, for discussion of requirements and typical plans.

1–40 LOCATION OF SIDEWALKS. In "Built-Over Areas" it is desirable in the interest of safety to set the walk five or more feet from the curb line as shown on figure 3, "Street Type Cross Section." However, in some instances it may be required to place the sidewalk adjacent to the curb where curb parking is permitted, to accommodate pedestrian traffic to and from parked cars. When the latter is the case, provision should be made by widening of the sidewalk, to accommodate the discharge and loading of persons or materials at the curb. In other areas illustrated by "Road Type Cross Section" shown on figure 3, sidewalks should be located back of ditch. Where no ditch exists, the maximum area available should be allowed between the outside edge of the shoulder and the sidewalk.

1–41 DESIGN OF SIDEWALK. Sidewalks should be designed to provide an economical all-weather surface suitable for pedestrian traffic and requiring minimum maintenance.

a. Cross slope and grade. A cross surface slope of ¼″ per foot should be provided for drainage. This should slope toward the direction of natural drainage in the area. It is unnecessary to maintain minimum grades and walks may be laid on flat grades.

b. Width. Sidewalk widths should be based on traffic requirements with two feet the width of a pedestrian traffic lane. Minimum width should not be less than four feet and width increased in increments of two feet to meet traffic requirements.

c. Drainage. Plain concrete, corrugated metal, or vitrified clay pipe culverts should be installed for drainage at natural drainage courses and at road intersections where sidewalks are to be carried across ditches adjacent to the roadway. For design detail see chapter 4, part XIII.

1–42 GRADING AND THE PREPARATION OF SUBGRADE. Grading and the preparation of subgrade should follow, in general, requirements provided for Project highways.

1–43 CONSTRUCTION TYPES—PERMANENT CONSTRUCTION. Construction should comply with one of the following types:

a. Aggregate base and bituminous surface. The construction of a stabilized base course composed of either gravel, slag, stone, or other approved materials, surfaced with a bituminous sand-mix or a bituminous concrete-mix provides a suitable design for walks. Typical construction of this type should be a 4″ base course with a 1″ surface course.

b. Concrete walks. Portland cement concrete walks may be provided at Army installations where pedestrian traffic justifies this type of construction. Concrete used in sidewalk construction normally will conform to Class B concrete, War Department Specification CE–204, with minimum thickness 4 inches. Where it is necessary and desirable to continue the sidewalk across driveways, private entrances, etc., provided for vehicular crossing concrete should conform to that specified under War Department Specification CE–806 and be of sufficient thickness to support the vehicular loads such portions of sidewalks will be subjected to. Concrete walks should be grooved longitudinally and transversely at 3- to 5-foot intervals to a depth of at least ¼-inch per inch of slab thickness to create planes of weakness. Expansion joints consisting of approved preformed bituminous filler or wood, approximately ½ inch in thickness should be installed to surround or to separate all structures or features which project through or against the sidewalk pavement slab. Expansion joints, similar in construction should be installed at regularly spaced intervals, between 30 to 50 feet apart transversely across sidewalk pavement slab.

1–44 CONSTRUCTION TYPES—TEMPORARY CONSTRUCTION. Construction should comply with one of the following types:

a. Stabilized base with or without bituminous surface. Stabilized soil, consisting of granular and colloidal materials combined in the proper proportions to secure maximum density and stability under all weather conditions will provide a suitable walk for temporary installations. The material may be obtained from selected sources in which the percentage of each class of material is within permissible limits, or suitable materials from separate sources, in required proportions, thoroughly mixed. A common form of this type of construction is the sand-clay road used throughout many of the southern states, or pit-run gravel in which sufficient clay or binder material is present to permit thorough compaction. Walks subject to infrequent use may be built of this material with no additional surface. Where these walks will be subjected to continuous usage, consideration should be given to applying a thin mat in the form of a bituminous seal coat or surface treatment, or stabilizing the upper inch of the base course with bituminous or other suitable materials.

b. Bituminous stabilization. Sidewalks may be constructed by stabilizing the soil in place with bituminous material. If necessary, selected material can be added to obtain a soil which can be economically stabilized with such materials. This type of construction should require no surfacing. Thorough compaction, with the use of an approved roller, is necessary.

OPEN STORAGE AREAS

1–45 GENERAL. This section deals primarily with the design and construction of surfaced areas required in connection with parking areas or spaces, motor pools and motor storage areas, open storage, utility yards, salvage yards, and miscellaneous repair yards designated and shown on typical lay-out plans. The construction of open storage areas should provide for erosion and drainage control and a type of surface consistent in cost with its functional requirements. General requirements for the different types of open storage areas are given in the following paragraphs.

1–46 PARKING AREAS. For location see part I and part II of Engineering Manual covering civil works and military projects respectively. These areas are available for the mass parking of passenger cars and light-weight trucks at shopping centers, administration buildings, industrial plants, and other places of public assembly. These areas should be located preferably off streets with properly designed entrances, exits, and buffer strips between parking and other areas.

The maximum car capacity per unit of area should be obtained, consistent with the functional requirements of the area. Parking lots devoted exclusively to parking of cars of civilian employees should have the space allotted to moving vehicles limited as much as possible. A greater freedom between moving and parked vehicles is desirable within parking areas designated for intermittent parking at shopping centers and administrative buildings. Maximum parking capacity is obtained by requiring vehicles to

park in double parallel lines bumper to bumper and at right angles to areas (access roads) allowed for moving traffic. Curbs or buffer rails should be provided to separate parking lines. An acre of ground will accommodate the parking of between 140 and 165 passenger vehicles with cars parked at right angles to access roads spaced approximately 60 to 70 feet apart. The actual number per acre that can be accommodated will depend on the overall dimension of the average vehicle to be parked and the freedom of movement desired between moving and parked vehicles.

These areas should preferably be surfaced. The areas should have sufficient slope to adequately control drainage. Selection of construction type should be based upon design factors set forth in paragraph 1–06 of this chapter.

1–47 MOTOR POOLS OR MOTOR STORAGE AREAS. These areas include all areas provided for the storage, servicing, and repair of organizational and functional equipment assigned to the post or attached tactical units. See part II of this Manual for location and general requirements.

The functional requirements of these areas differ from parking areas in that areas for the servicing and repair of this equipment are required as well as areas for storage or parking of vehicles. These areas logically divide themselves into two functional areas, that is a service area and a storage area. The former includes all areas adjacent to motor repair and storage buildings, grease, wash and inspection racks, fuel dispensing units, and similar miscellaneous facilities. These areas include access drives to the various service facilities and the necessary outside work areas.

The storage area is the area where the individual units of equipment are parked or stored while not in use. Maximum parking capacity can be obtained by requiring assigned vehicles to park in manner specified above for parking areas. The larger size of the average tactical unit and the lesser interference required between moving and parked vehicles reduces the per unit storage area potential to between 60 and 100 vehicles per acre. The potential capacity per acre stated above does not include necessary service area. The size of service area is dependent upon the type and number of service and storage facilities required.

For efficient and economical operation, both service and storage area should be surfaced. The provision of adequate drainage facilities is essential. The type of base and surface course construction is dependent upon the type and character of vehicles to be accommodated. A base and pavement course conforming to that specified for Class B highways should provide a suitable type for storage areas designated for the storage, servicing, and repair of wheeled vehicles and combined wheeled and track-laying vehicles (half tracks). At large motor pools designed to accommodate in excess of 300 vehicles, consideration should be given to the type of pavement courses selected for the service area, due to the increased frequency of operation over such areas. Motor parks, designated to accommodate armored division tank units, should be paved with portland cement concrete due to heavy static loads and the shear stresses imposed by turning of these units.

1–48 OPEN STORAGE. Allocation of suitable areas for the reception, classification, handling, repair, and storage of supplies, materials and equipment capable of being placed in the open, at little or no risk to damage from exposure to weather, are required at nearly all types of military projects. Open storage areas are provided at Army storage depots and at plant projects in accordance with authorized requirements. For typical lay out diagrams showing relation of these roads, rail and other facilities, see part II of this Manual.

The type of construction should be predicated on minimum requirements for the types and anticipated daily, monthly, or annual turnover of materials, supplies and equipment. Normally, an aggregate type base construction designed to accommodate wheel loads specified for Class C roads with a dust-free surface, and with lanes or driveways adequately strengthened and surfaced to accommodate operating equipment required in handling such supplies, materials, and equipment, should provide a satisfactory surface for efficient operation within these areas. Where fork-lift trucks, small-wheeled tractors, and trailers are used for inter-transfer of crated materials, supplies, and equipment, portland cement concrete

drives or runways may be required. Crane runways should be designed to accommodate wheel loadings specified for Class AA roads. Surface-treated base course of the macadam type is recommended.

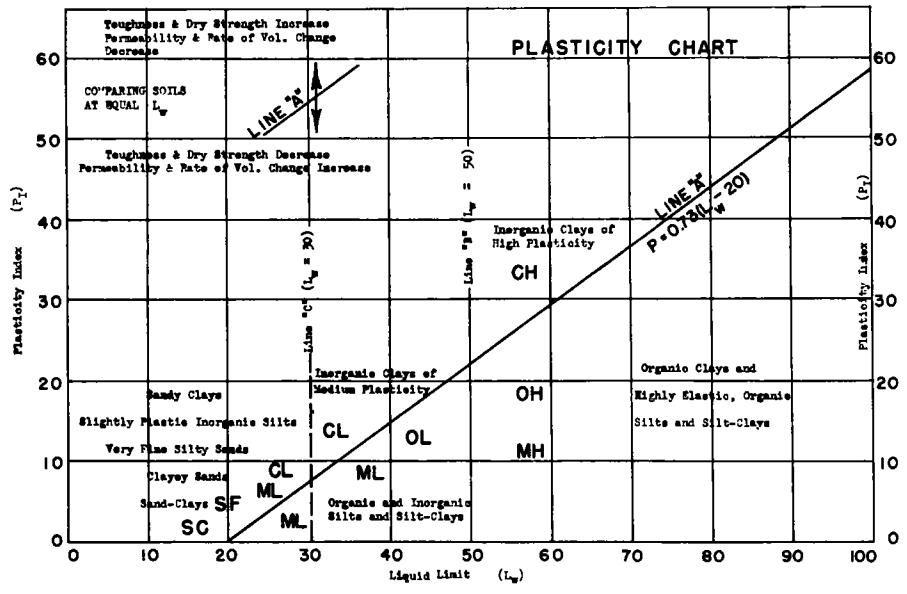
1–49 UTILITY YARDS. These areas will require comparatively impervious, dust free, and free draining surfaces. Type of surfacing will consist normally of an adequate base course as required for Class C roads with a suitable and adequate bituminous treatment or wearing course. The type of wearing course should be predicated on minimum requirements.

1–50 REPAIR YARDS. These areas require similarly constructed areas as that specified above for "Utility Yards." However, the increased activities and, in some cases, large heavy units handled require special attention in the selection of pavement types. Pavement types should be based on actual requirements and should be the minimum consistent in cost to functional requirements based on anticipated life expectancy.

1–51 SPECIAL REQUIREMENTS. Standing equipment imposes a static load on paved open storage areas. Pavement types, which provide little shear value or load distribution under certain climatic conditions and tend to deform and rut under static loads, should be avoided in paving open storage areas. Sand asphalt, sheet asphalt, and other bituminous types manufactured from fine aggregate require all-over traffic for best performance and are not considered suitable for standing loads. Bituminous pavement mixtures containing approximately 50 percent of coarse aggregate are recommended for surfacing of open storage area.

SOIL CLASSIFICATION

1		2	3	4		5	6	7	8	9	10	11	12	13	14	15
MAJOR DIVISIONS		SOIL GROUPS & TYPICAL NAMES	GROUP SYMBOLS	GENERAL IDENTIFICATION		OBSERVATIONS AND TESTS RELATING TO MATERIAL IN PLACE	PRINCIPAL CLASSIFICATION TESTS (ON DISTURBED SAMPLES)	VALUE AS FOUNDATION WHEN NOT SUBJECT TO FROST ACTION	VALUE AS BASE DIRECTLY UNDER WEARING SURFACE	POTENTIAL FROST ACTION	SHRINKAGE, EXPANSION, ELASTICITY	DRAINAGE CHARACTER-ISTICS	COMPACTION CHARACTERISTICS AND EQUIPMENT	SOILS AT OPT. COMPACTION LB. PER CU. FT. & VOID RATIO,*	CAL. BEARING RATIO FOR COMPACTED & SOAKED SPECIMEN	COMPARABLE GROUPS IN PUBLIC ROADS CLASSIFICATION
				DRY STRENGTH	OTHER PERTINENT EXAMS.											
COARSE GRAINED SOILS	Gravel and Gravelly Soils	Well Graded Gravel & Gravel-Sand Mixtures, Little or No Fines	GW	None	Gradation, Grain Shape	Dry Unit Weight or Void Ratio, Degree of Compaction, Cementation, Durability of Grains, Stratification & Drainage Characteristics, Ground Water Conditions, Traffic Tests, Large Scale Load Tests or CBR Tests	Mechanical Analysis	Excellent	Good to Excellent	None to Very Slight	Almost None	Excellent	Excellent; crawler type tractor, rubber tired equipment, steel wheeled roller	>125 *<0.35	>90	A-3
		Well Graded Gravel-Sand-Clay Mixtures, Excellent Binder	GC	Medium to High	Gradation, Grain Shape, Binder Exam. Wet & Dry		Mechanical Analysis, Liquid & Plastic Limits on Binder	Excellent	Fair to Excellent	Medium	Very Slight	Practically Impervious	Excellent; rubber tired equipment, sheepsfoot rollers	>130 *<0.30	>40	A-1
		Poorly Graded Gravel & Gravel-Sand Mixtures, Little or No Fines	GP	None	Gradation, Grain Shape		Mechanical Analysis	Good to Excellent	Poor to Good	None to Very Slight	Almost None	Excellent	Good; crawler type tractor, rubber tired equipment, steel wheeled roller.	>115 *<0.45	25-60	A-3
		Gravel with Fines, Very Silty Gravel, Clayey Gravel, Poorly Graded Gravel-Sand-Clay Mixtures	GF	Very Slight to High	Gradation, Grain Shape, Binder Exam. Wet & Dry		Mechanical Analysis, Liquid & Plastic Limits on Binder if Applicable	Good to Excellent	Poor to Good	Slight to Medium	Almost None to Slight	Fair to Practically Impervious	Good, close control essential; rubber tired equipment, sheepsfoot rollers.	>120 *<0.40	>20	A-2
	Sands and Sandy Soils	Well Graded Sands & Gravelly Sands, Little or No Fines	SW	None	Gradation, Grain Shape		Mechanical Analysis	Good to Excellent	Poor to Good	None to Very Slight	Almost None	Excellent	Excellent; crawler type tractor, rubber tired equipment.	>120 *<0.40	20-60	A-3
		Well Graded Sand-Clay Mixtures, Excellent Binder	SC	Medium to High	Gradation, Grain Shape Binder Exam. Wet & Dry		Mechanical Analysis, Liquid & Plastic Limits on Binder	Good to Excellent	Poor to Good	Medium	Very Slight	Practically Impervious	Excellent; rubber tired equipment, sheepsfoot rollers	>125 *<0.35	20-60	A-1
		Poorly Graded Sands, Little or No Fines	SP	None	Gradation, Grain Shape		Mechanical Analysis	Fair to Good	Not Suitable	None to Very Slight	Almost None	Excellent	Good, crawler type tractor, rubber tired equipment	>100 *<0.70	10-30	A-3
		Sand with Fines, Very Silty Sands, Clayey Sands, Poorly Graded Sand-Clay Mixtures	SF	Very Slight to High	Gradation, Grain Shape, Binder Exam. Wet & Dry		Mechanical Analysis Liquid & Plastic Limits on Binder if Applicable	Fair to Good	Not Suitable	Slight to High	Almost None to Medium	Fair to Practically Impervious	Good, close control essential; rubber tired equipment, sheepsfoot rollers	>105 *<0.60	8-30	A-2
FINE GRAINED SOILS Containing Little or No Coarse Grained Material	Fine Grained Soils Having Low to Medium Compressibility	Inorganic Silts & Very Fine Sands, Rock Flour, Silty or Clayey Fine Sands with Slight Plasticity	ML	Very Slight to Medium	Examination Wet (Shaking Test & Plasticity)	Dry, Unit Weight, Water Content & Void Ratio, Consistency - Undisturbed & Remolded, Stratification, Root Holes, Fissures, Etc., Drainage & Ground Water Conditions, Traffic Tests, Large Scale Load Tests, CBR Tests or Compression Tests	Mechanical Analysis, Liquid & Plastic Limits if Applicable	Fair to Poor	Not Suitable	Medium to Very High	Slight to Medium	Fair to Poor	Good to poor, close control essential; rubber tired equipment, sheepsfoot rollers	>100 *<0.70	6-25	A-4 A-6 A-7
		Inorganic Clays of Low to Medium Plasticity, Sandy Clays, Silty Clays, Lean Clays	CL	Medium to High	Examination in Plastic Range		Liquid & Plastic Limits	Fair to Poor	Not Suitable	Medium to High	Medium	Practically Impervious	Excellent; rubber tired equipment, sheepsfoot rollers	>100 *<0.70	4-15	A-4 A-6 A-7
		Organic Silts & Organic Silt-Clays Of Low Plasticity	OL	Slight to Medium	Examination in Plastic Range, Odor		Liquid & Plastic Limits From Natural Condition & After Oven Drying	Poor	Not Suitable	Medium to High	Medium to High	Poor	Poor to good; rubber tired equipment, sheepsfoot rollers	> 90 *<0.90	3-8	A-4 A-7
	Fine Grained Soils Having High Compressibility	Micaceous or Diatomaceous Fine Sandy & Silty Soils, Elastic Silts	MH	Very Slight to Medium	Examination Wet (Shaking Test & Plasticity)		Mechanical Analysis Liquid & Plastic Limits if Applicable	Poor	Not Suitable	Medium to Very High	High	Fair to Poor	Poor to very poor; sheepsfoot rollers.	<100 *>0.70	<7	A-5
		Inorganic Clays of High Plasticity, Fat Clays	CH	High	Examination in Plastic Range		Liquid & Plastic Limits	Poor to Very Poor	Not Suitable	Medium	High	Practically Impervious	Poor to good; sheepsfoot rollers.	> 90 *<0.90	<6	A-6 A-7
		Organic Clays of Medium to High Plasticity	OH	High	Examination in Plastic Range, Odor		Liquid & Plastic Limits From Natural Condition & After Oven Drying	Very Poor	Not Suitable	Medium	High	Practically Impervious	Very poor to fair; sheepsfoot rollers.	<100 *>0.70	<4	A-7 A-8
Fibrous Organic Soils with Very High Compressibility		Peat and Other Highly Organic Swamp Soils	Pt	Readily Identified		Consistency, Texture and Natural Water Content		Extremely Poor	Not Suitable	Slight	Very High	Fair to Poor	Compaction Not Practical			A-8



LEGEND FOR GROUP SYMBOLS

G = Gravel
S = Sand
M = Mo. Very Fine Sand, Silt, Rock Flour
C = Clay
Pt = Peat
F = Fines, Matl <0.1mm
O = Organic
W = Well Graded
P = Poorly Graded
L = Low to Med. Compressibility
H = High Compressibility

NOTES:

1. Column 7, values are for subgrade and base courses except for base courses directly under wearing surface.

2. Values in Columns 7 and 8 are for guidance only. Design should be based on test results in accordance with text.

3. Unit weights in Column 13 are for soils with specific gravities ranging between 2.65 and 2.75.

4. In Column 12, the equipment listed will usually produce the required densities with a reasonable number of passes when moisture conditions and thickness of lift are properly controlled. In some instances, several types of equipment are listed, because variable soil characteristics within a given soil group may require different equipment. In some instances, a combination of two types may be necessary.

a. Processed base materials and other angular materials. Steel wheeled rollers are recommended for hard angular materials with limited fines or screenings. Rubber tired equipment is recommended for softer materials subject to degradation.

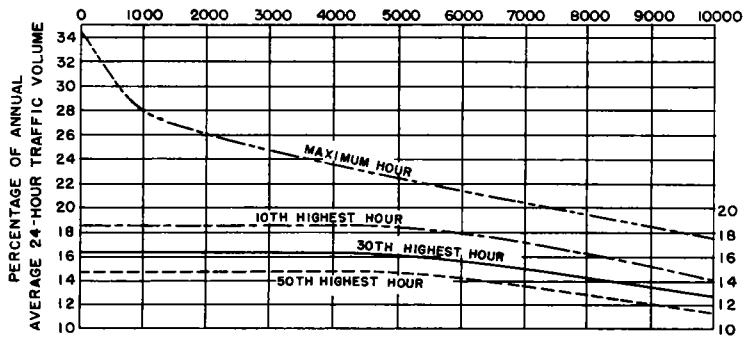
b. Finishing. Rubber tired equipment as recommended for rolling during final shaping operations for most soils and processed materials.

c. Equipment size. The following sizes of equipment are necessary to assure the high densities required for airfield construction:

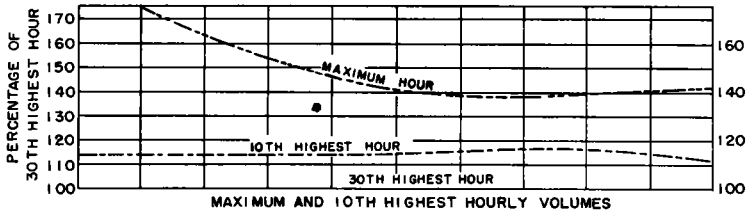
Crawler type tractor - total weight in excess of 30,000 pounds.

Rubber tired equipment - wheel load in excess of 15,000 pounds, wheel loads as high as 40,000 pounds may be necessary to obtain the required densities for some materials.

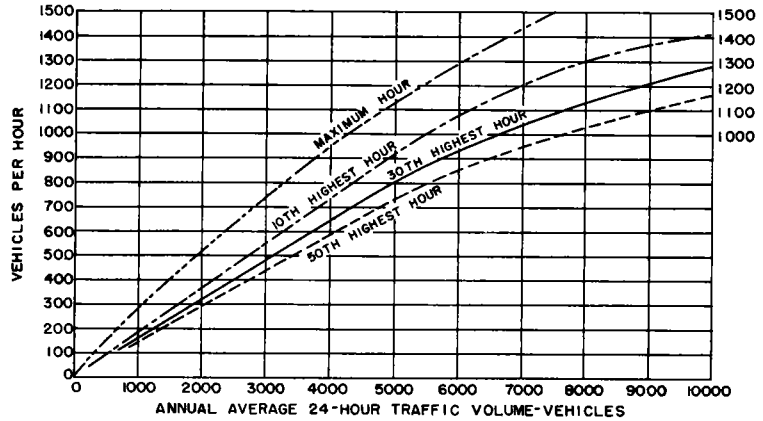
Sheepsfoot rollers - unit pressure (on 6 to 9 sq. in. foot) to be in excess of 350 pounds per square inch. Unit pressures as high as 700 pounds per square inch may be necessary to obtain the required densities for some materials.



PERCENTAGE RELATION OF VARIOUS HOURLY TRAFFIC VOLUMES

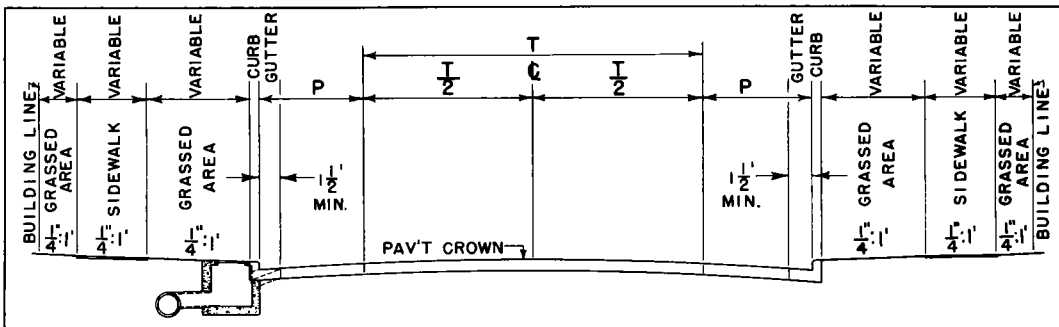


MAXIMUM AND 10TH HIGHEST HOURLY VOLUMES
AS A PERCENTAGE OF THE 30TH HIGHEST HOUR



ANNUAL AVERAGE 24-HOUR TRAFFIC VOLUME-VEHICLES
RELATION BETWEEN VARIOUS HOURLY TRAFFIC VOLUME DURING YEAR
AND ANNUAL AVERAGE 24-HOUR TRAFFIC VOLUMES

PEAK TRAFFIC VOLUMES

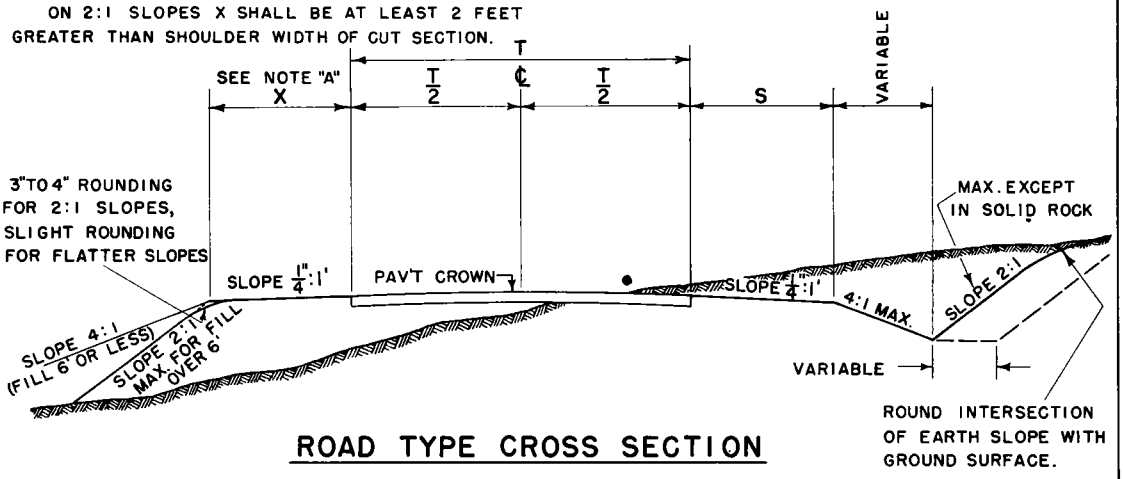


STREET TYPE CROSS SECTION

NOTE "A"

ON 4:1 SLOPES X SHALL BE EQUAL TO SHOULDER WIDTH OF CUT SECTION.

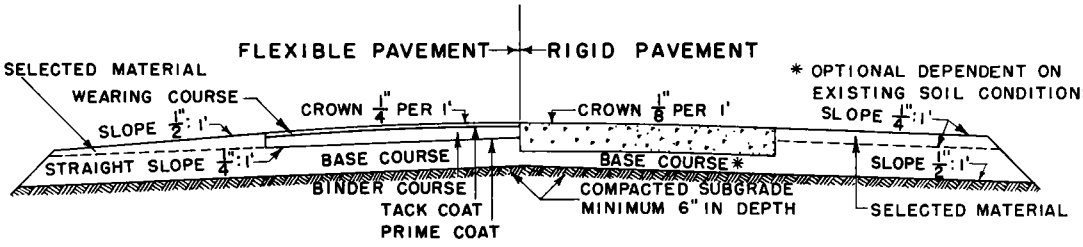
ON 2:1 SLOPES X SHALL BE AT LEAST 2 FEET GREATER THAN SHOULDER WIDTH OF CUT SECTION.



ROAD TYPE CROSS SECTION

LEGEND

T - TOTAL WIDTH OF TRAFFIC LANES
T/2 - ONE HALF OF T
P - WIDTH OF PARKING LANE
S - WIDTH OF SHOULDER



CROSS SECTION SHOWING DEVELOPMENT OF FLEXIBLE AND RIGID TYPE PAVEMENTS

NOTES

PAVEMENT CROWN AND CROSS-SECTION SLOPES AS SHOWN MAY VARY IN ACCORDANCE WITH DESIGN REQUIREMENTS AND EXISTING CONDITIONS. SEE TEXT.

FOR WIDTH OF TRAFFIC LANES, PARKING LANES, SHOULDERS AND DESIGN WHEEL LOAD, SEE TEXT.

THICKNESS OF BASE AND PAVEMENT COURSE WILL VARY IN ACCORDANCE WITH TRAFFIC CONDITIONS AND SOIL. FOR DESIGN OF BASE AND PAVEMENT COURSES SEE TEXT.

TYPICAL ROADWAY CROSS SECTIONS

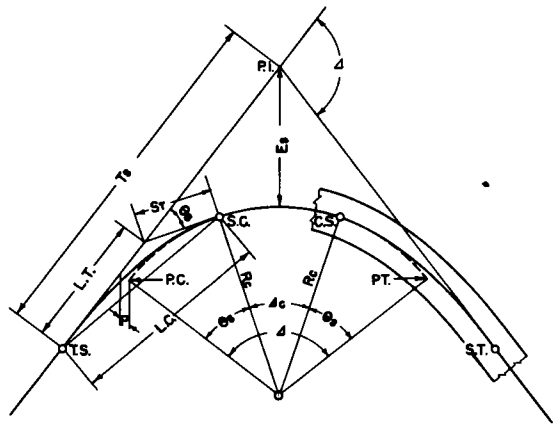
RECOMMENDED SUPERELEVATIONS WIDENINGS AND MINIMUM TRANSITION LENGTHS

D_c	R	30 MPH			40 MPH			50 MPH			60 MPH			70 MPH		
		S	W	L_s	S	W	L_s	S	W	L_s	S	W	L_s	S	W	L_s
1-00	5729.58	0		0	0		0	0		0	0		0	0		0
1-30	3819.72	.01		0	.02		0	.02		0	.04		0	.05		0
2-00	2864.79	.01		0	.02		0	.03		0	.05		0	.06		0
2-15	2546.48	.01		150	.03		150	.04		150	.06		150	.07		200
2-30	2291.83	.01		"	.03		"	.04		"	.06		150	.08		250
2-45	2083.48	.01		"	.03		"	.05		"	.07		150	.09		250
3-00	1909.86	.02		"	.03		"	.05		"	.07		200	.09		300
3-15	1762.91	.02		"	.04		"	.06		"	.08		200	.10		325
3-30	1637.02	.02		"	.04		"	.06		"	.08		200	.10		350
4	1432.39	.02		"	.04		"	.06		"	.09		250	.10		400
5	1145.92	.03		"	.05		"	.08		150	.10		300			
6	954.93	.03		"	.06		"	.10	2.0	200	.10	2.0	350			
7	818.51	.04		"	.07		"	.10	2.0	250						
8	716.20	.05		"	.08	2.0	"	.10	2.5	300						
9	636.62	.05		"	.09	2.0	150	.10	2.5	300						
10	572.96	.06		"	.10	2.5	200									
11	520.87	.06		"	"	2.5	200									
12	477.46	.07	2.5	"	"	2.5	200									
13	440.74	.07	2.5	"	"	3.0	250									
14	409.26	.08	2.5	"	.10	3.0	250									
15	381.97	.09	2.5	"												
16	358.10	.09	3.0	"												
17	337.03	.10	3.0	"												
18	318.31	"	3.0	"												
19	301.56	"	3.0	"												
20	286.48	"	3.0	"												
21	272.84	"	3.5	"												
22	260.44	"	3.5	"												
23	249.11	"	3.5	150												
24	238.73	"	3.5	200												
25	229.18	.10	3.5	200												

LEGEND

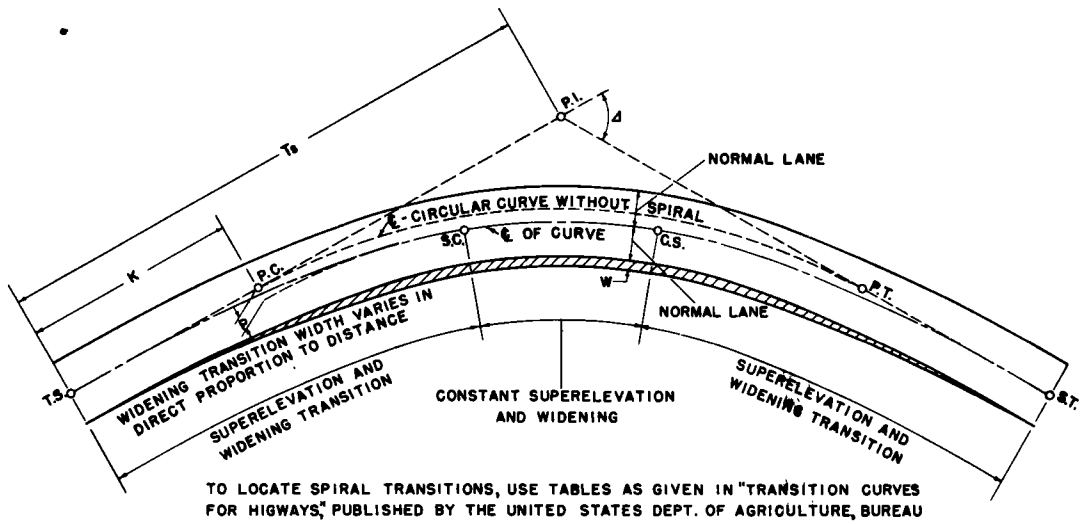
D – DEGREE OF CURVE
R – RADIUS (IN FEET) OF CURVE
S – SUPERELEVATION IN FEET PER FOOT OF WIDTH.
W – TOTAL WIDENING IN FEET FOR 2-LANE PAVEMENT.
L_s LENGTH OF SPIRAL

HORIZONTAL CURVES WITH TRANSITION SPIRALS - BOTH ENDS



TRANSITION SYMBOLS

P.I - POINT OF INTERSECTION OF MAIN TANGENTS.
T.S. & S.T. - COMMON POINT OF TANGENT AND SPIRAL, SPIRAL AND TANGENT.
S.C. - SPIRAL CURVE, COMMON POINT OF SPIRAL AND CIRCULAR CURVE OF NEAR TRANSITION.
C.S. - CURVE SPIRAL, COMMON POINT OF CIRCULAR CURVE AND SPIRAL OF FAR TRANSITION.
Rc - RADIUS OF CIRCULAR CURVE.
Ls - LENGTH OF SPIRAL BETWEEN T.S. AND S.C.
Ts - TANGENT DISTANCE P.I. TO T.S. OR S.T., OR TANGENT DISTANCE OF THE COMPLETE CURVE.
L.C. - STRAIGHT LINE CHORD. DISTANCE T.S. TO S.C.
K - DISTANCE FROM T.S. TO POINT ON TANGENT OPPOSITE THE P.C. OF THE CIRCULAR CURVE PRODUCED.
Es - EXTERNAL DISTANCE P.I. TO CENTER OF CIRCULAR CURVE PORTION.
L.T. - LONG TANGENT DISTANCE OF SPIRAL ONLY.
ST. - SHORT TANGENT DISTANCE OF SPIRAL ONLY.
P - OFFSET DISTANCE FROM THE TANGENT OF P.C. OF CIRCULAR CURVE PRODUCED.
Δ - INTERSECTION ANGLE BETWEEN TANGENTS OF ENTIRE CURVE.
Δc - INTERSECTION ANGLE BETWEEN TANGENTS AT THE S.C. AND AT THE C.S. OR THE CENTRAL ANGLE OF THE CIRCULAR CURVE PORTION OF THE CURVE.
θs - INTERSECTION ANGLE BETWEEN THE TANGENT OF THE COMPLETE CURVE AND THE TANGENT AT THE S.C., THE SPIRAL ANGLE.
W - WIDENING

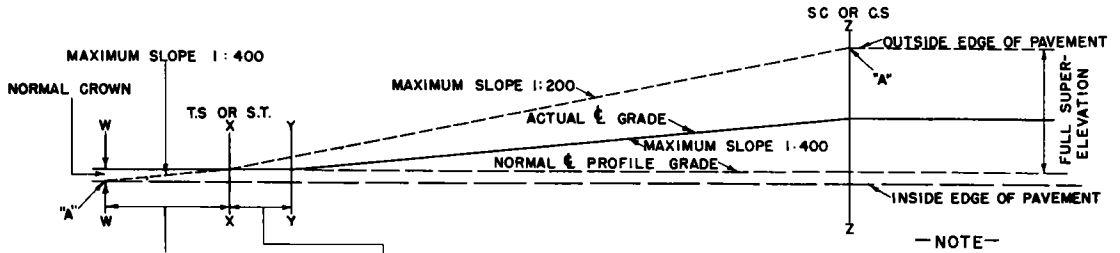


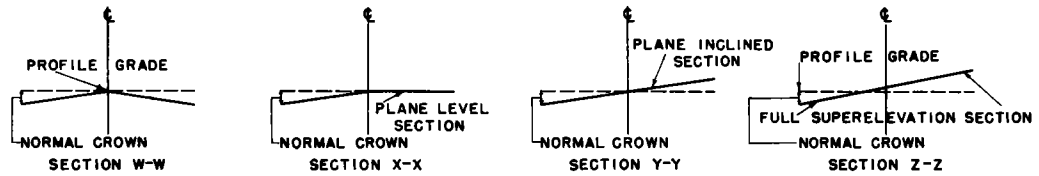
TO LOCATE SPIRAL TRANSITIONS, USE TABLES AS GIVEN IN "TRANSITION CURVES FOR HIGWAYS," PUBLISHED BY THE UNITED STATES DEPT. OF AGRICULTURE, BUREAU OF PUBLIC ROADS.

METHOD OF LAYOUT OF WIDENING AND SUPERELEVATION OF SPIRAL LANES

UNDIVIDED HIGHWAY

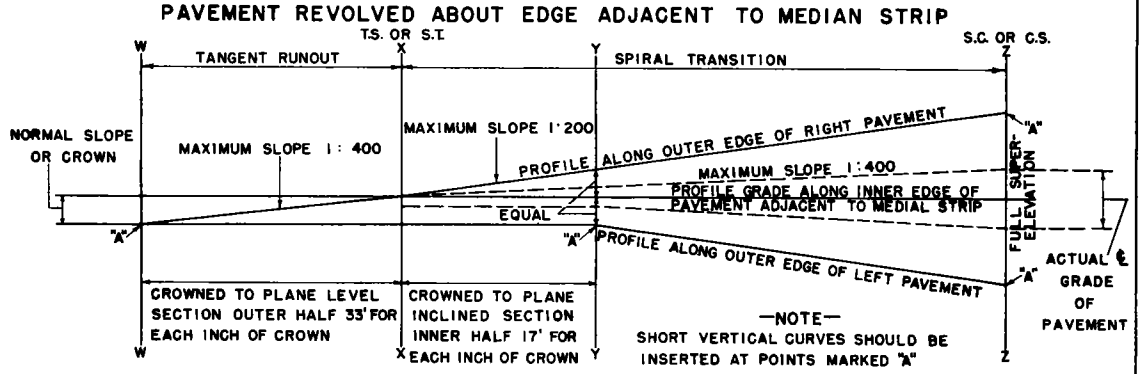
PAVEMENT REVOLVED ABOUT INSIDE EDGE



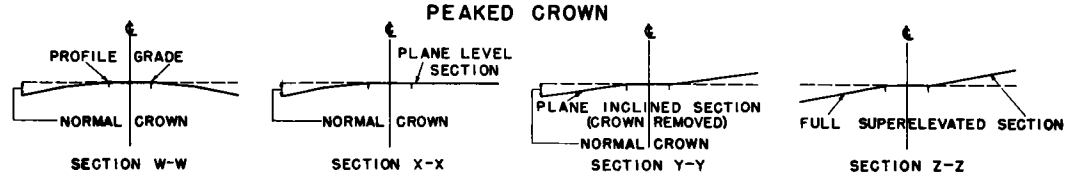


DIVIDED HIGHWAY

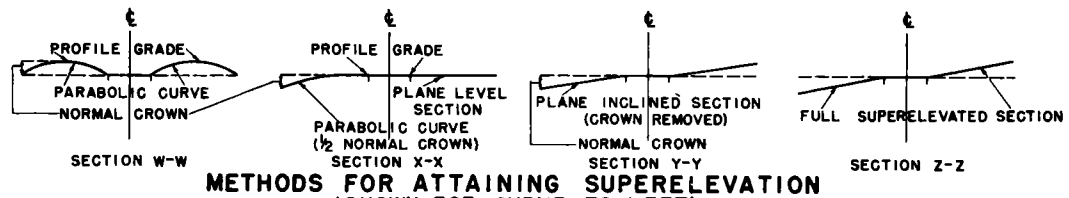
PAVEMENT REVOLVED ABOUT EDGE ADJACENT TO MEDIAN STRIP



PEAKED CROWN



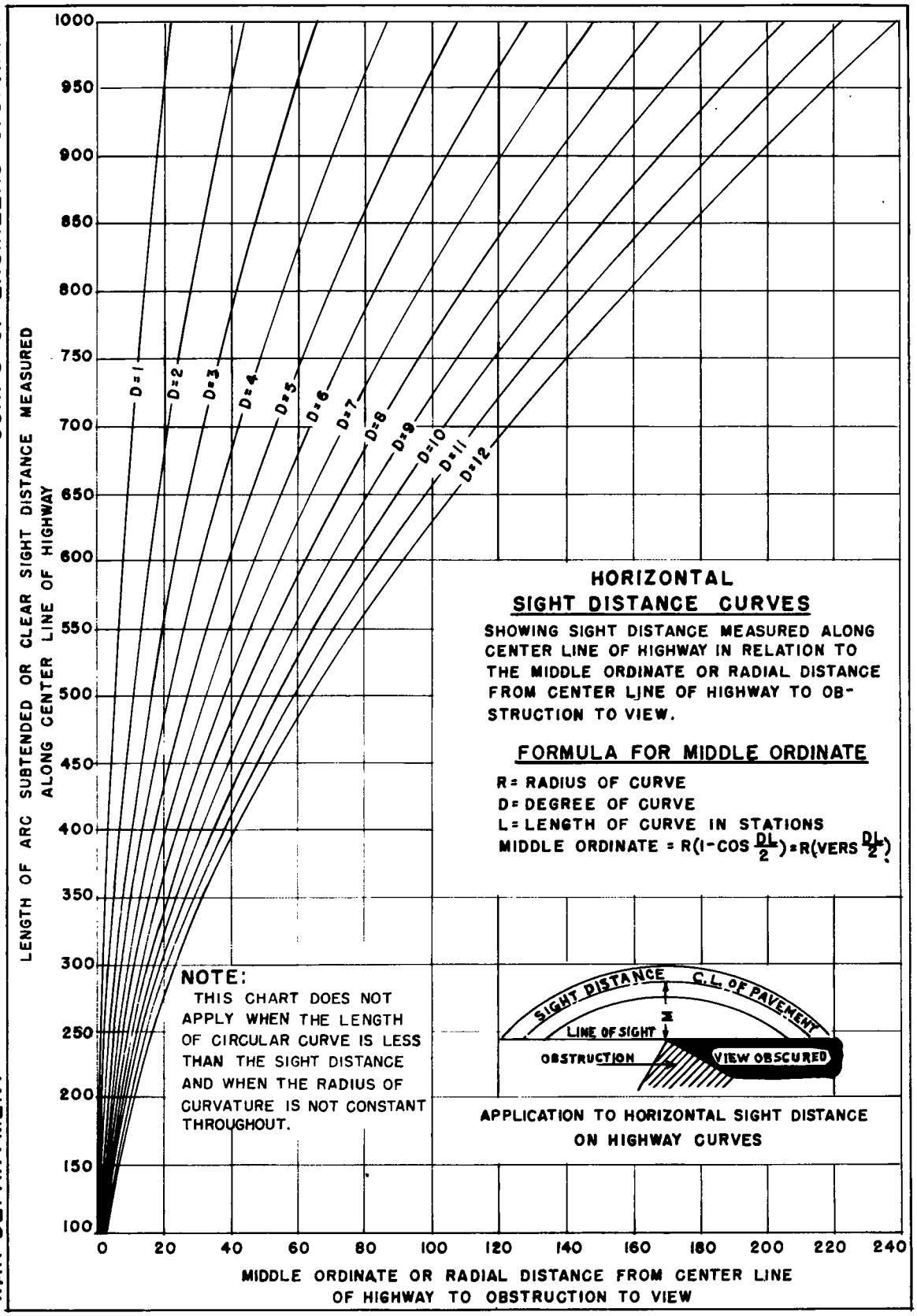
PARABOLIC CROWN



METHODS FOR ATTAINING SUPERELEVATION
(SHOWN FOR CURVE TO LEFT)

CORPS OF ENGINEERS U.S. ARMY

WAR DEPARTMENT



HORIZONTAL SIGHT DISTANCE CURVES

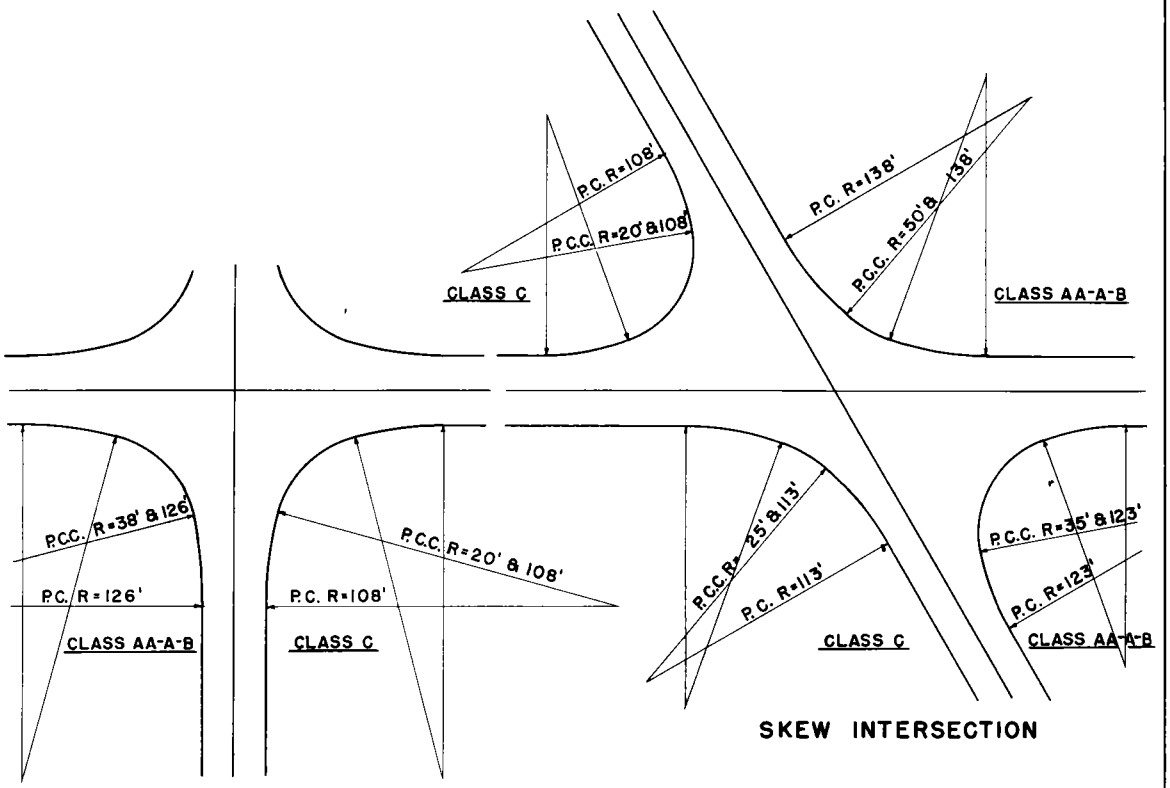
SHOWING SIGHT DISTANCE MEASURED ALONG CENTER LINE OF HIGHWAY IN RELATION TO THE MIDDLE ORDINATE OR RADIAL DISTANCE FROM CENTER LINE OF HIGHWAY TO OBSTRUCTION TO VIEW.

FORMULA FOR MIDDLE ORDINATE

R = RADIUS OF CURVE
D = DEGREE OF CURVE
L = LENGTH OF CURVE IN STATIONS
MIDDLE ORDINATE = $R(1-\cos\frac{DL}{2}) = R(\text{VERS}\frac{DL}{2})$

NOTE:
THIS CHART DOES NOT APPLY WHEN THE LENGTH OF CIRCULAR CURVE IS LESS THAN THE SIGHT DISTANCE AND WHEN THE RADIUS OF CURVATURE IS NOT CONSTANT THROUGHOUT.

APPLICATION TO HORIZONTAL SIGHT DISTANCE ON HIGHWAY CURVES



SKEW INTERSECTION

RIGHT ANGLE INTERSECTION

TRUCKS & BUSSES

(APPLICABLE TO CLASS AA, A, & B ROADS)

3 CENTER COMPOUND CURVE

ANGLES							
A	I	B	R_2	R_1 & R_3	M	Y	X
150°	30°	1/2 OF I=15°	32'	120'	3'	15.8'	153.4'
135°	45°	1/3 OF I 15°	32'	120'	3'	15.8'	107.3'
120°	60°	1/4 OF I=15°	35'	123'	3'	16.2'	88.6'
105°	75°	1/5 OF I=15°	35'	123'	3'	16.2'	72.3'
90°	90°	1/6 OF I=15°	38'	126'	3'	16.6'	63.8'
75°	105°	1/7 OF I=15°	45'	133'	3'	17.5'	59.6'
60°	120°	1/8 OF I=15°	50'	138'	3'	18.2'	54.4'

PASSENGER VEHICLES

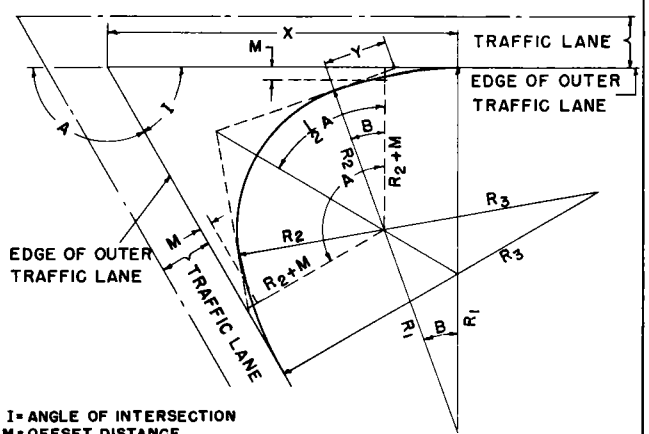
(APPLICABLE TO CLASS C ROADS)

3 CENTER COMPOUND CURVE

ANGLES							
A	I	B	R_2	R_1 & R_3	M	Y	X
150°	30°	1/2 OF I=15°	18'	106'	3'	13.96	101.15
135°	45°	1/3 OF I=15°	18'	106'	3'	13.96	73.48
120°	60°	1/4 OF I=15°	20'	108'	3'	14.22	62.62
105°	75°	1/5 OF I=15°	20'	108'	3'	14.22	52.75
90°	90°	1/6 OF I=15°	20'	108'	3'	14.22	45.78
75°	105°	1/7 OF I=15°	22'	110'	3'	14.48	41.96
60°	120°	1/8 OF I=15°	25'	113'	3'	14.89	38.97

NOTE "A"

RADII OF COMPOUND CURVES GIVEN IN ABOVE TABLES ARE BASED ON ESTABLISHING A RADIUS FOR THE INNER CURVE (R_2) AND COMPUTING THE RADII FOR OUTER CURVES (R_1 & R_3) ASSUMING A CONSTANT OFFSET 'M' AND A CONSTANT ANGLE 'B' AS SHOWN.



I = ANGLE OF INTERSECTION
M = OFFSET DISTANCE
R_2 = RADIUS OF INNER CURVE
R_1 & R_3 = RADIUS OF OUTER CURVE

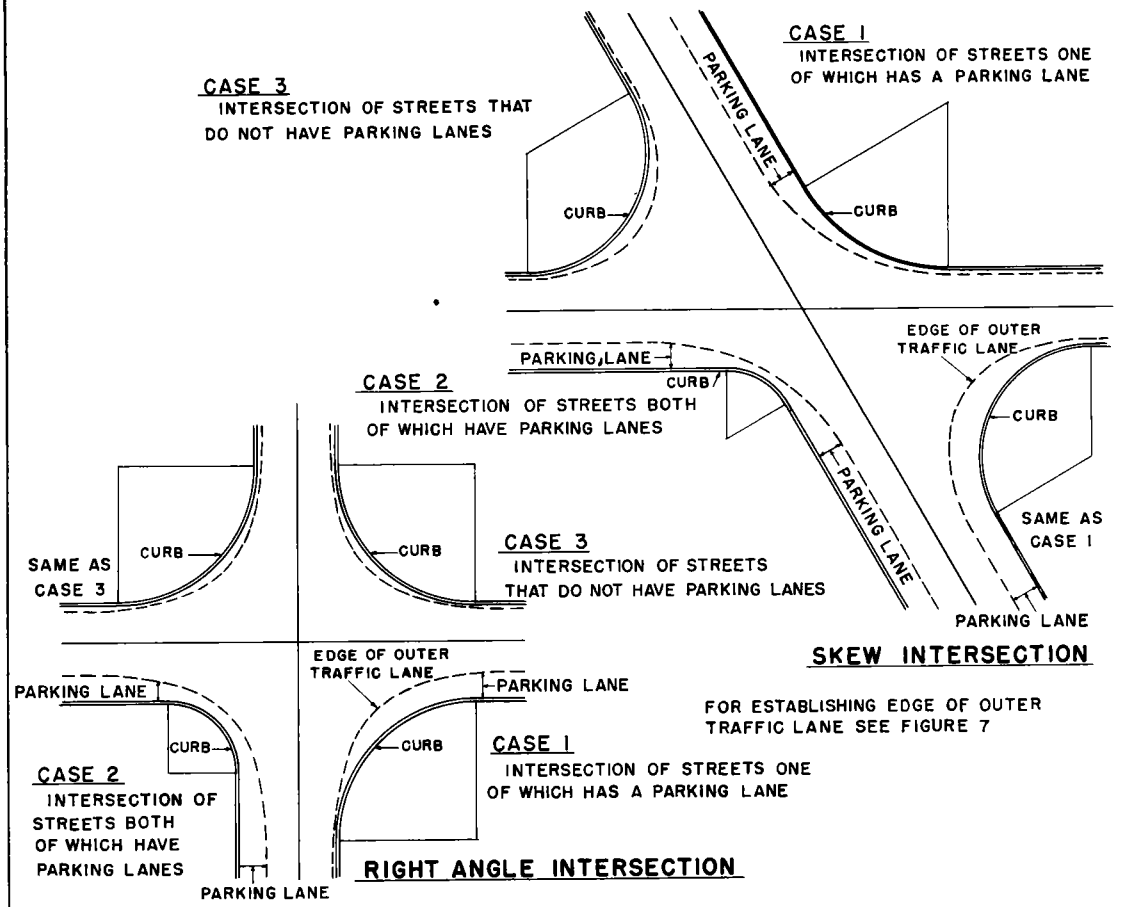
$$Y = \left(\frac{R_2 + M}{\cos B} - R_2\right) \cot B$$

$$R_1 \text{ OR } R_3 = \frac{Y}{\tan \frac{1}{2} B}$$

$$X = (R_2 + M) \tan \tfrac{1}{2} A + Y + Y \cos B - R_2 \sin B$$

SKETCH "A"
ILLUSTRATING METHOD OF COMPUTATION AND LAYOUT FOR FILLET CURVES

SKETCHES SHOWING MINIMUM DESIGN FOR EDGE OF PAVEMENT AT INTERSECTIONS OF ROADS (ALL CLASSES)



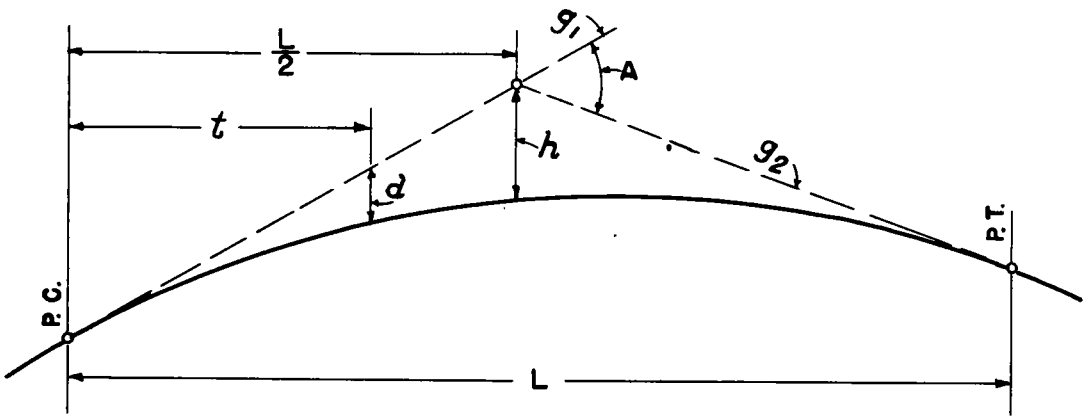
INTERSECTION ANGLE	ROAD CLASS	RADIUS OF CURB		
		CASE 1	CASE 2	CASE 3
60°	AA-A-B	28'	25'	32'
60°	C	15'	10'	20'
75°	AA-A-B	28'	20'	32'
75°	C	15'	10'	20'
90°	AA-A-B	28'	20'	35'
90°	C	10'	10'	20'
105°	AA-A-B	35'	15'	40'
105°	C	10'	10'	20'
120°	AA-A-B	35'	10'	45'
120°	C	10'	10'	25'

CURB RADII GIVEN IN THE ABOVE TABLE ARE BASED ON THE ASSUMPTION THAT:

a. THE TRAFFIC LANES OF ALL STREETS WITHOUT PARKING LANES WILL BE WIDENED 3 FEET IN ACCORDANCE WITH PROVISIONS OF PARAGRAPH 1-17 OF THE TEXT, AND THE FACE OF THE CURB WILL BE SET BACK 1-½ FEET FROM THE EDGE OF THE WIDENED TRAFFIC LANE.

b. WHEN PARKING LANES ARE PROVIDED, THE ABUTTING TRAFFIC LANES WILL NOT BE INCREASED 3 FEET IN WIDTH, BUT A PARKING LANE 8' FEET IN WIDTH WILL BE PROVIDED WITH FACE OF CURB SET FLUSH WITH THE OUTER EDGE OF PARKING LANE.

SKETCHES SHOWING RECOMMENDED MINIMUM RADII OF CURBS REQUIRED AT INTERSECTIONS OF STREETS



TERMS:

$g_1 + g_2$ = GRADES-PERCENT
A = ALGEBRAIC DIFFERENCE OF GRADES-PERCENT
L = LENGTH OF VERTICAL CURVE - STATIONS
t = DISTANCE FROM END OF CURVE - FEET
d = VERTICAL DISTANCE BETWEEN GRADE LINE AND VERTICAL CURVE - FEET

BASIC FORMULAE:

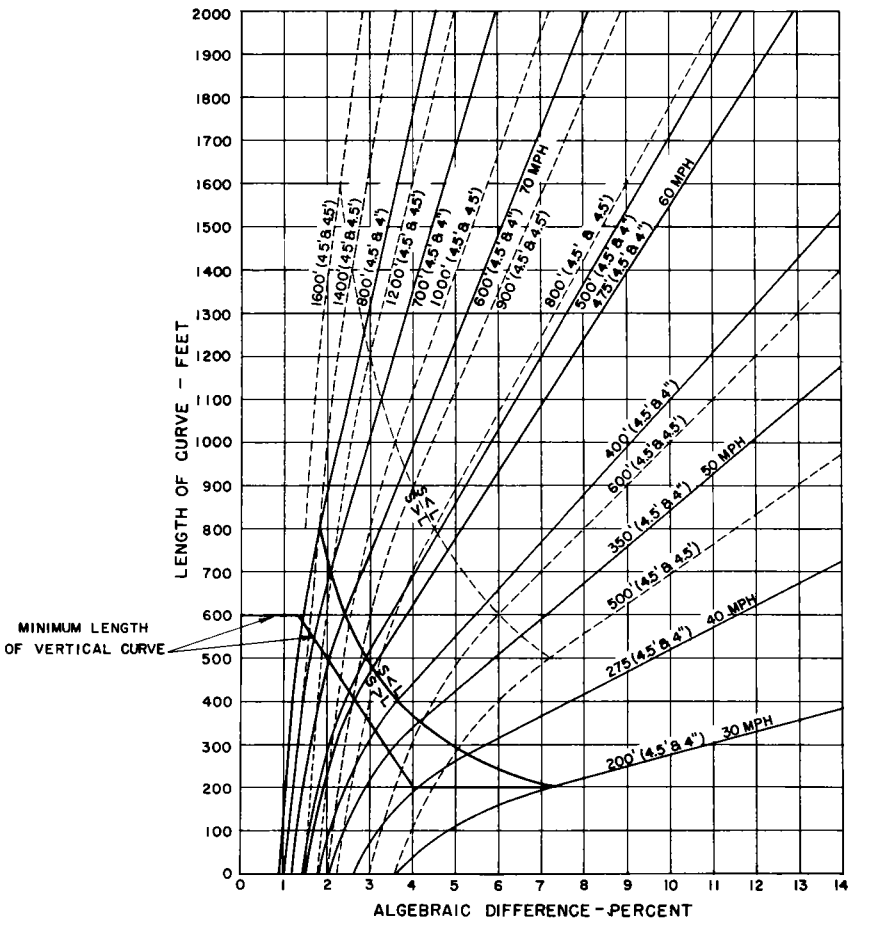
(1) $g_1 - g_2 = A$ (2) $h = \frac{AL}{8}$ (3) $\frac{d}{h} = \frac{t^2}{2500\,L^2}$

CALCULATION:

THE VALUE d MAY BE EXPRESSED AS $d = \frac{A}{L} \cdot K$

WHERE $K = \frac{t^2}{20{,}000}$

CALCULATION OF ELEVATIONS ON VERTICAL CURVES



NON-PASSING AND PASSING SIGHT DISTANCE CURVES

SHOWING RELATION OF GRADES AND VERTICAL CURVATURE TO VISIBILITY.

NON-PASSING SIGHT DISTANCE (N.P.S.D.)———

PASSING SIGHT DISTANCE (P.S.D.)– – – – – –

FORMULAS FOR SIGHT DISTANCE

S = SIGHT DISTANCE IN STATIONS

L = LENGTH OF VERTICAL CURVE IN STATIONS

g = ALGEBRAIC DIFFERENCE IN GRADES PERCENT

S > L SIGHT DISTANCE GREATER THAN LENGTH OF CURVES

$S = \frac{L}{2} + \frac{728}{g}$ FOR 4.5FT AND 4 INCHES (N.P.S.D.)

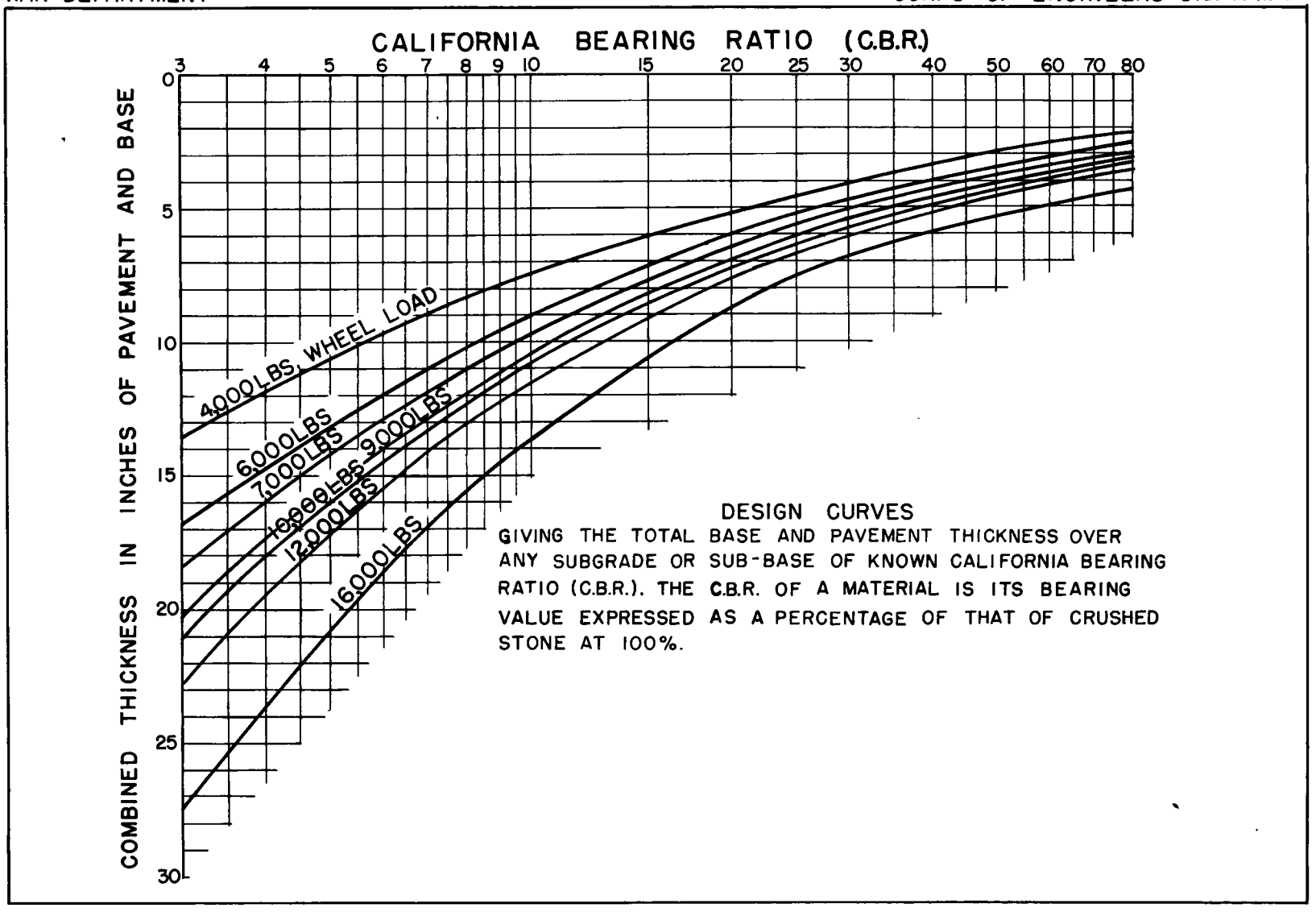
$S = \frac{L}{2} + \frac{18}{g}$ FOR 4.5FT. AND 4.5FT. (P.S.D.)

S < L SIGHT DISTANCE LESS THAN LENGTH OF CURVE

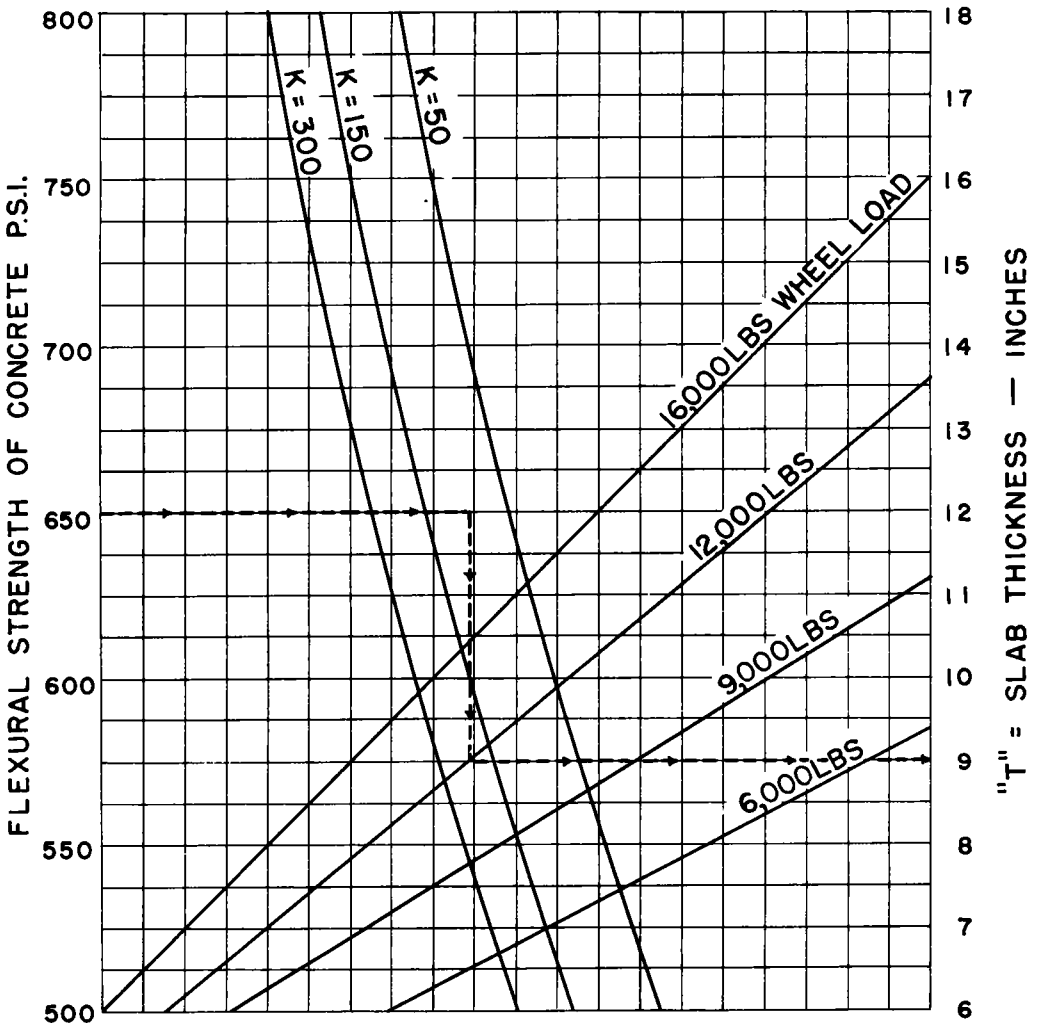
$S = 3.82\sqrt{\frac{L}{g}}$ FOR 4.5FT AND 4 INCHES (N.P.S.D.)

$S = 6\sqrt{\frac{L}{g}}$ FOR 4.5FT. AND 4.5FT. (P.S.D.)

SIGHT DISTANCE ON SUMMIT VERTICAL CURVES


CALIFORNIA BEARING RATIO (C.B.R.)
3 4 5 6 7 8 9 10 15 20 25 30 40 50 60 70 80
COMBINED THICKNESS IN INCHES OF PAVEMENT AND BASE
0 5 10 15 20 25 30
4,000 LBS. WHEEL LOAD
6,000 LBS
7,000 LBS
9,000 LBS
10,000 LBS
12,000 LBS
16,000 LBS
DESIGN CURVES
GIVING THE TOTAL BASE AND PAVEMENT THICKNESS OVER ANY SUBGRADE OR SUB-BASE OF KNOWN CALIFORNIA BEARING RATIO (C.B.R.). THE C.B.R. OF A MATERIAL IS ITS BEARING VALUE EXPRESSED AS A PERCENTAGE OF THAT OF CRUSHED STONE AT 100%.

DESIGN CURVES FOR CONCRETE PAVEMENT THICKNESS (HIGHWAYS)



EXAMPLE

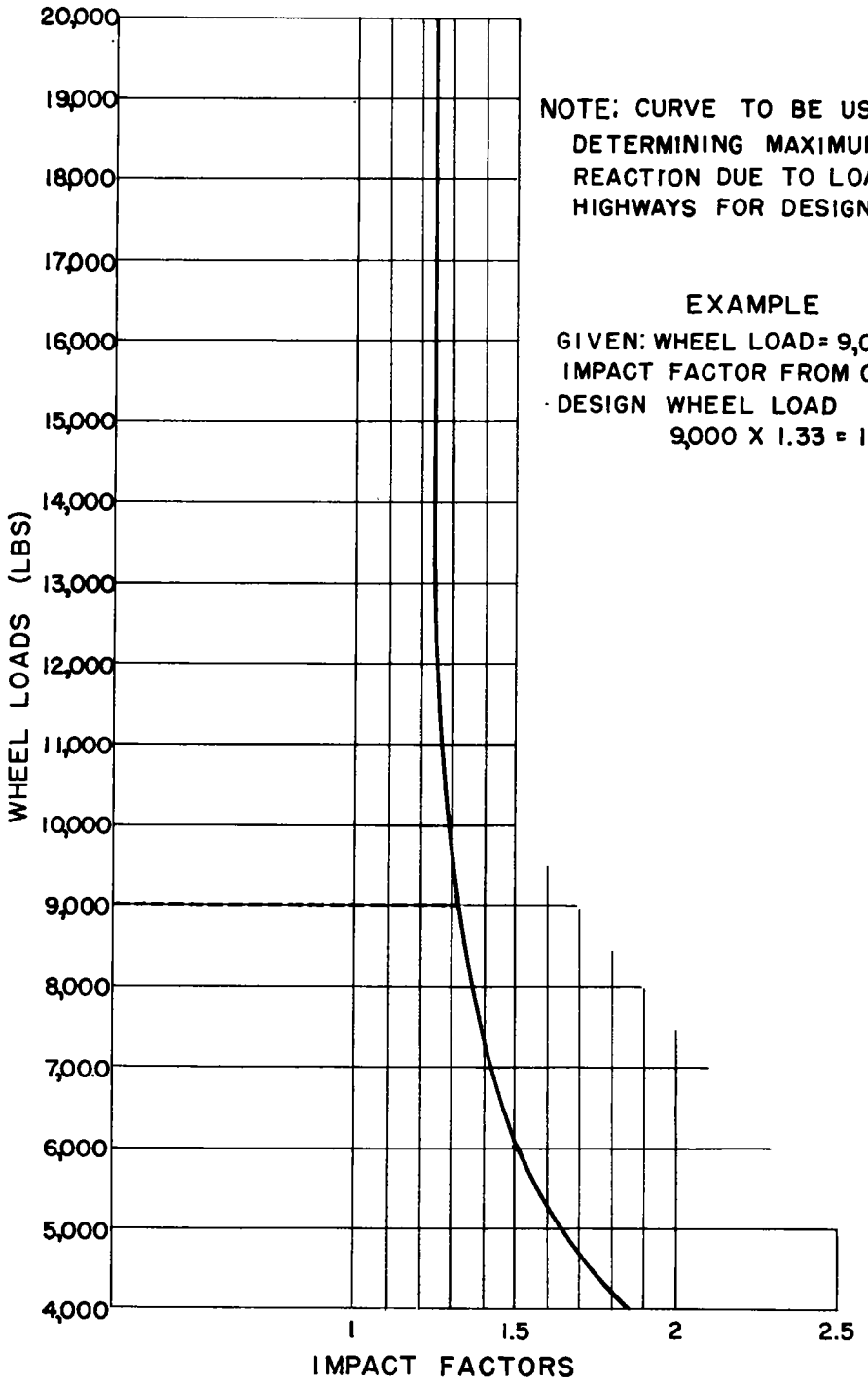
TO DETERMINE SLAB THICKNESS - "T"

GIVEN - CONCRETE P.S.I. = 650

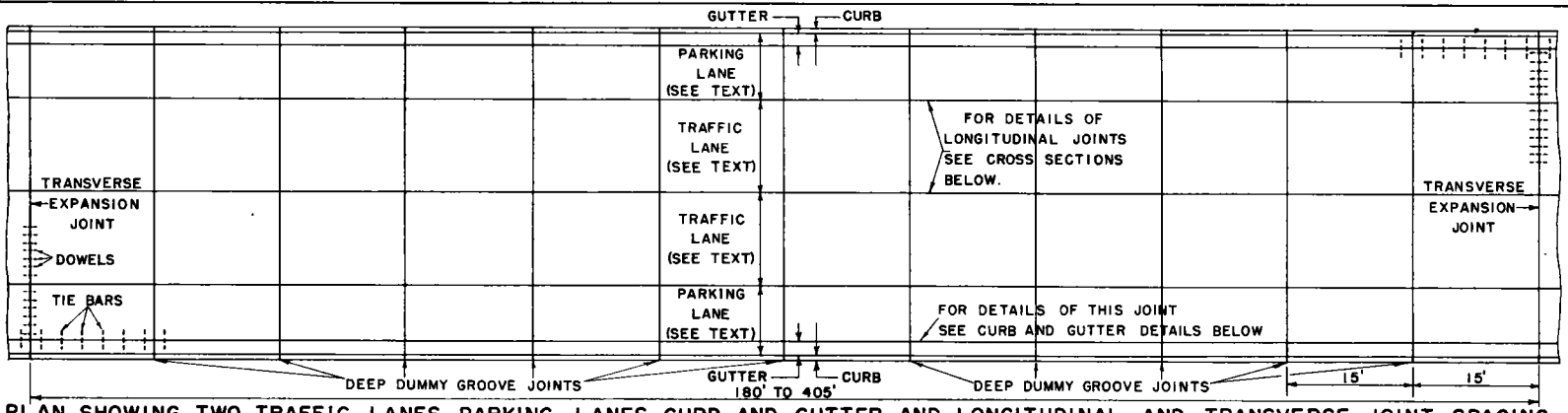
SUBGRADE MODULUS K = 100

WHEEL LOAD = 12,000 LBS

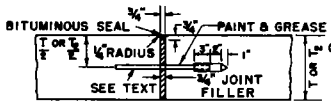
WITH ABOVE VALUES FOLLOW DOTTED LINE ON GRAPH THEN "T" = 9 INCHES (UNIFORM)



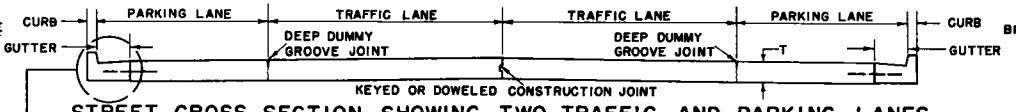
LOAD IMPACT FACTOR CURVE



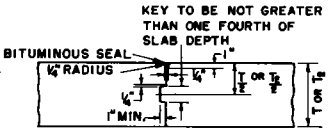
PLAN SHOWING TWO TRAFFIC LANES, PARKING LANES, CURB AND GUTTER AND LONGITUDINAL AND TRANSVERSE JOINT SPACING (NONREINFORCED CONCRETE PAVEMENT)



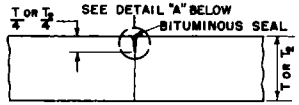
TRANSVERSE EXPANSION JOINT



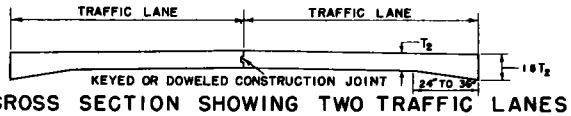
STREET CROSS SECTION SHOWING TWO TRAFFIC AND PARKING LANES WITH CURB AND GUTTER



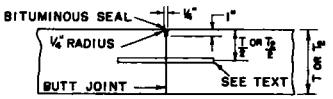
KEYED CONSTRUCTION JOINT



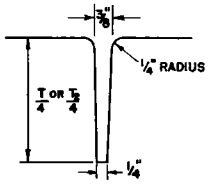
DEEP DUMMY GROOVE JOINT



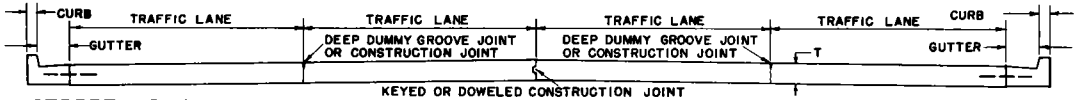
ROAD CROSS SECTION SHOWING TWO TRAFFIC LANES WITH THICKENED EDGES



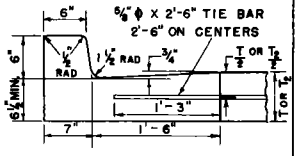
DOWELED CONSTRUCTION JOINT



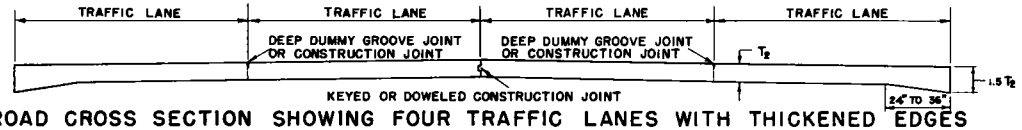
DETAIL "A"



STREET CROSS SECTION SHOWING FOUR TRAFFIC LANES WITH CURB AND GUTTER

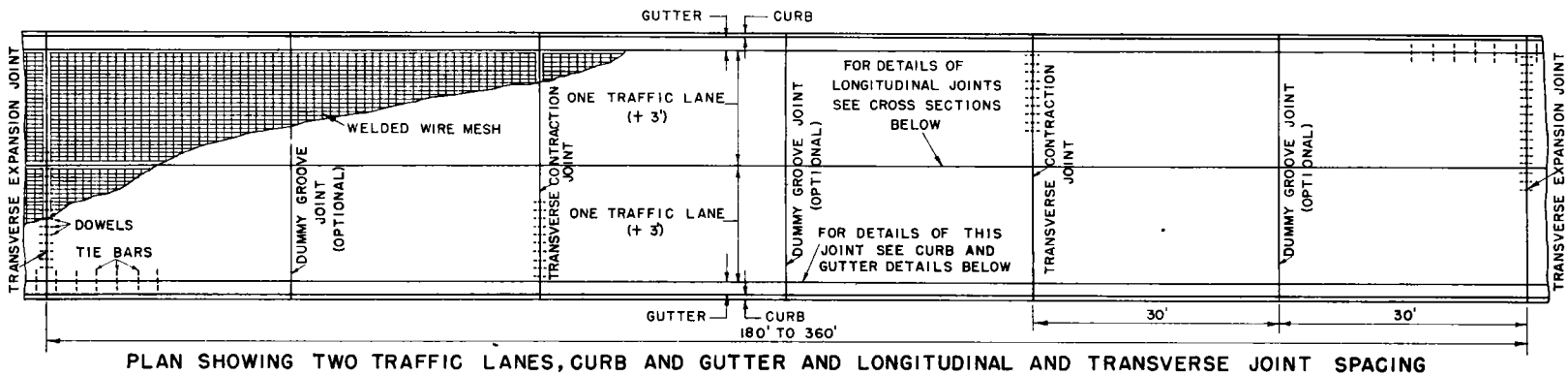


CURB & GUTTER DETAILS

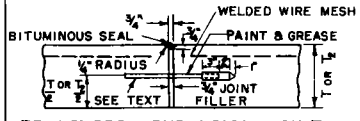


ROAD CROSS SECTION SHOWING FOUR TRAFFIC LANES WITH THICKENED EDGES

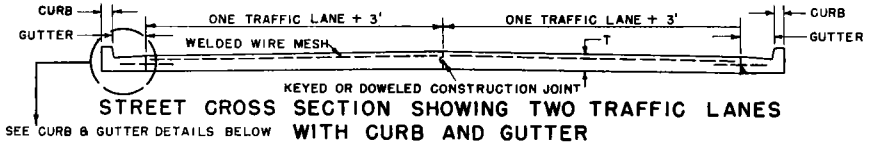
NONREINFORCED CONCRETE PAVEMENT DESIGN



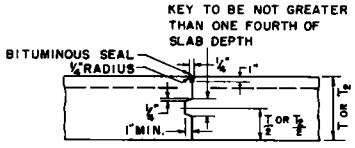
PLAN SHOWING TWO TRAFFIC LANES, CURB AND GUTTER AND LONGITUDINAL AND TRANSVERSE JOINT SPACING
(REINFORCED CONCRETE PAVEMENT)



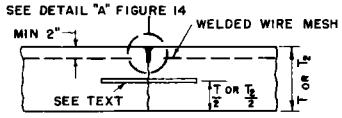
TRANSVERSE EXPANSION JOINT



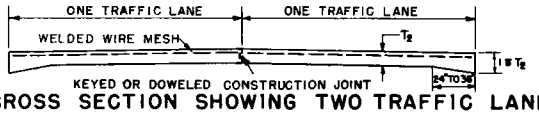
STREET CROSS SECTION SHOWING TWO TRAFFIC LANES WITH CURB AND GUTTER



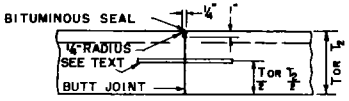
KEYED CONSTRUCTION JOINT



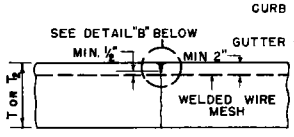
TRANSVERSE CONTRACTION JOINT



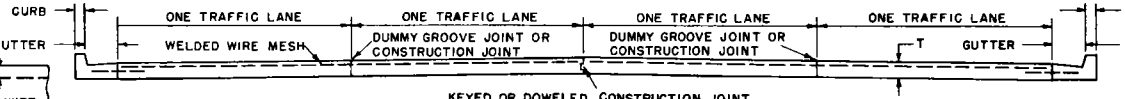
ROAD CROSS SECTION SHOWING TWO TRAFFIC LANES WITH THICKENED EDGES



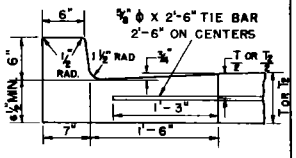
DOWELED CONSTRUCTION JOINT



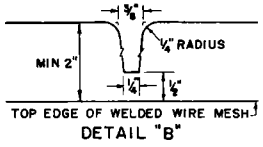
DUMMY GROOVE JOINT



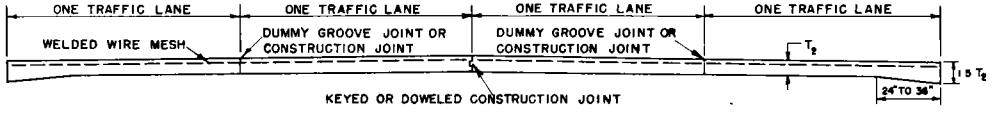
STREET CROSS SECTION SHOWING FOUR TRAFFIC LANES WITH CURB AND GUTTER



CURB AND GUTTER DETAILS



DETAIL "B"

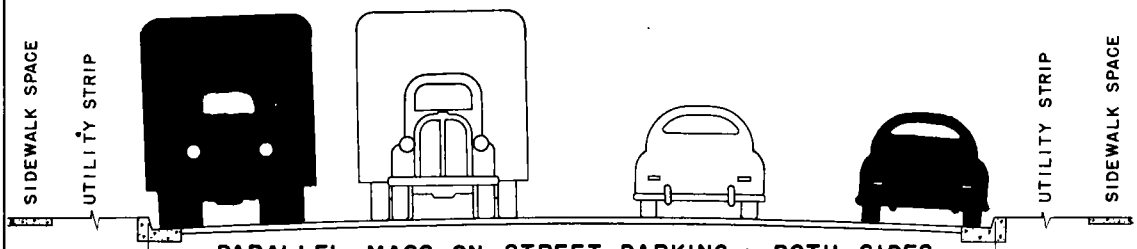


ROAD CROSS SECTION SHOWING FOUR TRAFFIC LANES WITH THICKENED EDGES

REINFORCED CONCRETE PAVEMENT DESIGN

ENGINEERING MANUAL PART X CHAPTER I APRIL 1947 FIGURE 15

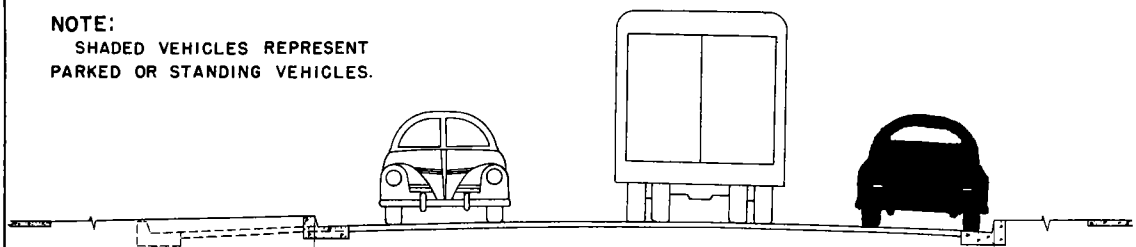
PAVEMENT WIDTHS FOR 2 - TRAFFIC LANE STREETS
(ALL TYPE ARMY INSTALLATIONS EXCEPT CEMETERIES)



PARALLEL MASS ON-STREET PARKING — BOTH SIDES

- CLASS AA - MIN. 40'
- CLASS A OR B - MIN. 36'
- CLASS C (WHERE TRAFFIC DENSITY EXCEEDS 50 V.P.H.) MIN. 36'
- CLASS C (WHERE TRAFFIC DENSITY IS LESS THAN 50 V.P.H.) MIN. 32'

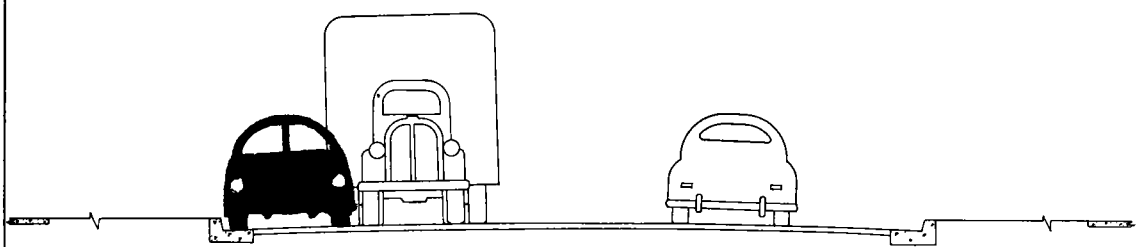
NOTE:
SHADED VEHICLES REPRESENT PARKED OR STANDING VEHICLES.



PARALLEL MASS ON - STREET PARKING — ONE SIDE ONLY

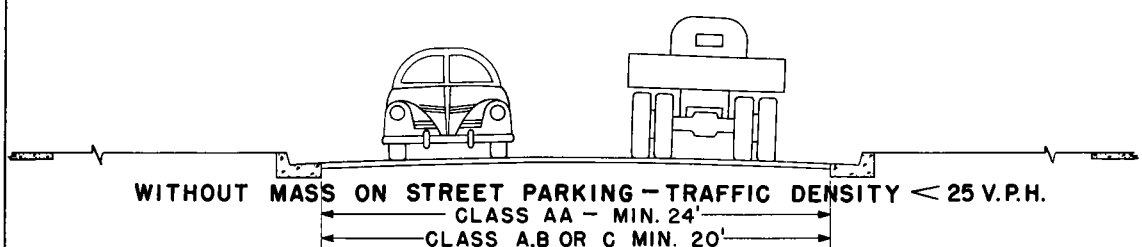
FUTURE WIDENING

- CLASS AA - MIN. 32'
- CLASS A OR B MIN. 28'
- CLASS C (EXCEEDS 50 V.P.H.) MIN. 28'
- CLASS C LESS THAN 50 V.P.H.) MIN. 24'



WITHOUT MASS ON-STREET PARKING — TRAFFIC DENSITY > 25 V.P.H.

- CLASS AA - MIN. 30'
- CLASS A OR B MIN 26'
- CLASS C (EXCEEDS 50 V.P.H.) MIN. 26'
- CLASS C (LESS THAN 50 V.P.H.) MIN. 22'



WITHOUT MASS ON STREET PARKING - TRAFFIC DENSITY < 25 V.P.H.

- CLASS AA - MIN. 24'
- CLASS A,B OR C MIN. 20'

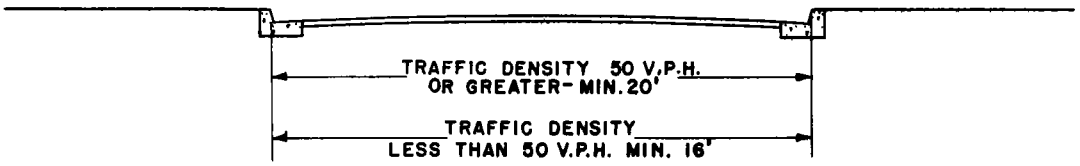
CLASS AA - ROUTES FOR TRAFFIC CONSISTING OF LARGE VOLUME OF HEAVY VEHICLES OF EITHER WHEELED OR TRACK-LAYING TYPE.

CLASS A - HEAVY DUTY ROUTES FOR TRAFFIC CONSISTING OF HEAVY VEHICLES OF EITHER WHEELED OR COMBINED WHEEL AND TRACK-LAYING TYPES.

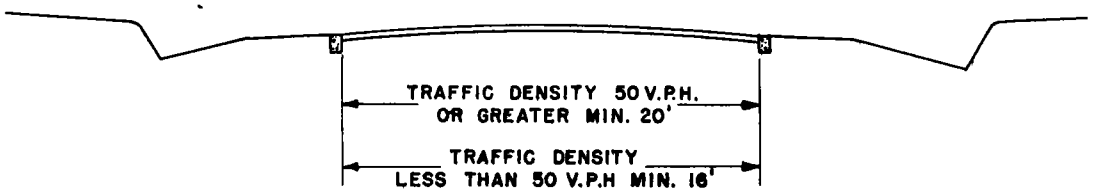
CLASS B - MEDIUM DUTY ROUTES FOR TRAFFIC CONSISTING OF VEHICLES PRINCIPALLY OF THE WHEELED TYPE.

CLASS C - ROUTES FOR TRAFFIC CONSISTING PRINCIPALLY OF PASSENGER CARS AND LIGHT TRUCKS.

TYPICAL STREET OR ROAD SECTION FOR CEMETERIES
(2 – LANE TRAFFIC)



STREET SECTION



ROAD SECTION

NOTE:
ALL STREETS AND ROADS CLASS "C".

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TRANSPORTATION FACILITIES
RAILROADS



ARMY SERVICE FORCES
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

1 6 1

CHAPTER 2
RAILROADS

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PART X

TRANSPORTATION FACILITIES

CHAPTER 2

RAILROADS
(Trackage, Design, Accessories)

GENERAL

2-01 SCOPE OF THESE INSTRUCTIONS. These instructions are intended to cover requirements for the design of railroad facilities at War Department projects. Good engineering practice will be followed in special conditions and problems not covered specifically.

2-02 STANDARDS. American Railroad Engineering Association standards for comparable facilities will be used as a basis of design.

2-03 DESIGN PROCEDURE. Development of the railroad layout should be coincident with that of the portion of the site plan which includes facilities to be served by rail. Such facilites should be so located that maximum grades and curvature will not exceed those recommended in paragraph 2-22 and 2-23 below and should be laid out to permit adequate rail service.

2-04 STATE REGULATIONS. Construction should conform with requirements of State Commissions and regulatory bodies with regard to structures, clearances, and safety.

2-05 JUSTIFICATION FOR RAIL FACILITIES. Direct rail service will be provided at all Ports, Staging Areas, Depots, Manufacturing Plants and major Troop Housing establishments. For other installations the justification will be determined by comparative costs of direct rail service, including construction, maintenance and operation with other means of transportation, or by military necessity.

2-06 RELOCATION OF EXISTING TRACKS. When it is necessary to relocate tracks of railroad prior to the abandonment of the existing right of way, new construction shall be of the same type as the abandoned track. A higher type of construction is permissible, only in compliance with written request of the railroad, providing that the railroad agrees to bear the additional cost.

2-07 AGREEMENTS. Negotiations with Carriers relative to rates and fares, terminal switching and arbitrary charges, and agreements covering traffic and operating features are the responsibility of the Chief of Transportation. Those covering construction and maintenance are the responsibility of the Chief of Engineers. Each agreement, preferably one carrying all features, should either be made or definite commitments obtained prior to initiation of construction. Recommendations of the service affected will be transmitted to the proper Technical Service by the Office of Chief of Engineers which will advise as to feasibility from a transportation standpoint. Agreements which include all features will be made by the Chief of Transportation with the concurrence of the Chief of Engineers. Agreements for construction and maintenance only will be made by the District Engineer, subject to the approval of the Chief of Engineers.

TRACKS

2-08 DESCRIPTION AND ALLOCATION OF COSTS. Trackage will consist of railroad connections, auxiliary tracks normally used by the railroad, access lines, construction material delivery tracks, and project trackage.

a. Railroad Connections. Railroad connections include the turnouts

from the Carriers' lines and track to the railroad right of way line. The cost of the connections must be borne by the railroad.

b. Auxiliary Tracks. Auxiliary tracks normally operated by the railroad include passing, set out or interchange tracks, and wyes. Any siding along the main track of the Carrier, for the purpose of clearing the main track during delivery, or to facilitate railroad operation should be the sole responsibility of, and the cost assumed by, the railroad. In establishments operated by the Government, interchange tracks are joint facilities, and, when located along the railroad, the railroad should participate in the construction costs. When, for Government operating convenience, the railroad delivers to a yard within the establishment, the cost of the yard will be borne by the Government. When wyes are essential for railroad operation, the railroad should participate in the costs. If the cost must be borne by the Government, the wye should be so located that it can be used by Government power.

c. Access Line. Where the establishment is not adjacent to the railroad, the access line is the track between the railroad right of way and connections to facilities to be served. The railroad may elect to provide the access line, particularly under competitive conditions; otherwise, construction will be by the Government on Government controlled right of way.

d. Tracks for Delivery of Construction Material. Construction of establishments which require railroad service during operation is normally of sufficient magnitude to warrant rail delivery of construction materials to the sites. Where the establishment is adjacent to a railroad, it is contemplated that tracks will be provided by the contractor or railroad for such delivery. But where the establishment requires an access line which can be effectively used by the contractor and the use of such a line is provided for in the contract, its construction should be given priority, particularly, if it will reflect a saving in construction costs to the Government. Other material delivery tracks should be so located and constructed that the largest possible portion consistent with satisfactory usability to the contractor will form a part of the project layout. Material from construction tracks not a part of the project layout may be incorporated in permanent tracks if it meets specification requirements.

e. Project Trackage. Project trackage includes all tracks within the project and will be constructed by and at the expense of the Government.

LAYOUTS

2-09 GENERAL. Project track layouts should be designed to provide flexibility and economy of operation, that is, minimum movement for service accomplished. Movement should be direct through interchange, classification and delivery. The capacity of interchange, classification and storage yards will depend on the volume of traffic and facilities of the serving railroad in the vicinity. Normally, the total yard capacity should be about 50% greater than the average daily movement through the installation. Interchange or receiving and dispatching tracks should be of length sufficient to hold the maximum single delivery. The number of classification tracks is determined by the number of classifications for distribution, and the length, by the average number of cars in each classification. Except in establishments with heavy traffic, where either terrain, extent of the reservation, or safety requirements will not permit, yard trackage is preferably confined to one yard, with the drill tracks in such position that switch targets are in the locomotive operator's line of vision. In general, project trackage should conform with typical layouts, with such modifications as are re-

quired to meet local conditions:

2-10 TROOP HOUSING. Typical layout plans are designed to provide the required track facilities, which normally include service to warehouse areas, facilities for troop and equipment loading, and to fuel storage areas. Individual rail service to Ordnance magazines, station hospitals, and laundry boiler houses will not normally be provided, except when justified by a definite saving in transportation costs, and then only with prior approval of the Office of the Chief of Engineers.

a. Warehouse Layouts. The typical warehouse layouts are designed to provide a switching track between house or service tracks with crossovers at fire breaks to facilitate spotting of cars and removal of empties. This layout provides for a connection only at one end of the warehouse area. Where terrain or operating conditions require a double-ended connection, the third track should be eliminated. Warehouse floors should be at car floor level. A track serving Quartermaster Utility Warehouses should be located to permit its use as a truck or team track, and provided with end and side loading platforms adjacent to a planned road. A single spur with fixed end loading ramp should be provided to serve the Ordnance Warehouse and Shop area.

b. Troop and Equipment Loading Facilities. Facilities for entraining troops will be provided at all major troop housing establishments. Troop movements are in two classes, emergency movements for a division with equipment and those of personnel only in various size units. For the first class, facilities will be provided for entraining at a rate equal to the capacity of the serving railroad to absorb the additional traffic, including accumulation of empties, with a maximum requirement of three entraining points. These facilities include tracks, preferably of full train length, provided with end ramps and side loading platforms, with stabilized areas alongside. The side loading platform should be at least 400 feet long. Where warehouse layouts conform with typical plans of warehouse areas, facilities will be adequate. For movements of personnel only, sufficient trackage for the average movement, with stabilized areas alongside at track level should be provided, preferably near the connection with the serving railroad.

c. Coal and Motor Fuel Storage. Coal storage layouts should be provided in accordance with requirements of Part IX, Chapter 3.

d. Depots. Track layouts should be designed in accordance with the requirements of Part II, Chapter 6.

e. General Hospitals. Rail service is advisable but not essential to General Hospitals. When such service can be provided with reasonable economy and will permit patients to be moved from train to ward without the use of ambulances, rail service should be provided. Determination of the necessity for rail service will be made jointly by the Surgeon General and the Chief of Engineers.

f. Storage of Hospital Trains. Facilities for storage and servicing hospital cars in active use should be provided at locations and of capacities as required by the Surgeon General and Chief of Transportation. These facilities include tracks in pairs on 18 foot centers, with space between pairs sufficient for single lane driveways; water and electric connections at intervals of two car lengths between tracks of each pair; steam connections, when heat is required, located near the clearance point of each pair; steam generating plant when required, battery charging equipment, drainage and sewer facilities, and a small building for storage of tools and equipment. The surface between tracks should be paved. For inactive storage a railroad yard will be satisfactory.

g. Ordnance and Chemical Warfare Plants. Generally, typical plans are not available on plant projects. The layout is designed by the using service and the Plant Operating Contractor.

ACCESSORIES

2-11 ENGINE HOUSE. In permanent installations where operation of the rail facilities is by the Government, engine houses will be provided. Engine houses will be planned for storage and light or running repairs, of length sufficient to accommodate the locomotive used, with spaces at ends for normal maintenance movement, and a stall width of about 20 to 22 feet. The location should be convenient to a running track with shortest practicable track connection. The house should contain the following:

a. Utility connections and service.

b. A single pit conforming in length with the size of the locomotive and in depth with A.R.E.A. standards.

c. Sand drying equipment and storage.

d. Fire proof storage for lubricants 8 feet by 8 feet.

2-12 FUEL STATIONS. Fuel oil facilities for Diesel and oil burning steam locomotives require a tank of not over 12,000 gallons capacity, provided with heating coils in cold climates, and a pump. The tank should be located on the engine house lead. The use of steam locomotives is not contemplated for any future installations, and no provision will be made for accessories for this type of equipment.

DESIGN

2-13 SPECIFICATIONS AND STANDARDS. Postwar railroad track construction, planned for an active life or more than five years is classed as permanent, and other tracks, temporary. For work not specifically covered by this Manual, specifications of the A.R.E.A., or the serving railroad for comparable tracks may be used.

2-14 DRAINAGE. Drainage design should be in accordance with the instructions, using pipe for culverts under railroad tracks as specified under OCE Specification 805.

2-15 STRUCTURES. Structures in permanent work should be designed for Cooper's E-60 loading, and selection of the type should give consideration to economy of construction. The design of temporary structures should comply with loading requirements of the serving railroad.

2-16 TRACK SCALES. Railroad track scales will not be provided for troop housing projects or depots.

2-17 RAIL. Rail in permanent tracks should be new and so far as possible of one standard section. When present engineer stocks of 75-pound A.S.C.E. Section are depleted, 80-pound A.S.C.E. Section, 39 feet long, will be the minimum. New rail must conform with U. S. Army Specifications 43-2A. In some instances where operation is by the railroad with heavy road power, the railroad requirement as to section will govern. In these instances, and in temporary tracks, relayer rail, purchased from the railroad, may be used. Relayer rail should be free from physical defects, reasonably straight with farily smooth surface. Top wear measured at the center should not exceed more than 1/8 inch and side wear measured at the side of the head 5/8 inch below the original top of the rail should not exceed 8 percent of the original width of the head.

2-18 TIES. Cross and switch ties should conform in all respects, and bridge ties as to quality of lumber and kinds of woods used, to Federal

Specification MM-T-371. The minimum size of cross ties shall be 6" 6" x 8" x 8' -0", of switch ties 7" x 9" x plan length, and of bridge ties 8" x 8" x 10' -0". Normally only treated ties will be used. However, in some areas where treatment plants are not economically available, or where the kind of wood specified in the above-mentioned specifications as not requiring treament is available, untreated ties may be used. Ties should be spaced 16 to the 33 foot rail length and 19 to the 39 foot rail length on house, yard and delivery tracks; 18 to the 33 foot and 21 to the 39 foot rail length on access lines.

2-19 SPLICE BARS. Splice bars should conform to U. S. Army Specification No. 43-3A, and should be of size, shape and drilling to fit the rail used. Where necessary to use abutting rails of different section, compromise joints, designed to hold the rails on an even surface and gage at the joint, should be used. Used splice bars in good condition may be used with relayer rail.

2-20 TIE PLATES. Tie plates will be used on all track, and should conform to U. S. Army Specification No. 43-6. Used tie plates in good condition may be used with relayer rail.

2-21 BALLAST. Selection of ballast depends on economics and availability. Stone, slag or gravel, graded to conform with A.R.E.A. standards is recommended. Cinders, where economically available, are acceptable for house and yard tracks. The minimum depth of ballast under ties should be 8".

2-22 TURNOUTS. Normally No. 8 turnouts with low switch stands will be used. Switch assemblies, stands, rigid bolted frogs and guard rail assemblies should conform with A.R.E.A. standard plans. Material and workmanship applicable to each item used should conform to Federal, U. S. Army or A.R.E.A. Specifications.

2-23 CURVATURE. Generally, curvature on any track should not exceed that in a No. 8 turnout, except in congested areas where power designed for high curvature is always available. In no case should the radius be less than 175 feet. Standard gage of 4'-8 1/2" should be used on curves up to 8° and should be widened 1/8" for each increment of 2° to a maximum of 4'-9 1/4". On access lines the outer rail on curves should be elevated in accordance with A.R.E.A. standards.

2-24 GRADES. The permissible maximum grade on access lines depends on tonnage handled in one train unit and on operating safety. The preferable criterion is to consider that the operation will be by the railroad, limiting the grade to that over which the railroad can operate satisfactorily with its power. If the operation is by the Government, the determination of tonnage units will permit the proper technical service to specify the power unit required. Grades on access lines should be compensated 0.04% per degree of curvature. Grades in the body of yards and on standing tracks should not exceed 0.4%.

2-25 VERTICAL CURVES. Vertical curves should be used at grade intersections on access and running tracks where the algebraic difference in gradient exceeds 0.4%. The minimum rate of change should be .4% per 100' station in sags or twice that amount on summits.

2-26 HIGHWAY CROSSINGS. When necessary for tracks to cross public highways at grade, requirements of the State or municipality, or of the A.R.E.A., as to type of crossing, drainage, signs, crossing protection and approaches will apply. The installation of any mechanical protecting device required by public regulation should be oovered by an agreement with the highway agency concerned. The design and construction of highway crossings at grade within Army installations should conform to criteria given in Part X, Chapter 1.

2-27 CLEARANCES. Except where standard clearances of the serving railroad or provisions of the State Law require greater clearances, the following minimum as measured from top of rail or center line of track will apply:

a. Overhead Wires:

Primary high voltage	28' -0"
Secondary power, telegraph, telephone and signal	27' -0"

b. Miscellaneous Overhead Structures:

Other than wires if local conditions permit	22' -0"

NOTE: Lesser overhead clearances should be protected by warning signs and telltales or as provided by statutes and should not be less than 18'-0"; all clearances less than 22' -0" should be listed in the operating contract with the serving railroad.

c. Side Clearances:

Canopies up to 15' -6" above top of rail	8'-6"
Canopies higher than 15' -6" above top of rail	5'-6"
Buildings	8'-6"
Platforms 3'-9" above top of rail	6'-2"
Refrigerator Platforms 3'-2" in height	6'-2"
Refrigerator Platforms 4'-7" in height	8'-6"
Low platforms 4" above top of rail	5'-0"

d. Warehouse and Engine House Entrances:

Overhead	17'-0"
Side: Engine house	6'-6"
Warehouse	7'-0"

e. Track Centers. Normal track centers of body tracks in yards will be 13'-0" and when parallel to a main or running track, the first body track 15'-0" from such track. Tracks in pairs for operation of locomotive cranes will be on not less than 18'-0" centers. Ladder tracks will be not less than 15'-0" centers from any parallel track.

NOTE: Dangerous conditions, due to close clearances should be protected by an appropriate type of warning device.

2-28 CONSTRUCTION OUTSIDE CONTINENTAL UNITED STATES: General requirement and project track layouts will conform with local requirements and applicable portions of criteria before outlined.

a. Design. Maximym curvature shall not exceed 20° for narrow gage, or 16° for standard gage, except where conditions absolutely require sharper curavture, and then only when equipment designed for this curvature is normall available. Grades will conform with Paragraph 2-23. Clearances shall meet United States safety standards.

b. Materials of Construction. Rail, turnouts and metal fastenings will normally be of United States standards and manufacture with minimum weight of rail 75 pounds per yard. Turnouts for various gages will conform with Plan No. T.O. 40-2. Ties will be of local material, where available. All ties necessarily produced in this country should have preservative treatment. Tie spacing will conform with local standards. Ballast will, in all cases, be produced locally.

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Appendix A

RAILROAD LAY-OUT DATA

1. SCOPE. The tables, with illustrative figures and formulae, are intended to provide solutions of problems in railroad track lay-outs typical to Army installations. The objectives are curvature limited to that which can be safely operated by road power, minimum track construction to meet operating requirements, and minimum switching movements for the required operation. In all cases computations are based on tangents through switch points and frogs to prevent bunching of curvature near turn-outs. The dimensions given in the tables may be used in planning, revision of existing lay-outs, and laying out on the ground. In all cases, the formulae may be used to determine essential dimensions for any other curvature or track spacing not set forth in the tables.

2. USE OF TABLES. *a.* Tables I to VI, inclusive, figure 1, cases I and II, give dimensions for minimum trackage in lay-outs where parallel tracks at various centers are reached from an access track over curves of 10°, 12°, and 14°, and combinations thereof. Curvature sharper than 12° is not recommended except where required by limited space. These tables may be used for the typical three-track warehouse lay-outs.

b. Table VII, figure 2, gives space requirements and lay-out dimensions for curved connections to a three-parallel track lay-out from access tracks at 90°, 60°, and 45° angles with the axis of the parallel tracks. The formula on figure 2 may be used for all other angles.

c. Table VIII, figure 3, gives spacing of frogs in cross-overs between parallel tracks in which the cross-over track is on reversed curves with sufficient tangent between curves to adjust the locomotive wheel base.

d. Table IX, figure 4, gives essential dimensions for ladder and yard tracks where the ladder must be on a curve. In the table all curvature is taken up in the turn-out leads, the distance between frogs being the chord distance subtended by the frog angle. The formula on figure 4 may be used for any combination of ladder curvature and turn-out spacing.

3. FIGURES. *a.* Figures 5, 6, and 7 show various types of ladder tracks, with all dimensions essential to design and lay-out. Type 3 and 4 ladders, with frog spacing at 99 feet, are intended to reduce rail cutting to a minimum where 33-foot rails are used. Type 5 and 6 ladders are intended for use where space is definitely limited and are not recommended except under this condition, or where the switches are mechanically operated.

b. Figure 8 is a tabulation of clearances required by law in various States.

c. Figure 9 shows standard roadbed and ballast sections.

d. Figure 10 is a plan of a Standard No. 8 Turn-Out.

e. Figure 11 is a tabulation of material required for 1,000 feet of track.

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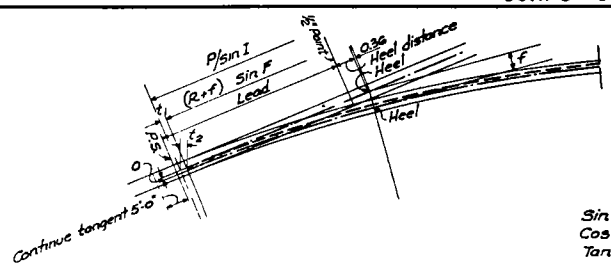
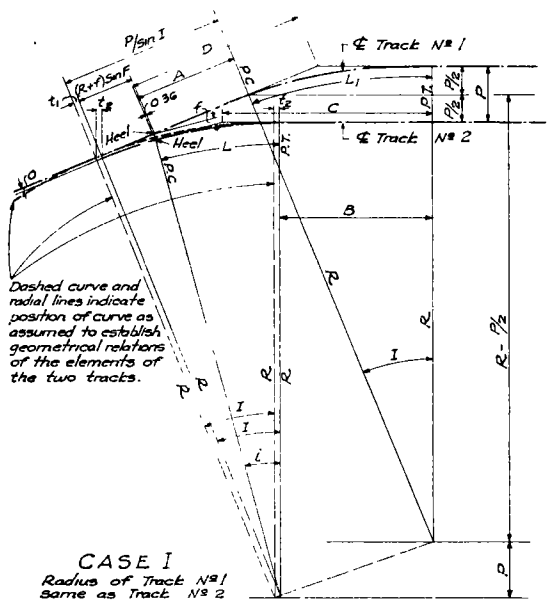
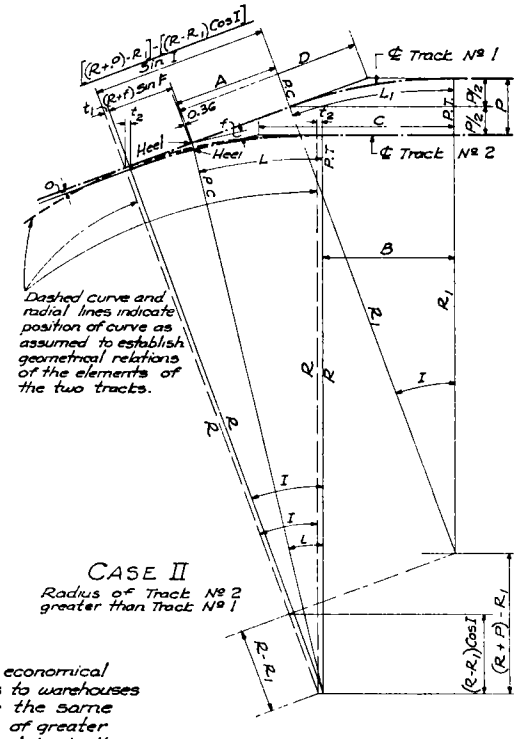


Sin 7°-09'-10" = .12451551
Cos 7°-09'-10" = .99221766
Tan 7°-09'-10" = .12549213



CASE I
Radius of Track Nº 1 same as Track Nº 2



CASE II
Radius of Track Nº 2 greater than Track Nº 1

Formula and procedure for determining the most economical yet satisfactory layout for curved entrance tracts to warehouses or other similar situations where both tracts have the same degree of curvature or curvature of tract Nº 2 is of greater radius than track Nº 1. Tables I to VI inclusive relate to this figure

Known factors are:

F = frog angle (Nº 8 used here having an angle of 7°09'-10" and a theoretical heel distance of 8'-3").
Lead = Distance from ½" point of frog to P.S.
R = radius of curves of tracts.
P = center to center of tracts

Required:

I = central angle of tract Nº 1
i = central angle of tract Nº 2 = I - F
$\cos I = \frac{R - P/2}{R}$, Case I

$\cos I = \frac{R_1 - P/2}{R_1}$, Case II
f = 5.76 for Nº 8 Frog 8'-3" theoretical heel distance.
$O = [(R+f)\cos F] - R$
- = 0.0 for 7°-50' curve
- = 1.2526 for 10° curve
- = 1.9947 for 12° curve
- = 2.5244 for 14° curve

t_2 = tangential correction = $\frac{O}{\sin I}$
t_1 = tangential correction $\frac{O}{\tan I}$
Distance $A = \frac{P}{\sin I} - [(R+f)\sin F - 0.36 + t_1]$, Case I
Distance $A = \frac{[(R+P)-R_1]-[(R-R_1)\cos I]}{\sin I} - [(R+f)\sin F - 0.36 + t_1]$, Case II
Distance $B = \frac{P}{\tan I} - t_2$ Case I
Distance $B = \frac{[(R+P)-R_1]-[(R-R_1)\cos I]}{\sin I} \cos I - (R-R_1)\sin I - t_2$, Case II
Distance C = Tang. distance track Nº 2 + B
Distance D = Tang. distance track Nº 1 + A
Dimensions to nearest .01 ft

TABLE I.—*Minimum track and operating movement*

CASE I—Reference fig. 1

R=573.69 D=10° TURN-OUTS NO. 8

P. ft.	I. degrees	Track No. 1		Track No. 2		Total-ft.		Total track ft.
		A-ft.	*L*-ft.	*B*-ft.	*L*-ft.	Track 1	Track 2	
13	8° 38′	6. 57	86. 33	77. 28	14. 80	92. 90	92. 08	184. 98
14	8° 58′	10. 16	89. 60	80. 75	18. 07	99. 76	98. 82	198. 58
15	9° 16′	13. 61	92. 75	84. 08	21. 22	106. 36	105. 30	211. 66
16	9° 35′	16. 93	95. 80	87. 28	24. 27	112. 73	111. 55	224. 28
17	9° 53′	20. 13	98. 75	90. 35	27. 22	118. 88	117. 57	236. 45
18	10° 10′	23. 25	101. 62	93. 32	30. 09	124. 87	123. 41	248. 28
19	10° 26′	26. 25	104. 41	96. 19	32. 88	130. 66	129. 07	259. 73
20	10° 43′	29. 17	107. 14	98. 97	35. 61	136. 31	134. 58	270. 89
21	10° 59′	32. 03	109. 79	101. 67	38. 26	141. 82	139. 93	281. 75
22	11° 14′	34. 79	112. 38	104. 30	40. 85	147. 17	145. 15	292. 32
23	11° 29′	37. 50	114. 91	106. 85	43. 38	152. 41	150. 23	302. 64
24	11° 44′	40. 14	117. 39	109. 33	45. 86	157. 53	155. 19	312. 72
25	11° 59′	42. 73	119. 83	111. 76	48. 30	162. 56	160. 06	322. 62
26	12° 13′	45. 26	122. 21	114. 13	50. 68	167. 47	164. 81	332. 28
27	12° 27′	47. 74	124. 54	116. 44	53. 01	172. 28	169. 45	341. 73
28	12° 41′	50. 16	126. 84	118. 70	55. 31	177. 00	174. 01	351. 01
29	12° 55′	52. 55	129. 09	120. 92	57. 56	181. 64	178. 48	360. 12
30	13° 08′	54. 90	131. 31	123. 09	59. 78	186. 21	182. 87	369. 08
31	13° 21′	57. 20	133. 49	125. 22	61. 96	190. 69	187. 18	377. 87
32	13° 34′	59. 47	135. 64	127. 30	64. 11	195. 11	191. 41	386. 52
33	13° 46′	61. 69	137. 75	129. 35	66. 22	199. 44	195. 57	395. 01
34	13° 59′	63. 89	139. 83	131. 35	68. 30	203. 72	199. 65	403. 37
35	14° 11′	66. 05	141. 88	133. 33	70. 35	207. 93	203. 68	411. 61
36	14° 23′	68. 18	143. 91	135. 27	72. 38	212. 09	207. 65	419. 74
37	14° 35′	70. 28	145. 90	137. 17	74. 37	216. 18	211. 54	427. 72
38	14° 47′	72. 36	147. 87	139. 05	76. 34	220. 23	215. 39	435. 62
39	14° 59′	74. 40	149. 81	140. 89	78. 28	224. 21	219. 17	443. 38
40	15° 10′	76. 41	151. 73	142. 72	80. 20	228. 14	222. 92	451. 06
45	16° 06′	86. 14	161. 00	151. 39	89. 47	247. 14	240. 86	488. 00
50	16° 59′	95. 35	169. 83	159. 49	98. 30	265. 18	257. 79	522. 97
55	17° 49′	104. 11	178. 12	167. 09	106. 59	282. 23	273. 68	555. 91
60	18° 37′	112. 49	186. 11	174. 25	114. 58	298. 60	288. 83	587. 43
65	19° 23′	120. 55	193. 78	181. 03	122. 25	314. 33	303. 28	617. 61
70	20° 07′	128. 31	201. 17	187. 49	129. 64	329. 48	317. 13	646. 61
75	20° 50′	135. 83	208. 31	193. 60	136. 78	344. 14	330. 38	674. 52
80	21° 31′	143. 10	215. 22	199. 45	143. 69	358. 32	343. 14	701. 46

TABLE II.—*Minimum track and operating movement*

CASE I—Reference fig. 1

$R=478.34'$ $D=12°$ TURN-OUTS No. 8

P. ft.	I. degrees	Track No. 1		Track No. 2		Total-ft.		Total track ft.
		A-ft.	*L*-ft.	*B*-ft.	*L*-ft.	Track 1	Track 2	
13	9° 27′	7. 23	78. 80	65. 91	19. 19	86. 03	85. 10	171. 13
14	9° 49′	10. 68	81. 78	69. 23	22. 17	92. 46	91. 40	183. 86
15	10° 10′	14. 00	84. 66	72. 40	25. 05	98. 66	97. 45	196. 11
16	10° 30′	17. 17	87. 45	75. 43	27. 84	104. 62	103. 27	207. 89
17	10° 49′	20. 22	90. 14	78. 34	30. 53	110. 36	108. 87	219. 23
18	11° 08′	23. 17	92. 79	81. 15	33. 18	115. 96	114. 33	230. 29
19	11° 26′	26. 03	95. 32	83. 85	35. 71	121. 35	119. 56	240. 91
20	11° 44′	28. 81	97. 80	86. 46	38. 19	126. 61	124. 65	251. 26
21	12° 02′	31. 49	100. 23	89. 00	40. 62	131. 72	129. 62	261. 34
22	12° 19′	34. 12	102. 59	91. 45	42. 98	136. 71	134. 43	271. 14
23	12° 35′	36. 66	104. 91	93. 84	45. 30	141. 57	139. 14	280. 81
24	12° 52′	39. 17	107. 18	96. 16	47. 57	146. 35	143. 73	290. 08
25	13° 08′	41. 61	109. 39	98. 42	49. 78	151. 00	148. 20	299. 20
26	13° 23′	43. 98	111. 57	100. 63	51. 96	155. 55	152. 59	308. 14
27	13° 39′	46. 32	113. 71	102. 76	54. 10	160. 03	156. 86	316. 89
28	13° 54′	48. 61	115. 80	104. 87	56. 19	164. 41	161. 06	325. 47
29	14° 09′	50. 85	117. 86	106. 92	58. 25	168. 71	165. 17	333. 88
30	14° 23′	53. 04	119. 89	108. 93	60. 28	172. 93	169. 21	342. 14
31	14° 38′	55. 21	121. 88	110. 89	62. 27	177. 09	173. 16	350. 25
32	14° 52′	57. 34	123. 84	112. 82	64. 23	181. 18	177. 05	358. 23
33	15° 06′	59. 43	125. 77	114. 70	66. 16	185. 20	180. 86	366. 06
34	15° 19′	61. 48	127. 68	116. 55	68. 07	189. 16	184. 62	373. 78
35	15° 33′	63. 50	129. 55	118. 37	69. 94	193. 05	188. 31	381. 36
36	15° 46′	65. 50	131. 40	120. 15	71. 79	196. 90	191. 94	388. 84
37	15° 59′	67. 46	133. 22	121. 90	73. 61	200. 68	195. 51	396. 19
38	16° 12′	69. 39	135. 03	123. 62	75. 42	204. 42	199. 04	403. 46
39	16° 25′	71. 31	136. 80	125. 31	77. 19	208. 11	202. 50	410. 61
40	16° 38′	73. 19	138. 56	126. 98	78. 95	211. 75	205. 93	417. 68
45	17° 39′	82. 28	147. 03	134. 91	87. 42	229. 31	222. 33	451. 64
50	18° 36′	90. 86	155. 05	142. 27	95. 44	245. 91	237. 71	483. 62
55	19° 31′	99. 03	162. 69	149. 15	103. 08	261. 72	252. 23	513. 95
60	20° 24′	106. 85	170. 00	155. 61	110. 39	276. 85	266. 00	542. 85
65	21° 15′	114. 35	177. 09	161. 71	117. 47	291. 44	279. 18	570. 62
70	22° 03′	121. 59	183. 75	167. 48	124. 14	305. 34	291. 62	596. 96
75	22° 50′	128. 57	190. 32	172. 94	130. 91	319. 09	303. 85	622. 94
80	23° 36′	135. 35	196. 65	178. 15	137. 04	332. 00	315. 19	647. 19

TABLE III.—*Minimum track and operating movement*

CASE I—Reference fig. 1

R=410.28 D=14° TURN-OUTS No. 8

P. ft.	I. degrees	Track No. 1		Track No. 2		Total-ft.		Total track ft.
		A-ft.	*L*-ft.	*B*-ft.	*L*-ft.	Track 1	Track 2	
13	10° 13′	7. 87	72. 95	57. 92	21. 86	80. 82	79. 78	160. 60
14	10° 36′	11. 16	75. 71	61. 13	24. 62	86. 87	85. 75	172. 62
15	10° 58′	14. 35	78. 37	64. 11	27. 28	92. 72	91. 39	184. 11
16	11° 20′	17. 38	80. 95	66. 99	29. 86	98. 33	96. 85	195. 18
17	11° 41′	20. 30	83. 45	69. 75	32. 36	103. 75	102. 11	205. 86
18	12° 01′	23. 12	85. 88	72. 40	34. 79	109. 00	107. 19	216. 19
19	12° 22′	25. 83	88. 24	74. 95	37. 15	114. 07	112. 10	226. 17
20	12° 41′	28. 48	90. 54	77. 42	39. 45	119. 02	116. 87	235. 89
21	12° 59′	31. 04	92. 79	79. 80	41. 70	123. 83	121. 50	245. 33
22	13° 18′	33. 53	94. 98	82. 11	43. 89	128. 51	126. 00	254. 51
23	13° 36′	35. 95	97. 14	84. 39	46. 05	133. 09	130. 44	263. 53
24	13° 53′	38. 31	99. 23	86. 53	48. 14	137. 54	134. 67	272. 21
25	14° 11′	40. 62	101. 28	88. 64	50. 19	141. 90	138. 83	280. 73
26	14° 28′	42. 88	103. 30	90. 71	52. 21	146. 18	142. 92	289. 10
27	14° 44′	45. 08	105. 28	92. 71	54. 19	150. 36	146. 90	297. 26
28	15° 01′	47. 25	107. 22	94. 67	56. 13	154. 47	150. 80	305. 27
29	15° 17′	49. 37	109. 13	96. 59	58. 04	158. 50	154. 63	313. 13
30	15° 32′	51. 45	111. 01	98. 46	59. 92	162. 46	158. 38	320. 84
31	15° 48′	53. 49	112. 85	100. 28	61. 76	166. 34	162. 04	328. 38
32	16° 03′	55. 50	114. 67	102. 07	63. 58	170. 17	165. 65	335. 82
33	16° 18′	57. 47	116. 46	103. 83	65. 37	173. 93	169. 20	343. 13
34	16° 33′	59. 41	118. 22	105. 54	67. 13	177. 63	171. 67	350. 30
35	16° 48′	61. 32	119. 96	107. 23	68. 87	181. 28	176. 10	357. 38
36	17° 02′	63. 20	121. 67	108. 88	70. 58	184. 87	179. 46	364. 33
37	17° 16′	65. 06	123. 36	110. 50	72. 27	188. 42	182. 77	371. 19
38	17° 30′	66. 89	125. 04	112. 09	73. 95	191. 93	186. 04	377. 97
39	17° 44′	68. 69	126. 69	113. 65	75. 60	195. 38	189. 25	384. 63
40	17° 58′	70. 47	128. 31	115. 19	77. 22	198. 78	192. 41	391. 19
45	19° 04′	79. 03	136. 16	122. 50	85. 07	215. 19	207. 57	422. 76
50	20° 06′	87. 12	143. 61	129. 25	92. 52	230. 73	221. 77	452. 50
55	21° 06′	94. 81	150. 69	135. 55	99. 60	245. 50	235. 15	480. 65
60	22° 03′	102. 17	157. 48	141. 43	106. 39	259. 65	247. 82	507. 47
65	22° 58′	109. 23	163. 99	146. 97	112. 90	273. 22	259. 87	533. 09
70	23° 50′	116. 05	170. 27	152. 18	119. 18	286. 32	271. 36	557. 68
75	24° 41′	122. 63	176. 34	157. 11	125. 25	298. 97	282. 36	581. 33
80	25° 31′	129. 07	182. 22	161. 78	131. 13	311. 29	292. 91	604. 20

TABLE IV.—*Minimum track and operating movement*

CASE II—Reference fig. 1

$R=573.69'$ $R_1=478.34'$ $D=10°$ $D_1=12°$ TURN-OUTS No. 8

P. ft.	I. degrees	Track No. 1		Track No. 2		Total-ft.		Total track ft.
		A-ft.	*L*-ft.	*B*-ft.	*L*-ft.	Track 1	Track 2	
13	9° 27′	7. 71	78. 80	62. 55	23. 03	86. 51	85. 58	172. 09
14	9° 49′	11. 29	81. 78	65. 40	26. 61	93. 07	92. 01	185. 08
15	10° 10′	14. 74	84. 66	68. 13	30. 06	99. 40	98. 19	197. 59
16	10° 30′	18. 05	87. 45	70. 75	33. 41	105. 50	104. 16	209. 66
17	10° 49′	21. 26	90. 14	73. 27	36. 65	111. 40	109. 92	221. 32
18	11° 08′	24. 36	92. 79	75. 69	39. 79	117. 15	115. 48	232. 63
19	11° 26′	27. 38	95. 32	78. 04	42. 83	122. 70	120. 87	243. 57
20	11° 44′	30. 30	97. 80	80. 31	45. 83	128. 10	126. 14	254. 24
21	12° 02′	33. 15	100. 23	82. 51	48. 74	133. 38	131. 25	264. 63
22	12° 19′	35. 94	102. 59	84. 66	51. 58	138. 53	136. 24	274. 77
23	12° 35′	38. 64	104. 91	86. 72	54. 36	143. 55	141. 08	284. 63
24	12° 52′	41. 29	107. 18	88. 75	57. 08	148. 47	145. 83	294. 30
25	13° 08′	43. 89	109. 39	90. 72	59. 74	153. 28	150. 46	303. 74
26	13° 23′	46. 43	111. 57	92. 63	62. 35	158. 00	154. 98	312. 98
27	13° 39′	48. 91	113. 71	94. 51	64. 92	162. 62	159. 43	322. 05
28	13° 54′	51. 36	115. 80	96. 34	67. 43	167. 16	163. 77	330. 93
29	14° 09′	53. 75	117. 86	98. 12	69. 91	171. 61	168. 03	339. 64
30	14° 23′	56. 11	119. 89	99. 87	72. 34	176. 00	172. 21	348. 21
31	14° 38′	58. 42	121. 88	101. 60	74. 73	180. 30	176. 33	356. 63
32	14° 52′	60. 70	123. 84	103. 28	77. 08	184. 54	180. 36	364. 90
33	15° 06′	62. 94	125. 77	104. 92	79. 40	188. 71	184. 32	373. 03
34	15° 19′	65. 14	127. 68	106. 54	81. 68	192. 82	188. 22	381. 04
35	15° 33′	67. 31	129. 55	108. 12	83. 93	196. 86	192. 05	388. 91
36	15° 46′	69. 45	131. 40	109. 68	86. 15	200. 85	195. 83	396. 68
37	15° 59′	71. 57	133. 22	111. 21	88. 34	204. 79	199. 55	404. 34
38	16° 12′	73. 65	135. 03	112. 70	90. 50	208. 68	203. 20	411. 88
39	16° 25′	75. 71	136. 80	114. 18	92. 63	212. 51	206. 81	419. 32
40	16° 38′	77. 74	138. 56	115. 64	94. 74	216. 30	210. 38	426. 68
45	17° 39′	87. 54	147. 03	122. 56	104. 90	234. 57	227. 46	462. 03
50	18° 36′	96. 82	155. 05	128. 97	114. 53	251. 87	243. 50	495. 37
55	19° 31′	105. 67	162. 69	134. 97	123. 70	268. 36	258. 67	527. 03
60	20° 24′	114. 13	170. 00	140. 59	132. 47	284. 13	273. 06	557. 19
65	21° 15′	122. 28	177. 02	145. 88	140. 89	299. 30	286. 77	586. 07
70	22° 03′	130. 13	183. 75	150. 87	149. 01	313. 88	299. 88	613. 76
75	22° 50′	137. 73	190. 32	155. 59	156. 86	328. 05	312. 45	640. 50
80	23° 36′	145. 10	196. 65	160. 08	164. 45	341. 75	324. 53	666. 28

TABLE V.—*Minimum track and operating movement*

CASE II—Reference fig. 1

R=478.34′ R_1=410.28′ D=12° D_1=14° TURN-OUTS No. 8

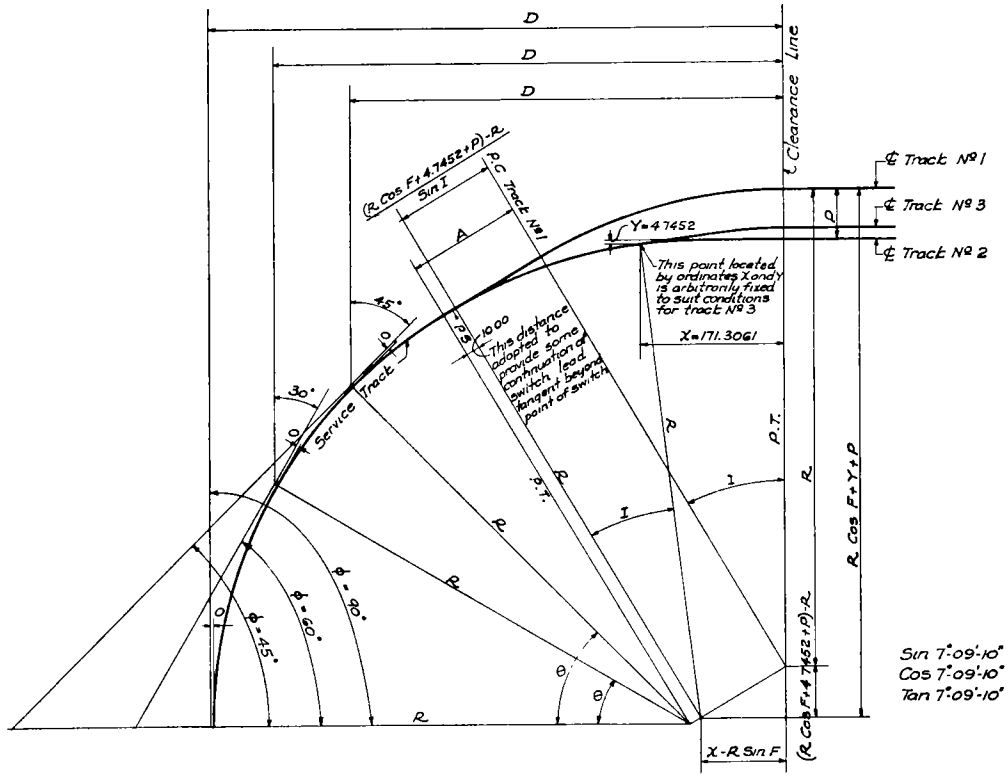
P. ft.	I. degrees	Track No. 1		Track No. 2		Total-ft.		Total track ft.
		A-ft.	*L*-ft.	*B*-ft.	*L*-ft.	Track 1	Track 2	
13	10° 13′	8. 41	72. 95	54. 83	25. 50	81. 36	80. 33	161. 69
14	10° 36′	11. 85	75. 71	57. 66	28. 72	87. 56	86. 38	173. 94
15	10° 58′	15. 14	78. 37	60. 35	31. 83	93. 51	92. 18	185. 69
16	11° 20′	18. 30	80. 95	62. 93	34. 84	99. 25	97. 77	197. 02
17	11° 41′	21. 35	83. 45	65. 40	37. 75	104. 80	103. 15	207. 95
18	12° 01′	24. 30	85. 88	67. 77	40. 59	110. 18	108. 36	218. 54
19	12° 22′	27. 15	88. 24	70. 06	43. 34	115. 39	113. 40	228. 79
20	12° 41′	29. 91	90. 54	72. 27	46. 03	120. 45	118. 30	238. 75
21	12° 59′	32. 61	92. 79	74. 41	48. 65	125. 40	123. 06	248. 46
22	13° 18′	35. 23	94. 98	76. 48	51. 21	130. 21	127. 69	257. 90
23	13° 36′	37. 78	97. 14	78. 49	53. 71	134. 92	132. 20	267. 12
24	13° 53′	40. 27	99. 23	80. 44	56. 16	139. 50	136. 60	276. 10
25	14° 11′	42. 71	101. 28	82. 34	58. 56	143. 99	140. 90	284. 89
26	14° 28′	45. 10	103. 30	84. 19	60. 90	148. 40	145. 09	293. 49
27	14° 44′	47. 43	105. 28	85. 99	63. 22	152. 71	149. 21	301. 92
28	15° 01′	49. 72	107. 22	87. 75	65. 45	156. 94	153. 20	310. 14
29	15° 17′	51. 97	109. 13	89. 47	67. 71	161. 10	157. 18	318. 28
30	15° 32′	54. 17	111. 01	91. 15	69. 90	165. 18	161. 05	326. 23
31	15° 48′	56. 33	112. 85	92. 79	72. 06	169. 18	164. 85	334. 03
32	16° 03′	58. 47	114. 67	94. 39	74. 18	173. 14	168. 57	341. 71
33	16° 18′	60. 56	116. 46	95. 96	76. 26	177. 02	172. 22	349. 24
34	16° 33′	62. 62	118. 22	97. 50	78. 32	180. 84	175. 82	356. 66
35	16° 48′	64. 65	119. 96	99. 01	80. 35	184. 61	179. 36	363. 97
36	17° 02′	66. 65	121. 67	100. 49	82. 35	188. 32	182. 84	371. 16
37	17° 16′	68. 63	123. 36	101. 96	84. 32	191. 99	186. 28	378. 27
38	17° 30′	70. 57	125. 04	103. 37	86. 27	195. 61	189. 64	385. 25
39	17° 44′	72. 49	126. 69	104. 77	88. 19	199. 18	192. 96	392. 14
40	17° 58′	74. 39	128. 31	106. 15	90. 09	202. 70	196. 24	398. 94
45	19° 04′	83. 52	136. 16	112. 69	99. 25	219. 68	211. 94	431. 62
50	20° 06′	92. 16	143. 61	118. 73	107. 93	235. 77	226. 66	462. 43
55	21° 06′	100. 39	150. 69	124. 34	116. 20	251. 08	240. 54	491. 62
60	22° 03′	108. 26	157. 48	129. 59	124. 12	265. 74	253. 71	519. 45
65	22° 58′	115. 82	163. 99	134. 50	131. 72	279. 81	266. 22	546. 03
70	23° 50′	123. 14	170. 27	139. 13	139. 04	293. 41	278. 17	571. 58
75	24° 41′	130. 20	176. 34	143. 49	146. 12	306. 54	289. 61	596. 15
80	25° 31′	137. 06	182. 22	147. 61	152. 98	319. 28	300. 59	619. 87

TABLE VI.—*Minimum track and operating movement*

CASE II—Reference fig. 1

R=573.69′ R_1=410.28′ D=10° D_1=14° TURN-OUTS NO. 8

P. ft.	I. degrees	Track No. 1		Track No. 2		Total-ft.		Total track ft.
		A-ft.	*L*-ft.	*B*-ft.	*L*-ft.	Track 1	Track 2	
13	10° 13′	9. 18	72. 95	50. 49	30. 60	82. 13	81. 09	163. 22
14	10° 36′	12. 79	75. 71	52. 85	34. 46	88. 50	87. 31	175. 81
15	10° 58′	16. 25	78. 37	55. 09	38. 19	94. 62	93. 28	187. 90
16	11° 20′	19. 59	80. 95	57. 24	41. 80	100. 54	99. 04	199. 58
17	11° 41′	22. 82	83. 45	59. 31	45. 30	106. 27	104. 61	210. 88
18	12° 01′	25. 95	85. 88	61. 29	48. 70	111. 83	109. 99	221. 82
19	12° 22′	28. 98	88. 24	63. 21	52. 01	117. 22	115. 22	232. 44
20	12° 41′	31. 93	90. 54	65. 06	55. 23	122. 47	120. 29	242. 76
21	12° 59′	34. 81	92. 79	66. 86	58. 38	127. 60	125. 24	252. 84
22	13° 18′	37. 61	94. 98	68. 59	61. 45	132. 59	130. 04	262. 63
23	13° 36′	40. 34	97. 14	70. 28	64. 45	137. 47	134. 73	272. 20
24	13° 53′	43. 02	99. 23	71. 92	67. 39	142. 25	139. 31	281. 56
25	14° 11′	45. 63	101. 28	73. 51	70. 26	146. 91	143. 77	290. 68
26	14° 28′	48. 20	103. 30	75. 06	73. 09	151. 50	148. 15	299. 65
27	14° 44′	50. 71	105. 28	76. 58	75. 86	155. 99	152. 44	308. 43
28	15° 01′	53. 17	107. 22	78. 05	78. 58	160. 39	156. 63	317. 02
29	15° 17′	55. 60	109. 13	79. 50	81. 25	164. 73	160. 75	325. 48
30	15° 32′	57. 98	111. 01	80. 90	83. 88	168. 99	164. 78	333. 77
31	15° 48′	60. 31	112. 85	82. 28	86. 47	173. 16	168. 75	341. 91
32	16° 03′	62. 62	114. 67	83. 63	89. 01	177. 29	172. 64	349. 93
33	16° 18′	64. 88	116. 46	84. 95	91. 52	181. 34	176. 47	357. 81
34	16° 33′	67. 11	118. 22	86. 24	93. 99	185. 33	180. 23	365. 56
35	16° 48′	69. 31	119. 96	87. 51	96. 42	189. 27	183. 93	373. 20
36	17° 02′	71. 48	121. 67	88. 74	98. 82	193. 15	187. 56	380. 71
37	17° 16′	73. 62	123. 36	89. 97	101. 19	196. 98	191. 16	388. 14
38	17° 30′	75. 73	125. 04	91. 16	103. 52	200. 77	194. 68	395. 45
39	17° 44′	77. 81	126. 69	92. 33	105. 83	204. 50	198. 16	402. 66
40	17° 58′	79. 87	128. 31	93. 48	108. 11	208. 18	201. 59	409. 77
45	19° 04′	89. 80	136. 16	98. 95	119. 10	225. 96	218. 05	444. 01
50	20° 06′	99. 22	143. 61	103. 98	129. 52	242. 83	233. 50	476. 33
55	21° 06′	108. 19	150. 69	108. 65	139. 44	258. 88	248. 09	506. 97
60	22° 03′	116. 79	157. 48	112. 99	148. 94	274. 27	261. 93	536. 20
65	22° 58′	125. 07	163. 99	117. 04	158. 06	289. 06	275. 10	564. 16
70	23° 50′	133. 07	170. 27	120. 84	166. 85	303. 34	287. 60	591. 03
75	24° 41′	140. 81	176. 34	124. 40	175. 35	317. 15	299. 75	616. 90
80	25° 31′	148. 33	182. 22	127. 74	183. 58	330. 55	311. 32	641. 87



Formula and procedure for determining space required between the service track and the nearest building or facility served with various distances between parallel delivery tracks and with various degrees of curvature.

In the formulae found for D (below) the term - O and O cos θ, may be omitted from the formula when there is no turnout involved between the lead tangent and curve. Accompanying table VII has been prepared including O and O cos θ.

Known factors are:

F = frog angle Nº 8 used here having an angle of 7°09'-10" and a theoretical heel distance of 8'-3".

R = radius of curves of tracks. Radius of track Nº 1 and Nº 2 same.

P = center to center of tracks Nº 1 and Nº 2.

Required:

I = central angle of track Nº 1

f = 5.76 for Nº 8 frog. 8'-3" theoretical heel distance.

O = [(R + f) cos F] - R.

- *0.0 for 7°-50' curve*
- *1.2526 for 10° curve*
- *1.9947 for 12° curve*
- *2.6244 for 14° curve*

$$\text{Tan } I = \frac{[(R \cos F) + 4.7452 + P] - R}{X - R \sin F}$$

$$\theta = 90° - \phi$$

$$\text{Distance } A = \frac{[(R \cos F) + 4.7452 + P] - R}{\sin I} + 10.00$$

Distance D, when $\phi = 90°$ = $(171.3061 - R \sin F) + R + O + 10.00 \cos I$

Distance D, when $\phi < 90°$ = $(171.3061 - R \sin F) + R \cos\theta + O \cos\theta + 10.00 \cos I$.

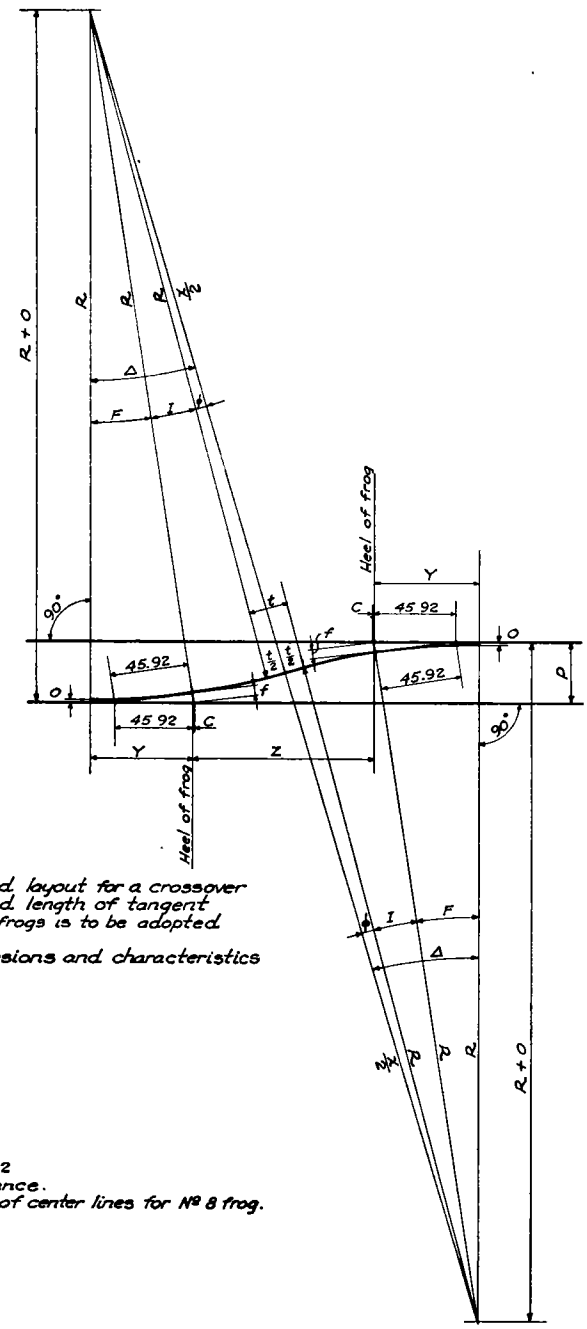
Dimensions to nearest .01 ft

TABLE VII.—*Space requirement*

Three-track lay-out—Service track at angles with axis of delivery area

Reference figure 2

P	$D=10°$ $R=573.69$					$D=12°$ $R=478.34$					$D=14°$ $R=410.28$				
	I	A	Distance *D*-ft.			I	A	Distance *D*-ft.			I	A	Distance *D*-ft.		
			$\phi=90°$	$\phi=60°$	$\phi=45°$			$\phi=90°$	$\phi=60°$	$\phi=45°$			$\phi=90°$	$\phi=60°$	$\phi=45°$
26	14° 45′	113. 27	684. 49	607. 46	516. 09	13° 36′	124. 97	601. 80	537. 45	461. 11	12° 55′	133. 29	542. 77	487. 47	421. 87
27	15° 17′	113. 53	684. 46	607. 43	516. 07	14° 05′	125. 21	601. 78	537. 43	461. 09	13° 22′	133. 56	542. 75	487. 45	421. 85
28	15° 49′	113. 80	684. 44	607. 41	516. 04	14° 34′	125. 45	601. 76	547. 41	461. 07	13° 49′	133. 80	542. 73	487. 43	421. 83
29	16° 20′	114. 08	684. 41	607. 38	516. 02	15° 02′	125. 71	601. 74	537. 39	461. 05	14° 16′	134. 04	542. 72	487. 41	421. 81
30	16° 52′	114. 36	684. 39	607. 36	515. 99	15° 31′	126. 01	601. 72	537. 37	461. 03	14° 42′	134. 29	542. 70	487. 39	421. 79
31	17° 23′	114. 66	684. 36	607. 33	515. 96	15° 59′	126. 24	601. 69	537. 34	461. 00	15° 09′	134. 55	542. 68	487. 37	421. 77
32	17° 55′	114. 96	684. 33	607. 30	515. 93	16° 28′	126. 52	601. 67	537. 32	460. 98	15° 36′	134. 82	542. 66	487. 35	421. 75
33	18° 26′	115. 27	684. 30	607. 27	515. 91	16° 56′	126. 81	601. 65	537. 30	460. 96	16° 02′	135. 09	542. 64	487. 33	421. 73
34	18° 57′	115. 59	684. 27	607. 25	515. 88	17° 24′	127. 11	601. 62	537. 27	460. 94	16° 28′	135. 37	542. 61	487. 31	421. 71
35	19° 27′	115. 88	684. 24	607. 22	515. 85	17° 52′	127. 41	601. 60	537. 25	460. 91	16° 55′	135. 65	542. 59	487. 29	421. 69
36	19° 58′	116. 26	684. 21	607. 19	515. 82	18° 20′	127. 72	601. 57	537. 23	460. 89	17° 21′	135. 95	542. 57	487. 26	421. 66
37	20° 28′	116. 60	684. 18	607. 16	515. 79	18° 47′	128. 04	601. 55	537. 20	460. 86	17° 47′	136. 25	542. 55	487. 24	421. 64
38	20° 58′	116. 96	684. 15	607. 13	515. 76	19° 15′	128. 36	601. 52	537. 17	460. 83	18° 13′	136. 56	542. 52	487. 22	421. 62
39	21° 28′	117. 32	684. 12	607. 09	515. 73	19° 42′	128. 70	601. 50	537. 14	460. 80	18° 38′	136. 87	542. 50	487. 19	421. 59
40	21° 58′	117. 69	684. 09	607. 06	515. 69	20° 10′	129. 04	601. 47	537. 12	460. 78	19° 04′	137. 20	542. 48	487. 17	421. 57
45	24° 23′	119. 66	683. 92	606. 90	515. 53	22° 23′	130. 85	601. 33	536. 98	460. 64	21° 10′	138. 92	542. 35	487. 04	421. 44
50	26° 43′	121. 82	683. 75	606. 72	515. 35	24° 32′	132. 84	601. 18	536. 83	460. 49	23° 13′	140. 81	542. 21	486. 91	421. 31
55	28° 58′	124. 15	683. 56	606. 54	515. 17	26° 38′	135. 00	601. 02	536. 67	460. 33	25° 12′	142. 86	542. 07	486. 77	421. 17
60	31° 07′	126. 65	683. 38	606. 35	514. 98	28° 38′	137. 32	600. 86	536. 51	460. 17	27° 07′	145. 06	541. 93	486. 62	421. 02
65	33° 10′	129. 32	683. 19	606. 16	514. 79	30° 35′	139. 79	600. 69	536. 34	460. 00	28° 58′	147. 41	541. 77	486. 47	420. 87
70	35° 08′	132. 12	682. 99	605. 97	514. 60	32° 26′	142. 41	600. 52	536. 17	459. 83	30° 46′	149. 90	541. 62	486. 31	420. 71
75	37° 0′	135. 07	682. 80	605. 77	514. 41	34° 14′	145. 15	600. 35	536. 00	459. 66	32° 29′	152. 52	541. 46	486. 15	420. 55
80	38° 48′	138. 14	682. 61	605. 58	514. 21	35° 57′	148. 03	600. 18	535. 83	549. 49	34° 09′	155. 27	541. 30	486. 00	420. 39



Sin 7°-09'-10" = .12451551
Cos 7°-09'-10" = .99221766
Tan 7°-09'-10" = .12549213

Formula and procedure for the design and layout for a crossover between parallel tracks when a predetermined length of tangent between curves in the track between heels of frogs is to be adopted and P is greater than 16 feet.

In this figure and formula known dimensions and characteristics pertaining to Nº 8 frogs are used.

Known factors are:

F = frog angle 7°-09'-10" for Nº 8 frog
P = distance between tracks
R radius of curves back of frogs
O = [(R+f) Cos F]-R
= 0.0 for 7°-50' curve
= 1.2526 for 10° curve
= 1.9947 for 12° curve
= 2.5244 for 14° curve
C = 0.36 constant for Nº 8 frog = $\frac{45.92}{\text{Cos } F} - 45.92$
f = 5.76 for Nº 8 frog . 8'-3" theoretical heel distance.
45.92 = distance from heel of frog to intersection of center lines for Nº 8 frog.
t = length of tangent between curves.

Required:

I = intersection angles - See figure.
Z = distance between heels of frogs.

$\text{Tan } \phi = \frac{\frac{t}{2}}{R}$

$X = \frac{2R}{\text{Cos } \phi}$

$\text{Cos } \Delta = \frac{2(R+O)-P}{X}$

$I = \Delta - (F + \phi)$

$Y = [(R+f) \text{ Sin } F] - C$

$Z = X \text{ Sin } \Delta - 2Y$

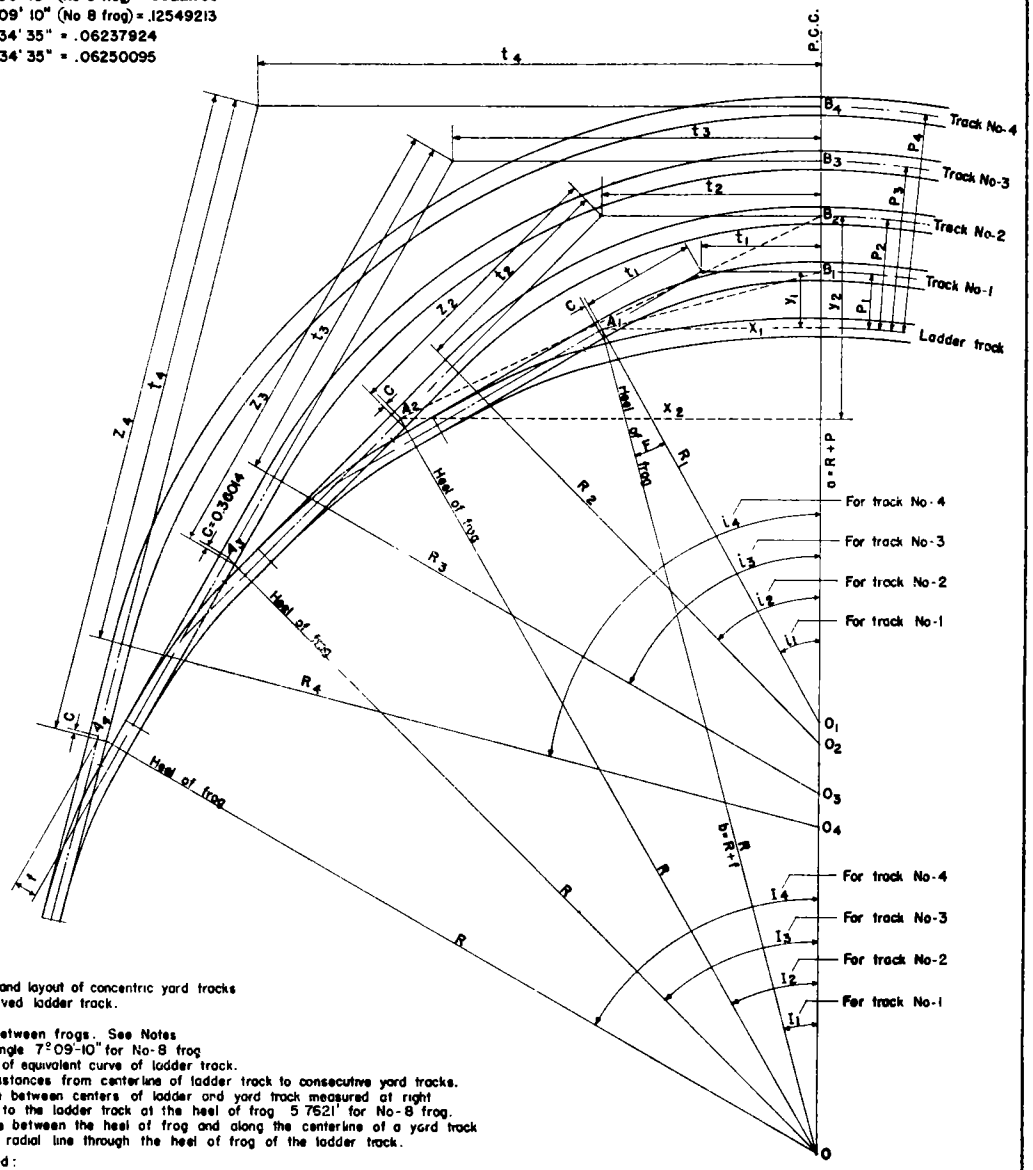
Dimensions to nearest .01 of a foot.

TABLE VIII.—*Dimensions of No. 8 cross-overs on reversed curves between parallel tracks more than 20 feet apart*

Reference figure 3

	$D=10°$ $t=30'$ $R=573.69'$		$D=12°$ $t=30'$ $R=478.34'$	
P	I	Z ft.	I	Z ft.
21	1° 46′	63. 78	2° 1′	62. 26
22	2° 2′	69. 16	2° 20′	67. 35
23	2° 18′	74. 39	2° 38′	72. 29
24	2° 33′	79. 50	2° 56′	77. 11
25	2° 49′	84. 48	3° 13′	81. 81
26	3° 4′	89. 36	3° 30′	86. 39
27	3° 18′	94. 13	3° 46′	90. 87
28	3° 33′	98. 81	4° 2′	95. 25
29	3° 47′	103. 40	4° 18′	99. 55
30	4° 0′	107. 89	4° 34′	103. 75
31	4° 14′	112. 30	4° 49′	107. 87
32	4° 27′	116. 64	5° 4′	111. 92
33	4° 40′	120. 90	5° 19′	115. 89
34	4° 53′	125. 09	5° 33′	119. 79
35	5° 6′	129. 20	5° 47′	123. 62
36	5° 18′	133. 26	6° 1′	127. 40
37	5° 31′	137. 25	6° 15′	131. 10
38	5° 43′	141. 18	6° 29′	134. 76
39	5° 55′	145. 06	6° 42′	138. 36
40	6° 7′	148. 88	6° 55′	141. 90
45	7° 4′	167. 24	7° 59′	158. 89
50	7° 58′	184. 49	8° 59′	174. 81
55	8° 49′	200. 81	9° 56′	189. 84
60	9° 37′	216. 32	10° 50′	204. 09
65	10° 24′	231. 13	11° 42′	217. 68
70	11° 9′	245. 30	12° 32′	230. 66
75	11° 53′	258. 91	13° 20′	243. 11
80	12° 35′	272. 02	14° 7′	255. 07

Sine 7°09' 10" (No 8 frog) = .12451551
Cos 7°09 10" (No 8 frog) = .99221766
Tan 7°09' 10" (No 8 frog) = .12549213
Sine 3°34' 35" = .06237924
Tan 3°34' 35" = .06250095



Design and layout of concentric yard tracks from a curved ladder track.

Given:

Distance between frogs. See Notes
F = frog angle 7°09-10" for No-8 frog
R = radius of equivalent curve of ladder track.
$P_{1,2,3}$ = distances from centerline of ladder track to consecutive yard tracks.
f = distance between centers of ladder and yard track measured at right angles to the ladder track at the heel of frog 5 7521' for No-8 frog.
C = distance between the heel of frog and along the centerline of a yard track and a radial line through the heel of frog of the ladder track.

Required:

Values of I, ι, t, R, and tangent back of heel of frog for all yard tracks.

Solution for Track No-1

Let $a = R + P$, $b = R + f$ Draw $A_1 B_1$ Angle $A_1 - B_1 = F$

$\tan \frac{1}{2}(A_1 - B_1) = \frac{a-b}{a+b}\left[\tan \frac{1}{2}(A_1 + B_1)\right]$ from which I_1, ι_1, R, and t_1 can be determined.

Solution for addional concentric yard tracks.

$X_{2,3}$ = distance from $A_{2,3}$ at right angles to radius at P C C
$y_{2,3}$ = distance along radius from intersection of X to centerline of the yard track.
$Z_{2,3}$ = distance from heel of frog of yard track to P.I of that track
$I_{2,3}$ and $\iota_{2,3}$, for each track = these elements for the preceding track plus the central angle subtended by the chord distance between frogs.

$X_{2,3} = b \sin I_{2,3} \cdots$

$y_{2,3} = a - b \cos I_{2,3} \cdots$

$$Z_{2,3} \cdots = \frac{y_{2,3} \cdots}{\sin I_{2,3} \cdots} + C$$

$$t_{2,3} \cdots = X_{2,3} \cdots - \frac{y_{2,3} \cdots}{\tan I_{2,3} \cdots}$$

$$R_{2,3} \cdots = \frac{t_{2,3} \cdots}{\tan \frac{1}{2} I_{2,3} \cdots}$$

Notes

Table IX has been developed based on curved ladders in which the distance between frogs subtends one frog angle.

Computations should be accurate to nearest $\frac{1}{100}$ of a foot.

TABLE IX.—*Railroad yard ladders parallel to tracks on curves*

Reference figure 4

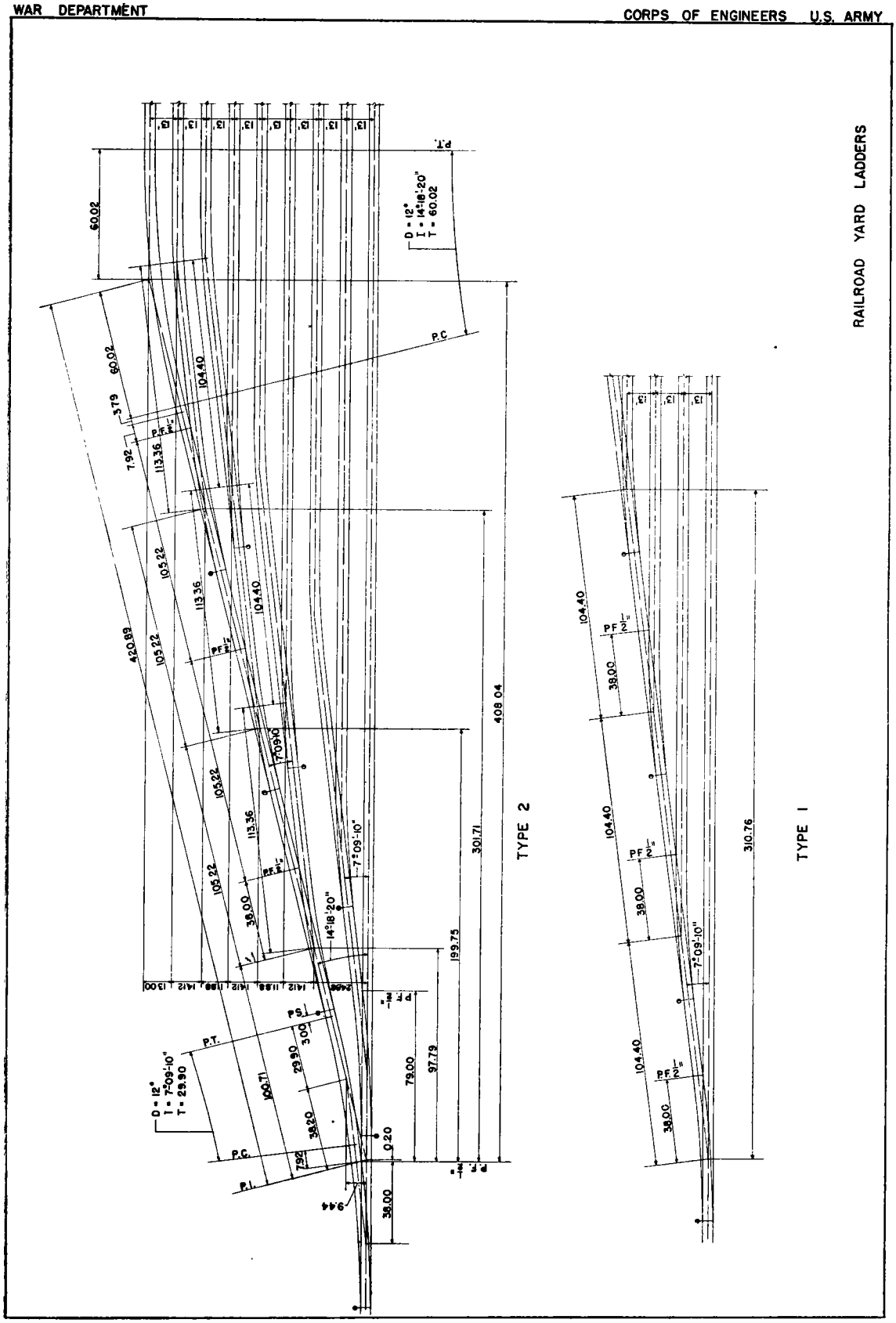
Sheet 1

Frog spacing ft.	Yard ladder				Yard track No. 1				Tan. back of heel	Yard track No. 2				Tan. back of heel
	Curvature	Heel of frog to P. C. C.			I_1	L_1	R_1-ft.	t_1-ft.		I_2	L_2	R_2-ft.	t_2-ft.	
		I	R-ft.	Dist.-ft.										
79	9° 3′	10° 18′	633.49	113.69	10° 18′	17° 27′	381.00	58.46	0.36	17° 27′	24° 36′	381.68	83.22	36.40
80	8° 56′	10° 10′	641.49	113.72	10° 10′	17° 19′	383.78	58.45	.36	17° 19′	24° 28′	386.16	83.75	36.30
81	8° 50′	10° 3′	649.50	113.75	10° 3′	17° 12′	386.54	58.45	.36	17° 12′	24° 21′	390.66	84.29	36.20
82	8° 43′	9° 55′	657.50	113.78	9° 55′	17° 5′	389.27	58.44	.36	17° 5′	24° 14′	395.18	84.83	36.10
83	8° 37′	9° 48′	665.50	113.81	9° 48′	16° 58′	391.98	58.44	.36	16° 58′	24° 7′	399.71	85.37	35.99
84	8° 31′	9° 42′	673.50	113.84	9° 42′	16° 51′	394.66	58.44	.36	16° 51′	24° 0′	404.26	85.93	35.86
85	8° 25′	9° 35′	681.51	113.86	9° 35′	16° 44′	397.29	58.43	.36	16° 44′	23° 53′	408.78	86.47	35.74
86	8° 19′	9° 28′	689.51	113.89	9° 28′	16° 38′	399.92	58.43	.36	16° 38′	23° 47′	413.34	87.02	35.62
87	8° 13′	9° 22′	697.51	113.91	9° 22′	16° 31′	402.52	58.43	.36	16° 31′	23° 40′	417.92	87.58	35.48
88	8° 8′	9° 16′	705.51	113.94	9° 16′	16° 26′	405.09	58.42	.36	16° 25′	23° 34′	422.49	88.13	35.35
89	8° 2′	9° 10′	713.52	113.96	9° 10′	16° 19′	407.64	58.42	.36	16° 19′	23° 28′	427.09	88.70	35.20
90	7° 57′	9° 4′	721.52	113.99	9° 4′	16° 13′	410.16	58.42	.36	16° 13′	23° 22′	431.70	89.26	35.05
91	7° 52′	8° 58′	729.52	114.00	8° 58′	16° 7′	412.64	58.41	.36	16° 7′	23° 16′	436.29	89.82	34.90
92	7° 46′	8° 52′	737.53	114.03	8° 52′	16° 1′	415.13	58.41	.36	16° 1′	23° 10′	440.93	90.39	34.75
93	7° 41′	8° 46′	745.53	114.06	8° 46′	15° 55′	417.59	58.41	.36	15° 56′	23° 5′	445.56	90.97	34.58
94	7° 37′	8° 41′	753.53	114.08	8° 41′	15° 50′	420.01	58.41	.36	15° 50′	22° 59′	450.23	91.54	34.42
95	7° 32′	8° 35′	761.53	114.10	8° 35′	15° 44′	422.41	58.40	.36	15° 45′	22° 54′	454.88	92.12	34.24
96	7° 27′	8° 30′	769.54	114.12	8° 30′	15° 39′	424.80	58.40	.36	15° 39′	22° 48′	459.55	92.70	34.06
97	7° 22′	8° 25′	777.54	114.14	8° 25′	15° 34′	427.16	58.40	.36	15° 34′	22° 43′	464.24	93.28	33.89
98	7° 18′	8° 20′	785.54	114.16	8° 20′	15° 29′	429.50	58.39	.36	15° 29′	22° 38′	468.93	93.86	33.71
99	7° 14′	8° 15′	793.54	114.18	8° 15′	15° 24′	431.81	58.39	.36	15° 24′	22° 33′	473.63	94.45	33.51
100	7° 9′	8° 10′	801.55	114.20	8° 10′	15° 19′	434.11	58.39	.36	15° 19′	22° 28′	478.34	95.04	33.32
101	7° 5′	8° 5′	809.55	114.22	8° 5′	15° 14′	436.39	58.39	.36	15° 15′	22° 24′	483.07	95.63	33.13
102	7° 1′	8° 1′	817.55	114.24	8° 1′	15° 10′	438.63	58.38	.36	15° 10′	22° 19′	487.79	96.21	32.94
103	6° 57′	7° 56′	825.55	114.26	7° 56′	15° 5′	440.87	58.38	.36	15° 5′	22° 14′	492.55	96.81	32.73
104	6° 53′	7° 52′	833.56	114.28	7° 52′	15° 1′	443.07	58.38	.36	15° 1′	22° 10′	497.29	97.40	32.53

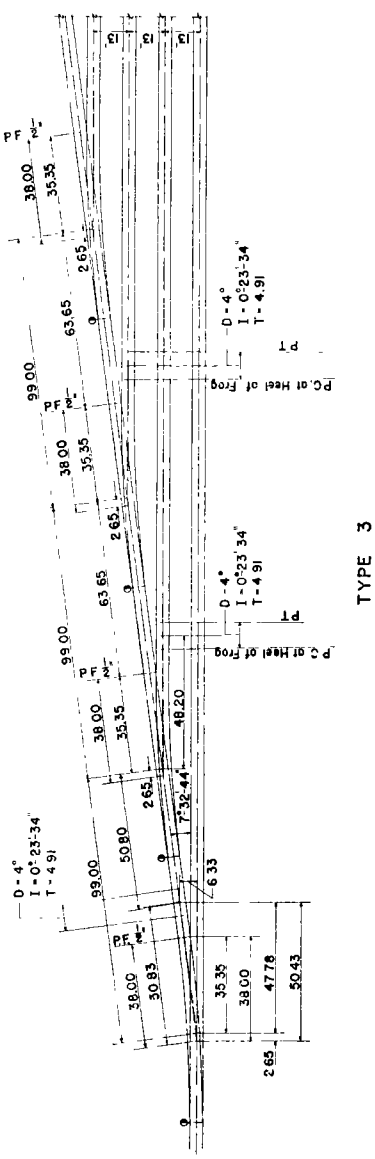
TABLE IX.—Continued

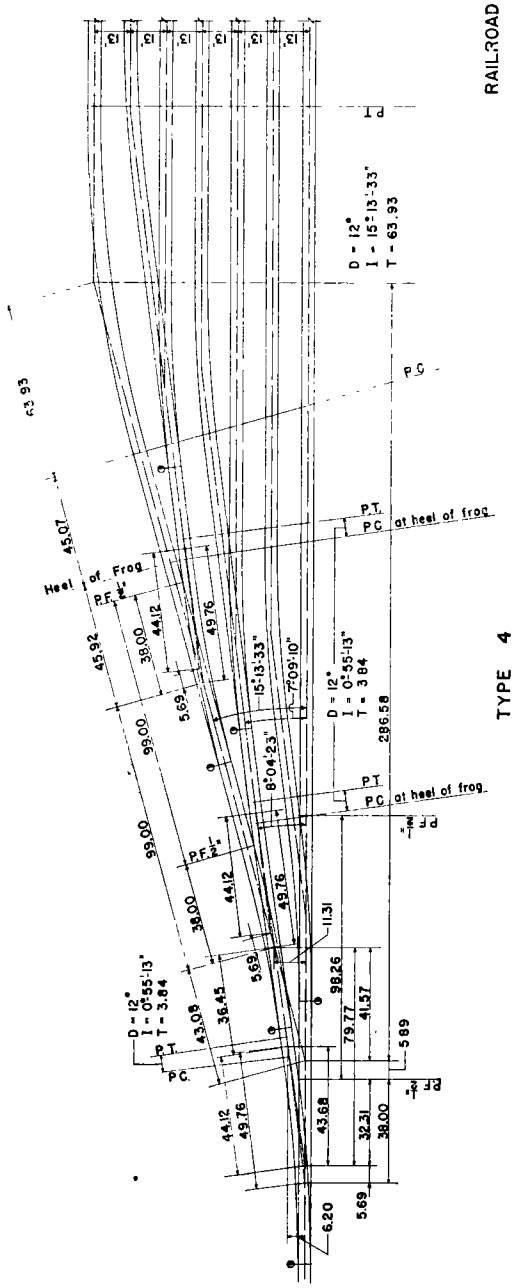
Sheet 2

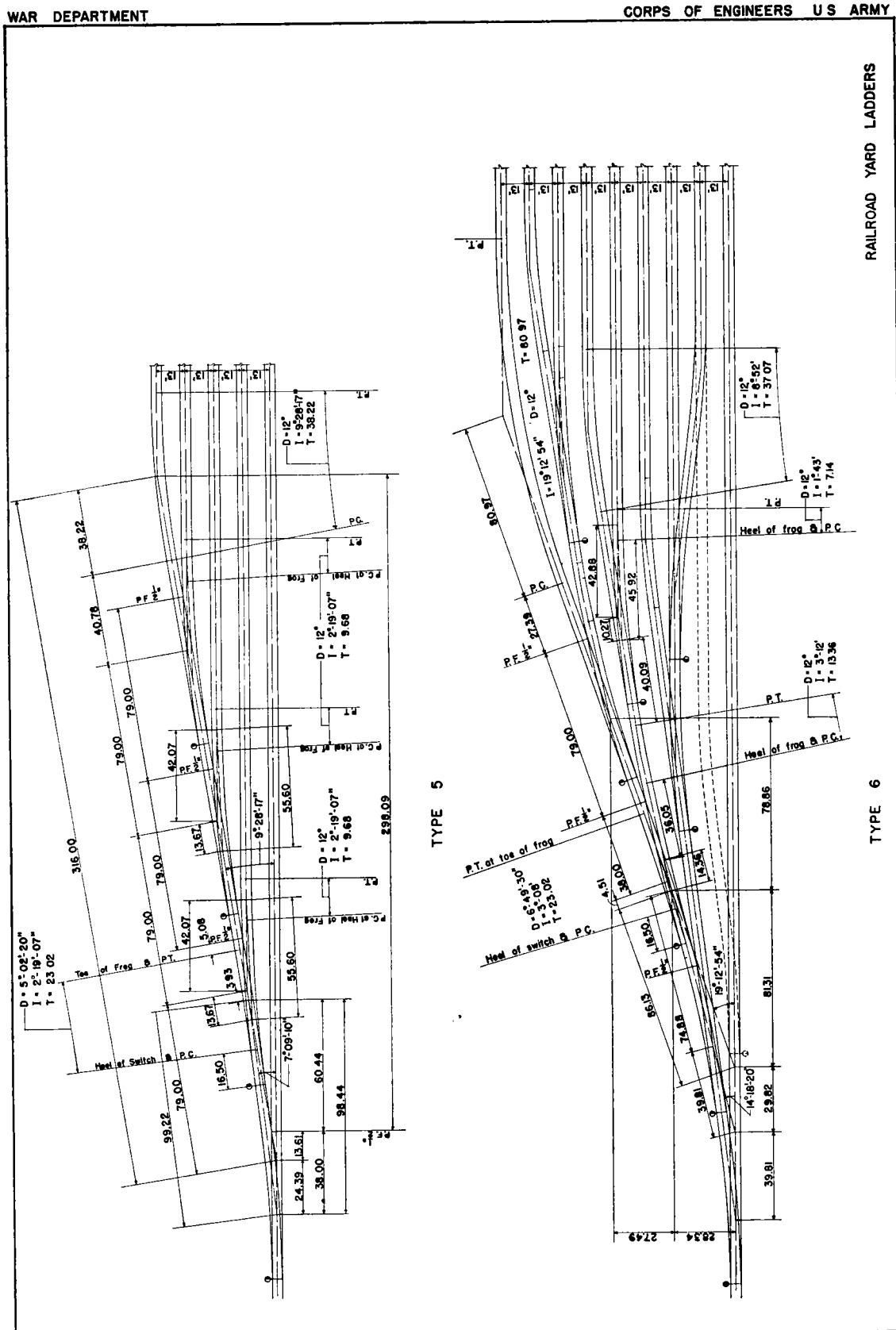
Frog spacing ft.	Yard track No. 3				Tan. back of heel	Yard track No. 4				Tan. back of heel
	I_3	L_3	R_3-ft.	t_3-ft.		I_4	L_4	R_4-ft.	t_4-ft.	
79	24° 36′	31° 45′	417. 11	118. 63	55. 11	31° 45′	38° 54′	454. 60	160. 56	65. 76
80	24° 28′	31° 37′	422. 76	119. 73	54. 91	31° 38′	38° 47′	460. 87	162. 20	65. 46
81	24° 21′	31° 30′	428. 38	120. 83	54. 69	31° 30′	38° 39′	467. 17	163. 85	65. 14
82	24° 14′	31° 23′	434. 01	121. 93	54. 46	31° 23′	38° 32′	473. 48	165. 51	64. 81
83	24° 7′	31° 16′	439. 67	123. 03	54. 23	31° 16′	38° 25′	479. 82	167. 18	64. 48
84	24° 0′	31° 9′	445. 35	124. 14	53. 99	31° 9′	38° 18′	486. 16	168. 85	64. 13
85	23° 53′	31° 2′	451. 02	125. 25	53. 73	31° 2′	38° 12′	492. 51	170. 51	63. 79
86	23° 47′	30° 56′	456. 73	126. 37	53. 48	30° 56′	38° 5′	498. 90	172. 19	63. 43
87	23° 40′	30° 49′	462. 46	127. 49	53. 21	30° 49′	37° 58′	505. 29	173. 87	63. 07
88	23° 34′	30° 43′	468. 20	128. 61	52. 95	30° 43′	37° 52′	511. 70	175. 55	62. 71
89	23° 28′	30° 37′	473. 95	129. 73	52. 68	30° 37′	37° 46′	518. 12	177. 24	62. 33
90	23° 22′	30° 31′	479. 73	130. 86	52. 39	30° 31′	37° 40′	524. 56	178. 94	61. 94
91	23° 16′	30° 25′	485. 49	131. 99	52. 11	30° 25′	37° 34′	531. 00	180. 62	61. 56
92	23° 10′	30° 19′	491. 30	133. 13	51. 82	30° 20′	37° 29′	537. 48	182. 33	61. 16
93	23° 5′	30° 14′	497. 13	134. 28	51. 51	30° 14′	37° 23′	543. 98	184. 04	60. 75
94	22° 59′	30° 8′	502. 96	135. 42	51. 21	30° 8′	37° 17′	550. 46	185. 74	60. 36
95	22° 54′	30° 3′	508. 80	136. 57	50. 90	30° 3′	37° 12′	556. 96	187. 45	59. 95
96	22° 49′	29° 58′	514. 66	137. 72	50. 58	29° 58′	37° 7′	563. 48	189. 16	59. 53
97	22° 43′	29° 52′	520. 54	138. 87	50. 27	29° 53′	37° 2′	570. 02	190. 88	59. 11
98	22° 38′	29° 47′	526. 43	140. 03	49. 94	29° 48′	36° 57′	576. 56	192. 60	58. 68
99	22° 33′	29° 42′	532. 33	141. 18	49. 61	29° 43′	36° 52′	583. 12	194. 32	58. 25
100	22° 28′	29° 37′	538. 25	142. 34	49. 27	29° 38′	36° 47′	589. 69	196. 05	57. 81
101	22° 24′	29° 33′	544. 18	143. 51	48. 94	29° 33′	36° 42′	596. 28	197. 78	57. 37
102	22° 19′	29° 28′	550. 12	144. 67	48. 60	29° 28′	36° 37′	602. 87	199. 51	56. 92
103	22° 14′	29° 23′	556. 08	145. 84	48. 25	29° 24′	36° 33′	609. 48	201. 25	56. 47
104	22° 10′	29° 19′	562. 04	147. 02	47. 89	29° 19′	36° 28′	616. 09	202. 98	56. 02


RAILROAD YARD LADDERS
TYPE 2
TYPE 1
D = 12°
I = 14°18'-20"
T = 60.02
D = 12°
I = 7°09'-10"
T = 29.90
P.T.
P.C.
P.I.
P.S.
P.F. 1/2"
7°09'-10"
14°18'-20"
60.02
104.40
113.36
105.22
420.89
38.00
408.04
301.71
199.75
97.79
79.00
100.71
29.90
38.20
7.92
3.00
0.20
9.44
310.76

RAILROAD YARD LADDERS






RAILROAD YARD LADDERS
TYPE 5
TYPE 6
Heel of Switch & P.C.
Toe of Frog & P.T.
P.C. at Heel of Frog
P.T. at toe of frog
Heel of frog & P.C.
Heel of switch & P.C.
D = 5°-02'-20"
I = 2°-19'-07"
T = 23.02
D = 12°
I = 2°-19'-07"
T = 9.68
D = 12°
I = 9°-28'-17"
T = 38.22
D = 12°
I = 19°-12'-54"
T = 80.97
D = 12°
I = 8°-52'
T = 37.07
D = 12°
I = 1°-43'
T = 7.14
D = 12°
I = 3°-12'
T = 13.36
D = 6°-49'-30"
I = 3°-08'
T = 23.02
P.T.
P.C.
P.F. 1/2"
316.00
298.09
79.00
99.22
98.44
60.44
55.60
42.07
38.22
40.78
13.67
5.08
3.93
16.50
13.61
24.39
38.00
80.97
42.88
45.92
27.39
10.27
40.09
36.05
14.36
4.51
16.50
86.13
74.88
39.81
29.82
81.31
78.86
27.49
28.34
19°-12'-54"
14°-18'-20"
7°-09'-10"
9°-28'-17"

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ENGINEERING MANUAL
FOR WAR DEPARTMENT CONSTRUCTION

PART XI

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FIRE PREVENTION



WAR DEPARTMENT
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

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2 SPRINKLER SYSTEMS AND STANDPIPES AND HOSE STATIONS.

3 FIRE ALARM SYSTEMS.

4 WATER SUPPLY FOR FIRE PROTECTION.

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Chapter 1

POLICY

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Part XI
FIRE PREVENTION
Chapter 1
POLICY

1–01 POLICY. War Department policy requires the provision of adequate fire protection at all installations. The purpose of this chapter is to establish the necessary features and devices to be incorporated in all construction and to be observed in subsequent alterations, additions, and extensions of buildings and structures in order to assure that construction for the War Department presents a maximum degree of protectibility from fire damage consistent with economic utilization. In general, the desired fire protection in building construction is attained by the maintenance of adequate separation between buildings, the limitation of individual building areas consistent with the type of construction, the subdivision of individual fire areas, the protection of exposures including vertical and horizontal openings, provisions of adequate exit and evacuation, and the provision of installed fire detection and extinguishing systems. All provisions for construction or subsequent changes thereto, together with detailed design and plans, should be thoroughly reviewed by qualified personnel at all levels of execution to assure that the incorporation of the desired features, as outlined herein, are accomplished in the resultant work.

1–02 DEFINITIONS. In order to obtain uniformity of conception with regard to types of construction referred to, the following definitions are applied in so far as this part of the Engineering Manual is involved:

a. Fire-resistive construction. A fire-resistive building is one in which the structural members are of noncombustible construction with exterior and interior bearing walls of approved masonry or reinforced concrete; exterior nonbearing walls, wall panels, columns and wall supporting girders, and trusses with fire-resistive rating of not less than 4 hours; and floors, roofs, and floor- and roof-supporting beams, girders, and trusses with a fire-resistive rating of not less than 3 hours. Buildings of semi-fireproof construction are similar to buildings of fire-resistive construction, except that columns and wall supporting girders and trusses have a fire-resistive rating of not less than 3 hours and roofs, floors- and roof-supporting beams, girders, and trusses have a fire-resistive rating of not less than 2 hours.

b. Heavy timber or mill construction. A building of mill construction is one having approved masonry or reinforced concrete exterior walls, interior bearing walls, fire partitions, and fire walls, heavy plank floors and roofs supported by heavy timber, masonry, or reinforced concrete walls or steel columns, beams, girders, or trusses spaced not closer than 6 feet centers. Semi-mill construction is a modified form of mill construction in which the main floor- and roof-supporting members are spaced wider apart and support secondary floor- and roof-supporting beams and purlins of smaller size spaced on not less than 3 feet or more than 6 feet centers. Joisted construction is a modification of semi-mill construction in that the walls may be masonry, concrete, or wood, and the secondary floor- and roof-supporting members, commonly called joists, are light members spaced not to exceed 3 feet on centers. In open joist construction the joists are exposed; that is, they are visible from below. In sheathed joist construction they are concealed by the installation of some sheathing material fastened to the lower faces of joists presenting a smooth ceiling surface.

c. Ordinary construction. A building of ordinary construction is one in which the exterior walls and bearing walls are of approved masonry or reinforced concrete, and in which the structural elements are wholly or partly of wood, of smaller dimensions than required for heavy timber construction, or of steel or iron not protected as required for fire-resistive construction or semi-fire-resistive construction.

d. Light noncombustible construction. A building of light noncombustible construction is one in which all structural members, including walls, floors, roof, and their supports, are of steel, iron, concrete, or other noncombustible materials, and in which the exterior inclosure walls are of masonry or concrete, or of other fire-resistive material which have not less than a 2-hour fire-resistive rating.

e. Frame construction. A building of frame construction is one in which walls and interior construction are wholly or partly of wood.

f. Unprotected metal construction. A building of unprotected metal construction is one in which the structural supports are unprotected metal, and in which the roofing and walls or other inclosures are of sheet metal or of other noncombustible materials, or of masonry deficient in thickness or otherwise not conforming to approved masonry.

g. Combustible construction. Buildings of combustible construction are all buildings which would be classified under the definitions expressed in *b*, *c*, and *e* above. Noncombustible construction are buildings which would be classified under the *a*, *d*, and *f* above.

1–03 SPACING OF STRUCTURES. Adequate separation of buildings and structures, the limitation of size of built-up areas, warehousing areas, and open storage areas are of prime importance from the standpoint of reducing the probability of conflagration and the spread of fire from building to building or from area to area. The provision of adequate separation of buildings is of greatest importance at projects where frame construction predominates. The minimum allowable spacing between buildings of various types of construction and occupancies for reasonable fire safety, as outlined in *a* to *g*, inclusive, below, is established. Application of the following data shall be coordinated with information presented in part II of the Engineering Manual.

a. Buildings of frame, ordinary, light noncombustible, or unprotected metal construction. These buildings, other than warehouses and hospitals, should be spaced with minimum clearances as follows:

Between one-story structures: 40 feet.
Between one-story and two-story structures: 50 feet.
Between two-story structures: 50 feet.

Buildings exceeding 25 feet in height (measured from grade to eaves), regardless of number of stories, shall have a minimum clearance of 50 feet. Where buildings exceed 10,000 square feet ground area, a minimum clear space of 80 feet will be maintained unless automatic sprinkler protection is provided.

(1) With buildings of ordinary construction, modified by having metal clad exterior doors, wired glass metal frame windows, and noncombustible cornices, exterior trim and roof covering, the above spacing may be reduced by 10 feet.

(2) In determining the spacing of structures, porches, lean-tos, or other projections are considered as part of the structure.

b. Buildings of fire-resistive construction. Buildings of full fire-resistive construction other than warehouses should have a minimum clearance of 20 feet between such structures not exceeding 25 feet in height. Higher structures shall have a minimum clearance of 30 feet. Where either exposed wall of adjacent buildings of complete fire-resistive construction is a blank wall no definite clearance is required. Where buildings of different types of construction are adjacent, the clearance required for the more combustible construction shall be provided.

c. Hospital buildings. The minimum allowable spacing between hospital buildings of various types of construction when connected by open and enclosed walkways or when detached shall be as follows:

Between one-story frame structures: 50 feet.
Between two-story frame structures: 50 feet.

Between one-story buildings of ordinary construction: 40 feet.
Between two-story buildings of ordinary construction: 50 feet.
Between one-story fire-resistive structures: 20 feet.
Between fire-resistive structures of two or more stories: 30 feet.

Where buildings of different heights are adjacent, the spacing between buildings shall be that required for the higher structure. Corridor construction will be such that totally inclosed courts will not result and parallel corridors will not violate building clearances as indicated above.

d. Warehouses and storehouses. Buildings used for storage of ordinary-hazard materials having a gross cubical content of 150,000 cubic feet or more without consideration of interior walls, partitions, or ceilings shall have a minimum spacing of 80 feet from any other structure. Smaller warehouses or storehouses shall have a minimum spacing in accordance with 1–03 *a*, above. Storage buildings for hazardous materials such as paint, oil, dope, chemicals, flammable liquids, and gases shall have a minimum clearance of 100 feet with frame or ordinary construction or 80 feet with fire-resistive construction. Where the exposed walls of such fire-resistive buildings have no openings, a clearance of 50 feet is permitted.

e. Buildings used for liquefied petroleum gas. Buildings used exclusively for the handling and distribution of liquefied petroleum gases and open-air handling and distribution stations shall have a clearance of 100 feet from any other structure. The tanks and associated equipment shall be installed in accordance with standards of the National Board of Fire Underwriters for storage and handling of liquefied petroleum gases.

f. Tent and hutment areas. Six-man tents shall be set in rows and spaced to provide 8 feet clearance on all sides. Not more than two rows shall be grouped and a clearance of not less than 30 feet shall be maintained between single or double tent rows or between tents and frame structures. Five-man hutments, accomplished by conversion of tents, shall conform to the clearance requirements for tents. Fifteen-man hutments shall be grouped in pairs back to back with a clearance of 8 feet between hutments. A minimum clearance of 30 feet shall be maintained between groups and also between groups and one-story structures.

g. Fire stations. Fire stations shall be so located that the following distances between fire stations and the following groups of buildings are not exceeded:

Barracks, living quarters, and administrative areas: 5 miles.
Warehouses, shops, and technical facilities: 2 miles.
Hospitals, measured to center of areas: ¾ mile.

Distances shall be measured along roads normally used by the fire department in responding to fire alarms.

1–04 FIREBREAKS. At posts, camps, and stations firebreaks shall be maintained at intervals not exceeding 1,000 feet in both directions, except at new posts where all buildings will be of fire-resistive construction. Firebreaks shall have clear width of 250 feet except that, in areas designated for hutment and tent housing, the minimum width of firebreaks may be 150 feet. Firebreaks shall be kept clear of buildings, timber, brush, and any type of combustible material except that fire-resistive structures other than warehouses, flammable goods storehouses, manufacturing or shop facilities, may be located in firebreaks provided the standard width of 250 feet between congested areas of combustible construction is maintained. Firebreak areas may be used for parade grounds, sports, other recreational facilities, and incidental small group parking of passenger vehicles, but should not be used for truck, tractor, trailer, tactical vehicles, or mobile artillery parking. Hospitals of combustible construction employing interconnecting open and enclosed walkways shall be divided into fire areas by fire-resistant enclosed walkways, fire-resistant walkway intersections, and draft stops. These features shall be accomplished in accordance with standard hospital plans, Office Chief of Engineers, and standard hospital plot plans for automatic sprinkler and fire-alarm systems.

1–05 FIRE PROTECTION FACILITIES. Fire protection will be provided by the following facilities. Such installations shall be accomplished in accordance with instructions and data contained in this part of the Engineering Manual in conjunction with other referenced parts of this manual, other applicable War Department manuals, and pertinent Army Regulations.

a. Water supplies. An adequate water-supply system with well-located fire hydrants, will be provided in accordance with instructions and data presented in part VII, Water Supply, of the Engineering Manual. In some instances where automatic sprinkler installations are involved, additional water requirements above those required only for mobile fire-fighting equipment may be necessary. Water requirements for automatic sprinkler protection are presented in part XI, chapter 4 of the Engineering Manual.

b. Mobile fire-fighting equipment. A full complement of mobile fire-fighting apparatus and trained personnel shall be available either at the project or from adjacent municipalities. The number of pieces of apparatus, types, and relative locations shall be in accordance with the current allowances as established by the Office, Chief of Engineers.

c. Hand fire extinguishers. An adequate supply of hand-operated fire extinguishers of various types shall be installed in accordance with data presented in chapter 5 of this manual.

d. Fixed interior fire protection systems. Fixed interior fire protection systems used at Army projects are automatic sprinkler systems, manual fire alarm systems, waterflow alarm signal systems, and watch report and manual fire alarm systems. The installation of interior fixed fire protection systems shall be provided in such buildings where because of location, construction, or occupancy such protection is warranted. Justification for and approval of such installations will be based on their necessity for protection of personnel, severity of exposure hazard, critical nature, monetary value, or importance of buildings, contents, housed facility or process, probable frequency and severity of fires, and the relative cost of replacement of building and contents to cost of the proposed protective system. The preparation of projects for the installation of fixed fire protection systems will be in accordance with information and data presented in chapters 2, 3, and 4.

e. Standpipes and small-hose stations. Standpipes and small-hose stations for first aid fire fighting purposes shall be installed in accordance with part V, chapter 4 and part XI, chapter 2 of this manual.

f. Exterior fire reporting facilities. Reliable exterior means of reporting fires to fire headquarters or other central point will be provided in accordance with information and data presented in chapter 3.

Chapter 2

SPRINKLER SYSTEMS AND STANDPIPES AND HOSE STATIONS

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Part XI

FIRE PREVENTION

Chapter 2

SPRINKLER SYSTEMS AND STANDPIPES AND HOSE STATIONS

2–01 INSTALLATIONS. Automatic sprinklers and/or standpipe and hose stations may be installed in certain buildings at any installation. Certain buildings for which such protection will be considered in the development of projects are listed in part in the following paragraphs. Other buildings which in the opinion of the project engineer warrant similar protection may be included in project submissions. All projects for such installations will be prepared on the basis of requirements of paragraph 1–05*d*. Automatic sprinkler protection will be considered in fire-resistive structures only when the value or importance of the contents or housed facility or severity of the potential fire hazard is sufficient to warrant this protection. The consideration of sprinkler protection in small structures housing units of the various occupancies listed in paragraphs 2–02 to 2–07, inclusive, will be based on the importance of, and the necessity for the particular small unit when due consideration is given to the availability of similar facilities at the property in question or at other associated properties. Hospital sprinkler systems shall be of the closed head automatic type, either wet-pipe or dry-pipe type, or a combination of the two types as local conditions require. The systems shall be designed in accordance with the criteria presented in paragraph 2–11. The installation shall be made in accordance with Guide Specification CE–700, Automatic Sprinkler Systems.

2–02 HOSPITALS. Automatic sprinkler protection will be provided in hospital buildings and enclosed combustible walkways as set forth in the following sub-paragraphs. Complete automatic sprinkler protection will not be provided in hospital buildings of fire-resistive construction, interconnecting enclosed walkways, or bridges of fire-resistive construction, or in open walkways and open or screened porches of combustible construction. Where such porches on sprinklered buildings are closed in, sprinklers will be installed.

a. Combustible buildings. Sprinkler protection shall be provided in the following types of buildings and enclosed interconnecting walkways and bridges when of frame or ordinary construction; all ward buildings, including those housing neuropsychiatric patients; all clinic, X-ray, physiotherapy and surgery buildings; patients' mess buildings; patients' recreation buildings, gymnasiums, theaters and occupational therapy buildings; patients' libraries; central service buildings; post exchanges and combination post exchanges, and post offices; patients' telephone lounges; patients' receiving and effects building; laundries, heating plants, and other buildings of the hospital group which are habitually occupied by patients or which, because of location or occupancy, constitute serious fire exposure or conflagration possibilities to the hospital group. Sprinkler heads will be omitted from individual detention rooms housing neuropsychiatric patients and from certain rooms in clinic and surgery buildings where sprinklers might be considered detrimental to the welfare of patients by appropriate medical authorities. With the exception of mess halls, laundries, and heating plants which are ordinary hazard occupancies, the buildings mentioned specifically above are in the light hazard class as defined by Pamphlet No. 13 of the National Board of Fire Underwriters. A combination laundry and dry cleaning plant would involve both ordinary and extra hazard occupancy.

b. Fire-resistive buildings. Automatic sprinkler protection in fire-resistive buildings habitually occupied by patients shall be provided only in those areas that are used for the storage or processing of moderate or large volumes of combustible materials including hazardous liquids, gases, or chemicals. This shall not be interpreted to include linen and blanket active supply rooms, small janitor closets, small laboratory facilities, or small distributed supplies of liquids and chemicals. Areas to be protected are such as mattress, linen and blanket storerooms, patients' effects storerooms, equipment repair and renovating rooms, bulk storage of liquids, gases, and chemicals, large laboratory facilities involving potential fire hazards, and large areas of similar occupancies or storage.

2–03 INDUSTRIAL FACILITIES. Automatic sprinkler protection may be provided in parts of industrial facilities plants, including aircraft assembly plants, aircraft modification centers, arsenals, ordnance plants, chemical warfare plants, etc.

a. Buildings protected. Sprinklers may be installed in all important buildings of combustible construction and in those areas of noncombustible construction where combustible materials are stored or processed and where operations which constitute fire or explosion hazards are carried on. This will include important technical research and testing laboratories, water pumping stations of combustible construction housing pumps necessary for adequate fire protection, important plant maintenance shops and other important supporting facilities for the particular plant. Sprinklers will not be installed in small unimportant buildings which are not exposure hazards to other structures.

b. Occupancy classification. In all probability each industrial facilities plant will include buildings or areas housing each of the three occupancy classifications. The classification of each fire area will be determined before deciding on the type of protection to be installed. Where occupancies of different classification occur in the same fire area, the protection installed shall be designed for the more hazardous occupancy.

c. Types of systems. All of the various types of sprinkler systems described in paragraph 2–09 may be installed in a single industrial facilities plant. Deluge systems shall be used in hangar areas of aircraft modification centers, airplane repair hangars, test flight hangars, paint and dope shops, large paint spray booths and dryers, and over-all occupancies which present possibilities of flash fires. explosion hazards, or probability of very rapid spread of fire over large areas. The use of deluge systems will be held to a minimum and proposed only where extra-hazard closed-head equipment will not furnish the protection required and full justification for the more expensive deluge equipment can be established. Extra-hazard systems shall be used over paint, oil, dope, and flammable liquids storage, over such processes as degreasing, stripping, heat treating, and other occupancies classified as extra-hazard but not requiring deluge systems or special systems.

Special systems shall be provided only where special industrial processes require supplemental sprinkler systems in addition to the regular room systems, such as fog nozzles, CO_2 or foam protection for paint dip tanks, oil quenching tanks, and similar processes involving open tanks of flammable liquids. Small open- or closed-head systems may be required for protection of hazardous machines or small local processes.

(2) Closed-head automatic systems shall be installed in buildings containing ordinary combustible storage and all other occupancies which are classed as ordinary or light hazard. All systems shall be designed in accordance with criteria presented in paragraph 2–11 to 2–14, inclusive.

2–04 DEPOTS AND PORTS. Sprinkler protection may be provided in various buildings at ports and depots as indicated below:

a. Buildings protected. Sprinkler protection may be considered for important warehouses, transit sheds, pier sheds, pier substructures of combustible construction, water pumping stations of combustible construction housing pumps vital to the maintenance of adequate fire protection, important packing, processing and repair buildings or shops, and other structures housing important supporting facilities of the depot or port.

b. Occupancy classification. The predominating occupancy classification will be ordinary hazard. Light and extra hazard occupancies may be present in less volume.

c. Types of systems. Sprinkler systems will be, in general, closed-head automatic systems of the wet-pipe or dry-pipe type. Deluge equipment may be required at certain air forces depots and ports. The use of preaction systems will be considered only for protection of combustible pier substructures where vibration or sway of the structure is such that it is impossible to maintain a dry-pipe system and automatic protection is required. They will be considered only in freezing zones where closed-head wet-pipe systems cannot be used. The design of systems shall be in accordance with paragraphs 2–11 to 2–16, inclusive.

2–05 POSTS, CAMPS, AND STATIONS. Sprinkler installations at posts, camps, and stations will be considered on the basis of the following information:

a. Buildings protected. Sprinkler protection will be provided in hospital areas in accordance with paragraph 2–02, in nitrocellulose film vaults, cabinets, and workrooms, large paint, oil, dope, and flammable liquids storehouses, water pumping stations of combustible construction housing pumps necessary to provide adequate fire protection, laundries and dry cleaning plants of combustible construction. Sprinklers may be installed in important warehouses and storehouses, repair shops of major importance, structures housing important research, experimental, development, and testing facilities, and other structures which because of value of contents, location, construction, or occupancy, present fire exposure or conflagration hazards.

b. Occupancy classification. In all probability protection will be provided for occupancies of all three classes.

c. Types of systems. Automatic closed-head wet- or dry-pipe type for protection of light, ordinary and extra-hazard occupancies will predominate. At certain air forces stations deluge equipment may be required.

2–06 TROOP HOUSING. Automatic sprinkler protection will be provided in multiple-story buildings of frame and ordinary construction more than two stories high. Sprinkler protection will not be provided in buildings of fire-resistive construction.

2–07 ARMY AIR FORCES INSTALLATIONS. Automatic sprinkler equipment at Army Air Forces properties will be provided in accordance with Army Air Forces policies governing such installations.

2–08 STANDPIPES AND HOSE STATIONS. Standpipes and hose stations will be treated as fixed fire protection systems and will be proposed for installation only where complete justification can be established. Normally justification will be based upon the area or height of buildings being such that the extension of exterior fire protection hose lines would be difficult.

a. Small-hose stations. In general small-hose stations (1½-inch hose) will not be provided in warehouses, storehouses, or buildings protected by automatic sprinklers. Such equipment may be provided in sprinklered laundries, dry cleaning plants, theaters, recreation buildings, and certain areas of industrial facilities plants, packing and processing buildings, repair shops, and similar occupancies where operations require the use of, or result in the production of considerable quantities of light combustible materials such as sawdust, shavings, excelsior, wastepaper, and similar materials. Installations may be made in important unsprinklered buildings where first-aid fire fighting equipment in addition to the standard fire extinguisher allotment can be justified. Small-hose stations should be considered in fire-resistive unsprinklered structures housing laundries, dry cleaning plants, theaters, recreation facilities, multiple-story hospitals, large multiple-story buildings for housing facilities, multiple-story industrial facilities plants, and similar occupancies.

b. Large-hose stations. Standpipes with large-hose stations (2½-inch hose) may be required on piers and wharves not accessible to mobile fire department apparatus and in very large hangar areas, repair shops, or industrial facilities plants where the building dimensions are such that all parts of the areas cannot be reached by large-hose lines not exceeding 300 feet in length when supplied from exterior hydrants or fire department pumpers. In multiple-story buildings exceeding two stories in height where small-hose stations are required, a large-hose station should be installed on each standpipe at each floor level above the first story. Hose, nozzle, and rack will be provided only where experienced personnel in handling large-hose lines will be immediately available.

2–09 TYPES OF SYSTEMS. Various types of sprinkler systems may be installed in certain buildings and parts of buildings at any army-owned or army-operated property. The type of system installed shall be that which will provide the best fire protection, due consideration having been given to the type of construction and the occupancy of each building or part of a building where the installation is to be accomplished. The various types of systems for use at Army properties are described briefly as follows:

a. Closed-head automatic systems. This type of system is the one most commonly used since it has a much broader scope of application than any other type. It consists of closed-type heads installed on an overhead piping system of graduated pipe sizes with the heads distributed over the area to be protected in a uniform and definite manner determined by the type of construction and the occupancy of the area. A reliable water supply is permanently connected to sprinkler piping and a control valve provided in the riser either of the alarm check-valve type for wet systems or a dry-pipe valve for dry-pipe systems. A shut-off valve is also provided on the water supply connection outside of and well away from the building. The system is fully automatic in that water is distributed by each sprinkler head when it "fuses" or opens and the heads open at or very close to certain fixed temperatures. The primary difference between wet- and dry-pipe systems is that in wet-pipe systems the piping is full of water up to the sprinkler heads and under the full pressure maintained in the outside underground water system; in dry-pipe systems the piping is filled with compressed air and water is held out of the system by the dry-pipe valve until a head opens releasing the air. A sudden drop in air pressure automatically trips the dry-pipe valve letting water into the system at full pressure. The wet-pipe system is slightly faster in starting actual water distribution because of little or no air to be exhausted; however, with modern dry-pipe valves and quick-opening devices the slight delay in obtaining water distribution from a dry-pipe system is not serious with well-designed layouts. These types of systems are used over all light and ordinary hazard occupancies.

b. Extra-hazard systems. This type of system is a minor variation of the closed-head automatic system and differs only in the number of sprinklers per system, floor coverage per sprinkler, and pipe sizes. This type of system should be used over extra-hazardous occupancies where rapid combustion with unusual resulting heat is expected, but not where flash fires, fires of explosive nature, or rapidly spreading fires are anticipated. Examples of such occupancies are paint, oil, dope, combustible liquids, and gases storage, nitrocellulose film storage and workrooms, pyroxilin plastic processing, and similar occupancies.

c. Deluge systems. This type of system is similar in design and arrangement to the extra-hazard systems, but differs in that the sprinklers used are open-type, the number of heads per system is limited, and the control valve is of a special type. Automatic operation of the system is accomplished by means of heat-actuated devices uniformly distributed over the ceiling which, when actuated by a predetermined rate-of-rise in temperature, automatically open the control valve flooding the area protected. Deluge systems are used only over extra-hazardous processes where there is danger of flash fires, fires of an explosive nature, or other types of fires resulting in a rapid spread of flame over a considerable area with high resulting temperature particularly where abnormally high head room exists. Examples of

such occupancies are hangar areas, combined paint and dope shops, large paint-spray hoods and driers, explosives processing, and similar occupancies.

d. Preaction systems. A preaction system is a modification of a closed-head dry-pipe system and differs in that the number of heads on any valve is increased to 1,000; the control valve is automatically tripped by the action of heat-actuated devices or manually tripped, and air pressure in the system is less than 3 p. s. i. and is provided only for supervision of the system. A preaction system without the supervisory feature will be used only for the protection of a structure in which vibration or sway of the structure is such that standard dry-pipe systems cannot be maintained. This shall not be interpreted as including anticipated vibration due to earthquake. An applicable use of such a system would be for the protection of the substructure of a pier or wharf of light construction. Automatic supervision of such a piping system is impractical, and maintenance of the system in satisfactory condition will depend upon frequent careful inspections and tests. Such a system can be considered only as a substitute and, before its use is proposed, investigation should be made with regard to the possibility of eliminating the structural defects prohibiting the installation of standard dry-pipe systems which are fully automatic and supervised with regard to breaks or leaks in the piping.

e. Special systems. Special systems are those designed for the protection of specific hazardous processes or machines such as heat-treating processes involving inflammable quenching liquids, paint and lacquer dip tanks, rubber compounding machines and calendars, powder blending cubicals, small paint or lacquer spray booths, airplane motor test cells, and similar unusual extra hazardous occupancies and processes. Such systems are usually supplemental installations in addition to the general sprinkler protection system of the room occupied by the special process. The use of special systems is to be avoided and will be authorized only when fully justified.

2–10 DESIGN CRITERIA. The design criteria presented in the following paragraphs 2–11 to 2–15, inclusive, will govern the development of projects for sprinkler installations. In conjunction with this information the standards of the National Board of Fire Underwriters' Pamphlet No. 13, The Installation of Sprinkler Equipment, will be used.

2–11 CLOSED-HEAD SYSTEMS. Closed-head automatic sprinkler systems will be designed in accordance with the standards of the National Board of Fire Underwriters for sprinkler equipment (Pamphlet No. 13) and such modification of those standards as appear in the following criteria:

a. Occupancy hazard. Systems will be designed for light, ordinary, or extra-hazard occupancy according to the present or contemplated occupancy of the building in question. Where mixed hazards, protected by one sprinkler system, are involved but are separated by permanent substantial partitions having a minimum fire resistance rating of 1 hour, that part of the system protecting each hazard, shall be designed for that hazard and have separate interior control valves and feed mains from a common riser. Where no separation exists, or the partitions are of light combustible construction, the entire system shall be designed for the greater hazard. Where existing light hazard areas may be converted at some future time to ordinary hazard occupancy (a considerable part of one warehouse section presently used as offices), the system shall be designed for the future occupancy.

b. Types of systems. Systems will be wet- or dry-pipe type as local conditions require. The use of a dry-pipe system, however, is to be avoided wherever possible. Where heating facilities are such that 50 percent or less of the sprinklers on a system would be exposed to freezing, those heads shall be controlled by a small dry-pipe valve taking its supply from the main wet system. If more than 50 percent of the heads are in unheated areas, the entire system shall be of the dry-pipe type.

c. Area coverage. Coverage per sprinkler head will vary with different types of construction and also with the class of occupancy. The maximum allowable coverage and head spacing for various types of construction and occupancy are as given in the following table:

Type of construction	Light hazard		Ordinary hazard		Extra hazard	
	Coverage per head (square feet)	Spacing between heads (feet)	Coverage per head (square feet)	Spacing between heads (feet)	Coverage per head (square feet)	Spacing between heads (feet)
Fire resistant	196	14	100	12	90	10
Mill	168	14	100	12	80	10
Semi-mill	144	14	90	10	80	10
Open joisted	80	[1] 8–10	80	[1] 8–10	70	[1] 7–10
Sheathed joisted	[2] 168	14	[3] 100	10	[3] 80	10
	120	12	[2] 80	10	70	[1] 7–10
			80	[1] 8–10	----------	----------
			[4] 90	10	----------	----------

[1] The first figure represents the maximum distance between heads at right angles to joists; the second figure the distance between branch lines. Where only one figure is shown for spacing of heads, this distance is permitted in either direction.

[2] This coverage and spacing should be provided where sheathing has a fire-resistant value equal to or better than ½-inch plaster board.

[3] This coverage and spacing is permitted under metal lath and cement plaster ceilings.

[4] This coverage and spacing is acceptable under combustible ceilings where unused attic spaces above are protected by sprinklers.

d. Drainage. The piping arrangement shall be such that as much of the system as possible will drain back to the main riser. A minimum drainage pitch of ¼-inch in 10 feet for wet-pipe systems and ½-inch in 10 feet for dry-pipe systems is required for branch lines, cross-feed mains, and feed mains. Low trapped heads requiring auxiliary drains or drain plugs are to be avoided. This is of particular importance in dry-pipe systems. Drains for trapped heads on dry-pipe systems shall be equipped with condensate chambers and bleeder valves.

e. Branch lines. Except where numerous small rooms are involved, branch lines should not extend through partitions or walls. Branch lines shall be limited to 6 heads on either side of a cross-feed main for extra-hazard occupancy and 8 heads with light and ordinary hazard, except that, with light-hazard occupancy and branch lines extending through partitions, a maximum of 10 heads will be permitted on branch lines using 2-inch starters, provided not more than 5 heads are in any room. With semi-mill and joisted construction branch lines shall be run at right angles to purlins or joists and a stagger arrangement of heads will be accomplished, except that under joisted, sheathed ceilings, where the sheathing is equivalent to ½-inch plaster board, a parallel arrangement of heads is acceptable. With mill construction and fire-resistive construction, involving beams or girders or both, branch lines shall be installed in the bays, and parallel arrangement of heads may be used. Under smooth ceiling fire-resistive construction branch lines may be run in either direction.

f. Position of heads. In general, sprinklers shall be installed in an upright position and under no condition will pendent heads be installed in dry-pipe systems. Cross-feed mains will be arranged so that sprinkler heads can be installed directly on branch lines without sprigs. The systems shall be designed so that the deflectors of sprinklers will be parallel to ceilings or roof slopes and not less than 4 inches nor more than 8 inches from roof decking, ceiling, or lower edge level of joists, purlins, or beams. No sprinkler shall be located less than 1 foot from the nearest face or edge of installed equipment such as large electric light shades, or structural members, which will interfere with uniform distribution from the head. Lower faces of joists, purlins, or beams will not interfere with distribution from heads located 4 inches below such faces. Not more than 14 branch lines shall be supplied by a cross-feed main on either side of a riser or feed main.

g. Size of systems. Pipe sizes and the number of sprinklers per system shall be in accordance with the standards of the National Board of Fire Underwriters for each class of occupancy except that for light and ordinary hazard 300 heads may be supplied by a 6-inch riser and 500 heads by an 8-inch riser in any fire area, provided the total number of heads in any subdivision of the fire area does not exceed 250 for 6-inch and 400 for 8-inch risers. In determining the number of heads in a subdivision area, sprinklers under mezzanines, galleries, and stock-bin decks, office areas in warehouses, and under low ceilings of light construction, and outside platforms are to be considered in separate areas from the main sprinkler system. In multiple-story buildings with good floor cut-offs each story will be treated as a separate fire area and the number of heads on any riser will not be limited, provided the requirements for each fire area are met and in the case of dry pipe systems the total capacity of the system does not exceed 1,000 gallons. Supply connections for subdivision sprinklers shall be taken from cross-feed mains, feed mains, or risers at points where the supplying main is at least one pipe size larger than the connecting pipe. Feed mains will not be increased in size because of subdivision sprinkler loads. Two-inch flushing nipples and caps will be provided on the ends of all cross-feed mains of 2 inches or larger. A 1-inch test connection, properly bushed, shall be installed on each system as near the end of the system as practicable and accessible. Only one test connection is required on each system.

h. Supply connections. Underground water supply connections shall be 4 inches or larger and in no case smaller than the sprinkler riser. Underground supply connections for sprinkler systems shall be used for no other purpose except that where small-hose stations are contemplated, they may be supplied from the sprinkler connection in accordance with subsequent paragraph 2–15 *a*. Where supply connections pass through unheated areas and will be subject to freezing temperatures, they shall be protected against frost in an approved manner. Four-inch supply connections will be used only for light hazard systems or ordinary hazard systems of less than 65 heads and then only when the distance between underground main and riser does not exceed 150 feet. Outside control valves shall be provided on each supply connection and will be located as far from the building protected as possible up to a distance of 50 feet. Post indicator valves shall be used wherever possible. Where such valves would be subject to mechanical damage and cannot be properly guarded or would interfere with operations of the using service, O. S. & Y. valves in pits will be used. Key-operated buried valves are not acceptable. Two 6-inch systems in the same fire area may be supplied from one 8-inch supply connection with an O. S. & Y. control valve on each system where such an arrangement would be economical. With this arrangement only one alarm valve or one dry-pipe valve will be required. Two systems on opposite sides of a fire wall may be supplied by one underground supply connection at the fire wall of the proper size for the larger system with separate alarm check valves or dry-pipe valves and O. S. & Y. shut-off valves provided on each system. Fire department connections are not necessary where the underground water supply system can supply sprinkler system water at adequate volume and pressure from municipal water supply connections, stationary fire pumps, gravity tanks, or reservoirs, or combinations of these sources. Where the existing water supply system cannot meet the above requirements, fire department connections will be provided either on each underground supply connection to sprinkler systems or arranged to serve a number of sprinkler risers.

i. Extra-hazard systems. Extra hazard systems shall be designed in accordance with criteria for closed-head systems and the following additional requirements. Eight-inch feed mains or risers shall not be used. The number of heads on a 6-inch feed main or riser shall not exceed 150. Two such systems in one fire area may be controlled by one alarm check valve or dry-pipe valve and supplied by one 8-inch underground connection, when such an arrangement would be economical.

j. Hospital sprinkler systems. Sprinkler systems for hospital buildings shall be designed in accordance with the above criteria for light or ordinary hazard occupancy and additional requirements as follows for hospitals which are laid out with buildings interconnected by enclosed walkways. Such systems shall be designed making use of CE standard sprinkler plans for type A general hospital as guides. One underground supply connection will serve several buildings. The feed main from riser to

the several buildings will be 4-inch pipe installed in the walkways close to either wall, and walkway heads will be supplied in groups by connections from the walkway main not larger than 2 inches. Building systems will be connected to the walkway main by 3-inch pipe with O. S. & Y. control valve and drain. A test connection will be required in each building. Sprinkler systems for neuropsychiatric ward buildings will be piped with concealed piping and all first-story heads pendent. Special, approved flush-type-head installations will be provided in the detention wards and small detention rooms unless specifically omitted by medical authorities. Attic heads will be regular type and installed perpendicular to slope of roof and not pendent. Where walkway mains supply walkway heads only, the size of main may be reduced to 3 inches at the last protected building and again reduced to 2½ inches at the fortieth head from the end. The remainder of the main will be sized for light hazard. The number of buildings grouped on one 4-inch main shall be limited so that a pressure loss in the main of 10 psi is not exceeded with a flow of 300 gpm. The grouping of buildings and riser locations shall be such that all fire department connections are readily accessible and all buildings on one riser are on the same side of an enclosed walkway that does not directly serve a group of buildings.

k. Dry-pipe systems. Dry-pipe systems will be designed in accordance with the above criteria and the following additional requirements. Frostproof enclosures or valve houses will be required to house dry-pipe valves and their auxiliary equipment except where the riser or supply connection and dry-pipe valve can be located in an adjoining heated area. Valve enclosures, whenever possible, will be located at exterior walls and may be either inside the main structure or outside. Entrance should be from the outside only and the type of construction will conform to that of the main structure. The floor will be concrete and will pitch to a wall scupper for drainage from valve houses above grade or to a sump or floor drain where valve enclosures must be below grade. One electric circuit to provide light, heat, and power to compressor motor, where required, will be provided, taking its current supply from the hot side of the main switch of the building power or light circuit with switch and fuses independent of other building circuits. Air compressors are to be provided in accordance with Guide Specification CE–700. Air compressors should preferably be located other than in valve houses where automatic operation is contemplated. Dry-pipe systems controlled by one dry-pipe valve will be limited in size to a total capacity of 1,000 gallons above the valve regardless of the number of heads involved. All dry-pipe systems having a capacity of 375 gallons or more shall be equipped with quick-opening devices. All main drains, auxiliary drains, and drains for all trapped heads shall be equipped with condensate chambers and bleeder valves. All condensate chambers shall be connected so that they will accomplish their function without interfering with full use of the drain connection except that, for five or less trapped heads, the condensate bleeder valve will serve as a drain.

l. Pier substructure protection. Systems for pier substructure will conform to all above criteria and will be designed to conform to pier substructure fire walls and fire stops. Pipe sizes will be for ordinary hazard, coverage shall not exceed 80 square feet per head and, where two lines of heads are required in a bent, a stagger arrangement of heads will be used.

2–12 DELUGE SYSTEMS. Deluge sprinkler systems shall be designed according to standards of the National Board of Fire Underwriters for extra-hazard occupancy using applicable data presented in paragraph 2–11 above and incorporating such modifications as may be included in the following criteria:

a. Size of systems. Systems will, in general, be limited to 125 heads each. In no case will the number of heads per system exceed 150. Open heads shall be used and will be installed in an upright position perpendicular to the slope of roof or ceilings except that, where conditions require branch lines to slope downward to the small end, the end heads on such branch lines will be pendent. Maximum coverage per head shall not exceed 90 square feet under fire-resistive construction with heads not exceeding 10 feet apart in either direction; 80 square feet under mill, semi-mill, and exposed steel construction with heads not exceeding 10 feet apart in either direction; 70 square feet under open wood joist construction

with branch lines running across joists and not exceeding 10 feet apart. Where roof or floor joists are sheathed on the under side with material equivalent to metal lath and cement plaster, a coverage of 80 square feet is permitted with heads spaced not exceeding 10 feet in either direction, with branch lines running across the joists. With sheathing of less fire-resistance value, the construction will be treated as open joist. Branch lines will not exceed 6 heads on either side of a cross main and not more than 14 branch lines will be located on either side of a cross-main connection to a feed main. A stagger arrangement of heads will be provided except under smooth ceilings of fire-resistive and mill construction.

b. Draft curtains. Systems will be square or rectangular in outline and long narrow designs are to be avoided. Where more than one system is required in a fire area, draft curtains of noncombustible material will be provided surrounding each system. Structural members such as trusses shall be utilized as far as possible for the support of draft curtains. Curtains must be tight against roof decking and extend downward a distance equal to one-sixth of the total height from floor to ceiling but not less than 2 feet. Where the headroom does not exceed 25 feet, curtains need not exceed 3 feet in depth.

c. Control valves and supply connections. Each system shall be controlled by a quick-opening valve tripped by heat-actuated devices operating on the temperature rate-of-rise principle. The valve will be located as near the system as possible and an O. S. & Y. control valve will be installed adjacent to the quick-opening valve on the supply side. When the quick-opening valve must be in a hazardous location to be near the system controlled, a second remotely located, manually operated control valve, either of the O. S. & Y. or post indicator type will be provided. This valve may control several automatic valves. The heat-actuated devices shall be located at the ceiling or roof decking in each sprinklered area and spaced as required for the type of device used. In addition to automatic tripping, the quick-opening valve will be equipped so that it may be tripped manually at the valve and at remotely located manually operated tripping stations. Where comparatively flat roofs or ceilings exist, the system should be designed for central supply using extra-hazard pipe sizes. With steep pitched or high arched roofs the cross feed main and supply connection to the system shall be made at the proper point to provide approximately equal discharge from all sprinklers on the system. Extra hazard pipe sizes need not be adhered to where variation is necessary to accomplish equal discharge from all heads. Variation in the size of sprinkler orifices will not be resorted to in obtaining equal discharge. Where two or more deluge systems are in the same fire area, the water supply connections to underground supply mains and system risers shall be arranged and sized so that all systems will receive approximately equal quantities of water per head.

2–13 PREACTION SYSTEMS. Preaction systems will be designed in accordance with criteria for closed-head dry-pipe systems and ordinary occupancy hazard, with the following modifications. One quick-opening valve will supply not more than 1,000 heads, which will be divided into groups of not more than 250 heads each by fire stops. Each area between fire stops will be treated as a separate fire area. If the type of construction and size of area require more than 250 heads, two groups of approximately the same number of heads will be provided. Each group will be connected to the feed main at one point only except that, where areas require 100 heads or less, two groups may be supplied by one connection. Each connection will be equipped with an O. S. & Y. valve and drain. The feed main will be sized in accordance with the National Board of Fire Underwriters' standard pipe schedule for ordinary hazard except that pipe larger than 8 inches will not be used on the discharge side of quick-opening valves.

2–14 SPECIAL SYSTEMS. Special systems involving the use of regular, sidewall, window or cornice type sprinklers or fog nozzles are classed as such because of the fact that the location, spacing of heads, and coverage will not conform to criteria previously presented, but must of necessity be varied to meet the requirements encountered in each situation. Extra-hazard requirements with regard to spacing of heads and coverage will not be exceeded. Piping interconnecting several heads will be sized for extra-hazard occupancy. Feed mains to grouped heads will be one pipe size larger than for the

number of heads in the group where supply lines to such groups are of excessive length. Special systems making use of fog nozzles, carbon dioxide or foam equipment will be designed in accordance with the recommendations of the manufacturer of the equipment proposed.

2–15 STANDPIPES AND HOSE STATIONS. Standpipes and hose station protection shall be accomplished in accordance with the following criteria used in conjunction with the standards of the National Board of Fire Underwriters' Pamphlet No. 14, Standpipe and Hose Stations. In event of conflict these criteria will take precedence. No hose station, either large or small, will be connected on the air side of a dry-pipe valve or the discharge side of a deluge system.

a. Small-hose stations. (1) Small-hose stations shall be so located that every part of the area to be protected, including closets and small rooms, can be reached with 75 feet of hose. No allowance will be made for effective range of stream after leaving nozzle.

(2) Small-hose stations in sprinklered areas may get their water supply from sprinkler risers on the supply side of all inside sprinkler control valves or from domestic or service water supply pipes, when such supply pipes are of suitable size and no valves other than the control valve at the point of connection to the underground water system exist between the underground main and the point of connection for small-hose stations. Not more than four small-hose stations on any floor will be supplied by one connection from a sprinkler supply line. Supply pipe will be 2 inches for one hose station and 2½ inches for two and three stations and 3 inches for four stations when all four stations are on the same side of the supply connection. Where the supply connection feeds both ways, a 2½-inch connection is acceptable. Where more than one hose station is supplied by one connection, an O. S. & Y. control valve will be provided at the source of supply. In multiple-story sprinklered buildings the small-hose stations above the first-story may be supplied by standpipe risers from the first-story supply lines or from a standpipe riser located at the source of supply, whichever arrangement is more economical. Riser standpipes from first-story supply lines will have a minimum size of 2 inches supplying the top story hose stations, 2½ inches for the next three stories and then 3 inches down to main supply, for heights exceeding four stories. The supply line in the first story will be one pipe size larger than the size of riser standpipe base. Where one riser standpipe located at the source of supply is used, it will be sized the same except that the top section will be 2½-inches.

(3) In unsprinklered buildings one and two stories high when domestic or service water connections are not available, small-hose stations will be supplied by a separate connection from the underground water main. This connection will be not less than 4 inches in size and will have an outside post indicator valve control and will be equipped with a fire department connection where more than four hose stations are required in one area. The number of hose stations on one supply connection will not be limited; second-story hose stations may be supplied by 2-inch riser standpipes from the first-story supply lines. Supply lines will be sized as follows considering the number of hose stations in one story only: one station, 2 inches; two and three stations, 2½-inches; four to eight stations, 3½-inches; excess of eight stations, 4 inches.

(4) In unsprinklered, multiple-story buildings more than two stories high large-hose stations will also be required wherever small-hose station equipment can be justified. In such buildings the small-hose stations will be supplied from the large-hose station riser standpipes by a separate connection other than the large-hose station on each floor.

b Large-hose stations. Large-hose stations will be located to permit the use of 100 feet of hose for interior installations and 200 feet of hose for pier and wharf installations. Pier and wharf standpipes will be siamese outlets equipped with two hose valves, hose, nozzle, and spanner wrenches for one stream with a spare nozzle for a second stream if required. This will permit the use of two streams from any standpipe by bringing out extra hose only. Supply lines for large hose stations on piers and wharves will be connected to wet-pipe supply mains for sprinkler systems on the supply side of all sprinkler control valves. Each connection to a siamese hose station will be 4 inches in size. Where sprinkler supply mains are

not available, the supply main for large-hose stations will be sized as follows: the end hose station, 5 inches; next three stations, 6 inches; all subsequent stations, 8 inches. The supply main will be connected to a reliable source of supply not less than 8 inches in size with a siamese fire department connection provided at the shore end. Fire boat connections will be permitted only when the fire protection water supply is raw water and independent of all potable water supplies. Where supply mains and standpipes for hose stations will be subjected to freezing temperatures, insulation must be provided. Winter control valves and drains for each hose station located close to the insulated supply main and protected will be acceptable, when such an arrangement is feasible and economical. Interior large-hose stations in buildings will be supplied by separate supply connections from underground supply mains. This connection will be not less than 6 inches in size where more than two stations are required and will have an indicator post control valve. In no case will large-hose stations be supplied from sprinkler system supply connections. Supply lines inside the buildings will be sized as follows considering the stations in the first-story only: the end station only, 3 inches; two stations, 4 inches; three, four and five stations, 5 inches; more than five stations, 6 inches. Riser standpipes in multiple-story buildings will be not less than 3 inches for the top story and 4 inches for the next five stories. In excess of six stories standpipes will be 6 inches at the base. In no case will the supply lines in the first-story be less than the base size of any riser standpipe.

2–16 DRAFT CURTAINS AND PIER DRAFT STOPS. Draft curtains will not be required in conjunction with sprinkler installations, other than deluge systems and pier substructure protection, where fire areas do not exceed approximately 40,000 square feet. Warehouses, open sheds, transit sheds, and pier sheds having undivided areas in excess of this area will be equipped with draft curtains dividing the area into equal areas not greater than 40,000 square feet each. Wherever feasible, draft curtains will be installed on structural members, such as trusses, girders, or beams; will be tight against roof decking and shall extend downward a distance of approximately one-sixth the head room but not less than 24 inches. In open sheds, eave skirting will be provided in accordance with paragraph 5–05*h*. Pier draft stops will be provided in accordance with paragraph 5–05*f*. Draft curtains will be provided in conjunction with all deluge sprinkler systems in accordance with paragraph 2–12*b* above. Where draft curtains and pier draft stops are involved, sprinkler systems will be designed to conform to such construction in that branch lines will not extend through the curtains or fire stops. Draft curtains in large areas of industrial facilities plants and repair shops, will be provided only where special conditions of construction or occupancy warrant the installation.

2–17 WATERFLOW ALARMS. Waterflow alarm signal facilities will be included in all projects for the installation of sprinkler systems. The provision of this facility will be in accordance with criteria established in paragraph 3–12.

2–18 CONTRACT PLANS AND SPECIFICATIONS. Contract plans, specifications, and design analysis for authorized sprinkler installations will be forwarded to Office, Chief of Engineers, for review and comment. Revisions of original plans or specifications will be submitted and approval will be obtained before contracts are let for sprinkler installations.

a. Contract plans. Contract plans will consist of a plot plan, at scale not less than 1-inch equal to 100 feet (not reduced), showing buildings to be protected, underground water mains and sizes, hydrants, proposed water supply connections to sprinkler systems and control valves, all adjacent buildings within 200 feet of the buildings to be sprinklered, with notes indicating the construction and occupancy of such buildings and actual flow test data indicating the available water at the required sprinkler pressure at the various buildings.

(1) A typical detail sprinkler lay-out plan, at scale of not less than ⅛-inch equal to 1 foot, will be submitted for each type of construction involved in the project with sufficient cross sections, elevations,

and notes to indicate clearly the construction involved, including material, location and spacing of trusses, beams, girders, height between floors, ceilings and roofs, joists, purlins, roof decking, floors, galleries, bins, bin decks, stairs, partitions, and other pertinent structural data influencing sprinkler-system design, such as ceilings, insulation, and such obstructing equipment installations as crane rails. Typical lay-outs of each type of supplemental sprinkler groups, such as warehouse platform canopies, low-ceiling office or stockroom areas, decked-over bin areas, under-mezzanines or galleries and similar areas should be included. Where several buildings of the same type of construction, same size or a multiple and of the same occupancy classification are involved but have varying interior arrangements of partitions, bins, or other construction requiring minor changes in sprinkler system design, an outline plan at small scale for each building should be furnished showing the variations of interior arrangements. These plans will indicate by figures the number of heads in each roof area and each supplemental area, such as low-ceiling areas.

(2) Single-line diagram drawings, not necessarily to scale, showing each type of sprinkler riser involved should be included, showing the relative arrangement of alarm valve, dry-pipe valve, fire-department connection, check valve, and system control valves and other equipment which may be required.

(3) Typical sprinkler lay-out plans will be simple drawings using single lines for pipe, small circles for sprinkler heads on plans and triangles on sections, and standard fire protection symbols as recommended by the National Board of Fire Underwriters for other equipment items. Detail drawings of sprinkler heads, pipe fittings, or valves are not required.

b. Project specifications. Project specifications will be prepared using Guide Specification CE–700, eliminating such parts of the guide specification as have no application to the project in question.

c. Design analysis. The design analysis to accompany contract plans and specifications will include a complete description of the waterworks system upon which the sprinkler systems will be dependent, with flow test data determined by representative tests in the vicinity of buildings or groups of buildings to be sprinklered. Clear descriptions of the occupancies of each building should be presented, as well as of the type of system proposed, and all unusual features of design not clearly indicated on plans.

Chapter 3

FIRE ALARM SYSTEMS

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3–02 TYPES OF SYSTEMS.
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Part XI

FIRE PREVENTION

Chapter 3

FIRE ALARM SYSTEMS

3–01 GENERAL. Fire alarm systems will be provided at Army installations for the purpose of accurately, speedily, and economically transmitting a warning signal indicating the presence of a fire. The operation of the fire alarm systems shall cause the sounding of adequate warning signals to permit safe evacuation of building personnel and the transmitting of signals to fire headquarters or stations of key personnel to signify the existence and location of a fire.

3–02 TYPES OF SYSTEMS. Fire alarm systems to be installed at army installations shall consist of the following types: fire reporting telephones (supervised), combination watch report and fire alarm systems, manual fire alarm systems, and waterflow alarm systems.

3–03 FIRE REPORTING TELEPHONE SYSTEMS. These systems are manual exterior systems and may be installed in posts, camps, and stations for the purpose of reporting a fire, which might be observed by a person traveling the streets or thoroughfares in the vicinity of a building or group of buildings. The design of these systems will be in accordance with standards agreed upon by the Office, Chief of Engineers, and the Chief Signal Officer. Fire reporting telephone systems described under these paragraphs will be of the supervised type. This type of system shall consist of facilities installed at the receiving equipment in fire headquarters which will indicate by visual and audible signals that a ground or other trouble exists in the circuit provided between the reporting phone and the receiving equipment. When a receiver is lifted at a fire reporting station, the call will be transmitted to fire headquarters switchboard and the number of the station calling will be automatically registered on an annunciator. The registering of the station on the annunciator will cause an audible and visible signal. The annunciator shall be so installed that the station number registered on the annunciator will remain visible until cleared manually. Switchboard attendant at fire headquarters may make connection with the station calling for the purpose of securing, from the person reporting the alarm, additional information which may be of assistance to the fire department.

3–04 RESPONSIBILITY FOR INSTALLATION AND MAINTENANCE. The procurement and installation of fire-reporting telephone systems, including switchboards, annunciators, fire-reporting telephones, and connecting circuits, will be accomplished by the Signal Corps or appropriate responsible signal agency. Where coded manual transmitters and recording devices are required to transmit signals from fire headquarters to other fire stations, it will be the responsibility of the Signal Corps to install these facilities. The procurement and maintenance of coded manual transmitters and recording devices will be the responsibility of the Corps of Engineers or appropriate responsible signal agency. Circuits provided in conjunction with fire-reporting systems will be in accordance with paragraph 3-05. Where more than two fire stations, including fire headquarters, exist at a post, fire calls received at fire headquarters will be relayed by a coded manual transmitter to the coded sounding and recording devices located in the other fire stations. In addition to the coded manual transmitter at fire headquarters,

there will be installed an approved punch type or inked ribbon type recording device which will operate in conjunction with the coded manual transmitter. The recording device will be installed as a means of automatically recording the transmission of fire calls for record purposes. Where only two fire stations, including fire headquarters, exist at a post, fire calls will be relayed from fire headquarters to the other fire station by a reserved telephone line. Fire reporting telephone systems of a supervised type will usually be installed at posts where more than ten fire-reporting stations are to be provided. Where ten or less fire-reporting stations are required, manual fire alarm boxes of a coded, noninterfering type should be provided as a part of the interior coded fire-alarm system. If no fire-alarm system is installed, or it is more economical, fire-reporting telephones of the supervised type should be provided.

3–05 CABLE FACILITIES. The Signal Corps or appropriate responsible signal agency will provide exterior circuits, when used with fire-reporting systems, from the fire-reporting stations to the switchboard and annunciator in fire headquarters and the circuits between coded manual transmitters in fire headquarters and other fire stations when manual transmission of signals is required. Fire department headquarters requiring the installation of facilities for receiving coded fire alarm and fire reporting telephone signals shall have the fire reporting telephone signals manually transmitted through the same exterior circuits provided to transmit coded fire-alarm signals between receiving equipment in main fire-department headquarters and coded sounding equipment in other fire stations.

3–06 CONDITIONS GOVERNING FIRE REPORTING TELEPHONE INSTALLATIONS. Fire reporting telephone systems will not be used for any purpose other than for reporting fires.

a. Cantonments. Fire reporting telephone systems of a supervised type, as described in paragraph 3–03 will be installed in cantonments.

b. General hospitals. General hospitals will be provided with an independent fire reporting system when this type of hospital is in an isolated location and is not a part of or adjacent to an Army post. Fire reporting telephones of a supervised type will be installed where more than ten stations are required. Where ten or less stations are required, manual fire alarm boxes of a coded noninterfering type will be provided as a part of the interior coded manual fire alarm system, unless it is more economical to install fire reporting telephones. Fire reporting telephone circuits will terminate at the receiving equipment in the hospital fire station. General hospitals located adjacent to, or considered a part of a post, will have a fire reporting system installed in accordance with the above paragraph except that the equipment will be made a part of the post fire reporting system. Where a general hospital is located adjacent to or within a city and is dependent on municipal fire fighting equipment for complete fire protection, it is advisable that the *exterior* fire reporting system be similar to and an extension to the city fire alarm system. No receiving equipment for exterior fire alarm systems will be required at the hospital where the city fire alarm system is utilized. Signals received at the hospital sounding and recording equipment from the interior manual fire alarm system will be relayed to the city fire alarm system in accordance with the requirements set forth in paragraph 3–11*d*.

c. Station hospitals. Fire reporting telephones will be installed throughout the hospital area (except fire roads between buildings) as described in paragraph 3–04. These telephones will be made a part of the post fire reporting telephone system.

d. Airfields and air forces stations. Fire reporting telephone systems will be installed at airfields and air forces stations similar to that described in paragraph 3–03 for posts and camps. Telephone boxes should be installed along the hangar line to be available to each group of buildings. Telephone boxes should be installed on buildings where the installations of standards or stub poles would constitute a hazard to field operations.

e. Ports and supply depots. Fire reporting telephone systems of the supervised type will be installed in the warehouse areas (including open sheds) where more than ten exterior fire reporting stations are required. These systems will report to fire headquarters located at the port or depot and will be in-

stalled in accordance with paragraph 3–03. Coded noninterfering fire alarm boxes of a supervised type will be installed to report through circuits provided for interior watch reporting and fire alarm systems or waterflow alarm systems in warehouse areas (including open sheds) at ports or depots where ten or less exterior fire reporting stations are required. Where interior watch reporting and fire alarm systems or waterflow alarm systems are not installed in port or depot warehouse buildings or open sheds, a fire reporting telephone system of the supervised type will be installed where ten or less stations are required. Where watch reporting and fire alarm systems are provided in the open shed areas, no exterior fire reporting telephones will be installed, as the fire reporting boxes or facilities provided with the watch reporting and fire alarm systems will be available for exterior fire reporting. (For location of boxes provided for watch reporting and fire alarm systems in open sheds, see paragraph 3–10*c*). Fire reporting stations should be located on both sides of railroad sidings at approximately 1,000-foot spacing. Fire reporting stations will be installed on only one side of the tracks at road intersections as it is assumed that roads will remain open for passage of motorized traffic and thus permit unobstructed vision or access to the fire reporting station.

f. Plans for fire reporting telephone systems. (1) Plans for fire reporting telephone systems submitted to the Office of the Chief of Engineers, following final approval of the project, should indicate all construction, building designations, streets, thoroughfares, and preferably the electrical distribution system, including the location of existing or proposed poles. Where the installation of additional fire reporting telephones is contemplated, it is important that the plans indicate the location of adjacent existing fire reporting telephones. In expanded areas which are not directly adjacent to the post, the location of the area with relation to the post and the distance between areas should be indicated on the plans. Main fire headquarters and all fire stations should be indicated and identified on the plans.

(2) Guard reporting telephone systems are a function of the Signal Corps or appropriate responsible signal agency and should not be included in the review of fire reporting telephone systems.

3–07 FIRE REPORTING TELEPHONES. Phones provided at Army installations will be of the mine type, housed in an unlocked weatherproof metal case and installed in accordance with the following:

a. Distribution of fire reporting telephones. Fire reporting telephones should be located to protect built-up areas consisting of grouped buildings and isolated buildings having special occupancy. Telephones should be located throughout the post along streets and thoroughfares (except fire roads between buildings in hospital areas) so that not more than 500 feet of travel along these thoroughfares is necessary from a telephone to any building other than isolated buildings or group of buildings separated from the post. This spacing will result in the telephones being spaced approximately 1,000 feet apart. Telephones should preferably be located at street intersections. Effort should be made to cover all streets so that there is at least one phone on each street. Fire reporting telephones should be so located along the thoroughfare that the topography or other obstructions will not prevent clear detection of the fire phone. Consideration should be given, wherever possible when locating fire reporting telephones, to anticipating possible future construction so that a more economical distribution of fire phones can be provided. Fire reporting telephone boxes may be installed on existing power line poles, commercial standards or 4 inch x 4 inch stub poles of a suitable height, or on the exterior of a building. Center of the box should be 5 feet above grade level. Fire reporting facilities will not be required at sewage disposal plants, pumping stations, incinerators, etc., where they are in isolated locations and where the installation of long run of cable is required. The administration telephone, where provided, should be used for reporting fires from these locations. Fire reporting telephones will not be installed within buildings.

b. Identification of fire reporting telephones. All fire reporting telephone locations will be identified by ruby lights (vaporproof) and banded markings. Ruby lights should be installed above the telephone box a minimum height of 8 feet above grade level. Where fire reporting telephones are located at the corner of a building, the ruby light should be installed at a 45° angle so as to be visible from two direc-

tions. Fire reporting stations located on poles or standards will be identified by a 2-foot wide red band around the support and centered on the telephone box. At the top and bottom of the red band shall be painted a 6-inch wide white border around the standard. Where fire reporting telephone stations are located on walls of buildings, a red bull's-eye 2 feet in diameter surrounded by a 6-inch white border will be provided and the bulls'-eye shall center on the telephone box. Identification markers are the responsibility of the Corps of Engineers.

3–08 COMBINED WATCH REPORTING AND FIRE ALARM SYSTEMS. Watch reporting and fire alarm systems will be of a coded type and will be installed and maintained by the Corps of Engineers. Federal Specification W–F–396*a* (Fire Alarm Systems; Electric, Manual, Coded, Shunt Noninterfering Type) will be used as a guide for the installation of these systems.

3–09 CONDITIONS GOVERNING COMBINED WATCH REPORTING AND FIRE ALARM INSTALLATIONS. Combined watch reporting and fire alarm systems may be installed in depot or post warehouses, open sheds or other important shops, repair or manufacturing buildings at Army installations where such protection may be justified in accordance with paragraph 1–05*d*. Generally, watch reporting and fire alarm systems will not be installed in buildings protected by automatic sprinkler systems.

3–10 DESIGN CRITERIA. Coded watch reporting and fire alarm systems shall be electrically supervised, with shunt partial noninterfering, manually operated type boxes. (See par. 3–08). The systems described under these paragraphs shall be of the type that an open circuit or a ground or a combination of both will not prevent the transmission of a clear intelligible signal before the trouble is cleared. This feature will be accomplished entirely by automatic operation. The system will be a closed-circuit system of a type approved by an appropriate nationally recognized commerical or U. S. Government testing laboratory. The system will comply in all respects not specifically excepted with applicable provisions of the Standards of the National Board of Fire Underwriters' Pamphlet No. 72 (Proprietary, Auxiliary, and Local Systems for Watchman, Fire Alarm and Supervisory Service). Signal circuit or circuits between the protected buildings, and the recording and sounding equipment at main fire headquarters shall comply with the requirements for Class A proprietary systems as specified in paragraphs 412, 413, and 414 of the Standards of the National Board of Fire Underwriters' Pamphlet No. 72. These systems will include circuit facilities between watch reporting and fire-alarm boxes and receiving equipment in guard headquarters which will permit the emergency operation of the systems in case of a single break or ground and eliminate the possibility of confusing a trouble signal with a fire signal. The system should be arranged with one circuit for each watch reporting tour. The system shall be operated from house current through a rectifier, with trickle-charged, floating storage batteries to operate the system under trouble conditions for a period of 60 hours with full load. Systems requiring ten or less fire alarm signaling stations can be installed to operate on direct house current without battery stand-by except in buildings requiring the transmission of coded waterflow alarm signals. Systems installed to transmit waterflow alarm signals will operate on house current through rectifiers with 60-hour storage battery stand-by regardless of the number of waterflow alarms installed. In multiple-story buildings exceeding three stories in height and requiring the installation of more than ten signal stations, the system will require operation on house current through rectifiers with a 60-hour storage battery stand-by. Where the systems operate through a rectifier with the storage battery stand-by to operate the system in event of house current supply failure, it will be necessary to install one control and charging board with test facilities necessary for proper operation of system and to charge the batteries. The use of full shunt noninterfering type equipment will not be required but may be installed where low bid is received from an approved bidder or manufacturer of this type of equipment. Where this type of system is installed, it will be installed in accordance with Federal

Specification W–F–391*a* (Fire Alarm Systems; Electrical, Manual, Coded, Positive Noninterfering Type).

a. Receiving equipment. Receiving, recording, and sounding apparatus for combined watch reporting and fire-alarm systems shall be installed in guard headquarters. Both types of signals will be received and recorded by this equipment and fire-alarm signals received in guard headquarters shall be relayed automatically to the receiving and recording equipment installed in the fire station nearest the area from which the fire-alarm signal was transmitted. Signals received in this fire station will be transmitted automatically to the receiving equipment in the main fire headquarters. Where a more economical installation is possible by first reporting the fire-alarm signals from guard headquarters to the receiving equipment in the main fire headquarters having facilities for retransmitting automatically the signals to the receiving equipment in all other fire stations in the post or depot, then the less expensive system should be installed. The circuits used to relay fire calls from guard headquarters to fire headquarters or fire stations need not be of a type that can be operated under trouble conditions, but these circuits must be supervised to the extent that a failure of current supply, ground, or other trouble conditions will give a trouble signal.

b. Cable facilities. The Signal Corps or appropriate responsible signal agency will provide exterior circuits from the buildings protected by watch reporting and fire-alarm systems to guard headquarters receiving equipment and circuits for retransmitting of signals from guard headquarters to fire station and fire headquarters only where circuits are available and the current characteristics of the alarm systems are suitable. Where Signal Corps circuits are to be used, the alarm contractor shall contact the Signal Officer or appropriate responsible signal agency to determine all points of attachment.

c. Signal stations. The watch reporting and fire-alarm systems contain stations designed for the transmission of both watch reporting and fire-alarm signals from the same or separate boxes. Coded manual signal boxes shall be installed to comply with Federal Specification W-F-396*a* (Fire-Alarm Systems; Electrical, Manual, Coded, Shunt Noninterfering Type). Manual fire-alarm boxes shall be of an approved pattern of the pull-lever or break-glass type. Watch-reporting boxes shall transmit signals by key operation only. Combination watch-reporting and fire-alarm boxes shall be of the break-glass and key-arrangement type. Signal stations shall be located inside buildings to be accessible for use by both building personnel and watchmen. Stations should be so located that complete coverage of a storage area or building by the watchman is accomplished with minimum number of stations. Stations should be so located that the maximum watchman's tour distance between boxes does not exceed approximately 200 feet. Wherever possible, the station should be adjacent to an exit doorway. Signal stations provided in open sheds should be installed approximately 200 feet apart and located on the outside face of the exterior supporting members for the sheds.

d. Identification of signal stations. Signal stations installed in buildings and in the open shed areas will not require ruby lights or painted markers.

3–11. MANUAL FIRE-ALARM SYSTEMS. These systems shall be of a coded type and will be installed and maintained by the Corps of Engineers. Manual fire-alarm systems will be installed in accordance with the provisions specified in paragraph 3–10 with the exception that no watch reporting facilities will be provided and systems will not transmit signals to the receiving equipment in guard headquarters. Manual alarm systems will be installed at the following installations for the purpose of transmitting an appropriate signal to hospital fire station and fire department headquarters. Manual fire-alarm boxes will not be required in hospital buildings which are completely protected by automatic-sprinkler systems.

a. General hospitals. Manual alarm systems will be installed in corridors at all general hospitals. Manual fire alarm boxes will be of an approved pattern of the pull-lever or break-glass type and will be installed in corridors at approximately 200-foot intervals with the first box located approximately 100 feet from the end of corridors. Wherever possible, consideration should be given to locating manual

fire alarm boxes adjacent to emergency exits. Where emergency exits are installed at the ends of corridors, it is considered advisable to locate the first fire alarm box adjacent to the exit instead of locating the box the 100-foot distance mentioned above.

b. Station and post hospitals. Hospital buildings not exceeding two stories in height which are interconnected by open or enclosed walkways will not require interior manual fire alarm protection. Manual fire alarm systems will be installed in the walkways and the spacing of the boxes will be in accordance with paragraph 3–11*a*, with the exception of manual fire alarm boxes in the neuropsychiatric ward areas. One manual fire alarm box should be installed in the enclosed walkway or corridor adjacent to each neuropsychiatric ward building where automatic sprinkler protection is not provided in the small detention rooms.

c. Depots, camps, and posts. Manual fire alarm facilities will be provided at these installations in accordance with the last sentence of paragraph 3–04.

d. Receiving equipment. The main control and signal recording equipment provided at isolated general hospitals shall be installed in the hospital fire station. The operation of a manual fire alarm box or waterflow alarm will transmit a coded signal to the control and recording equipment in the hospital fire station. Signals received at this fire station shall be transmitted automatically to the recording and sounding equipment located in one of the hospital rooms where a responsible person is on duty 24 hours a day. An exception to the above installation should be considered when the general hospital is not provided with a fire station due to its close proximity to a city and is, therefore, dependent on municipal fire department for protection. In this case the coded signals will be sounded and recorded on the hospital receiving equipment (located in a room where a responsible person is on duty 24 hours a day) and relayed automatically, if permitted by municipal authorities, to the city fire alarm system. When municipal regulations do not permit the automatic transmission of alarm signals from private to municipal alarm systems, the coded signals received at the hospital receiving equipment will be manually transmitted to the municipal alarm system. Where a general hospital is located at or adjacent to an Army post or station, the fire alarm systems in the general hospital area will become a part of the post or station fire alarm system and the receiving equipment will be installed in the main fire headquarters, fire station, and hospital area similar to that required for the installation of receiving equipment for station and post hospitals referred to in the following paragraph.

(1) The main control and signal recording equipment provided at station and post hospitals will be installed in the hospital fire station, if one is provided, or in the fire station nearest the hospital area. Coded fire alarm or waterflow alarm signals originating in the hospital area will be transmitted to the coded recording and sounding equipment located at the fire station and transmitted automatically to the receiving equipment in fire department headquarters and to the coded sounding equipment provided in one of the hospital rooms, where a responsible persons is on duty 24 hours a day.

(2) The main control and signal recording equipment, provided at post warehouse areas at Army installations, will be installed in the fire station nearest the warehouse area. Coded signals sounded and recorded at this fire station will automatically be transmitted to the signal recording equipment located at main fire department headquarters. All coded fire alarm signals received in main fire department headquarters will be automatically retransmitted to coded sounding and recording devices installed in all other fire stations at the post.

e. Identification of manual alarm stations. Ruby lights and painted markers will be provided at installations where exterior manual alarm stations are installed as part of the interior fire alarm system in lieu of exterior fire reporting phones. Where such facilities are installed, the fire alarm stations should be properly distributed in accordance with paragraph 3–07*a* and *b*.

3–12 WATERFLOW ALARMS. Waterflow alarm facilities will be provided for all automatic sprinkler systems for the purpose of providing a local and transmitted signal to indicate the operation of a system or systems. These facilities in the case of dry-pipe systems will provide automatic advance

warning of abnormal or dangerous conditions existing in the system which might cause failure in the operation of the sprinkler system.

a. Transmitted alarm facilities. (1) Alarm valves and dry-pipe valves installed on automatic sprinkler systems will have an alarm transmitter and circuits provided to transmit a coded signal to fire station receiving equipment, indicating the operation of the sprinkler system. Sprinkler alarm transmitter may be either a pressure-actuated or electrically operated device. Where interior alarm facilities are utilized to transmit waterflow alarm signals, the devices will be an approved type suitable for use on the existing system. Facilities will be provided to transmit a coded waterflow signal from each underground supply connection.

(2) Where waterflow (paddle type) indicators are installed, the equipment will be provided to transmit a coded signal to fire station receiving equipment indicating the operation of the sprinkler system. Utilization of the interior alarm facilities for the transmission of waterflow alarm signals will be permitted subject to the conditions stated in the above paragraph.

b. Local alarm facilities. (1) One exterior local noncoded waterflow alarm of the electric or water motor gong type will be provided for each underground supply connection. Local alarms will operate continuously, until manually cleared. Local electric alarm gongs, where installed in conjunction with automatic sprinkler systems of the wet pipe or deluge type, will be actuated by electric supply circuits originating on the line side of the main house switch. Where dry-pipe sprinkler systems are installed, the electric supply circuits for the local electric alarm gongs will be connected to the electric circuits installed for the heating unit in the valve house. Where dry-pipe valves are located in heated areas, electric current for local alarm signals will be provided as required for wet-pipe or deluge-type sprinkler systems. Exterior local alarms will not be required on sprinkler systems in buildings at hospital areas.

(2) One exterior local low air-pressure alarm of the electric gong type will be provided at each dry-pipe valve house and arranged for actuation by a pressure switch. Electric circuits for the local low air-pressure alarms will be connected to the circuits provided for the heating units in the valve house. Where feasible, the electric circuits for the local waterflow alarm and local low air-pressure alarm may be connected to the same exterior gong.

Chapter 4

WATER SUPPLY FOR FIRE PROTECTION

4–01 BASIC WATER SUPPLY.
4–02 WATER PRESSURE.
4–03 VOLUME.
a. Light hazards.
b. Ordinary hazards.
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d. Special systems.
4–04 SOURCE OF SUPPLY.
4–05 DEFICIENT WATER SUPPLY.
a. Elevated tanks or reservoirs.
b. Automatic fire pumps.
c. Power for fire pumps.
d. Starting of fire pumps.
e. Fire pump suction supply.

Part XI
FIRE PREVENTION
Chapter 4
WATER SUPPLY FOR FIRE PROTECTION

4–01 BASIC WATER SUPPLY. The basic water supply requirements for fire protection will be in accordance with criteria established in part VII of the Engineering Manual. At installations where automatic sprinkler protection is provided, additional water supply either in volume, increased pressure, or both may be required for satisfactory operation of sprinkler systems. Where the water supply for sprinkler protection is furnished through gridiron systems also furnishing domestic and industrial water supplies, the domestic and industrial demands must be given consideration in accordance with part VII of the Engineering Manual when determining the volume of water available for sprinkler operation. The minimum pressure and volume requirements for satisfactory sprinkler operation are outlined in the following paragraphs.

4–02 WATER PRESSURE. The water pressure required for satisfactory sprinkler operation is a residual pressure of 15 psi at the top of sprinkler systems with the required volume of water flowing. In determining the available flow at the required residual pressure in any sprinkler system, an allowance for height only will be made where the distance from the underground supply main to the distribution point of the system is not more than 100 feet. Where longer supply connections are involved, an additional allowance for friction losses in the supply connection will be made. Friction losses in distribution piping of sprinkler systems will be disregarded except in the design of open head deluge systems for installation under steep pitched or arched roofs.

4–03 VOLUME. The initial and total volumes of water required for sprinkler service vary with the hazard classification of the occupancy being protected. The hazard classification of occupancies will be determined in accordance with the recommendations of the National Board of Fire Underwriters as presented in Standards for the Installation of Sprinkler Equipments, Pamphlet No. 13. The initial volume of water is defined as that volume immediately and automatically available at the required pressure without manual operation of any valves or pumps on the water system or the use of mobile fire department pumping engines. The total volume is that amount of water available on demand by the manual operation of valves or stationary fire pumps on the water supply system. The minimum water requirements for the various classifications are as follows:

a. Light hazards. Hospitals, office buildings, etc., require a minimum initial flow of 500 gpm for 1 hour and a total flow at 1,000 gpm for 2 hours at the required sprinkler pressure.

b. Ordinary hazards. Warehouses and industrial facilities plants in general, repair and processing shops, and similar occupancies require an initial volume of 1,000 gpm for 1 hour and a total volume of 2,000 gpm for 2 hours both at the required sprinkler residual pressure. This total volume is based on 1,000 gpm sprinkler requirement and 1,000 gpm for hose streams and supplemental sprinkler water through mobile pumping engines.

c. Extra hazards. Paint and dope shops, film vaults and work rooms, airplane repair hangars, paint, oil, dope and volatile combustible liquid storage, and some occupancies of industrial facilities plants require various amounts of water depending on the type and size of sprinkler system installed and the probable number of heads that will operate in any one fire. In every case the total and initial volume of water will be the same. With closed head systems the probable number of sprinklers to operate will be based on ceiling height in the area protected as follows: 25 feet or less, 65 heads; 25 to 35 feet, 100 heads; in excess of 35 feet, 60 percent of all the heads in all draft stop areas that are wholly or

partly directly over any 50 feet radius floor area. The volume of water required will be not less than 1-hour supply for open head deluge systems and 2-hours supply for closed head systems.

d. Special systems. Water requirements for special systems shall not be less than the requirements for extra hazards. Where fog nozzle equipment is used, the water supply in regard to volume and pressure will be as required for the type and number of nozzles installed. The installation of extensive special systems is not contemplated and the necessity for special water requirements above the water required for the sprinkler system protecting the building housing the special process or equipment requiring the special protective system are not anticipated.

4–04 SOURCE OF SUPPLY. The most satisfactory source of water supply for sprinkler systems is an elevated tank or reservoir. Other acceptable sources of supply are adequate connections from dependable municipal water systems or post, camp, or station utilities and fire protection water systems.

4–05 DEFICIENT WATER SUPPLY. In many cases the basic water supply as provided under part VII of the Engineering Manual will provide both initial and total volume at the required pressure. Where a deficiency is apparent, it shall be corrected in the most economical and dependable manner. It may be accomplished by the installation of additional elevated storage, additional or larger connections from dependable and ample municipal water systems, reinforcing existing underground distribution systems to deliver the required water at the sprinklered buildings, the use of fire pumps or a combination of the above methods. The existing water systems should be studied carefully and the correction of deficiency accomplished in accordance with part VII of the Engineering Manual incorporating the following requirements:

a. Elevated tanks or reservoirs. Where the installation of an elevated tank or reservoir is contemplated as the initial water supply for sprinkler systems, a minimum capacity of 75,000 gallons should be provided. An existing tank of 50,000 gallons' capacity, otherwise suitable for the initial supply for sprinklers, may be acceptable where the initial demand does not exceed 1,000 gpm.

b. Automatic fire pumps. In the event that the initial supply is deficient in quantity at the required pressure from any of the above sources, the deficiency will be made up by automatically started fire pumps. Automatic pumps used to make up deficiency in initial supply to sprinkler systems will be capable of furnishing the entire initial supply at the required pressure, unless the characteristics of the water system are such that only the deficiency need be provided.

c. Power for fire pumps. Fire pumps intended to be started automatically will be electric motor drive. Such pumps may be dual drive with the automatic starting equipment on the electric motor only. Power for manually started fire pumps required to make up deficiency in total sprinkler demand will be in accordance with criteria established in part VII of the Engineering Manual.

d. Starting of fire pumps. Automatic starting of fire pumps, except where several large deluge sprinkler systems are involved, may be accomplished by drop in pressure in the underground distribution system where characteristics of the water supply system are such that a sprinkler demand of 500 gpm will cause sufficient line pressure drop at the pump and maximum domestic and industrial demand will not cause unnecessary starting of pumps. Where distribution system pressure drop cannot be utilized and where large open head deluge systems are involved, automatic fire pumps will be started by waterflow from any sprinkler system. Fire pumps required to provide the total sprinkler demand for other than deluge systems shall be started manually. Automatically started fire pumps will not be arranged to be stopped automatically. Equipment for the control of automatic fire pumps will be in accordance with the standards of the National Board of Fire Underwriters.

e. Fire pump suction supply. If the initial or total volume of water supply is available without the use of fire pumps but at insufficient pressure, the necessary pumps may be provided as a booster pump installation, provided the underground water distribution system adapts itself to such an arrangement. Where the volume is deficient, fire pump suction supply will be furnished from ground reservoirs in accordance with part VII of the Engineering Manual.

Chapter 5

EMERGENCY AND PROTECTIVE FEATURES

5–01 GENERAL.
5–02 EVACUATION REQUIREMENTS.
5–03 EMERGENCY EXITS.

a. Interior stairways.
b. Fire escapes.
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5–05 FIRE AREAS IN BUILDINGS.

a. Fire walls.
b. Fire cut-off partitions.
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5–06 STRUCTURAL IMPROVEMENTS.

a. Fire stops.
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i. Fireproof paints.
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Part XI

FIRE PREVENTION

Chapter 5

EMERGENCY AND PROTECTIVE FEATURES

5–01 · GENERAL. The criteria covered in this chapter have been developed in accordance with a policy of good fire prevention engineering and are considered necessary to provide adequate emergency signals, exit facilities, fire fighting equipment, and construction requirements necessary to safeguard the prompt evacuation of the building occupants and to provide reasonable means of extinguishing or limiting the spread of a fire which might cause loss of life or property.

5–02 EVACUATION REQUIREMENTS. A local fire alarm system will be provided in all buildings, except hospitals, of frame or ordinary construction, consisting of three or more stories and having an occupancy of more than 20 persons above the first floor. Systems will consist of alarm sounding and visible alarm devices and alarm sending stations. Alarm sounding devices such as gongs, klaxons, or other devices will be installed in such numbers, and so distributed as to be effectively heard in any room above all other noise. All of the sounding devices on the premises will sound immediately upon the operation of any alarm station. A visible alarm device will be provided in addition to a sounding device in the office or room occupied by authorized personnel in charge of the building. Electrical alarm systems are preferable to mechanical alarm systems where conditions are such as to require more than one sending station and usually where more than one sounding decive is required. Mechanical systems are sometimes preferable where but one station is required. Alarm sounding stations will be provided on each floor near all main exits and in corridors leading to the natural path of escape from the building and should be so located that every part of the building is within 200 feet of a station. Where the buildings, exclusive of hospital buildings, are of fire-resistive construction, the alarm sounding devices will be installed in accordance with requirements stated above, except that alarm sounding devices will be installed so that the operation of a sending station will cause a general alarm in all sections of the floor *only* on which the alarm sending station is located and in the room occupied by the personnel in charge of the building. All hospital buildings, three or more stories, regardless of the type of construction, occupied or used by patients, will be provided with suitable means for transmitting alarms of fire from each section of each floor to the nearest fire station. Hospital buildings not exceeding two stories in height which are interconnected by enclosed walkways will not require facilities for transmitting manual fire alarm signals. Manual fire alarm stations will be installed along the enclosed walkways for the purpose of transmitting manual fire alarm signals from the hospital buildings in accordance with paragraph 3–11*b*. Local exterior alarms should not be provided for any hospital buildings.

5–03 EMERGENCY EXITS. Exit facilities will be installed in all buildings so that a minimum of two exits are provided from each floor and located as remote from each other as practicable. Exits should be so located that no person will be required to travel more than 125 feet to reach an exit from any portion of the floor regardless of type of construction or occupancy except in assembly buildings, motor repair shops, aircraft hangars, large industrial facility plants, and buildings of extra-hazard occupancy. Stair towers, other exits, and cross corridors leading to stairs or exits in multiple story

fire-resistive hospital buildings will be so located that dead end areas in excess of 80 feet in length will not result. Required travel from any portion of the floor to an exit in assembly buildings will be limited to 100 feet. In large undivided areas of motor repair shops, aircraft hangars, and industrial facility plants, no limit will be established regarding minimum travel to exits, but such buildings should be given special consideration as to the sufficient number of convenient exits from all parts of the building. Buildings of extra-hazard occupancy should have additional exit facilities to assure the safety of the occupants. In motion picture projection booths the exit requirements should be in accordance with Pamphlet No. 40 as published by the National Board of Fire Underwriters. All exits will lead directly to or through an exit corridor to a street or an exterior open area leading to a street. Hinged exit doors including screen doors must open in the direction of exit travel and should be unlocked, except where panic hardware is installed. Exit doors should be installed so that the swing will not obstruct or interfere with the travel along an exit corridor, stairway, or other required exits. All fire exit doors will be self-closing or automatic. Only one means of egress, centrally located, will be required in buildings of fire-resistive construction having a low hazard occupancy and not exceeding 2,500 square feet in area on each floor.

a. Interior stairways. Interior stairways which are counted as emergency exits in buildings, other than in buildings of fire-resistive construction, will be enclosed with a minimum of 1-hour fire-resistive walls, partitions and doors (self-closing) except the top story. Top story will be enclosed only where it is impossible to enclose the stairways on the floor level below the top floor. All stairway enclosures will be smokeproof. Stairways, landings, and doors used as fire exits will be of such width and construction that the average number of occupants to occupy each floor can be safely and speedily evacuated. Exit facilities in buildings used to house hospital patients will be so designed as to permit evacuation of patients in beds and stretchers. No door shall open immediately on a flight of stairs. A landing at least equal to the width of the door shall be provided between the door and the stairs. Winding stairs or stairs with less than three risers shall not be permitted for exit use. Exit corridors should not contain steps and their widths should not be less than the widths of the exit doors to which they lead. Enclosures for exit stairways in buildings of fire-resistive construction will have a minimum of 2-hour fire-resistive walls or partitions and doors.

b. Fire escapes. Fire escapes serving buildings, other than hospital patient buildings, of more than two stories above the ground level, will be permanently attached, self-supporting structures of other than vertical ladder type, and will be of a type suitable to the climatic conditions of the locality. Fire escapes should be placed against blank walls, or all openings under and adjacent to the fire escape protected by fire doors or metal frame windows having wired glass. Fire escapes on two-story buildings not used to house hospital patients or female occupants may be permanently attached self-supporting vertical type ladders. Where enclosed escapes or vertical ladders are not installed, an open stair and platform type fire escape should be provided.

(1) Exterior fire escapes when installed on patient hospital buildings or on other buildings where deemed necessary will be enclosed with walls and doors having a minimum fire-resistive quality equal to the interior exit stair enclosure for the building. These fire escapes, when of other than fire-resistive construction, should be protected by sprinklers where such protection is installed in the building.

(2) Horizontal exits consist of a protected opening through a fire wall or a fire partition or a bridge or corridor connecting one or more buildings. Horizontal exits will lead into areas only which provide for a safe means of egress to a street or open court leading to a street.

(3) Ramps, open or enclosed, used as exits will not exceed in slope 1 foot in 10 feet, and ramps used to evacuate hospital patients will be limited to a maximum 5-percent slope. Width of a ramp will not be less than the exit door leading to the ramp. Ramps should have a nonslip surface. Open ramps should be protected with guard rails, except where the height does not require such protection.

(4) Slide escapes of either the straight or spiral type chute are acceptable except for places of public assembly. Where installed on buildings housing hospital patients, the chutes will be of such design that patients can be evacuated on mattresses.

c. Elevators. Elevators where installed in multiple-story buildings may be used as exits but the required number of emergency exit stairs, fire towers, and fire escapes will be provided.

d. Escalators. Escalators of the stair type will be recognized as stair exits when installed in compliance with the recommendations for interior fire stairs, including stair enclosures.

e. Exit clearances. Emergency exits will include all doorways, openings, or such doorways and openings together with connecting corridors, passageways, or stairways used for the safe evacuation of occupants from a building to a street or an open area which provides safe access to a street. The number of emergency exits required for every room, gallery, balcony, tier, or other area having a capacity of more than 600 persons will have at least three exits and where the capacity exceeds 1,000 persons at least four exits. The aggregate clear width of emergency exits will be not less than at the rate of 22 inches for every 100 persons to be accommodated and in no case should the minimum clear width of a single emergency exit be less than that provided by the installation of a 36-inch wide door.

f. Panic hardware. All emergency exit doors in mess halls, theaters, chapels, and gymnasium and recreational buildings, if used for theatricals, motion pictures, or when equipped with seats, for viewing athletic games and having a seating capacity exceeding 100 persons will be equipped on the inside with special panic bolts, latch releases, and closing hardware, as described in the last amendment to Federal Specification FF–H–106.

g. Exit lighting. Exit doorways, openings, corridors, stairways, or other forms of exits used for evacuation of occupants from any part of a building will be properly lighted in accordance with the provisions in chapter 2, part VI of the Engineering Manual.

5–04 EXTINGUISHERS. The distribution and installation of fire extinguishers for structures covered by standard plans, OCE, and in special government installations, will be in accordance with the requirement schedules included in the "War Department Corps of Engineers Equipment Manual for Area and Post Engineers." In buildings not covered by standard plans, OCE, the following tabulation should be used as a guide for the distribution of fire extinguishers:

Type of construction	Occupancy	Type	Maximum floor area (square foot)	Units required	Maximum travel distance to a unit (foot)
Frame or ordinary	Ordinary or extra hazard	Water pump tanks, soda-acid, carbon tetrachloride, carbon dioxide, or foam.	2, 500	1	75
Fire-resistive	Ordinary hazard	do	5, 000	1	100
Fire-resistive	Extra hazard	do	2, 500	1	75

Buildings or areas within a building where special fire hazards exist will be provided with an approved type of extinguisher for the particular hazard involved. Number of units required will be at the discretion of the using service.

5–05 FIRE AREAS IN BUILDINGS. Fire areas in warehouses, storehouse buildings, and open sheds, regardless of the type of construction, should not exceed 40,000 square feet between standard fire walls in buildings and open sheds used for ordinary hazard occupancy. Fire areas in long narrow warehouses, storehouse buildings, and open sheds, regardless of the type of construction, used for ordinary hazard occupancy will be limited in size by the installation of standard fire walls located approximately 250 feet apart, provided the fire area between fire walls does not exceed 40,000 square feet. Warehouse

and storehouse buildings used for the storage of flammable liquids, paints, dope, gases, chemicals, or other materials considered as hazardous or highly combustible should be restricted to areas between fire walls not exceeding 20,000 square feet.

a. Fire walls. Fire walls will be installed to *prevent* the passage of fire from one building to another or from one fire area of a building to another fire area. Fire walls separating buildings or dividing warehouse or storehouse buildings into separate fire areas will be of masonry construction with minimum thickness of 11 inches for reinforced concrete, 12 inches for brick, and 16 inches for load-bearing hollow clay tile. Tile fire walls will be constructed of two units with at least two cells each in wall thickness. Fire walls in warehouses of frame or ordinary construction will extend from the ground to a height not less than 3 feet above the roof and will be securely bonded to exterior walls of masonry constructed warehouses. Fire walls in warehouses with frame or sheet metal walls will be returned on the exterior face of the building 3 feet 6 inches in both directions from the center line of the fire wall and the returns will be parapeted 3 feet above the roof. Sheathing and wall framing should butt against ends of fire wall returns and should not extend over the face of masonry returns. In warehouses of complete fire-resistive construction or where roof on one side of the fire wall is fire-resistive construction, fire wall need not be parapeted. Warehouses having frame or sheet metal exterior walls which have continuous loading platforms or canopies of combustible construction will have that section of the platform and canopy adjacent to the fire wall return of noncombustible construction or in the case of the canopy the section can be omitted. Masonry winged walls will be permitted for warehouses of combustible construction only where loading platforms and canopies are not required. The minimum projection of the wing wall from the exterior face of the buildings should be 3 feet. Fire walls may be used as bearing walls provided roof members are not framed into the required wall thickness. Where roof framing is supported on ledger strips bolted to fire walls, the anchor bolts should not extend through the wall. The thickness for the type of materials specified in this paragraph for fire walls is the minimum requirement necessary for fire resistance only and any additional thickness considered necessary for structural strength should be added to the minimum thickness. In addition to dividing large storage areas into separate fire areas, the installation of fire walls should be accomplished to separate boiler rooms, film vaults, film workrooms or storage, dry cleaning plants, and other areas having similar occupancies when such rooms or areas are attached to or located within a building. Large manufacturing or processing facilities within warehouses or industrial buildings should be separated from the storage areas by fire walls.

b. Fire cut-off partitions. Fire cut-off partitions will be installed within buildings to separate areas having hazardous occupancy from other areas containing ordinary or light occupancy and to provide means of resisting the passage of a fire between these areas. Partitions will be constructed of materials which will *resist* for a minimum period of not less than 4 hours the passage of a fire between these areas. However, where an approved automatic sprinkler system is installed in the room having a hazardous occupancy, the cut-off partition may be constructed of materials having a 2-hour fire-resistive rating.

c. Fire doors. The number of openings, as well as their sizes through fire-walls and fire cut-off partitions, should be kept to a minimum without interfering with the satisfactory operations within the building. All openings will be protected by sliding, rolling, or hinged type automatic-closing fire doors, bearing the Underwriters' Laboratories, Incorporated, Class A labels. Fire doors for openings exceeding 120 square feet in area will carry a label for oversized doors, indicating that the materials and construction are equal to the requirements of the Underwriters' Laboratories, Incorporated, Class A. Fire door hardware and method of door installation will be in accordance with the standards of the National Board of Fire Underwriters for the protection of openings in walls. All openings in standard fire walls will be Class A, requiring the installation of a Class A fire door on both sides of the fire wall. All lintels, sills, and door frames for openings in fire walls will be of noncombustible material. No openings will be provided through divisional fire walls in warehouses used for storage of flammable liquids, paints, dope, gases, or chemicals.

d. Draft stop partitions. Concealed spaces, not accessible to fire fighters, created by sheathing or

ceilings, should be restricted to a minimum. Concealed spaces, not protected by automatic sprinklers, formed between combustible roofs and ceilings, should be divided into areas not exceeding 3,000 square feet by means of a tight partition which should extend from the roof sheathing to the ceiling. Access doors through these partitions, where required, should be constructed similar to the partition.

e. Corridor draft stops. Where draft stops are required by standard hospital plans, OCE, such installations should be installed in accordance with Standard Details, OCE. In such cases where the areas below the walkways or connecting corridors are inclosed below the first floor, the standard draft stop should be extended to the grade level.

f. Pier draft stops. Draft stops will be provided under piers at 150-foot intervals, extending from below low water to the underside of the pier deck. Draft stops will be constructed of two layers of two 2-inch wood plank, one vertical and one diagonal, or of other materials and construction which will be structurally equal to or better than the wood plank construction.

g. Curtain boards. Curtain board installations will be required only in buildings which are to be protected by automatic sprinkler systems and should be installed in accordance with the requirements of paragraph 2–16. It is considered advisable in buildings having vertical or horizontal openings, such as stairs, shafts, light wells, elevator, and dumb waiter, which are not inclosed and, where sprinkler protection is provided, to install curtain boards having a minimum depth of 12 inches around the opening. Curtain boards should be constructed of substantial noncombustible material.

h. Eave skirting. Open sheds to be equipped with automatic sprinklers should have vertical eave skirting extending below the eave soffet a minimum depth of 24 inches. Skirting should completely encircle the open shed. Combustible material may be used for the skirting.

5–06 STRUCTURAL IMPROVEMENTS. In existing or new construction it is considered advantageous to provide means other than fire walls, draft stops, fire stop partitions, and adequate separation of buildings, to restrict or limit the starting of or the spread of a fire which might travel from one area to another area within a building or from one structure to another structure. The following requirements should be considered for all types of buildings and provided where applicable.

a. Fire stops. All partitions in multi-story buildings of frame construction will have complete fire stops at each floor level, including the attic, in order to prevent effectively the spread of fire due to flue action between studding.

b. Screening of ventilators. Ventilators in the roof and attic area of buildings shall be screened. The number and size of ceiling ventilators should be kept to a practical minimum and where installed will be screened.

c. Needless openings. All unnecessary holes through ceilings or walls, including holes around pipes, ducts, and chutes, will be sealed up tightly or covered by suitable plates or escutcheons. Steam and hot water pipes passing through combustible materials should have a clearance of not less than 1 inch on all sides of the pipe except that small branch lines supplying radiators can have a 3/8-inch clearance.

d. Hearths. Range, ovens, and hot water heaters will be set on substantial masonry hearths. Top of hearths for ranges and ovens should be flush with the finished floor. The supports for the hearths installed in one story buildings will be of masonry construction extending to grade level. Where masonry hearths are installed on floors above the first floor level, the hearth will be supported by noncombustible material. Where hearths are required, they will extend a distance of not less than 12 inches on sides and rear and 18 inches in front of ranges or ovens. No hearths will be required where the floors and supports are of fire-resistive materials.

e. Space heaters. Space heaters, where installed on combustible materials, should be set in a wood frame constructed of 2″ x 4″, with the 4-inch side laid to the floor and the lumber should be securely fastened to the floor. Next to the finished wood floor should be placed a ¼-inch asbestos board or other similar material having equal or better fire-resistive quality on which should be placed a layer of concrete to the depth of wood frame or brick laid flat with dry sand joints. The wood frame should be of sufficient

size to extend 18 inches in front of heater and 12 inches on the sides and back. No base protection will be required for space heaters where installed on floors of fire-resistive construction.

f. Protection for combustible materials. Combustible materials adjacent to ranges, ovens, heaters, smoke pipes, and hot air ducts should be reduced to a minimum and where installed should be protected by adequate clearance of shielding with noncombustible materials. Minimum clearance between ranges, ovens, and heaters including smoke pipes and hot air ducts within 6 feet of furnaces and combustible materials should be not less than 18 inches except that clearance less than 18 inches, but not less than 6 inches may be permitted provided combustible materials are protected by a shield of ¼-inch asbestos board or other similar material having equal or better fire-resistive quality supported by noncombustible insulators so arranged to provide a free air space of not less than 1 inch between the shield and the combustible material.

g. Smoke pipes. Noninsulated or insulated smoke pipes passing through combustible materials should be installed in accordance with Standard Details, OCE, or as recommended by the Building Code of the National Board of Fire Underwriters. Hot air ducts, adjacent to or passing through combustible walls, partitions, or floors in excess of 6 feet horizontal distance from the outside of the furnaces should have a clearance of at least 1 inch clear air space.

h. Hoods. A hood should be installed over ranges, deep fat fryers, and other kitchen equipment. Hoods and ducts should be of metal. A clear space of 6 inches should be provided between hoods or ducts and combustible construction.

i. Fireproof paints. Paints recommended for fireproofing combustible materials may be employed for purposes of additional protection but will not be accepted in lieu of the installation of fire-resistive insulating materials or reducing minimum clearances.

j. Lightning protection systems. Lightning protection systems will be installed on all buildings, control towers, elevated water tanks, and smokestacks, except structures of steel construction, which are permanently grounded, exceeding 50 feet in height. Where lightning protection is warranted, the systems will be installed in strict accordance with the provisions in chapter 3, part VI of the Engineering Manual.

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DRAINAGE AND EROSION CONTROL
DRAINAGE FACILITIES FOR
ROADWAYS AND BUILT-OVER AREAS



WAR DEPARTMENT
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

Chapter 4

DRAINAGE FACILITIES FOR ROADWAYS AND BUILT-OVER AREAS

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Part XIII. Chapter 4

DRAINAGE FACILITIES FOR ROADWAYS AND BUILT-OVER AREAS

4–01 SCOPE. These instructions are intended to cover the major requirements for drainage structures in connection with roadways and built-over areas of Army installations. Good engineering practice should be followed in regard to special conditions and problems and to items not covered specifically by these instructions.

4–02 DEFINITIONS. The following will comprise the construction that is contemplated:

a. Surface drainage.—Paved and unpaved gutters and ditches, pipe lines, culverts, bridges, inlets, manholes, headwalls, dropwalls, spillways, and miscellaneous drainage structures shall be provided as required for roadways and other areas and for the collection and disposal of surface storm drainage.

b. Subsurface drainage.—Pipe lines, pipe lines with porous materials for backfilling of ditches, and blind or French drains with the trenches backfilled with porous materials without pipe lines, together with the necessary structures for outlet purposes shall be constructed where necessary for the collection and disposal of subsurface or "ground" water.

4–03 INVESTIGATIONS. A detailed study of the surface and subsoil drainage requirements will be necessary. Outlet conditions, high water and its frequency of occurrence, normal water elevations and rainfall intensities for storms occurring at frequencies comparable to design storm period should be determined for the particular location under study. Topography and existing and probable future finished surfacing as affecting run-off should be studied; soil conditions including types and perviousness of the soil, and amount and movement of the "ground" water, and the probability of freezing conditions and depth of frost should be determined. Climatic conditions and rainfall records must be secured. Test holes may be necessary to judge the elevation of "ground" water and its probable variation throughout the seasons of the year, particularly during periods of greatest rainfall. The use of ponding or storm water storage basins, where feasible, must be determined.

4–04 PIPE LINES AND OPEN DITCHES. Surface drainage usually will be handled by a system of pipe lines, inlets, and manholes. Curbs and gutters, and paved valley gutters will be generally used as aids in drainage control for pavements in "built-over areas." Open ditches and culverts may be used for outlets in "other areas," where feasible, and in other locations where pipe lines cannot be justified on the basis of first cost, serviceability, cost of maintenance, health considerations and safety factors, if any, that are involved. Reference is made to Engineering Manual, part X, chapter 1, "Roads, Walks, and Open Storage Areas" regarding "built-over areas" and "other areas."

4–05 SUBSURFACE DRAINS. Soil and ground-water conditions may make the use of subsurface drains necessary. Where it is necessary to install subsoil drains, independent outlets or outlets free from "back water" conditions, where practicable and within reasonable cost, should be provided. Subsoil drains should be so designed that "back water" will not enter any portion of the subsoil drain where such design does not involve a lay-out that is unduly expensive. Subsurface drains should not be used unless investigation definitely determines their need and then will be limited to requirements based on present and continuing need for the same.

4–06 DATA. Proper drainage design will necessitate information on the conditions outlined above and on the following:

a. Maps, charts, and data.—Maps, charts and data, referred to in Engineering Manual, part I, Surveys and Maps, and that are available for the particular area in question shall be secured for drainage studies.

b. Surveys and maps.—For surveys and map data that will be necessary for detailed drainage analysis and design, reference is made to Engineering Manual, part I, Surveys and Maps, chapter 1, Topographic Surveys and Maps, paragraphs 1–01 to 1–07, inclusive.

c. Characteristics of drainage area.—Characteristics of the waterway and of the watershed, size and shape of drainage area, slope of ground, and elevation of critical points, must be secured.

d. Existing facilities.—Location, size, elevation of invert and condition of pipe, and location, size, elevation and width of bottom and side slopes of open ditches or channels that are existing and will form a part of the new drainage system shall be determined. Location, size and elevation of other utility lines at all points where interference may result should be determined.

4–07 DESIGN.

a. Design storm. The degree of protection required from damages due to rainfall and the adequacy of the storm drainage installations for roads and built-over areas of Army installations depend largely on the conditions peculiar to the particular project. Generally design storms should be based on a frequency of 10 years. For conditions tending to induce severe damages from periodic flooding and for installations where flooding for short periods of time may be seriously detrimental to operational requirements a design storm frequency of not less than 15 years should be employed. Certain projects, due to the importance of the project or its location with respect to other projects, may require a design storm frequency basis in excess of 15 years. An installation requiring a design storm frequency of 15 years or more may be an existing installation that is to be retained and rebuilt for postwar use. There may be an existing utility such as a steam trench or existing floor levels of certain buildings, that cannot be economically modified, and that require additional safeguards from flooding. It may be more economical, based on costs and necessity for uninterrupted service, to provide drains of a size to accommodate say a 15-year, or greater, design storm, than to remodel the existing steam trench or buildings to prevent flooding that would likely occur with a storm system based on a 10-year period. However, such cases are exceptional and should be treated as such with justification well-established for the use of the longer time period.

b. Type of surfacing.—Type of surface covering, turfed, wooded, areas devoid of grass or plant growth, pervious surface due to sandy or gravelly soil, highly impervious soil, rocky, or areas largely impervious due to pavements, sidewalks or roof areas, shall be determined.

c. Design assumptions.—Basic assumptions of design, including design rainfall frequency, intensity-duration curve, infiltration rate or rainfall-run-off coefficients, method used in estimating run-off, inlet time for critical points and time of concentration for the various sections of the system, coefficient of roughness for the particular kind of pipe and for open ditches must be decided.

d. Coefficients for pipe.—The following coefficients for general conditions are considered applicable:

For smooth, carefully laid, clay and concrete pipe with normal spacing of manholes and with rounded, free flowing junctions provided, a coefficient of friction, $n=0.013$ shall be used. For clay and concrete pipe lines with less favorable flow conditions the coefficient shall be $n=0.015$. For bituminous coated, corrugated metal pipe with paved invert, $n=0.019$ to $n=0.021$ for plain corrugated pipe shall be used. For special conditions, coefficients shall be modified to fit particular requirements.

e. Determination of run-off.—The amount of run-off shall be determined by the rational method, from the previously determined area or areas, percentage of imperviousness and the rate of rainfall in inches per hour, which may occur during the time of concentration. Rainfall intensity for the time of concentration shall be determined from figure 2, chapter 1, part XIII, Engineering Manual. High rainfall intensities in inches per hour for short periods of duration shall be carefully checked to avoid excessive pipe sizes. Where little or no damage will result from infrequent overflow and material savings may be effected thereby, the design should not be based on the maximum expected run-off. Where excessive damage can be expected to result from overflow, the design should provide for the maximum expected run-off. Where surface storage of storm water can be advanta-

geously provided, due allowance for such storage shall be made in the run-off provided for by pipe lines and ditches. For areas of such size as to require open ditches, larger sized culverts or bridges, the run-off in cubic feet per second, as herein determined, should be checked by other formulas, and where possible, comparison made with the carrying capacity of existing, adjacent structures on the same or similar watersheds that are considered adequate in size.

f. Pits and basements.—Pits or basements shall not be directly connected to storm sewer systems where there is a probability of flooding by "backing up" through the drain.

g. Drainage structures.—Inlets, manholes, headwalls, and spillways shall be so constructed as to produce a minimum of interference to smooth, uniform flow of the water through the structure.

h. Hydraulic gradient.—In the design of pipe lines and ditches the hydraulic gradient shall be determined to such extent as is practicable for the particular project in question. The hydraulic gradient shall be used as the basis of design. The invert gradient for pipe lines and the gradient of bed of the stream for open ditches shall not be used as the basis of design.

i. Strength of pipe.—The dead load and probable live load to which the various pipes will be subjected shall be determined and pipe of ample strength specified. Strength of rigid pipe and deflection of flexible pipe are discussed in the following subparagraphs *j* and *k*.

j. Rigid pipe.—See figure No. 5, minimum and maximum cover for clay and reinforced concrete culvert pipe, and figure No. 6, minimum and maximum cover for storm drain pipe. Attention is invited to the fact that the minimum and maximum cover shown by tables No. 5 and No. 6 are for the conditions as therein indicated. For conditions differing from those stated in these tables due allowances shall be made in amount of minimum and maximum cover. In determining the loads on pipe for culverts and storm drains reference is made to volume 1, "Design of Sewers, American Sewage Practice," by Metcalf and Eddy, and to the following bulletins by Engineering Experiment Station, Iowa State College, Ames, Iowa:

No. 96, The Theory of External Loads on Closed Conduits in the Light of the Latest Experiments.

No. 108, Loads on Pipe in Wide Ditches.

No. 112, The Supporting Strength of Rigid Pipe Culverts.

k. Deflection of flexible pipe.—The deflection of corrugated metal pipe due to dead and live loads shall be determined. Metal of such gage shall be selected, together with vertical elongation of the pipe when necessary, so that ample safeguards for the pipe will be provided as to strength and resistance to deflection due to the loads. This is considered particularly important for pipe of 36 inches in diameter and larger, especially for pipes with less than approximately 2½ feet of cover, and for pipes with more than about 10 feet of cover, depending upon conditions governing the particular installation. Conditions for the particular installation, for pipe less than 36 inches in diameter, and for depths less than the 2½ feet minimum and of more or less depth than 10 feet may require vertical elongation of the pipe. For determination of deflections of flexible pipe reference is made to bulletin No. 153, dated 1941, "The Structural Design of Flexible Pipe Culverts," by Prof. M. G. Spangler, Iowa Engineering Experiment Station, Iowa State College, Ames, Iowa. For heavy live loads and heavy loads due to considerable depth of cover it is considered of prime importance that a selected material, preferably bank run gravel or crushed stone where such materials can be secured within reasonable cost, be used and thoroughly compacted for the backfilling adjacent to the pipe. As a general rule, computed vertical deflection of the pipe of 2 percent or more of the nominal diameter of the pipe shall be compensated for by vertical elongation of the pipe by approved shop or field methods of strutting as directed by the contracting officer. As an example a 48-inch, No. 12-gage corrugated iron pipe with 10 feet of cover, projecting conduit conditions, with earth load of 120 pounds per cubic foot, is assumed. Live load is disregarded. It is also assumed that selected granular material, well compacted, is used for the backfilling material adjacent to the pipe. Under these conditions the vertical deflection will amount to about 1.2 inches or 2½ percent of the nominal diameter. For a 72-inch, No. 8-gage corrugated

iron pipe with 20 feet of cover, and with other assumptions as above stated, the vertical deflection will amount to about 2.7 inches or 3¾ percent of the nominal diameter. After completion of the project the struts shall be removed at such time as designated by the contracting officer.

4–08 DRAINAGE DITCHES. Deep ditches and steep side slopes adjacent to roadways and in areas subject to frequent use shall be avoided. Where it is possible economically to develop and maintain turfed side slopes, the side slopes of ditches should not be steeper than four horizontal to one vertical to facilitate mowing and operations incident to maintenance. Ditches with comparatively flat side slopes must be protected by rigid traffic control against indiscriminate crossing of these ditches by vehicles. Steep grades and high velocities induced by large volumes of water may require paved ditches, baffles or drop walls, or paved spillways to control erosion. Where practicable, ditches should have sufficient gradient, depending on the type of soil encountered, to provide velocities that will be "self-cleaning" but will not cause erosion.

4–09 CULVERTS.

a. Roads.—For roadways and areas subjected to vehicular traffic or heavy loads, the minimum inside diameter of culvert pipe shall be 12 inches where the over-all length of the drain does not exceed 30 feet. Where the length of culvert exceeds 30 feet the minimum inside diameter shall be 15 inches in order to facilitate cleaning. To reduce the depth of ditch where large capacity is required, multiple pipes may be used. Box culverts, generally of reinforced concrete design, will be employed where economical.

b. Sidewalks.—Culverts for sidewalks, where they are an extension or continuation of the roadway culvert, shall be similar to construction outlined in paragraph *a* above. For small drainage areas where only a small flow of water will result, which often do not have a defined water channel, and where the culvert is of short length, 6-inch or 8-inch pipe culverts may be ample, if so placed as to be comparatively free from accumulations of debris or ice and snow. If at locations that may require frequent cleaning the size of pipe should be increased.

c. Design.—Culverts at certain locations may be so placed with respect to the contemplated depth of headwater, depth of submergence, if any, at outlet, and gradient of the culvert (pipe or box), that the size of the culvert may necessarily be determined by several factors. Among such factors, first cost, probable damages due to storms in excess of design storm, cost of maintenance, damages due to erosive velocities through the conduit, design of the inlet and outlet structures, soil conditions, erosion and possible silt deposits due to sudden decrease in stream velocities should be given careful consideration. Capacities of culverts may be materially increased if rounded, free flowing entrance conditions are provided. As a general rule culverts should be so designed as to prevent high head water, as compared to the elevation of the tail water or outlet stream, with due consideration to the amount of ponding, if any, that may be justified and to the hydraulic features that are involved. The length of culverts shall be sufficient to provide for the requirements of the roadway, including full width of shoulders and the embankment. Proper allowances should be made for embankment slopes and expected settlement of the same. For determination of sizes for pipe and box culverts, attention is invited to bulletin No. 1, "The Flow of Water Through Culverts," by Yarnell, Nagler and Woodward, University of Iowa, on account of the simplicity of the formulas used. The discharge for pipe culverts with straight endwall entrance and of any size and length, when flowing full, are as follows:

Concrete pipe, beveled lip entrance.

$$Q=\frac{A\sqrt{2gH}}{\sqrt{1.1+\frac{0.026L}{D^{1.2}}}}$$

Concrete pipe, square cornered entrance.

$$Q=\frac{A\sqrt{2gH}}{\sqrt{1+0.31D^{0.5}+\frac{0.026L}{D^{1.2}}}}$$

Vitrified-clay pipe, regular bell end upstream.

$$Q=\frac{A\sqrt{2gH}}{\sqrt{1+0.023D^{1.9}+\frac{0.022L}{D^{1.0}}}}$$

Corrugated-metal pipe.

$$Q=\frac{A\sqrt{2gH}}{\sqrt{1+0.16D^{0.6}+\frac{0.106L}{D^{1.2}}}}$$

In these formulas,

Q=discharge in cubic feet per second.
A=cross-sectional area of pipe in square feet.
D=diameter of pipe in feet.
L=length of culvert in feet.
H=head on pipe in feet or the difference in the water level at the two ends of the culvert.
g=acceleration of gravity.

The discharge for concrete box culverts with straight endwall entrances when flowing full, are as follows:

Box culverts with rounded lip entrances.

$$Q=\frac{A\sqrt{2gH}}{\sqrt{1.05+\frac{0.0045L}{R^{1.25}}}}$$

Box culverts with square cornered entrances.

$$Q=\frac{A\sqrt{2gH}}{\sqrt{1+0.4R^{0.3}+\frac{0.0045L}{R^{1.25}}}}$$

R=mean hydraulic radius of the culvert in feet.

Forty-five degree wingwalls set flush with corrugated-metal pipe culvert increase the capacity about 10 percent over that obtained for same type pipe culvert with straight endwall.

Forty-five degree wingwalls used in connection with a vitrified clay pipe culvert produce a carrying capacity substantially equal to that with the regular bell end upstream.

The beveled lip end at the entrance of a concrete pipe culvert is a great aid in reducing the entrance loss, especially in the larger sizes.

For carrying capacity of culverts, reference is also made to "Handbook of Hydraulics" by Horace Williams King, and to bulletin No. 56, "The Hydraulics of Culverts," by F. T. Mavis, Pennsylvania State College Engineering Experiment Station.

4–10 STORM DRAINS. Pipe laid with tight joints, collecting inlets and manholes will ordinarily form the major portion of the storm water system. Manholes will be provided at points of change of grade or alignment or changes in size of pipe. Manholes may also be required at junction points of entering laterals or branches where such laterals or branches are of sufficient importance or where maintenance requirements may justify the manhole. Intervals between manholes

may vary from about 300 feet to 400 feet. This spacing for manholes may be increased where long lines of large sized pipe are required. For the ordinary drainage system an 8-inch pipe shall be the minimum size, conditioned on its carrying capacity and amount of water to be provided for. Determination of run-off in cubic feet per second shall be by the rational method as indicated for culverts, 4–07*e*, above.

a. Sizes of pipe for storm drains.—The size of storm drains required shall be determined by Manning's formula as indicated in Nomograph form, figures 22, 23 and 24, Engineering Manual, part XIII, chapter 1.

4–11 SUBSURFACE DRAINS. Pipe for subsurface drains consists of perforated pipe, sewer pipe laid with open joints, tile or porous sewer pipe or tile, or of the "skip pipe" type. Porous material is generally used as backfilling material for a stated height above top of pipe and in certain cases with the pipe laid on a layer of porous material. The porous material must be properly graded depending upon adjacent soil type and gradation and the conditions governing water flow. The backfilling for the top portion of the trench shall be with material more nearly impervious to exclude the surface water. Blind or French drains, constructed without pipe, have the trench backfilled or partly backfilled with porous material as provided above for subsurface drains. Suitable outlet, preferably independent of the balance of the storm drain system should be provided for all subsurface drains. If it is necessary to outlet a subsurface drain into a storm drainage system, every effort should be made to outlet the subsurface drain above the hydraulic gradient of of the storm drain in order to prevent the possibility of "back water" into the subdrain. For subsurface drains the minimum size shall be 6 inches diameter. The maximum size, except under unusual conditions, should be 18 inches diameter. Flows in excess of the capacity of this size should be handled through tight joint conductors with small sized open joint collector drains. Minimum slope for 6-inch subsoil drains (for water practically free of sediment) will generally be 0.15 percent. For extremely flat terrain or where considerable savings can be effected, a gradient as low as 0.10 percent may be used.

a. Determination of subsoil drainage requirements.—In determining the amount of water in cubic feet per second to be taken care of, reference is made to Engineering Manual, Part XIII, Chapter 2, "Subsurface Drainage Facilities for Airfields," particularly paragraphs 2–03, 2–06*c* and 2–10. Where subsoil drainage is made necessary by a layer of comparatively coarse sand or gravel overlying an impervious or nearly impervious layer of soil, or where such pervious layer is between impervious layers, the amount of subsurface drainage in cubic feet per second may be greatly increased and must be studied as a special problem. This is particularly true if the pervious layer of sand or gravel collects considerable surface water by outcropping above the point at which the subsurface water is to be collected. Conditions on airfields that may require manholes, observation basins, and risers on subsurface systems for points of access are not considered applicable to general subsurface drains for roads and built-over areas. Manholes, observation basins, and risers should only be used where their construction can be well justified from a maintenance standpoint.

b. Determination of pipe sizes.—The sizes of pipe for subsurface drains shall be determined from the requirements in cubic feet per second as determined for storm drain sizes.

4–12 CHOICE OF PIPE. The kind of pipe selected for culverts, storm drains and subsurface drains shall be determined on probable first cost, serviceability, estimated maintenance costs and probable length of life of the project and of the pipe. Unusual features indicating acid or alkaline waters of a strength that may be injurious to any particular kind of pipe, or abrasive material carried in suspension of such an amount as to be injurious to any of the kinds of pipe normally specified, shall be given consideration in the selection of the particular kind of pipe to use. Every effort shall be made to secure competition in the bids for the pipe to be installed.

4–13 INLETS. Inlet construction generally should be as indicated in figure No. 3, standard type A and type B inlets, and figure No. 4, standard type C inlet. For inlets so located that they

will not be subjected to traffic or other loads the grates and frames may be altered in thickness and weight. Where the inlets are so located that water will flow to the inlet from all sides, and the inlet grates are slightly depressed so that orifice flow conditions may be assumed, the area of waterway openings shall not be less than double the computed area required to provide for the cubic feet per second of water contemplated for the particular inlet area. Area of waterway openings will be determined by the formulae

$$A=\frac{Q}{C\sqrt{2gH}}$$

Where A=net waterway area in square feet.
Q=water reaching the inlet in cubic feet per second.
C=0.6, assumed orifice coefficient.
h=assumed head in feet. Factors recommended from 0.2 foot to 0.4 foot.
g=32.2. Factor of safety not less than 2.

When inlets are so located that comparatively long grates are necessary to collect "sheet" flow of water, the collecting box, length of grating and area of waterway openings shall be determined for the particular location. The area of waterway openings required shall be determined by low flow over the grate openings considered as weir flow as called for in paragraph 3–04 and figure No. 2, chapter 3, part XIII, Engineering Manual.

4–14 MANHOLES. Manholes shall be constructed in accordance with figure No. 1 for standard manholes and in accordance with figure No. 2 for the larger sized type A manholes. Type A manhole shown on figure No. 2 for 36-inch diameter pipe and larger shall be constructed similar to the standard manhole shown on figure No. 1, except that the inside diameter shall not be less than the inside diameter of pipe plus 1 to 2 feet as may be required. Type A manhole with diameter larger than 3½ feet shall also be used for two or more entering pipes where the sizes of such pipes, or the angle of entrance of the pipes, are such as to require larger diameter of manhole to provide ample wall space and proper grooving or curvature of the masonry or concrete to facilitate smooth flow conditions. Where depth of manhole will not permit corbeling of the upper part of the manhole, a reinforced concrete slab shall be used for the top. The design of the slab shall be such as to provide ample strength for the particular loads to which the slab may be subjected and for support of the frame and cover. For the larger-sized pipe (say larger than 48 inches), and for large sized lateral connections, specially designed rectangular-shaped, reinforced concrete junction boxes may be used in lieu of the rounded manhole. Where access to the manhole or junction box is necessary, manhole frame and cover and ladder rungs shall be provided.

4–15 HEADWALLS, SPILLWAYS, DROP STRUCTURES, DRAINAGE CHUTES, AND STILLING BASINS. Miscellaneous drainage structures such as headwalls, spillways, drop structures, drainage chutes, and stilling basins shall be constructed in accordance with the applicable portions of part XIII, chapter 3, "Drainage and Erosion Control Structures for Airfields" of the Engineering Manual.

4–16 DITCH LINING. Open ditches so located and constructed that soil conditions, high velocities due to comparatively steep gradients or excessive flow of water, steep side slopes, changes in direction of the ditch, lack of protective turf or other causes may require ditch lining or partial ditch lining to prevent erosion. Ditch linings may also be necessary to promote increased velocity and greater run-off on account of flat grades or may be essential to prevent excessive maintenance costs or on account of health considerations. The lining of ditches should be resorted to only where justification can be clearly shown. The ditch linings may be of plain or reinforced concrete, bituminous materials, or plain or grouted riprap. For general open-ditch construction, development of a suitable turf by seeding, strip sodding or sodding will be more economical than the pavement types and with proper maintenance should prove satisfactory. Reference is made to paragraph

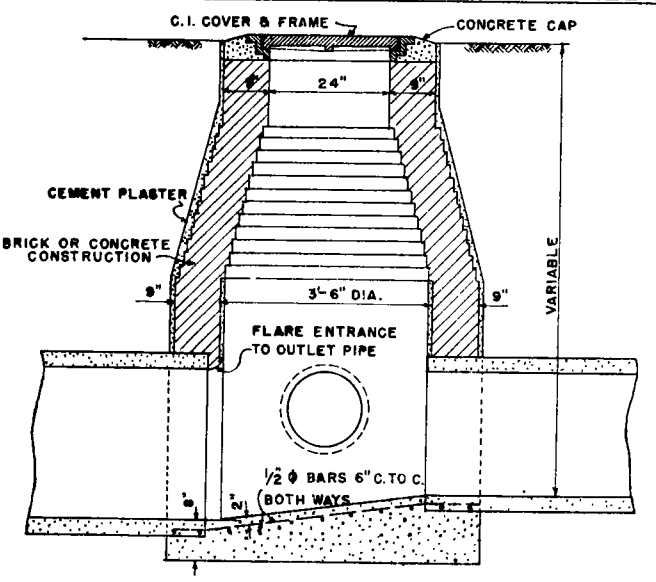
3–10, part XIII, chapter 3, "Drainage and Erosion Control Structures for Airfields" of the Engineering Manual.

4–17 EROSION CHECKS. Erosion in open ditches and water courses may require erosion checks similar to those indicated in paragraph 3–11, part XIII, chapter 3, "Drainage and Erosion Control Structures for Airfields" of the Engineering Manual.

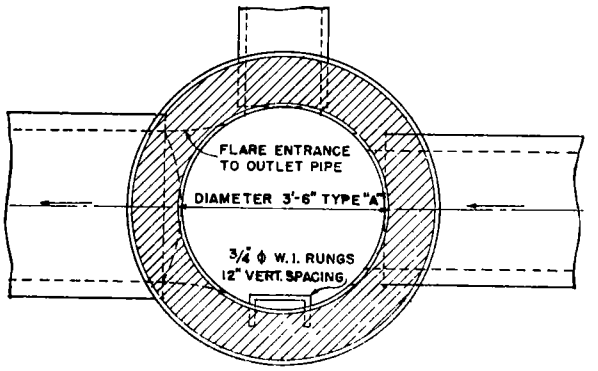
4–18 BRIDGES. Bridges shall be constructed with substructure of wood or concrete foundation piling, concrete or masonry piers and abutments or combinations of the same. The superstructure shall consist of reinforced concrete or steel, with the floor of reinforced concrete and wearing surface of portland cement concrete or bituminous concrete. For tertiary type roads and for temporary construction, wooden bridges may be provided. Wood used in permanent bridge construction shall be treated with wood preservatives. The clear waterway for a bridge shall be such that, after making due allowances for interferences caused by pile bents, piers, and abutment construction, the anticipated run-off for the contributing watershed will be adequately provided for. In determining the waterway requirements consideration shall be given to probable damages by flooding of properties above the bridge, possibility of damages due to accumulation of drift materials, importance of uninterrupted traffic, first cost, maintenance costs, adequacy and stability of the structures and to possibility of scouring due to increased velocities through the structure. For the clear width of bridges and for width of roadway attention is invited to Engineering Manual, part X, chapter 1, "Roads, Walks, and Open Storage Areas." Widths, vertical clearances, and general design requirements, including loading, shall comply with the requirements as indicated above and to the standard specifications for highway bridges adopted by the American Association of State Highway officials, 1944, and conditions in line with standards of the Public Roads Administration. For bridges in particular locations the loading requirements may necessarily be changed to accommodate light or heavy tanks or other special equipment of the War Department.

4–19 SUBMISSION OF DESIGN ANALYSIS. See orders and regulations of the War Department pertaining to drainage plans and design analysis to be submitted to Office, Chief of Engineers. Maps showing topography, finished grades, location of roads, buildings, and other installations, and location of proposed drainage facilities such as ditches, pipe lines with types of pipe, ponding areas if any, manholes, inlets, culverts and bridges, and necessary details with sizes of ditches, pipes, culverts and bridges, elevations of inverts of pipe and bottom of ditches shall be furnished Office, Chief of Engineers. This data shall also include necessary profiles, cross-sections, charts and other pertinent data and complete design analysis. Reference is made to Engineering Manual, part I, Surveys and Maps, chapter 1, regarding surveys, maps, and data to be submitted to Office, Chief of Engineers.

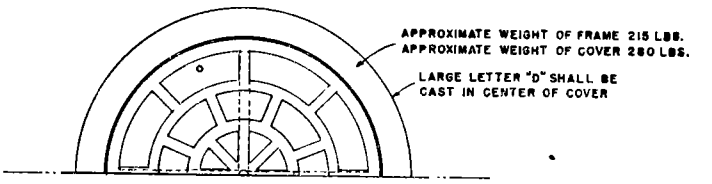
4–20 FIGURES NO. 1 TO NO. 6, INCLUSIVE. Figures No. 1 to No. 6, inclusive, attached, form a part of this Engineering Manual, chapter 4, as indicated.



ELEVATION

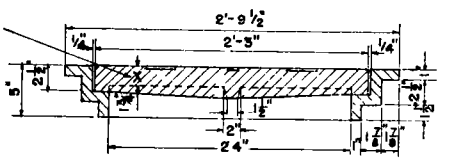


SECTION



HALF PLAN - MANHOLE COVER & FRAME

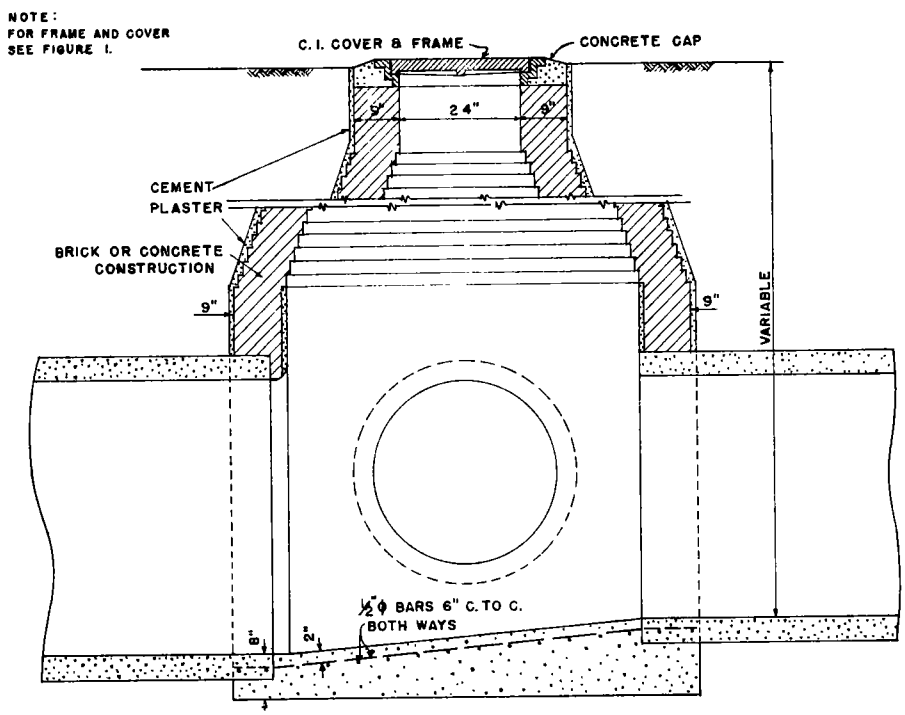
FOR MANHOLES SO LOCATED THAT COVER WILL NOT BE SUBJECTED TO TRAFFIC, THE THICKNESS OF COVER SHOWN AT "X" AS 1 3/4" MAY BE 1" MAKING WEIGHT OF COVER APPROXIMATELY 200 POUNDS.



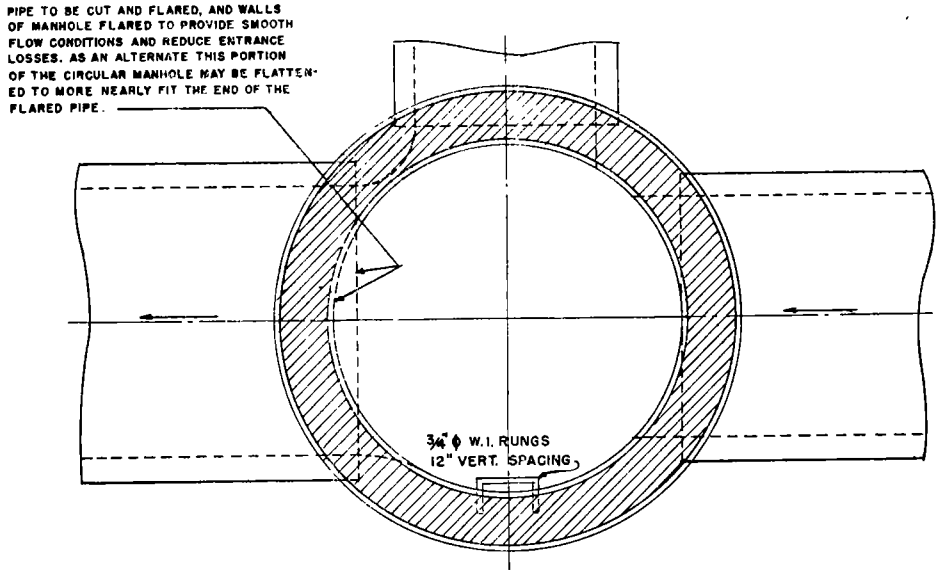
SECTION - MANHOLE COVER & FRAME

STANDARD STORM DRAINS MANHOLE

ENGINEERING MANUAL PART XIII CHAPTER 4 APRIL 1946 FIGURE 1

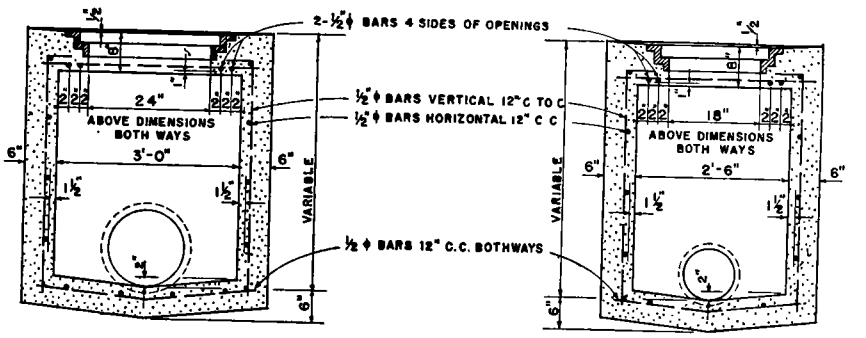


ELEVATION



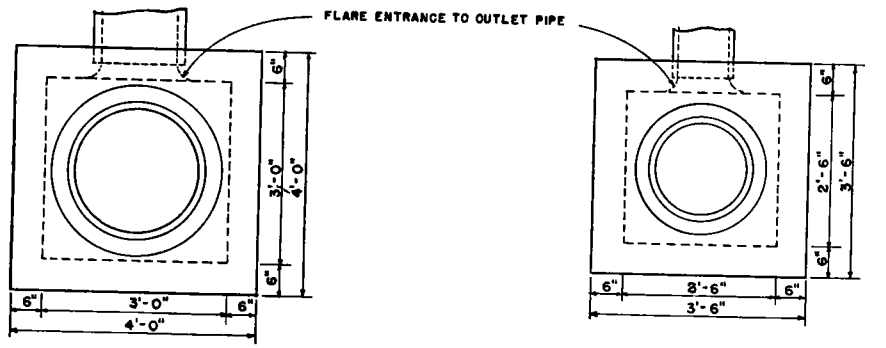
SECTION

STANDARD STORM DRAINS MANHOLE
(TYPE "A")



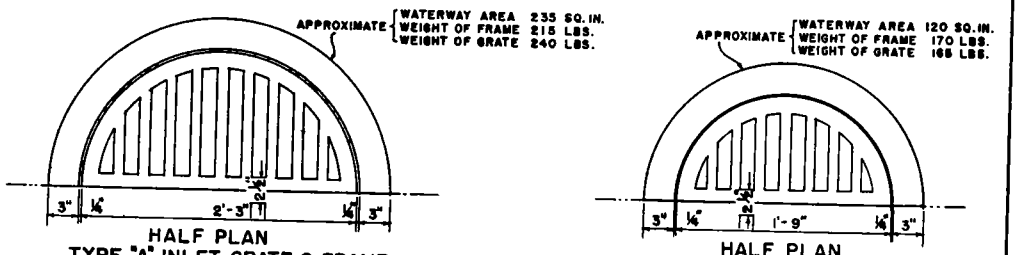
SECTION - TYPE "A" INLET

SECTION - TYPE "B" INLET



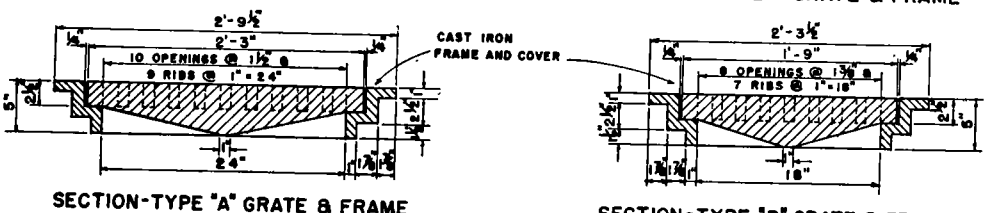
PLAN - TYPE "A" INLET

PLAN - TYPE "B" INLET



HALF PLAN
TYPE "A" INLET GRATE & FRAME

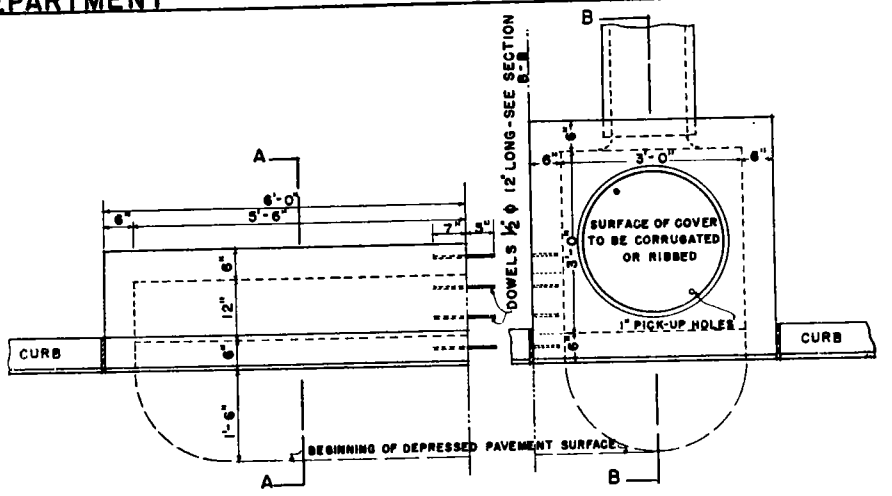
HALF PLAN
TYPE "B" INLET GRATE & FRAME



SECTION - TYPE "A" GRATE & FRAME

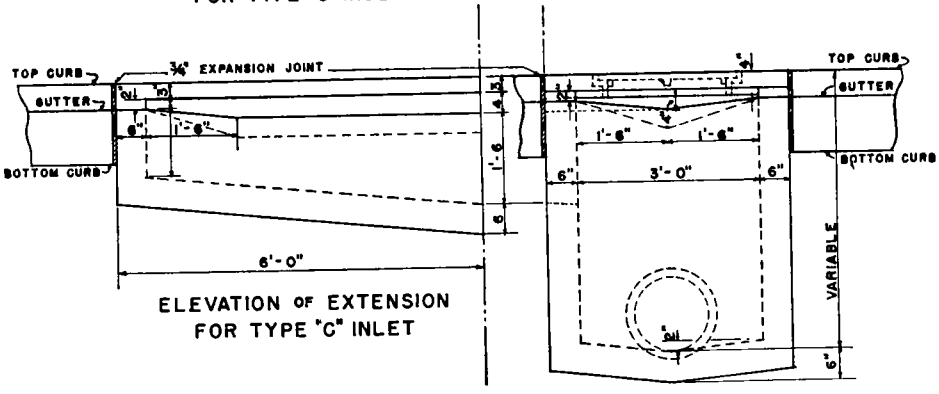
SECTION - TYPE "B" GRATE & FRAME

STANDARD TYPE "A" AND TYPE "B" INLETS



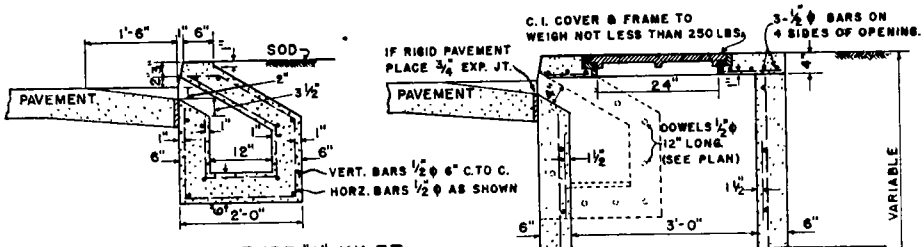
PLAN OF EXTENSION FOR TYPE "C" INLET

PLAN OF TYPE "C" INLET



ELEVATION OF EXTENSION FOR TYPE "C" INLET

ELEVATION OF TYPE "C" INLET



SECTION A-A TYPE "C" INLET EXTENSION

SECTION B-B TYPE "C" INLET

NOTES

COVER SHALL BE PROVIDED WITH A LOCKING DEVICE, IF REQUIRED, AND OF A TYPE AS ORDERED BY THE CONTRACTING OFFICER.

LENGTH OF EXTENSION FOR TYPE "C" INLET, AND THE AMOUNT OF WATERWAY OPENING, SHALL BE VARIED AS NECESSARY, DEPENDING UPON THE AMOUNT OF WATER TO BE PROVIDED FOR, THE LOCATION OF THE INLET AND BY LOCAL CONDITIONS.

STANDARD TYPE "C" INLET

WAR DEPARTMENT — CORPS OF ENGINEERS U.S. ARMY

MINIMUM AND MAXIMUM COVER FOR CLAY AND REINFORCED CULVERT PIPE
BASED ON THE FOLLOWING ASSUMPTIONS

1. Earth load only, load distribution due to rigid pavement not considered.
2. Average soil conditions at 120 lbs. per cubic foot.
3. Pipe laid in accordance with first class pipe laying conditions.
4. Test loads in pounds per lin. ft. of pipe are for 3-Edge Bearing Method, for clay and non-reinforced concrete pipe, and the load on reinforced concrete pipe to produce a crack of 0.01".
5. Safe load computed by test load multiplied by 1.875 and divided by a factor of safety of 1.5.
6. Wheel load of 16,000 lbs., plus impact factor of 50% for cover 0.0' to 2.0', ins., and 25% for cover 2.5' and more.
7. Computations for live load based on three feet length of pipe.
8. Assumed culvert pipe laid with 0.7 projection (p) of pipe above solid (natural soil) surface and with embankment fill with a settlement-deflection ratio $r_{sd} = 0.7$, equivalent to 0.5 projection condition.
9. For cover over pipe not exceeding two feet it is considered advisable to use pipe not less than three feet in length, and the minimum cover here shown shall not be reduced for lengths of individual pipe that are more than three feet.
10. For conditions other than as stated above the depth of safe minimum and maximum cover may vary depending upon conditions, and due allowances shall be made for such variations.
11. Minimum and maximum cover for intermediate and larger sizes than those shown in Table shall be determined similarly.
12. Where cover over pipe is less than the minimum, or greater than the maximum shown, the pipe herein indicated shall be reinforced with concrete cradle or otherwise safeguarded, or stronger pipe specified.

SPECIFICATION	KIND OF PIPE	CLASS OF PIPE	12"			15"			18"			24"			36"			48"			60"			72"		
			STRENGTH TEST LOAD 3-EDGE LBS. PER LIN FT. OF PIPE	MIN. COVER IN FEET	MAX. COVER IN FEET	DO.			DO.			DO.			DO.			DO.			DO.			STRENGTH TEST LOAD 3-EDGE LBS PER LIN FT. OF PIPE	MIN COVER IN FEET	MAX. COVER IN FEET
			1.	2.	3.	1.	2.	3	1.	2.	3.	1.	2.	3.	1.	2.	3.	1	2.	3.	1.	2.	3.	1.	2.	3.
AASHO M41-42	Rein. Concrete	St. St.	2250	2'	10'	2625	2'	10'	3000	2'	10'	3000	2½'	7'	4050	2'	6'	5400	2'	7'	6000	1½'	7'	6600	1'	6'
AASHO M41-42	Rein. Concrete	Ex. St.										4000	2'	10'	6000	1½'	10'	8000	1'	11'	9000	1'	10'	9900	1'	10'
AASHO M65-42	Clay	Ex. St.	2250	2'	10'	2750	2'	10'	3300	2'	11'	4400	1½'	11'	6000	1½'	10'									
ASTM C76-41	Rein. Concrete	St. St.	2250	2'	10'	2625	2'	10'	3000	2'	10'	3000	2½'	7'	4050	2'	6'	5400	2'	7'	6000	1½'	7'	6600	1'	6'
ASTM C76-41	Rein. Concrete	Ex. St.										4000	2'	10'	6000	1½'	10'	8000	1'	11'	9000	1'	10'	9900	1'	10'
Fed. Spec. SS-P-361a	Clay	Ex. St.	2250	2'	10'	2750	2'	10'	3300	2'	11'	4400	1½'	11'	6000	1½'	10'									

FIGURE 5

MINIMUM AND MAXIMUM COVER FOR STORM DRAIN PIPE
BASED ON THE FOLLOWING ASSUMPTIONS

1. Loads due to trench backfilled materials and to 16,000 lb. wheel load on earth. Live load distribution due to rigid pavement not considered.
2. Average soil conditions of 120 lbs. per cubic foot.
3. Width of trench assumed 16" wider than outside diameter of pipe.
4. Pipe laid in accordance with first class pipe laying conditions.
5. Test loads in pounds per lin. ft. of pipe are for 3-Edge Bearing Method, for clay and non-reinforced concrete pipe, and the load on reinforced concrete pipe to produce a crack of 0.01".
6. Safe load computed by test load multiplied by 1.875 and divided by a factor of safety of 1.5.
7. Wheel load of 16,000 lbs., plus impact factor of 50% for cover 0.0' to 2.0' and 25% for cover 2.5' and more.
8. Computations for live load based on three feet length of pipe.
9. For cover over pipe not exceeding two feet it is considered advisable to use pipe not less than three feet in length, and the minimum cover here shown shall not be reduced for lengths of individual pipes that are more than three feet.
10. For conditions other than as stated above the depth of safe minimum and maximum cover may vary depending upon conditions, and due allowances shall be made for such variations.
11. Minimum and maximum cover for intermediate and larger sizes than those shown in Table shall be determined similarly.
12. Where cover over pipe is less than the minimum, or greater than the maximum shown, the pipe herein indicated shall be reinforced with concrete cradle or otherwise safeguarded, or stronger pipe specified.

SPECIFICATION	KIND OF PIPE	CLASS OF PIPE	8"				10"				12"				15"				18"				24"				30"				36"				48"				60"			
			STRENGTH TEST LOAD 3-EDGE LBS. PER LIN FT. OF PIPE	MIN. COVER IN FT. DEAD + LIVE LOADS	MAX COVER IN FT. DEAD + LIVE LOADS	MAX. COVER IN FT EARTH LOAD ONLY	DO.				DO.				DO.				DO.				DO.				DO.				DO.				DO.				STRENGTH TEST LOAD 3-EDGE LBS PER LIN FT. OF PIPE	MIN. COVER IN FT. DEAD + LIVE LOADS	MAX. COVER IN FT. DEAD + LIVE LOADS	MAX COVER IN FT. EARTH LOAD ONLY
			1	2.	3.	4.	1.	2.	3	4	1.	2.	3.	4.	1.	2	3.	4	1.	2	3.	4.	1.	2.	3	4	1.	2.	3.	4.	1	2.	3.	4.	1.	2	3	4.	1	2	3.	4.
Fed. Spec. SS-P-371	Non-Rein. Concrete		1300	2½'	12'	12'	1400	2½'	11'	11'	1500	3'	10'	10'	1750	3'	9'	10'	2000	3'	9'	10'	2400	3½'	7'	9'																
Fed. Spec. SS-P-371	Rein. Concrete																						2400	3½'	7'	9'	2700	4'	6'	8'	3000	4'	5'	7'	3400	-	-	6'	4000	-	-	6'
Fed. Spec. SS-P-361a	Clay	St. St.	1000	4'	8'	8'	1100	5'	5'	7'	1200	-	-	7'	1400	-	-	7'	1700	4'	6'	8'	2400	3½'	7'	9'	3200	3'	9'	10'	3900	2½'	10'	10'								
Fed. Spec. SS-P-361a	Clay	Ex. St.	2000	2'	30'	30'	2000	2'	30'	30'	2250	2'	30'	30'	2750	2'	30'	30'	3300	2'	30'	30'	4400	2'	25'	25'	5000	2'	21'	21'	6000	1½'	21'	21'								
ASTM C14-41	Concrete		1300	2½'	12'	12'	1400	2½'	11'	11'	1500	3'	10'	10'	1750	3'	9'	10'	2000	3'	9'	10'	2400	3½'	7'	9'																
ASTM C75-41	Rein. Concrete										1800	2½'	12'	12'	2000	2½'	12'	12'	2200	2½'	11'	11'	2400	3½'	7'	9'	2700	4'	6'	8'	3000	4'	5'	7'	3400	-	-	6'	4000	-	-	6'
ASTM C13-41T	Clay	St. St.	1000	4'	8'	8'	1100	5'	5'	7'	1200	-	-	7'	1400	-	-	7'	1700	4'	6'	8'	2400	3½'	7'	9'	3200	3'	9'	10'	3900	2½'	10'	10'								
ASTM C200-41T	Clay	Ex. St.	2000	2'	30'	30'	2000	2'	30'	30'	2250	2'	30'	30'	2750	2'	30'	30'	3300	2'	30'	30'	4400	2'	25'	25'	5000	2'	21'	21'	6000	1½'	21'	21'								

*Where space is indicated by a blank (-), the pipe are not suitable for the combined dead plus live loads.

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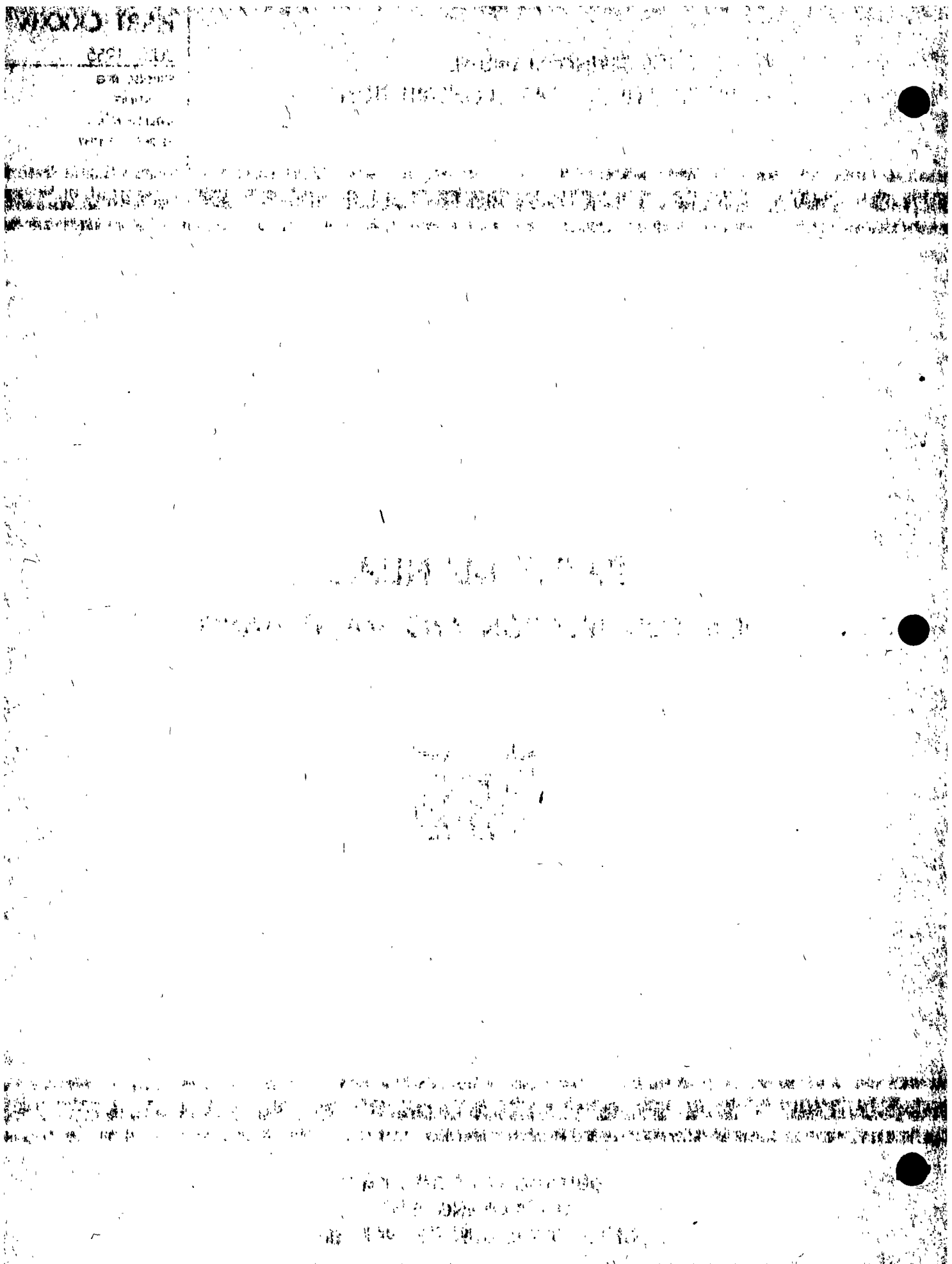

PART CXXXIV

PAINT MANUAL

NEW CONSTRUCTION AND MAINTENANCE

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PART CXXXIV

PAINT MANUAL

NEW CONSTRUCTION AND MAINTENANCE

INTRODUCTION

1–01. PURPOSE AND SCOPE

A large amount of experience in paints and painting of Corps of Engineers' structures and plant has been acquired by several organizations within the Corps. It is the purpose of this manual to make available the information gained by this experience, in order to bring about a general improvement in the cost and effectiveness of protective coating work. Additionally, the manual intends to assist engineering and operating personnel in obtaining the background for more successful adaptation of the provisions of the Civil Works Construction Guide Specification for Painting CE–1409 and of the Guide Specification for Military Construction, Painting, General (For Building Construction), CE–250. This manual will be used as a reference manual only and will not replace or supersede War Department Technical Manuals in the TM 5–600 series for Repairs and Utilities activities. It is intended primarily as a manual of field painting for fixed structures and appurtenant works. In case of conflict between this manual and guide specifications for Civil Works and Military Construction, the specifications will govern. With the exception of a brief section devoted to the painting of floating plant used in civil works activities, it is not intended that this manual be applicable, except in an incidental way, to the painting of Corps of Engineers' equipment.

The manual is not intended to be a general textbook on paints and painting, but rather, to furnish detailed information on equipment, materials, and procedures which have proven satisfactory in actual practice at various Corps of Engineers installations. It contains a general discussion of paint materials, and a brief section is devoted to the sampling and testing of paints. A painting schedule similar to that shown in Civil Works Construction Guide Specifications, CE–1409 is included for convenience of the reader. Equipment and methods for cleaning and preparation, in the field, of surfaces for paint application are described together with inspection of these operations. Parts of it deal quite extensively with the selection of coating materials for various surfaces and exposure conditions. There are also discussed certain protective coating systems and procedures which were omitted from the guide specifications for reasons of brevity.

Very little distinction is made throughout the manual between contract and hired labor painting. The information furnished is normally applicable to either method of doing the work. However, in those instances where discussion is made of such subjects as selection of cleaning equipment and materials, the reader should realize that it is not directly applicable to contract work where the end result is specified and not the means to that end. It is considered, however, that this information is valuable background material for resident engineers and inspectors who are administering contract painting work.

The bulk of the data presented is applicable to both maintenance and new construction painting. It is believed that sufficient information is included to permit its adaptation to specific situations involving either type of work.

While cathodic protection is not within the scope of this manual, its application to the protection of ferrous metals subject to immersion in water is covered in a general way.

1-02. GENERAL

Protection of surfaces is in all probability one of the most important elements entering into the maintenance cost of structures in which large areas of exposed steel and woodwork predominate. The protection problem may even become evident in the design stage when the engineer over-designs to provide a factor of safety for the corrosion or deterioration he estimates will take place. Inadequate control of metal corrosion and deterioration of wood results in an economic loss of many millions of dollars annually. In addition, conservation of natural resources demands that unnecessary and inexcusable waste of materials through inadequate protection be prohibited. Figure 1 illustrates the corrosion which has taken place at the waterline on a structural steel drydock gate after thirty-five years in the rather mildly corrosive waters of the upper Mississippi River, despite intermittent protective measures (picture taken after blast cleaning). Adequate maintenance practice would have minimized this condition.



FIGURE 1. *Example of corrosive action.*

One of the principal means of preventing deterioration is through the use of organic coatings such as paints. The paint industry has made important progress in the improvement of protective coatings, and further important progress is in prospect. The prompt adoption and proper use of these improved materials is the least that can be expected of those responsible for the protection of metal and wood surfaces. The time has long since passed when one general oil-base type of coating is used on all field coated surfaces regardless of its surface characteristics and the exposure conditions to which it will be subjected. The present-day fund of knowledge, improved equipment, and variety of materials available in the coating field require that the engineer devote more study to the protection of the things he builds.

In connection with improvement of painting operations, it is considered worthwhile for each District and Division to designate an employee from within the existing organization (not necessarily a trained paint technician) whose work would include acting as an adviser on matters relating to paints and painting. The duties of this employee, probably in conjunction with other work, would include: keeping himself informed on the specifications, manuals, and other directives on paints and painting disseminated by the Corps of Engineers and other Government agencies; advising other interested members of the organization on matters related to protective coatings; assisting in the preparation of specifications for paint procurement and contract or hired labor painting; assisting in the selection of paints for specific jobs; providing technical guidance in maintenance painting operations; supervising inspection of painting operations; and supervising the keeping of paint service records.

The words "paint" and "painting" are used broadly in this manual to indicate all common types of protective and decorative coatings, applied hot or cold, by brush, spray, or other means. While it is recognized that materials such as varnishes, lacquers, sealers, and certain bituminous coatings technically are not paints, they are, for present purposes, included in that general category.

1-03. REFERENCES TO STANDARD SPECIFICATIONS

The standard specifications of the organizations listed below are referred to herein by use of the indicated abbreviations.

Standard	*Abbreviation*
General Services Administration	Fed. Spec.
Office of Standardization, Dept. of Defense	MIL or JAN Spec.
American Society for Testing Materials	ASTM Spec.
American Water Works Association	AWWA Spec.

DISCUSSION OF PAINT MATERIALS AND COATINGS

1-04. GENERAL

The pigments, oils, resins, driers, thinners, solvents, plasticizers, and other materials used in the formulation of paints are far too numerous to permit the inclusion of a description of each in this manual. However, in order to acquaint the reader with the different paint materials, they are discussed briefly as a class, and in some instances, a description of the more important of the materials in a class are described.

1-05. PIGMENTS

Pigments used in the formulation of paint are usually opaque and finely divided, and are derived from a wide variety of materials. They are substantially insoluble in the paint liquid, but may be at least partially soluble in water. The properties of any paint are greatly affected by the types and quantities of each pigment used in the formulation. Pigments in paints generally will have one or more of the following roles:

(1) Protect the paint vehicle or binder from the effects of weathering and abrasion.

(2) Provide color desired for appearance and decorative effect.

(3) Assist in passification of metal surfaces.

(4) Impart self-cleaning characteristics to a film and provide a suitable surface for repainting.

(5) Add volume and adjust consistency of a paint.

(6) Provide "tooth" for the bonding of succeeding coats.

(7) Aid in the storage properties of a paint (certain pigments will help hold others in suspension).

(8) Increase imperviousness of a film.

(9) Assist in the drying of the film by acting as a catalyst, promoting oxidation and polymerization.

(10) Control the penetration of the vehicle into the surface being painted.

(11) Assist in producing the type of finish desired, such as high gloss, satin, and flat finishes.

(12) Provide hiding ability to the paint.

From the hundreds of pigments available, the paint formulator selects those which either alone or in combination will, when dispersed in the vehicle, provide a film of the characteristics required for the exposure conditions. The Raw Materials Index, issued by the National Paint, Varnish, and Lacquer Association, Inc., Washington, D. C., lists several hundred pigments as manufactured by various producers together with technical information, such as bulking value, fineness, and oil absorption. Accordingly, it is apparent that a description of individual pigments cannot be included herein. It is also evident that for optimum results to be obtained, the paint formulator must have wide experience with the materials he uses or have the benefit of the composite experience of others. Most formulations must be a compromise, providing a majority of the desired characteristics. For example, a pigment combination in a house paint which produces good self-cleaning properties may have less overall durability than one in which the pigment combination is designed with the object of durability only. In most of the special paints described in this manual emphasis has been placed on obtaining long life.

1–06. VEHICLES AND VEHICLE CONSTITUENTS

The vehicle of a paint is the liquid portion thereof which would remain if all of the solid pigment particles were removed and may consist of one or more of the following constituents: drying oils, driers, thinners, plasticizers, and resins. An oil vehicle will be made chiefly of drying oils, thinners, and driers; a varnish will differ from an oil vehicle in that the drying oils will be modified by the use of resins; a lacquer vehicle will contain chiefly resins, solvents, and plasticizer; an emulsion vehicle will contain chiefly an oil or resin or both, water, preservatives, and emulsifying agents. The oils, resins, plasticizers, and other vehicle non-volatiles make up the binder for the pigment and are the materials which make possible the formation of a continuous film. The thinners and solvents are volatile constituents which leave the paint film by evaporation, after application, and are added only to permit the paint to be readily applied. Vehicles of the varnish and lacquer type are frequently used, without pigmentation, where clear films are required. However, since it has been defined in terms of pigmented paints, the word "vehicle" is not properly applicable to clear lacquers and varnishes when used as such. Vehicles and various components of vehicles are briefly described in the succeeding subparagraphs.

a. **Drying Oils.** An oil is classified as a drying oil if it will set or harden under normal exposure conditions when applied as a thin film. The hardening process may be the result of oxidation or polymerization or both. Oxidation is the chemical combination of the constituents of the drying oil with oxygen to form new compounds. Polymerization is a chemical reaction in which two or more molecules of the same substance combine to form larger

molecules without changing the basic chemical composition. Drying oils, particularly linseed, may be used as such in a paint vehicle or they may be processed with resins to form varnish vehicles having greatly modified properties. Drying oils normally employed are the following:

Linseed oil. Linseed oil is the most widely used drying oil employed in the formulation of paints and varnishes. The raw oil is obtained from the pressing of flax seeds. Linseed oil is available in various types and grades including raw, boiled, acid refined, alkali refined, and bodied oil. Raw linseed oil dries too slowly for most purposes and therefore requires processing and/or the addition of driers to hasten the hardening rate of the film. Boiled oil was formerly produced by heating the raw oil at temperatures from 500° to 550° F., after which there were added oxides of manganese and lead. Most boiled oil today, however, is prepared by heating at much lower temperatures or not at all, with the necessary drying characteristics being effected by the addition of a mixture of soluble lead, manganese, and cobalt driers. Boiled oil dries much more rapidly, develops a higher gloss, and its film is considered more impervious to moisture than raw oil. The alkali and acid refined oils are pale, impurity-free, non-reactive products and are generally employed for specialized purposes, such as: varnish making, grinding of particular pigments, and preparation of pale vehicles for white paints. Bodied oils are those that have been thickened by heat treating and/or blowing air through them, thereby increasing their viscosity, or "body." The film forming and drying characteristics of bodied oils may differ greatly from those of the original oil. Moreover, the method of bodying the oil (e.g., heating in an open kettle, heating under vacuum, or simultaneously heating and blowing air through the oil) brings about marked differences in the characteristics of the applied films. In general, bodied drying oil films dry more quickly, are tougher, have better water, chemical, and after-yellowing resistance than films of unbodied oil. (After-yellowing is the term used to describe the tendency of the dried film to turn yellow with age.)

Tung oil. Tung oil, also commonly known as china wood oil or simply wood oil is obtained from the nuts of the tung tree. The raw oil dries more rapidly and forms more water resistant films than linseed oil but tends to wrinkle and become opaque during drying. Although it is used to some extent in its unprocessed form as an additive to certain paints, it is principally employed in the manufacture of high-quality varnishes. Test and practical experience indicate that tung oil, combined with certain resins, produces paint vehicles with excellent water and wear resistance and durability in exterior exposure.

Perilla oil. This oil is a light yellow, natural liquid obtained from the seeds of the oriental perilla plant. It is faster drying than linseed oil but not as fast as tung oil. It produces a brilliant, tough, fairly waterproof film but has a tendency to "after-yellow" and embrittle in aged films. In its raw state it has a high surface tension which tends to impart unfavorable "crawling" (the tendency of a paint, upon application, to draw up into globules or droplets, thus exposing at some places the original surface), characteristics to drying films of the material. This characteristic is eliminated by heat treatment and by mixing with other oils. Its use is confined generally to the manufacture of varnish type vehicles.

Oiticica oil. This oil is derived from the fruit of a tree which is native to Brazil. In its natural state, oiticica oil is a semi-solid. It is rendered permanently liquid by heating at 450° F. for about an hour. Oiticica oil is used principally in the preparation of varnishes and varnish type paint vehicles. It more closely resembles tung oil than any of the other commonly used drying oils. Varnishes prepared with oiticica oil form films which get about as hard as those prepared with tung oil, but are somewhat less water resistant and tend to embrittle more on aging. Notwithstanding these shortcomings, however, oiticica is potentially the best substitute for tung oil in high quality varnish vehicles.

Soybean oil. This oil, obtained from processing soybeans, is the slowest drying of all of the oils herein described, although modifying developments promise to improve this characteristic. Although soybean oil is not extensively employed as such, it is fairly frequently

blended with oils having better drying properties and used in white and light tinted paints because of its excellent non-yellowing characteristics. Its greatest use is in the production of alkyd resin type varnish vehicles in which its slow drying characteristics are modified in the processing so as to eliminate this defect.

Dehydrated castor oil. Natural (or raw) castor oil, obtained from the seeds of the castor plant, is non-drying. However, by a chemical process which in effect removes a molecule of water from the principal chemical constituent of castor oil, the oil takes on typical drying oil characteristics. The dehydrated oil is similar to perilla in bodying rate (in varnishes), drying speed, and resistance properties. Dehydrated castor oil imparts excellent color stability and flexibility to varnishes made with it.

Fish oil. This oil is obtained from the bodies of many different species of marine fish. Fish oils are sometimes used as a substitute for linseed oil in lower price range paints for exterior use. They are not, however, recommended for interior use because of their tendency to give off unpleasant odors. Fish oils produce films which tend to become tacky in humid weather, and are slow drying. Hence they are most useful when used in conjunction with better drying oils. Fish oils are generally believed to have greater elasticity than linseed but this belief has not consistently been confirmed by experimental work.

b. **Volatiles (Thinners, Solvents).** Volatiles, more commonly called thinners, are volatile organic liquids which are used principally to reduce the viscosity of a vehicle or paint to a suitable brushing or spraying consistency. Some volatiles act as active solvents dissolving the non-volatile vehicle constituents in the paint, whereas others act simply as diluents, separating vehicle molecules. Diluents when used alone do not have the ability, generally, to dissolve the non-volatile vehicle. For example, vinyl lacquers and the more familiar nitrocellulose lacquers are commonly reduced with a thinner which is a mixture of an active solvent and a large proportion of diluent. The latter, if used alone or in too great a proportion, would result in non-solution of the resins, precipitation, gelling, or other harmful effects on the vehicle. The type and quantity of solvents or diluents to be used varies with the paint, method of application, considerations of economy and many other factors. The volatiles play an important role in controlling the application and drying characteristics of a paint and at least partially control many other properties of the paint, such as ability to penetrate and/or wet the surface being coated, leveling, lap time, dispersion of pigments, and ease of brushing or spraying. Control of these characteristics is largely effected by virtue of the relative evaporation rate of the various volatile materials. For example, toluene evaporates 14 times as fast as mineral spirits. Some of the more common thinners or solvents are: mineral spirits, turpentine, hi-flash naphtha, xylene, acetone, and various alcohols, ethers, ketones, and esters. Water, of course, is used as a thinner for water emulsion paints. In the selection of volatiles to reduce a paint in the field, directions of the manufacturer or of the specifications generally should be followed, since some paint vehicles will not tolerate certain thinners or may require a disproportionately high volume of a particular thinner to effect the reduction in viscosity desired. The improper use of thinners, either the wrong type or too great a quantity, very often results in reduced life of the coating. With respect to safety, the potential flash fire hazard incurred in painting operations is in direct relation to the flash point and vapor pressure of the volatiles used. It should be remembered that volatiles in a paint eventually leave the applied film completely. Therefore, they can add nothing to the desired dry film properties and can, when improperly used, be deleterious. In lacquers particularly the volatiles are a large proportion of the total cost of materials.

c. **Driers.** A drier may be defined as a catalytic agent which, when added to a drying oil or a paint or varnish containing oil, hastens hardening of the film. In general, modern paint dryers may be classified as soaps of certain heavy metals. Chemically speaking, these soaps are the salts formed by replacing the hydrogen radical of certain organic acids with the

heavy metal radical. The most common driers used in paints are oil-soluble naphthenates of cobalt, manganese, and lead. Lead driers promote hard drying throughout the thickness of the film and influence the rate of polymerization of the vehicle more than they do the rate of oxidation. Lead driers are not as strongly catalytic as others in promoting drying of paint films. Cobalt driers assist oxidation strongly and, if used alone, may cause wrinkling because of rapid drying of the outer layer of the film. Manganese driers are intermediate in most respects between lead and cobalt; they promote through drying as well as surface drying but, if used alone, the film tends to be brittle. A given paint or vehicle may make use of one, two, or all of the three drier types, depending on the nature of the paint product. The amounts of driers used in a paint, oil, or varnish vary according to the strength, solubility, and other characteristics of the driers, the nature of the paint to which they are to be added, and the intended use of the finished product, but in modern concentrated form the amounts used, by volume, are quite small. In addition to acceleration of the drying of the film, driers may have an important effect on water resistance, durability, flexibility, and other film characteristics. Too much drier or improper combination of driers may adversely affect the durability of the film. Finished paint products should be purchased with driers added whenever practicable, since the addition of driers in the field is readily susceptible to error. Other metallic soaps such as those of iron, zinc, calcium, aluminum, copper, and mercury are used in paint to obtain fungicidal, flatting or drying characteristics or to aid in suspension of pigments.

d. **Resins.** Natural and synthetic resins available to the paint industry are so varied in properties and many in number that they will be only mentioned at this point. This same complexity and multiplicity makes a definition almost impossible. As a general statement it may be said that resins are usually solids or semi-solids, are usually transparent, non-crystalline, electrically non-conductive and have indefinite melting points. Together with drying oils, they comprise the bulk of film forming materials, or binders in the surface coating field. Some resins are used by themselves as the principal binder in a coating while other resins are combined with drying oils. In subsequent sections, the most important resins insofar as this manual is concerned, will be discussed at some length. The natural resins are, in general, exudations from trees or insects and the synthetic resins are manufactured from basic organic materials such as petroleum, alcohol, coal tar, and vegetable oils. The synthetic resins enjoy wider use than natural resins because of their more consistent quality and the generally improved properties of the vehicles made with them. Some of the natural resins are Damar, Batu, Kauri, Resin, Shellac, and Gilsonite, the last being a naturally occurring asphalt. The synthetic group includes alkyd, phenolic, urea, melamine, coumarone indene, maleic, chlorinated rubber, petroleum resins, terpene resins, cellulose compounds, vinyl, styrene, silicone, and many other resins.

e. **Varnishes.** Varnishes contain oil, resins, thinners, and driers. Drying oils and resins are combined in definite proportions and types, depending upon the vehicle characteristics desired, by heating according to a definite and controlled procedure, to produce the desired combination. Thinners and driers are then added. Other materials such as anti-skinning agents, flatting agents, plasticizers, and waxes may be added to the varnish at some stage of the manufacture. Sometimes a varnish is designated by its oil length, or the number of gallons of drying oil added to 100 pounds of resin. Thus a 40-gallon varnish is one in which 40 gallons of drying oil are used for each 100 pounds of resin. The performance requirements of the varnish control to a large extent the selection of resins, oils, and other materials to be combined. The quantities of each and to some extent the processing procedure also are governed by the qualities the varnish is to possess. Such qualities or characteristics include flexibility, toughness, adhesion, hardness, stability in storage, drying time, color, non-reactivity with pigments, resistance to various exposures, surface texture, viscosity, and freedom from skinning. The large number of resins, oils, and other available

components makes it possible to produce varnishes adaptable to many uses. Varnishes may be used as such for clear coatings or as vehicles for pigmented paints. Other paint vehicles, such as lacquer liquids, are discussed with paints and lacquers in the section which follows.

1–07. CLASSIFICATION OF ORGANIC COATINGS

The materials mentioned in the preceding paragraphs are used to make many different types of organic finishes for decorative and protective purposes. These coatings are well known to everyone as oil paints, enamels, primers, lacquers, emulsions, sealers, stains, etc. A description of the composition, formulation, manufacture, testing, performance characteristics, properties, and uses of these various types of finishes is beyond the scope of this manual. However, it is believed that engineers and inspectors concerned with painting work should know some of the principal features of a number of these coatings, and for this reason a brief discussion is given in the paragraphs which follow.

a. **Oil Type Paints.** These paints consist principally of a drying oil (usually linseed) mixed with one or more pigments. Added driers and thinners generally complete the makeup of a paint of this type. Oil paints may also be modified by the addition of a small percentage of varnish. Exterior surfaces of houses and metal surfaces in atmospheric exposures are usually coated with paints of the oil type. The vehicle in these paints may be a combination of raw and processed oils or it may be composed of a single oil, depending upon the properties desired in the paint. The pigments and quantities thereof used in oil paints are usually selected on the basis of cost and their ability to impart to the paint the various properties desired, such as durability, economy, brushability, color, impermeability, and reflectance. The oil type paints are characterized by easy application, slow drying, and good ability to wet the surface being coated. They normally fail in such a manner as to permit recoating without costly surface preparation.

b. **Enamel.** As a paint term, enamel no longer has a very specific meaning in the paint field. Enamel is commonly thought of as a pigmented, varnish vehicle paint which has good flow and leveling properties and dries fairly rapidly (in 4 to 16 hours) at normal temperature or in a shorter time at baking temperatures by solvent evaporation, oxidation, and polymerization. However, some specially processed oil paints may exhibit the properties of an enamel and not contain any varnish. Enamel is also popularly thought of as furnishing a film of relatively high gloss, but many low-gloss paints are now designated as enamels. In general, enamel paints do not have as good ability to wet the surface and coat irregularities in the surface as do oil paints, and they generally fail by chipping, cracking, blistering, or similar action resulting from gradual decrease of elasticity with age. Enamel films are generally harder, tougher, and more resistant to abrasion and moisture penetration than oil type paints. They can be applied by brushing, spraying, or dipping. When the application is by brush, the paint should be flowed on the surface rather than brushed out as in the procedure with oil paints. Enamels of the baking type are widely used in industrial finishing.

c. **Lacquer.** The term is usually given to those coatings which dry completely and rapidly by evaporation of the volatile constituents without further oxidation or polymerization of the non-volatile portion of the vehicle. Coatings based on cellulose derivatives, such as nitro-cellulose, are the best known examples of lacquer liquids commonly used. Both the clear and pigmented liquids come under the classification of lacquer. Vinyl, urea, chlorinated rubber, melamine, and several other resins dissolved in suitable solvents may be called lacquers. Dispersion resin liquids, of which one group may be regarded as almost completely polymerized phenolic resin-oil complexes dispersed in a volatile solvent, may be considered to be in the lacquer class, in that they dry rapidly by a process which is principally solvent evaporation. Lacquers are normally applied by spray and since they generally have a comparatively low non-volatile content, each coat forms a relatively thin film compared to those of enamel and oil type paints. A hard, brittle coating, a tough and elastic coating, a

high or low gloss film, and many other variations can be made by proper choice of lacquer materials. Some lacquers have a primary purpose of beautification of the product on which they are used and protection is of secondary importance. However, the durability of lacquer finishes on some makes of automobiles is testimony that good protection is realized with certain lacquer materials. The relatively new vinyl paints which are technically lacquers have outstanding durability characteristics in many types of exposure.

d. **Emulsions.** These paints are distinctly different from other paints in that the vehicle is an emulsion of binder and water. The binder may be oil, oleoresinous varnish, resin, or other emulsifiable binding material. They differ in physical characteristics from oil or varnish paints. The emulsion paints have the advantages of easy application, drying by evaporation of water, easy reduction of viscosity with water, and tools used for application are easily cleaned with soap and water. Fed. Spec. TT–P–29, "Paint; Latex Base, Interior Flat White, and Tints" describes a typical water-thinned paint of the resin-emulsion, or latex type. This type paint is useful as a decorative coating for interior walls and ceilings and has become enormously popular in recent years for this purpose. It may be applied to plaster, concrete, brick, masonry, wallboard, etc. Paints of the latex type are not generally intended for use over metal and wood. The vehicle of the TT–P–29 latex base paints is a dispersion of synthetic resin particles in water prepared by emulsion polymerization and may contain thickening agents, protective colloids, emulsifying agents, and anti-foaming compounds. Latex paints can be washed with soap and water after a suitable drying period. Latex paints formulated especially for exterior surfaces of concrete, masonry, and similar surfaces are reportedly giving satisfactory results, although the breadth of experience with these coatings leaves something, as yet, to be desired.

e. **Coal Tar Coatings.** Coal tar coatings are based on coal tar pitch which is a distillation residue of coal tar. The pitch may be cutback in aromatic hydrocarbon solvents to make a coal tar coating which is applied in the same way as any other paint, or the solid pitch, modified in various ways, may be used by heating to a viscous liquid and applying hot with daubers or by flow-on methods. The material commonly called coal tar enamel is of the hot-applied type and consists of specially processed pitch combined with an inert mineral filler. The AWWA Spec. C203–51 describes an enamel which has been found to have outstanding durability in continuous underwater exposure. The cutback or cold-applied material is inferior in durability to the hot-applied enamel, but it is much easier to apply. The characteristics and use of these materials are described in more detail in subsequent sections.

SPECIFICATIONS, SAMPLING, AND TESTING

1–08. USE OF STANDARD SPECIFICATIONS

Much confusion can result from the use of standard specifications (e.g. Federal, Military, A.S.T.M.) if the user and specification writer are not thoroughly acquainted with them. The problem is at its greatest where paints are concerned because of the large number of materials involved and the rapid changes in specifications for paint products. Application of the following practice should be of assistance in avoiding difficulties.

(1) The latest issue of the standard specifications should be used in preparing project or procurement specifications. It is not uncommon to find a reference to a standard specification which has been superseded by one of an entirely different number or even replaced by one issued by another agency. This situation is the result presumably of making use of outmoded indexes of standard specifications.

(2) Where one standard specification covers several types or grades, it is not uncommon for the project specification writer to fail to designate which type and grade is to be used, thus presumably leaving the selection up to the contractor who will, of course, be guided by cost rather than applicability. In a considerable number of cases the types and grades desig-

nated within a standard specification cover a very wide range of paint materials, some of which might be suitable and others entirely unsuitable for a particular usage. The attention of users of Federal Specifications and other standards for paints and paint materials is invited to the notes in the rear of the specifications which frequently contain considerable explanatory information relative to the selection and uses of the various grades and classes.

1–09. SPECIFYING OF STANDARD PRODUCTS

Although this manual describes a number of paint components on a standard product basis, an attempt has been made to keep such references to a minimum and to restrict them to certain raw materials for which no standard specifications are available. Specifying of a mixed paint on a "similar and equal" basis is seldom if ever justified since specifications issued by Government or independent agencies cover most intended paint usages adequately. Moreover; the determination as to whether a complex material such as a mixed paint is "similar and equal" to a standard presents virtually an unsolvable problem within the testing time available. The special formulations shown in this manual are generally sufficient to cover the majority of unusual exposure conditions for which satisfactory standard specification paints are unavailable.

1–10. SAMPLING AND TESTING OF PAINT MATERIALS

The sampling and testing of paints should, insofar as possible and particularly where considerable quantities of paint are involved, be performed by the Government. In this connection, reference is made to Military Standard MIL–STD–105A, "Sampling Procedures and Tables for Inspection by Attributes." Authenticated test reports or certificates of compliance furnished by the contractor are not always an assurance of actual compliance with the specifications.

In general, the determination of the characteristics of the materials entering into the special phenolic and vinyl formulations shown in detail in paragraph 1–60 cannot adequately or economically be determined from an examination of the mixed paints. Therefore, separate samples of raw materials and processed vehicles entering into the manufacture of the finished product should be obtained and tested prior to or concurrently with the examination of the finished product. Separate sampling and testing of ingredients entering into Federal and other standard specification paints is not generally considered necessary. However, the submission of separate samples of important raw materials and a separate sample of the vehicle should be required whenever it appears that testing of only the finished product itself is insufficient to provide the desired assurance of compliance. The need for testing of raw materials, in addition to the finished product, is recognized in some of the Federal Specifications themselves. For example, Fed. Spec. TT–P–86a for red lead paint requires that samples of the finished product be accompanied by separate samples of the resin and vehicle used in the manufacture of the type IV (phenolic) paint covered by the specification. Fed. Spec. TT–P–57 for zinc chromate-iron oxide paint indicates that separate samples of pigments, oils, resins, driers, and thinners may be required when specifically requested by the contracting agency.

In connection with the procurement of large quantities of paint under Government contract, involving particularly vinyl or phenolic type paints, it is considered that plant inspection may frequently be advisable. This type of inspection, if adequately carried out, enables the laboratory testing to be reduced to a minimum. It is desirable that the employee assigned to plant inspection have experience in this work, but it is not absolutely necessary. The most important phase of plant inspection is to determine that approved raw materials are entering into the manufacture of the finished products and to inspect the batching operations to determine that the correct proportions are being used. An alert inspector with limited paint experience can perform these functions almost as adequately as one with broader experience. A suggested sequence of operations for the sampling and testing of a

Government contract for several large-quantity items of paint is as follows:

(1) Submission by the paint manufacturer, immediately upon being awarded the contract, of samples of all raw materials he proposes to incorporate into the finished products. Samples of raw materials for mixed paints which are covered by Federal or other standard specifications would not normally be required, except where specifically provided for by the standard specification itself or where specifically required by the procuring agency. In addition to samples of the required raw materials, the manufacturer should submit a list indicating the trade name and/or code number by which the raw material producer identifies the material. These provisions, relative to identification of materials, can in many instances save much analytical work.

(2) The raw materials are tested in the laboratory to the extent considered necessary and a copy of the notice of approval, together with the aforementioned raw material list are furnished to the plant inspector who now has the means of following any given batch of finished product through the manufacturing operations. In case of doubt he would take samples of ingredients actually being used in batching operations for checking against samples originally submitted. He should personally observe all batching operations, cooking of processed vehicles, reducing and thinning operations, sampling of finished products, packaging of paint, and labeling of containers.

(3) Samples of finished products should be laboratory tested for color, fineness of grind, consistency, pigment content, vehicle non-volatile, and similar easily conducted tests. If there is any doubt as to the quality of plant inspection or any question in the plant inspector's mind as to the accuracy of control and thoroughness of the manufacturing operations, the samples should be given as complete a chemical and physical analysis as is practicable.

(4) Filled containers should be suitably marked by the plant inspector to insure that approved materials are shipped. If the finished product is held in storage tanks pending approval by the laboratory, the inspector should seal the storage containers or take whatever measures are necessary to insure that the material as packaged is identical to that sampled and approved.

(5) In some instances, particularly where plant inspection was inadequate or omitted, it may be desirable to sample the paint as actually delivered, but prior to payment, and compare with the original samples which were approved for shipment. Experience has shown that the nature of paint products makes it necessary for purchasers on a specification basis to be constantly aware of the avenues whereby unsatisfactory materials can end up undetected at their final destination.

A question arises in connection with the need for inspection and testing of paint products when the purchases involve quantities of less than 100 gallons. Although testing costs will be proportionately high in such cases, the entire omission of inspection and tests is considered inadvisable, unless the manufacturer is one with which the contracting agency has had considerable satisfactory experience. For such small quantities, testing of raw materials and plant inspection should probably be omitted in the interest of economy. The submission of samples and testing of the finished products are, however, recommended. Where very limited quantities are involved, consideration should be given to curtailing the scope of laboratory tests.

Agencies submitting samples of paint to the laboratory for testing should be careful to include all pertinent information. A copy of the regulating specifications should be included, if it is one that is little used. If the materials are to comply with Federal or other standard specifications, the testing agency should be informed exactly as to the applicable specification, revision thereof, and amendments. Finally, information should be furnished as to the quantity of paint represented by each sample, since, in the case of small quantities, the information presents an opportunity for the testing agency to suggest that economy be effected by conducting only the most essential tests.

The laboratory selected for the paint analysis work should be one which has available chemists who have had several years' experience with paint materials and painting work. Since the procuring agency will probably not have anyone who can interpret the test results from a knowledgeable background, it would seem logical to request the laboratory to furnish an opinion as to the acceptability of the material.

CLEANING AND PREPARATION OF FERROUS SURFACES

1–11. GENERAL

Iron and steel surfaces which are to be painted should be free of soil (rust, dirt, paint, oil, grease, and other foreign materials) and scale if the maximum durability of the coating is to be realized. Studies by many investigators of a large number of coated ferrous surfaces over a period of years have shown that the life of some coatings can be shortened by as much as 50 to 75 percent by inadequate cleanliness of the surface prior to painting. Although the best performance will result from completely clean surfaces and the most thorough metal preparation obtainable, it may not always be economical to resort to such meticulous cleaning measures. This seeming contradiction is illustrated by comparing the degree of surface cleanliness required for exterior atmospheric-exposed steel and that required for steel subject to immersion in water. Experience has shown that removal of *all* scale, rust, and other foreign matter to base metal is generally unnecessary to obtain an adequate paint job on structural steel surfaces which will be subject only to normal exterior atmospheric exposure, provided that primers based on vehicles containing a large proportion of free linseed oil are used and provided that heavy, stratified rust is not present. Such oil type primers have the ability to effectively wet the surfaces and penetrate to base metal beneath the edges of semi-adherent millscale as well as through residual and tightly adherent rust. The cleaning prescribed herein for atmospheric-exposed steel (Military Equipment excepted) consists of solvent cleaning to remove grease followed by scraping, power wire brushing, or other mechanical methods short of blasting (unless blasting is preferred by the contractor) to remove loose scale and loose rust. The fact that these imperfect cleaning methods are generally the maximum required for structural steel outside the Corps of Engineers as well as within is indicative of the general opinion that complete cleaning of normal atmospheric exposed steel is not warranted from an economy standpoint. Moreover, power wire brushing, scraping, etc., are usually suitable for spot cleaning in connection with repainting surfaces which are in atmospheric exposure only. Occasionally in maintenance work, atmospheric-exposed structures will have been allowed to deteriorate to the point where the steel cannot be satisfactorily cleaned by methods short of blasting. In such cases, however, the blast job may be relaxed to provide the "brushoff" degree of cleanliness described in paragraph 1–12*c*(2). In the case of military equipment used for military operations, the cleaning and preparation of ferrous surfaces should be done in accordance with MIL–T–704B without deviation.

Structural steel surfaces subject to water-immersion and abrasion are required herein to be sandblasted to base metal. (In some shop work, pickling of new steel is permitted.) This high degree of surface cleaning is considered to be justified not only for new steel but for most repainting work as well under these severe exposure conditions because the materials which are the most durable in underwater exposure are generally deficient in wetting properties and particularly unsuited to any but meticulously cleaned surfaces. Structural components such as gates and valves, some surfaces of which are in atmospheric exposure and some of which are in underwater exposure, are generally blast cleaned overall and painted with one of the prescribed underwater paint systems to avoid two different treatments on one integral surface. The reason for the single system is chiefly one of simplicity of field operations; experience has shown that the greater the number of paint materials used on a job the more likelihood there is for errors in issuance of stocks, thinning and mixing of paints,

and application. Also, with some systems, difficulty can be encountered in obtaining satisfactory performance at the junction of the two different coatings. Where the two differently exposed surfaces are not adjoining, such as the upstream and downstream surfaces of crest gates, and where the downstream surfaces are not subject to immersion, it may be found advantageous to coat such surface with a different coating system, irrespective of some of the above objections.

1-12. METHODS OF SURFACE PREPARATION FOR FERROUS METALS

The cleaning methods which are commonly used are wire brushing, sand, grit or shot-blasting, chipping and scraping, and pickling. Oxy-acetylene flame treating is used to some extent on structural steel for loosening scale prior to wire brushing and to dehydrate the surfaces. Weathering of new, unpainted structural steel to remove millscale, at one time a more or less common practice, should not be permitted unless the surfaces are to be subsequently blast-cleaned. Extensive investigative work has shown that a tight millscale surface is a better base for receiving paint than one which has rusted and been superficially cleaned by methods short of blasting or pickling. This means that new structural steel for service in atmospheric exposure (i.e., steel which is not to be blast-cleaned) should be cleaned and shop primed as soon as practicable after rolling or fabrication and prior to shipment to the construction site. Structural steel surfaces which are to be prepared by blasting should, in general, be cleaned in the field after erection.

a. **Wire Brushing, Chipping, and Scraping.** These procedures will not produce surfaces cleaned to base metal if there is appreciable corrosion or millscale present, but they are frequently the only methods that can be used because of reasons of feasibility and economy. These mechanical cleaning methods should be preceded by removal of grease and oil by means of steam cleaning, emulsion cleaners, solvents or a combination of methods, provided that the materials employed do not leave detrimental residues on the surface. Wiping cloths and solvents if employed for this purpose should be changed frequently to avoid leaving oil films on the surface. Power wire brushing will normally result in better surface preparation than hand brushing, but in either case only the loose scale and rust will be removed. On heavily corroded metal, the bristle cannot reach the bottom of the pits. Hard, tightly adhering corrosion products, millscale and paint will not be removed. Prolonged application of the wire brush to an area will avail little toward better cleaning and will tend to polish the steel surfaces. This burnished effect does not lend itself to the establishment of good adhesion of paint coatings and should not be permitted. Generally speaking, a cleaning rate slower than 2 square feet a minute is of little avail toward better cleaning. There appears to be no standardization of power wire brushes for this purpose as regards brush shape, bristle type, and size, or speed of rotation. Portable, air or electric driven, brushes generally have a speed of 3,000 to 6,000 r.p.m. and may weigh up to 18 or 20 pounds. A cup type brush with bristles made of 0.01 to 0.03-inch (diameter) steel wire is generally employed. Chipping with pneumatic hammers occasionally is necessary to remove old paint coatings and very heavy, hard rust scale. In general, the use of impact tools such as chipping hammers, scaling hammers and rotary scalers should be controlled so as to not leave sharp, projecting ridges which may become focal points for later corrosion. Scraping, since it is a time consuming operation and of slight to moderate effectiveness, should be limited to cleaning of small areas which cannot be cleaned more efficiently by other means. Power sanding, using abrasive wheels or discs may be employed in some cases. Thorough chipping and scraping, followed by equally thorough wirebrushing, is necessary on welds, in order to remove slag, flux and weld spatter. It is emphasized again that structural steel surfaces prepared by these methods are suitable only for receiving primers with good wetting properties such as those made up with a vehicle which consists of all or a large proportion of uncombined linseed oil.

b. **Pickling.** Acid and electrolytic pickling of ferrous metals produce surfaces which

are very satisfactory for the reception of coatings. This method of cleaning is restricted to shop work where facilities for pickling are available. For acid pickling, the steel is immersed in a vat of sulphuric, hydrochloric, phosphoric, nitric, or hydrofluoric acid held at an elevated temperature. The acid used and its concentrate depends on the nature of the oxide to be removed and the composition of the steel. For pickling of hot-rolled, low-carbon steel, sulphuric is the most commonly used acid. Chemical inhibitive compounds are generally used in the pickling solution to check the attack of the acid on bare metal areas which are cleaned more rapidly than others. Thus the inhibitors minimize unnecessary metal loss, reduce the evolution of hydrogen, and help keep down acid fumes. Agitation and aeration of the bath increase the rate of solution of iron in dilute acids. The acid treatment is followed by a hot water rinse to remove residual acid that might remain active on the surface. The acid concentration, temperature of solution, and time of immersion are all carefully controlled to assure removal of scale and corrosion products without appreciable attack of the base metal. A modification of the simple pickling and rinsing procedure involves the use of sulphuric acid for scale removal, followed by a water rinse, and finally immersion in a hot dilute phosphoric acid bath to form an iron-phosphate surface. A variation of the above sulphuric-phosphoric acid pickling method employs sulphuric acid for scale removal, followed by a hot water rinse and followed finally by a 2-minute immersion period in a hot, dilute sodium dichromate-phosphoric acid solution. Redeposited salts and sludge deposits which may interfere with paint performance, and absorption of hydrogen which may cause metal embrittlement (reportedly, hydrogen embrittlement is a factor to be considered only with high carbon steel) and blistering of subsequently applied paint films are possibilities when acid pickling is used. Only competent and experienced concerns should be permitted to use the method. In electrolytic pickling, the steel is made the anode or cathode in an acid or akaline electrolyte and a current is passed through the solution. Pickling, particularly of large quantities of structural steel, should not be made a mandatory cleaning method in construction specifications since shop facilities for such work are scarce. Morever, pickling should not generally be included as an alternate to blast cleaning, since the latter is the preferred method in that it produces more dependable results. Specification SSPC–SP8–52T of the Steel Structures Painting Council, Mellon Institute, Pittsburgh, Pa., covers the pickling of structural steel.

c. **Blast Cleaning.** This method is by far the most effective for cleaning structural steel in the field. The argument is sometimes presented that blasting removes more metal than is generally lost through corrosion. That this is not true has been shown by at least one investigation in which metal losses in 90 days of weathering under high humidity conditions were three times that of the metal removed by a blast cleaning job. Moreover, blasting removes metal uniformly over the entire area whereas the same weight of metal lost through corrosion may be concentrated and take the form of destructive pitting. Although a certain amount of new structural steel is shop-blasted and primed, facilities are not generally available for shop blasting of the large pieces and the extensive quantities of steel required by construction projects. Moreover, blast cleaning at the project site permits closer control of all cleaning, pretreatment, and painting operations, and eliminates the possibility of damage to the shop coating through handling and shipping and during prolonged storage of the steel at the project site. Shop blasting of major quantities of steel should not, therefore, be required in construction specifications nor should it be generally permitted as an alternate to field blasting. However, where structural components are shipped to the building site in an assembled or partially assembled form and where shop facilities are determined to be adequate, shop-blasting and priming may be permitted in individual cases. There are two principal methods of blast cleaning, one being dry and the other wet. The wet system differs from the dry in that water, or a solution of water and a rust inhibitor, is incorporated with the blast abrasive. The water is either mixed with the abrasive in the pressure tank or is introduced into the blast stream just behind or just in front of the blast nozzle. The wet

method reduces to a minimum the dust associated with blasting, but it is not suited to all types of work. Steel structures containing a large number of ledges formed by upturned angles and horizontal girders present a large amount of troublesome cleanup work if the wet method of blasting is used, because wet sand and other blast residues trapped on these ledges is more difficult to remove than dry materials. A sufficient amount of sludge adheres to wet blasted surfaces to necessitate removal by rinsing, brushing, or compressed air blowdown. Moreover, there is an ever-present tendency of the blasted surface to rust even though an inhibitor is used with the mixing water and/or rinse water. It is believed that wet blasting is considerably slower than dry blasting. The attendant damp, humid conditions, and tendency to apply paint to damp or wet surfaces are not conducive to obtaining consistently good results from coatings applied to wet-blasted areas. Wet sandblasting is not described in detail in this manual. By dry blasting methods the steel can be cleaned thoroughly and, except during rainy or very humid weather, will remain dry and relatively corrosion-free for several hours; a period of time sufficient to apply a protective coating. There are two general types of dry blast cleaning methods which may be used in the field. The first is the conventional one which removes the scale and corrosion products with no provisions for disposal of these materials and the spent abrasive, except to permit them to escape into the atmosphere or be deposited on surrounding surfaces. Conventional dry blasting creates a large amount of dust which makes it mandatory that blast nozzle operators wear protective clothing and that precautions be taken to protect the vital parts of nearby machinery. The second method employs vacuum equipment which collects corrosion products and spent blast abrasives simultaneously with the blast cleaning, thus greatly minimizing the annoyance and hazard of the dust. The latter is commonly known as vacuum-blasting and may be described as a closed, recirculating system. Since dry blast cleaning will be used extensively by many field organizations, it is described in detail in the paragraphs which follow.

(1) *Conventional Blast Cleaning.* The term conventional blast cleaning (or open-blast cleaning) is used to designate the usual method of field blasting, in which no effort is made to alleviate the dust hazard or reclaim the blast abrasive, as distinguished from vacuum-blasting which minimizes the dust hazard and in which the blast abrasive is reclaimed. In figure 2 conventional blast cleaning is being performed on a dam gate in the Mississippi River.

(2) *Classification of Dry, Blast Cleaned Steel Surfaces.* Any degree of cleanliness of steel surfaces can be obtained by blast cleaning, depending upon the operator and time spent on the work. Often operating officials are undecided as to what constitutes a blast cleaned surface. Three grades of blast cleaning have been set up in specification form by the Steel Structures Painting Council, Mellon Institute, Pittsburgh, Pennsylvania and are summarized below:

(a) White Metal Blast Cleaning (Council Specification SSPC-SP5-52T). This classification covers complete removal of all corrosion products, all millscale, all paint, and all other foreign matter from the surface of the metal. The end result is a light gray steel surface of uniform appearance with a good anchor pattern for strong adhesion of subsequently applied coatings. A single 5/16-inch nozzle sand-blasting at 100 lbs./sq. in. pressure will produce from 75 to 140 sq. ft. of cleaned area an hour on new, flat, millscale-bearing steel sheets. The blasting rate on irregular, heavily corroded and, particularly, pitted surfaces would be greatly reduced.

(b) Commercial Blast Cleaning (Council Specification SSPC-SP6-52T). This classification contemplates a good but not perfect blasting job and generally includes the removal of practically all rust, millscale, and other foreign matter from the surface of the metal. The surface will not necessarily be uniform in cleanliness and appearance since variations in the surface condition will affect the final result. This grade of blasting also produces an anchor pattern highly suitable for firm bonding of subsequently applied coatings. A commercial blast cleaned surface is defined as one which is cleaned at least as well as a surface

which has been cleaned at the rate of 3 sq. ft. a minute with a standard grade of Ottawa sand and a new ¼-inch nozzle at 90 pounds nozzle pressure.

(c) Brushoff Blast Cleaning (Council Specification SSPC-SP6-52T). This classification contemplates the removal of all loose rust and all loose millscale. Tight millscale and minor amounts of adherent rust and old paint are permitted to remain on the surface. The surfaces are sufficiently roughened by the blasting to provide a good anchor for paint coatings. A brushoff blast cleaned surface is defined as one which is cleaned at least as well as a surface which has been cleaned at the rate of 8 sq. ft. a minute with a standard grade of Ottawa sand and ¼-inch nozzle at 90 pounds nozzle pressure.

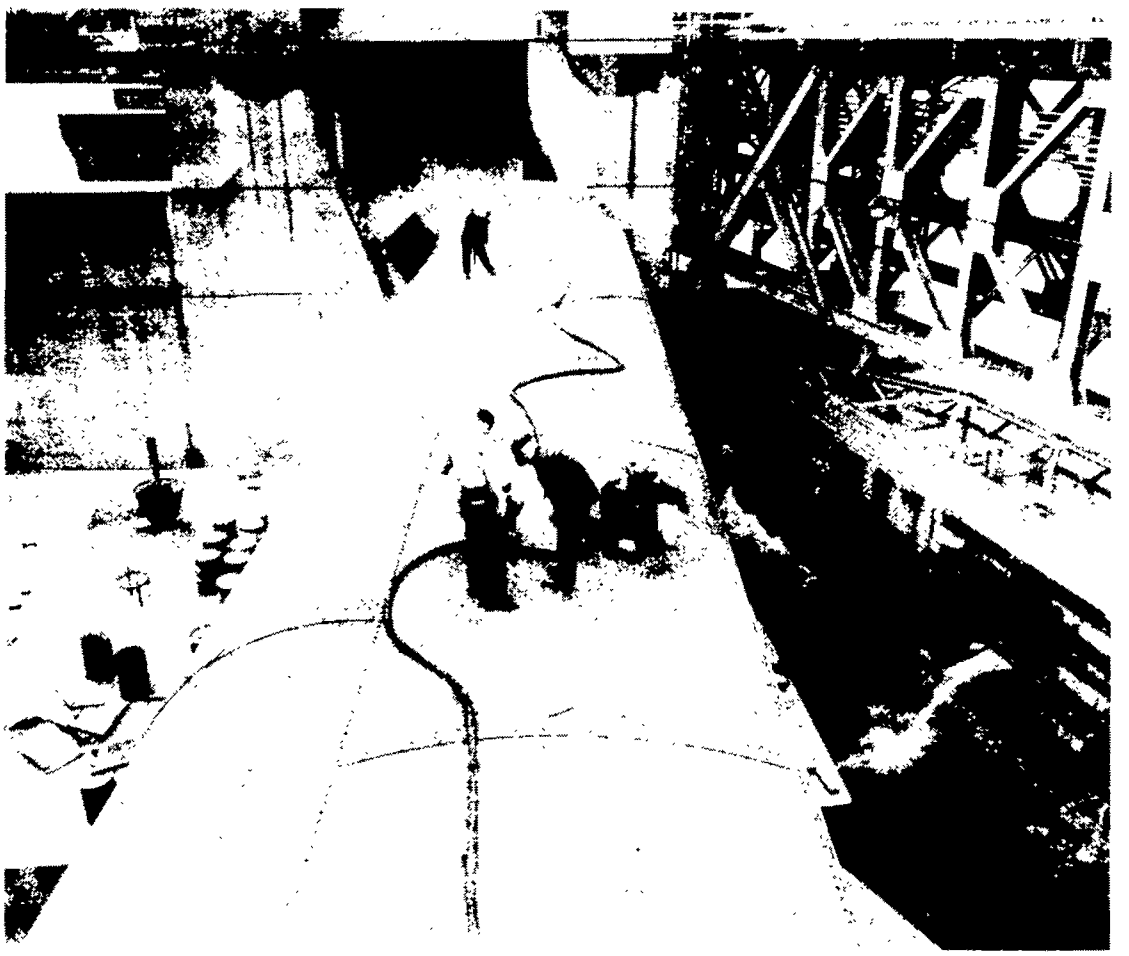

FIGURE 2. *Blasting cleaning operations.*

It is obvious that only the white metal blast cleaning specification of the Council clearly describes the end result to be attained. The commercial and brushoff classification provide a fairly clear idea as to the degree of surface cleanliness to be expected on an average surface. However, the ultimate definition of these two grades of blast cleaning is in terms of comparison standards established on the specific surfaces under consideration with standard abrasive, nozzle size, blasting pressure and a *fixed blasting rate.* Thus the degree of surface cleanliness achieved under the Council's commercial and brushoff blasting specifications is in the final analysis dependent on the precleaning surface condition. For example, a commercial blasting job on new steel plates carrying thin, easily removable millscale and a very minor amount of rust might turn out to be equal to a white metal blast job. At the other extreme,

a commercial blast job on heavily corroded and pitted metal might provide only that degree of cleanliness associated commonly with brushoff blasting. Of course the Steel Structures Painting Council recognizes this situation and implies, in those situations where the end cleaning turns out in actual practice to be inadequate, that a greater cleaning effort be required. The additional cleaning effort would be paid for by the contracting agency. This payment for additional work would obviously present difficult problems on CE construction projects. This discussion does not intend to imply that the above definitions of commercial and brushoff blasting are not useful. Rather it is intended to show the difficulties involved in attempting to standardize those intermediate grades of blast cleaning where something less than *complete* removal of rust, millscale and other foreign material is contemplated. In general it is believed that anyone having in mind the use of the commercial and brushoff classifications in a contract specification should emphasize the end result to be obtained and should not try to identify that end result with the maximum work effort that will be required, either directly or indirectly. However, the difficulty in attempting to describe with reasonable exactness the degree of surface cleanliness to be attained in blasting work, other than the white metal classification, should not be overlooked. Word descriptions have many shortcomings and even photographic standards leave much to be desired. Indeed it would seem that the only adequate means of showing prospective bidders what is contemplated would be to provide, for their prebidding inspection, representative areas which have been blast cleaned to the degree of cleanliness that will be required and which would later be used as control standards during inspection of the contract work.

The white steel surface finish is the grade of blasting generally contemplated in this manual for the cleaning of new ferrous surfaces subject to underwater exposure and abrasion in both fresh and sea water because it is believed that this very high quality surface preparation can be done at reasonable cost when the steel is new and relatively free from corrosion and because the severe exposure conditions justify very thorough cleaning.

Where old, heavily corroded steel subject to immersion and abrasion is involved the situation is somewhat different and judgment is frequently required in determining the quality of blasting to be required for these surfaces. For example, consideration of the effort required to remove the last vestige of rust from pits may well indicate a slight relaxation of the white metal classification originally contemplated, provided the residual corrosion is extremely minor in extent, and is of a thin, adherent nature. Cases have been observed in which rigid adherence to a white steel surface cleaning requirement would have brought about a 25 to 50 percent increase in cleaning cost in order to remove the last minute traces of rust from deeply pitted surfaces, and this without probable significant increase in paint durability. It is emphasized that while one would permit only a very minor relaxation from the white metal classification on surfaces subject to severe exposure conditions (e.g. immersion and abrasion), and then only in the case of pitted, difficult-to-clean surfaces, there are situations in both new construction and maintenance painting where the lesser degrees of blast cleaning may be indicated. Surfaces subject to periodic condensation or infrequent immersion might be blast-cleaned to the commercial grade and, if so, would still be adequately prepared to receive phenolic, vinyl and other coatings with poor wetting properties. Also, there have been occasions when a contractor has offered voluntarily to blast clean atmospheric exposed surfaces even though power tool cleaning only was specified. Since even brushoff blast cleaning is superior to power tool cleaning there should be no hesitation in accepting, as a substitute, this minimum grade of blast cleaning. Whether cleaned by power wire brushing or brushoff blast cleaning the atmospheric exposed surfaces would be primed with a good wetting primer such as red lead-in-linseed oil (Fed. Spec. TT-P-86a, Type I).

(3) *Materials for Blast Cleaning.* Abrasives commonly used for blast cleaning preparatory to painting are sand, iron shot, and crushed iron grit. However, the use of the latter two is fairly well restricted to shop work or vacuum blasting where it can be reclaimed;

it is far too costly for use on field work where considerable loss of abrasive is inevitable. Shot is spherical in form and is not considered as suitable as crushed steel grit for surface preparation prior to painting, since the rounded shot tends to work the metal and is less effective in etching the surface. Sand is quite readily available in most localities and is an excellent abrasive for field blast cleaning work. The sand employed for blasting surfaces preparatory to application of paint systems should be free of clay and dust and composed principally of hard grains and of such particle size as to be mostly passed by the 20 and retained on the 50 mesh sieve (U. S. Standard sieves). Although sand graded between these sieve sizes is very efficient in blasting rate and produces a desirable anchor pattern for coatings of average thickness, the gradation should not be adhered to slavishly if economies can be effected by procuring sand with a somewhat greater range of particle size. For example, 10 percent larger than the No. 20 sieve or the same percentage smaller than the No. 50 sieve does not reduce the efficiency of a blasting sand sufficiently to preclude its use if appreciable savings in materials cost are effected. Of course, these outsize fractions should be controlled sufficiently to prevent the inclusion of unworkably large particles at one end of the scale and dust at the other.

The cost of dry blasting sand can vary from about two dollars per ton to more than twenty dollars per ton, depending upon the processing and transportation costs. Often a misconception of what is required of good blasting sand results in the purchase of material, either specially processed or otherwise, from some distant source when equally or more efficient naturally occurring sand, requiring little more processing than drying, is readily available near the job. Limited experimental work conducted in the field by the Rock Island District Paint Laboratory on various types and grades of sand illustrates the difference in blasting efficiency that can result. The data obtained follows:

Test No.	*Material*	*Area blasted per ton of sand (sq. ft.)*	*Area blasted per nozzle hour (sq. ft.)*	*Essential gradation (U.S. Std. sieve sizes)*
1.	Natural sand (ungraded) from mouth of Des Moines River	212	81	12–40
2.	Natural sand (ungraded) from Mississippi River near Hannibal, Missouri	165	112	12–50
3.	Natural sand (graded) from near Muscatine, Iowa	148	60	10–20
4.	Natural sand (ungraded) from Mississippi River near Burlington, Iowa	287	96	20–70
5.	Ottawa sand	286	120	30–70

A comparison of blasting efficiency of the sands should be limited within two groups, tests 1, 2, and 3 being in one group and tests 4 and 5 forming the other group. In other words, tests 4 and 5 cannot be compared with 1, 2, and 3, since the blasting equipment and surfaces were different for the two groups. Tests 1, 2, and 3 were made on heavily corroded steel using new $\frac{3}{8}$-inch nozzles, 100 psi pressure at the receiver, 180 feet of hose, and the same setting of controls of the sandblast machine for each test. One operator performed all tests. Tests 4 and 5 were controlled in the same manner and were made on heavily corroded steel but were performed by a different operator at another site. All of the natural sands were composed principally of hard quartz particles, with this constituent comprising approximately 70 percent (by volume) of the total. The remainder of the particles were principally of igneous and metamorphic origin. The particle shape of the natural sands is approximately $\frac{2}{3}$ rounded and $\frac{1}{3}$ angular. The Ottawa sand is composed entirely of quartz particles and their shape approximates that of the natural sands. The cost of the specially graded sand, test 3, and the Ottawa sand, test 5, was considerably higher than that of the other sands used. Although these tests are perhaps insufficiently refined to distinguish small differences in blasting efficiency, they do show that the blasting rate and the area cleaned per ton of sand can vary greatly and particularly that the very coarse blasting sands are less efficient than the finer ones. Sand manufactured by crushing of larger particles may be found more efficient than the natural

sands because of the greater angularity and sharpness of the particles, although the question of optimum particle shape is itself a matter of some controversy. Irrespective of the shape and size of the sand particles, the quality of the material must be suitable for blast cleaning. The material must be hard enough to clean efficiently and durable enough to resist excessive breakdown. With respect to durability a very considerable amount of breakdown can be tolerated in field operations where reclamation of the abrasive is impracticable, although a large proportion of particles which pulverize to dust on impact are objectionable for obvious reasons. In those cases where a large amount of area is to be cleaned, it is considered necessary to make a field study of the blast materials available and their relative cost and blasting efficiency to obtain the most economical job. Sandblast data obtained from large-scale maintenance painting operations at three sites along the Mississippi River is shown in the table below. These operations involved blast cleaning of interior and exterior surfaces of tainter and roller gates to a finish which might be described as just short of the white metal classification. Blast nozzles with 3/8-inch diameter orifice were used by both crews who performed the work. The surfaces at each location were generally heavily corroded prior to cleaning. The blasting sand was in all cases taken from the Mississippi River and differed principally in gradation only. The coarse sand had been used as standard blasting material for some time before its inefficiency was discovered in the brief tests described above.

Field Data on Blasting Sand

Crew No.	*Area Cleaned (sq. ft.)*	*Sand used lbs./sq. ft.*	*Gradation of blasting sand, % passing U. S. Standard Sieve Nos.*				
			10	*20*	*30*	*50*	*100*
1	126,950	7.1	99	92	78	12	1
1	152,246	8.4	99	89	68	15	1
2	211,580	6.7	99	89	75	14	2
2	140,000	33.3	100	5	0	....	..

The surface texture (anchor pattern) obtained from blast cleaning with sand which is mostly 20–50 mesh size is better for most paint coatings applied to metal surfaces than that obtained with a coarser sand. The latter etches the surfaces more deeply, leaving high points which may be too thinly coated with paint and thus may act as focal points for corrosion. The thickness of the coating to be applied should therefore be considered to some extent when the selection of the blasting sand is made. A coating which does not have great film thickness will perform better on a surface prepared with fine sand than one prepared with coarse sand. The same coating applied to a greater film thickness will tolerate and may be benefited by a somewhat deeper etched surface, such as would be obtained by the use of a relatively coarse blasting sand. However, for most coatings on structural steel where films are applied to a total thickness of approximately 5 to 6 mils, sands graded with most particles falling between the numbers 20 and 50 sieve should prove satisfactory. Heavily applied coatings, such as the cold-applied coal tar paint and hot-applied coal tar enamel, described in paragraphs 1–18 and 1–19, would tolerate and perhaps perform somewhat better on surfaces which are blasted with sand which contains a large percentage of 10 to 20 mesh particles, although the preceding data indicates that lower blasting efficiency with such abrasive can be expected. Iron shot and crushed steel grit roughen the surfaces more severely than a comparable size sand and when these metallic abrasives are used for surface preparation prior to applying coatings 5 mils or less in thickness it is important that the size of the largest particles be limited so that all of the abrasive passes the 16 mesh sieve. Page 20, Volume I (Good Painting Practice) of the Steel Structures Painting Manual, published by the Steel Structures Painting Council, Mellon Institute, Pittsburgh, Pennsylvania, shows some interesting data on the maximum height of profile produced by the various gradation of several types of abrasive. The maximum height of profile is the vertical distance from the bottom of the deepest pits to the top of the highest peaks on the blasted surfaces.

(4) *Conventional Sandblast Equipment.* Whether the metal cleaning is to be done by contract or by hired labor forces, it is important that those responsible for the work have a thorough knowledge of the equipment required to accomplish the work efficiently. The selection of sandblast nozzles, hoses, machines, compressors, and sand handling equipment will govern to a large extent the efficiency of the operation. Because of the differences in the nature of various blast cleaning jobs, both as to the structure and the organization available to do the work, it is not possible to make a positive recommendation of the equipment to be used. In general, low cost, medium quality blasting sands are used only once in field blasting work, i.e., they are not reclaimed, dedusted, and recirculated through the blasting machine. As the cost and quality (resistance to breakdown) of the sand increases, consideration should be given to the feasibility and economy of reclaiming and reuse of abrasive. The following specific information may be helpful for the selection of equipment:

(a) Sandblast Machines. A number of machines for open blasting in the field are available from manufacturers of this equipment. Twin-compartment machines allow continuous operation without loss of time for charging with abrasive. The size and capacity of machines to be obtained will depend upon the quantity and type of cleaning work, the air supply, method of charging, and other features of the work. Where large areas are being sandblasted overall it is considered justified to use large equipment with all available improvements making for decreased delays and shutdown time. Equipment for cleaning small areas or for touchup work should be less elaborate and of smaller capacity. Controls for stopping and starting the machine from the nozzle may be found advantageous. Controls are available from the Pangborn Corporation and probably other blasting equipment manufacturers which permit the blast stream to be shutoff at the nozzleman's will and which, as a safety measure, interrupts the blast stream automatically when the nozzleman's grip on the control is loosened. It has been found that nozzleman-operated controls have the tendency to encourage less production on large, contiguous surfaces but may be advantageous in blasting small, isolated areas. Also, the desirability of the automatic, dead-man type of control, from a safety standpoint, cannot be questioned. The advice of manufacturers of sandblasting equipment should be solicited by inexperienced operating personnel.

(b) Sandblast Nozzles. A large variety of nozzles are manufactured for sandblasting work. Nozzles are made of ceramic material, cast iron, various steel alloys, or tungsten carbide. The number of hours of blasting that can be obtained from one type of nozzle will be greatly different from that of another type but cost and other factors may nullify the seeming advantage of the longer-life nozzle. Therefore, it is recommended that several types be tried before a large supply is stocked. For cleaning structural steel, the nozzle length should be approximately six times its orifice diameter. Special nozzles are available for blasting the interior surfaces of pipe and other hard-to-reach places. It is quite evident that where the supply of air and blast materials are ample and the areas to be cleaned are large, nozzles of large orifice diameter will produce more cleaned area per man-hour than nozzles of smaller diameter. Since the cleaning rate will vary as the cross-sectional area of the orifice, a twofold increase in orifice diameter will result in a fourfold increase in blasting rate. The quantity of sand used per hour at 90 lbs. per sq. in. pressure with a ⅜-inch nozzle is in the neighborhood of 1,000 to 1,500 pounds and the operation requires 216 cubic feet per minute of air. Correspondingly, a ½-inch nozzle operating at the same pressure will consume 1,800 to 2,400 pounds of sand and will require 376 cfm of air. The ½-inch nozzle requires a 1½-inch diameter hose which is stiff and unwieldy for blast cleaning irregular complex surfaces where considerable manipulation of the nozzle is required. However, this difficulty may be eliminated in some cases by inserting a short length of smaller diameter hose at the nozzle. In any event, for most efficient operation on large areas, the nozzle size should be kept to the maximum practicable.

(c) Sandblast Hose. Manufacturers of sandblast equipment recommend that

the hose diameter (inside) be 3 to 4 times greater than the nozzle diameter. For greatest efficiency, the hose length should be held to the minimum practicable, although a length of 150 feet or more can be used. Accidents resulting from static electricity can be eliminated if the hose is of the self-grounding type. A 1-inch diameter hose has sufficient flexibility for convenient use in nearly all circumstances. The flexibility of the hose decreases as the diameter and thickness increase. A 1¼-inch hose is satisfactory for most blast work, but larger diameter hoses are likely to be inflexible and difficult to manipulate when blasting surfaces other than large flat areas.

(5) *Sand Drying and Handling for Conventional Blast Cleaning.* Sand blast operations require large quantities of dry sand and the efficient drying and handling of this sand requires careful study. Drying of sand with salamanders and similar equipment has not proven very successful because of the large amount of labor required for firing and sand movement. The purchase of dried sand from commercial sources is occasionally economical where competitive bidding by a number of processors can be obtained. This procedure involves an extra cost in that transportation and storage facilities must be such as to keep the sand dry until it is used. The use of a rotary type drier has been found economical in the field in at least two districts of the Corps of Engineers. It consists essentially of a 26-inch diameter drum about 14 feet long supported in a horizontal position, a motor to rotate the drum, and a screw feed assembly. The drier is fired with oil, the moist sand is fed by conveyor into one end and emerges dry at the opposite end, and the over-size particles are automatically removed as the sand emerges from the drier. The capacity of the drier is about 2½ tons of sand per hour. A drier of this type has been obtained from the Mines Equipment Company, St. Louis, Missouri.

Dry sand can be handled efficiently by bucket or belt conveyors. Where a suitable crane or hoist is available, it has been found in many instances to be a good practice to have movable, bottom-discharge hoppers which can be transferred from the dry sand storage area to a gravity feed position immediately above the sandblast machine. Such hoppers should be of sufficient capacity to provide material for several hours of blasting. Sand movers based on the air jet or ejector principle are effective but use compressed air at a very high rate. Sometimes a combination of handling methods is needed, depending upon the type of structure being cleaned. Details of materials handling can best be worked out by each organization. Study and ingenuity in devising methods of handling the sand will be profitable.

(6) *General Notes on Conventional Field Blasting.* A skilled blaster will conserve sand and obtain much more cleaned area per hour than one less skilled. Operating personnel frequently fail to recognize the importance of securing experienced blasters or training those less proficient. The nozzle distance from the surface being cleaned will vary somewhat, depending upon the original condition of the surface and the surface conditions to be attained, but generally for high quality cleaning it should be between 12 and 18 inches; excessive distance can result in loss of efficiency because of loss of velocity of abrasive particles and excessive spread of the blast pattern. With respect to the angle between nozzle and surface to be blasted, theoretically the greatest impact is achieved by holding the nozzle perpendicular to the surface. However, with the nozzle perpendicular to the surface the rebounding particles may interfere with the oncoming abrasive from the nozzle. Thus, in practice the nozzle is generally held at a slight angle from perpendicular. Moreover, in some cleaning work the attainment of maximum impact may not lead to the greatest cleaning efficiency. For example in the removal of paint and bulky, poorly-adherent corrosion products, a 45-degree nozzle angle is probably more effective than the near-perpendicular position. The sand feed should be as much as the nozzle will handle without obtaining slugs and spurts of abrasive. The customary blasting pressure for structural steel work is in the neighborhood of 80–100 psi. For steel of small cross section and for light weight metals,

the air pressure should be reduced to avoid excessive deformation. If the air is obtained from a general supply line, a pressure regulator is necessary to maintain the desired pressures and will result in more uniform work. Sufficient volume of compressed air for blasting should be available to keep the nozzle pressure at the desired maximum. Compressors should be equipped with traps and separators to provide dry, oil-free air. Lines and hose lengths should be kept to the minimum practicable. Operators of dry blasting equipment must be supplied with air-fed respirators in addition to the regular protective clothing. The air supply line to the respirator should contain a carbon monoxide alarm system when internal combustion engines are operating in the vicinity of the intake of the air supply. Surfaces to be blasted should be solvent-cleaned of grease and oil before blasting is started, unless, as is frequently the case, the blasting job itself produces grease-free surfaces. Greater attention to this detail is required where the abrasive is reused and hence subject to possible grease contamination. The protection of surfaces not to be blasted should not be overlooked. Deposition of dust and spent abrasive on nearby machinery can be very harmful unless adequate precautions are taken. Grease and oil should be removed from adjacent machinery with exposed working surfaces in order to facilitate post-blasting cleanup work. Before a blast-cleaned surface is pretreated or painted, the dust which has collected must be blown down or brushed off. Careful scheduling of painting and sandblasting operations is required in order to avoid excessive deposition of dust and abrasive onto freshly painted surfaces. Insofar as possible the two operations should be carried on at different hours unless the operations are separated sufficiently, in space, as to avoid difficulty. A partial solution to the problem consists of having blast operators start their daily work several hours earlier than the painters.

(7) *Vacuum blasting.* Equipment is available for vacuum blasting which may be found suitable for some types of work. It consists essentially of an automatic, double compartment, continuous operating blast machine, a dust collector, a vacuum pump, an abrasive separator and reclaimer, and special blast nozzles, or guns. A source of compressed air for the blasting operation must be supplied separately. The blast nozzle is inclosed in a hollow metal cone to which a circular brush is attached on the open (large) end. A flexible vacuum line of large capacity is connected into the side of the cone for the purpose of removing spent abrasive and dust. The brush, when held against the surface to be blasted, prevents the escape of spent abrasive and corrosion products and offers sufficient resistance to the passage of air so that a partial vacuum can be maintained within the cone. The combination of vacuum and blast equipment retrieves the spent blast abrasive while simultaneously cleaning the steel. In the process of retrieving the abrasive, the dust and corrosion products are removed to a dust collector, thus minimizing the dust hazard. Any type of abrasive can be used, but normally steel grit is employed because of its great resistance to particle breakdown. The blasting operation consists briefly of moving the grit by compressed air from the blast machine through a hose to the blast nozzle, returning by vacuum the grit and dust from the cone surrounding the nozzle to the reclaimer, and removing the dust to the dust collector. The abrasive charge within the machine is recirculated until it is unsuitable for further use. All reclaiming and dust separation operations are automatic. Experimental use of this equipment in 1950 on approximately 23,000 square feet of structural steel in dam tainter gates led to the following observations:

(a) In vacuum blasting, practically no dust escapes to contaminate the atmosphere. In semi-open blasting (i.e., holding the cone containing the nozzle a slight distance away from the surfaces and making no attempt to immediately reclaim the bulk of the abrasive) with steel grit abrasive, the dust created is appreciable, but not nearly as great as with conventional sandblasting equipment using sand as the abrasive. In semi-open blasting, however, sufficient dust is generated to require the use of respirators by workmen.

(b) The vacuum method of blasting in the field is much less efficient than

conventional sandblasting methods for structural surfaces such as those which make up tainter and roller gates. It is impracticable to blast highly irregular surfaces by the vacuum method, unless provisions are made for catching the appreciable amount of grit lost in the operation. If the machine were placed in a shop and adapted specifically for cleaning repetitive, small-scale surfaces, it would probably be found more efficient.

(c) The surfaces to be cleaned by close blasting (i.e., with the enclosing cone held firmly against the surface to prevent abrasive loss) should not be too heavily coated with rust, silt, algae, and other foreign matter. Under extreme conditions of surface contamination, the machine may not be able to function more than a few minutes without becoming clogged.

(d) As a semi-open blaster, the equipment has proven useful during the winter season for cleaning the interior surfaces of enclosed dam gates. The supplying of sandblast sand for use with conventional equipment is sometimes difficult when the river is filled with ice. Since only a relatively small quantity of steel grit is used on the interior of gates where it can be trapped and reclaimed, the supplying of abrasive does not become a problem.

(e) The minimum number of workmen required to operate the machine is two. Even though all operations, except holding and guiding of the blast nozzle and cleaning the dust collector, are automatic, the degree of concentration required of the operator for closed blasting is such that continuous operation of the machine on vertical and/or irregular surfaces requires frequent relief of the operator.

d. **Flame Treating.** The process consists of passing a neutral or slightly oxidizing oxy-acetylene flame over the steel surfaces to be painted. It originally was called flame cleaning and more recently flame priming and these terms are believed still to be in common usage by engineers. The flame is passed over the surface at an angle of about 45° and at a speed of from 10 to 20 feet per minute. For flat surfaces, the apparatus is provided with a row of small, brush-like flames; for rivet heads, corners, and areas not easily accessible, a circular group of flames is sometimes employed. The heat thus applied removes or loosens semi-adherent and loose millscale as a result of the difference in expansion between the scale and the steel. Rapid vaporization of any moisture beneath the scale facilitates the action. Immediately after the flame has passed over the metal, the surface is wire-brushed to remove all loose particles. Application of paint should follow as soon as practicable, while the temperature of the metal is well above ambient in order to obtain the maximum benefit from the flame treatments. However, thorough wire brushing of the surfaces should not be neglected in order merely to apply the paint while the surfaces are still hot from the flame treatment. The oxy-acetylene flame will burn oil, grease, and paint, but, because of their slow rates of combustion it is considered inefficient for removal of such materials. Moreover, the prolonged heating necessary to effect their removal may be sufficient to cause warping of the base metal surfaces. Some of the scale and corrosion products are loosened and/or popped-off, but the wire-brushing which follows the flame heating accomplishes most of the cleaning which is obtained. The method is in no way comparable in effectiveness to blast cleaning, since the surfaces are not roughened to provide better adhesion of coatings, and all of the scale and rust are not removed. However, some advantages of flame treating are:

(1) The durability of paints may be improved somewhat when they are applied to warm surfaces rather than cold surfaces.

(2) Any moisture on the steel surfaces is removed, provided the flame is applied for a sufficiently long time.

(3) Flame treating and wire-brushing produces cleaner surfaces than wire-brushing alone.

(4) The equipment is easily portable and does not require skilled workmen for operation.

The flame treating procedure has been studied briefly in the Rock Island District. The equipment was used to a limited extent on maintenance painting of structural steel surfaces during winter months. In this work the object was not to clean the steel but to remove any moisture present and provide a warm surface. The surfaces were sandblasted and then heated with the oxy-acetylene flame just prior to painting. The temperature of the metal was 30° F. prior to heating and was raised to 130° F. with two passes of the flame priming gun. It took an average of 24 minutes on each 100 square feet of steel skinplate (thickness ⅜-inch) to change the temperature from 30° to 130° F. Within a few minutes after heating the steel was painted, and after one hour the temperature of the metal had dropped to 65° F. Other observations that were made in connection with this work follow: Immediately upon application of the flame to the cold surfaces a visible film of condensed moisture from the gas combustion products, became apparent and a fairly low rate of flame travel had to be maintained to evaporate the film. The source of this moisture has erroneously been reported by some as coming from the metal itself and they have stated that the heat "drove the water from the steel." Within a few minutes after being flame treated, a large portion of the sandblasted steel surfaces turned rusty in color, although the film of rust was extremely thin and adherent. In a structural member, transmission of heat away from the point of impingement of the flame is slow. Areas a foot away from a point heated to 150° F. with the flame remained relatively cold to the touch; the back side of the steel reached approximately the same temperature as the side which was directly under the flame.

In connection with other experimental work, it has been found that the improvement in durability of a phenolic type coating resulting from heating steel above normal painting temperatures is slight, unless temperatures of approximately 230° F. are maintained for about two hours. Paints based on vinyl resins, alkyd vehicles, and those in which the vehicle is principally linseed oil were not included in the experimental work. It is questionable whether flame treating can be justified on the basis of improving the durability of the coating as a result of application to warm surfaces. For winter painting work, some advantage might be gained in the use of flame treating to warm the steel and dispel surface frost and moisture. The cost of such treatment, though not known with accuracy, is very appreciable and can hardly be considered justifiable in view of the limited objective of the flame treating operation. In any event, it could be used only on bare steel surfaces prior to application of the prime coat of paint inasmuch as applied films would be subject to damage from the impinging flame. Whether flame treating followed by wire brushing can be economically justified over wire brushing alone cannot be determined easily or conclusively but it is highly doubtful. On surfaces cleaned by wire brushing, a good wetting primer should be used for best performance, and, with durable finish coats, this coating will not need much attention for a period of about ten years in normal atmospheric exposure. In this period of time it is questionable whether the effects of flame treating would be distinguishable. For underwater surfaces, blast cleaning is considered necessary and therefore flame cleaning has little indicated use.

1-13. METAL-CONDITIONING AND PRETREATMENT OF SANDBLASTED FERROUS SURFACES

It will be noted that the schedule of painting herein (par. 1-54*c*(2)) requires the use of either a phosphoric acid pretreatment (chemical metal conditioner) or vinyl type wash coat pretreatment of sandblasted ferrous surfaces which are to be coated with certain phenolic and vinyl type paint systems. It will also be noted from the schedule that either of the two pretreatment methods may be used in conjunction with phenolic type paint systems, although the *vinyl wash coat pretreatment is generally to be preferred.* In the case of certain vinyl paint systems, the vinyl type wash coat *must* be used. The use of these pretreatment methods for a number of years in several districts of the Corps has produced conclusive evidence that for underwater and high humidity exposure they add materially to the durability of the pro-

tective coating system. In addition to imparting added durability to the coating system, the vinyl wash coat affords temporary protection to freshly cleaned surfaces before the first prime coat of paint is applied. The vinyl wash coat treatment will protect surfaces for a day or two even under moderately adverse weather conditions. The chemical metal conditioner may give limited protection for a few hours under conditions of high humidity but in general the protection afforded is not as positive nor as extended as that furnished by the vinyl type wash primer. In atmospheric exposure, where blast cleaning generally is not required, these treatments were not found beneficial and are, therefore, not recommended for this exposure condition. Information concerning the use of these metal conditioners follows:

a. **Chemical Metal Conditioner.** This material, MIL-M-10578A, Type II, a mixture of phosphoric acid, wetting agent, water-soluble oil solvent, and water *normally requires dilution* in the proportion of three parts of water by volume to one part of the conditioner before it is used, because it is purchased in a concentrated solution. An acid concentration of about 5 to 7 percent (by weight) will produce the desired reaction with steel when the area to be treated is not exposed to high summer temperatures, direct sunlight, and strong wind. Wind and sunlight cause too rapid evaporation of the mixing water, resulting in a concentrated acid mixture which may lie on the surface and not completely react with the metal. When a dry, powdery surface, grayish-white in color, develops within a few minutes after application, the acid has reacted properly and has the proper dilution. If used on very damp, humid days, the surfaces to which the conditioner have been applied may take a considerable time to dry and show the characteristic reaction. If a dark color develops and the surface is somewhat sticky, the acid is too concentrated. In such cases, wiping with water-dampened rags and allowing to dry again may bring about the desired appearance. If not, the surfaces should be rinsed with water and retreated with a somewhat more dilute solution. It is sometimes necessary, in order to obtain the proper reaction, to use one concentration on warmed surfaces in direct sunlight and a different concentration on shaded areas. A practical procedure for field use of the chemical conditioner is to take small quantities of the concentrated conditioner, dilute them with 2, 3, 4, and 5 parts by volume of water and apply each of these solutions to small areas of the work. After drying, the reaction of each with the metal can be observed and the dilution ratio that gave the best reaction can be selected for preparation of the working volume. The compound is easily applied with whitewash brushes which permit working the conditioner into the pits, around rivets, and other similar irregular surfaces. It can also be applied by spray, but the brush method is preferred to assure intimate contact of the liquid with the metal and to avoid the use of dangerously excessive amounts. An alert and conscientious inspector is very important to insure the successful use of the metal conditioner. It has been noted that inexperienced personnel tend either to be too careless or too cautious in using the conditioner. Surfaces which generally do not show the gray powdery reaction should be remedied as indicated before, but the fact that every square inch of a relatively large area does not show the characteristic appearance should not be cause for corrective action or alarm. Treated surfaces usually present a somewhat mottled appearance. The danger of damage to the subsequently applied paint film is not great if the chemical conditioner is applied only in amount sufficient to thoroughly wet the surfaces and if unreacted acid which normally collects along angles and ledges formed by butt straps, beams, and channels is removed by wiping with damp rags and redried before paint is applied. If the excess acid is not removed, it will lie dormant under the paint coating until water diffuses through the film, at which time the acid may become active and adversely affect the paint.

The chemical pretreatment solution is intended in this manual for use principally on sandblasted structural steel surfaces. Its intended action therefore will be limited to metal conditioning and *does not include removal of rust.* The conditioner is not recommended for use on structural steel surfaces which include poorly cleaned areas, millscale, and other foreign material, because the acid will not react the same on each area. Similarly, the con-

ditioner is not recommended for touchup work because the paint surrounding the area being repaired may be damaged by the acid in the conditioner.

It is emphasized that when the metal conditioner is used, as described in this manual, there is a deviation from the instructions contained in the MIL–M–10578A, Specification for Type II material in that wiping off of the treated surfaces is not contemplated. Rather it is the intention herein to apply the solution sparingly and permit it to react and dry. It is considered impracticable to wipe off the large scale structural surfaces contemplated and, on the basis of wide experience, such wipe-off procedures are unnecessary if precautions are taken to insure that the reaction of acid with the metal goes forward to completion. This does not mean, of course, that areas showing excess acid and an unsatisfactory reaction should not be wiped off as a safety precaution. It is emphasized that Type I material covered by MIL–M–10578A should *not* be used since its acid content is too high for the contemplated use.

b. **Vinyl Type Wash Coat Pretreatment.** The wash coat material (popularly known as WP–1) is procured under Military Specification MIL–C–15328A, "Coating, Pretreatment (Formula No. 117 for Metals)," and is furnished as two separate components consisting of base solution (resin component) and diluent (acid component). Twenty-five parts by weight or volume of the diluent are *slowly* added and thoroughly mixed into one hundred parts of the base solution just prior to use. *If the diluent is added too rapidly, without thorough mixing or if the base solution is poured into the diluent, the mixture will gel and be unusable.* The vinyl type wash coat base material (resin component), by its nature, tends to settle on storage, and care must be taken that the settled material is thoroughly redispersed prior to use. The diluent (acid component) contains a specific amount of included water. The water content, with respect to the stability of the base-diluent mixture, is quite critical and difficulties with gelling, upon combining the two components, have occasionally been encountered in the field, even though the mixed materials showed no such incompatibility in tests at the time of procurement. The gelling difficulty, when caused by a deficiency of water, was overcome by carefully adding small increments of water to test batches until a point was reached where the base-diluent mixture on longer gelled. Field batches were then adjusted by adding the determined amount of water to the diluent prior to mixing with the base solution. An excess of water in the diluent may also cause gelling of the mixture. If the diluent as furnished contains a sufficient excess of water to cause gelling, it would appear that little can be done except to obtain new diluent or blend the unsatisfactory material with diluent containing less than the normal amount of water. Spray equipment employed for application should be cleaned as soon as practicable after use with normal Butanol, 99 percent grade Isopropanol, or denatured ethyl alcohol since even satisfactory wash coat materials may form insoluble gels after the base solution-diluent mixture has stood more than 8 hours. Wash coat material which has gelled in spray lines is practically impossible to remove.

The wash coat should be applied at a coverage rate of about 250 to 300 square feet per gallon, using relatively low atomization and fluid pressure, to give a thin but continuous film of 0.3 to 0.5 mil dry film thickness. More than 0.5 mil should not be applied under any circumstances. A DeVilbiss No. 704 air cap with E fluid tip (or equivalent) works well for application of the wash coat. The spray gun should be held fairly close and perpendicular to the surfaces during spraying to avoid excessive overspray and loss of volatiles. Since gauges for measuring dry film thickness on blast roughened field surfaces are not accurate in the case of such thin films, it is advisable to prepare small, smooth steel panels with several different known thicknesses for use by the inspector. By means of these panels he can determine by visual comparison whether the proper thickness of the wash coat is being applied. The dry wash coat film should be thick enough to give a continuous film, but should not be so heavy as to completely hide the underlying metal, i.e., the base metal should show faintly through the dry film. Specification MIL–C–15328A prescribes the use of a small amount of lampblack pigment in the washcoat base, whereas the formulation originally used did not contain lamp-

black. The presence of the black pigment makes for more complete hiding and hence increases the difficulty somewhat of estimating proper thickness of application by visual inspection. Nevertheless, a little experience will soon enable the inspector to determine whether too much or too little of the vinyl type wash coat is being applied. Generally, one fairly rapid pass of the spray gun is sufficient to apply an adequate thickness of the wash coat.

If, when the specified amount of diluent has been added to the base solution, the mixture does not deposit as a wet, uniform film when sprayed on the steel, it should be additionally thinned with 99 percent Isopropanol or with normal Butanol (Fed. Spec. TT–B–846). The normal Butanol is preferable during periods of high humidity since it tends to reduce blushing difficulties (blushing is caused by condensation of water within or on the drying film and manifests itself as a lighter-than-normal colored film with poor physical characteristics). The diluent, when used in the prescribed amount, adds a carefully controlled amount of acid to the mixture and should not be used for this additional thinning. It will be found that more thinning will be required to obtain good application characteristics in very warm, windy weather than under more moderate conditions.

It is important that the wash coat solution be applied within 8 hours after the diluent is added, even though its condition appears satisfactory after the time limit has expired. The vapors from the solvents in the wash coat, though no more toxic than turpentine, are quite penetrating and will prove disagreeable in confined areas, unless adequate ventilation or air-fed respirators are provided. Although the wash coat reportedly exhibits better adhesion to incompletely cleaned structural surfaces than most paints, it will not give good results over grease, loose millscale, or corrosion products. It would be expected to perform fairly well on surfaces prepared by the brushoff blast cleaning method previously described, but is not recommended at this time for steel surfaces prepared by wirebrushing. On all structural steel surfaces subject to underwater exposure for which the wash coat is specified in this manual, blast cleaning which approximates the white steel surface finish is contemplated.

It is to be noted that dry films of the vinyl type wash coat normally undergo some color change and that the end color after a 24-hour drying period may vary with weather conditions, thickness, etc. The fact that the dried film does not always exhibit exactly the same appearance should not, therefore, give rise to alarm. It is rather popularly believed that the vinyl type wash coat can be applied over visibly wet surfaces without adverse results. In practice, this has led to trouble, since the applied wash coat may dry on top of the water film without absorbing it, thus resulting in poor adhesion to the base metal or the applied film may turn white and be lacking in strength and distensibility. A slight dampness of the surfaces may be tolerated although thoroughly dry surfaces are recommended as a general practice. If the wash coat *must* be applied to damp surfaces, it should be applied by brush or swab so as to break up and incorporate the film of water which otherwise tends to remain interposed between the metal and wash coat film. Although the wash coat is more adaptable to spraying, it can be brushed or swabbed on without appreciable difficulty.

Subsequent coats of paint may be applied after one hour of drying of the wash coat. Longer periods of drying up to several days are permissible as long as damage to the wash coat film from corrosion or other causes has not taken place.

SELECTION OF COATINGS AND PAINTING OF FERROUS METAL SURFACES

1–14. GENERAL

The selection of a coating system should involve careful consideration of the exposure factors involved. No single paint or type of paint will be satisfactory from an appearance and durability standpoint under the multitude of surface and exposure conditions which are inci-

dental to various Corps of Engineers' structures. In many instances, the over-enthusiasm of paint salesmen has led to recommendations for specific exposure conditions which are wholly inconsistent with the capabilities of the paint coating. In numerous other instances, it is the consumer himself who makes the error and takes a paint system which has given good service under one set of exposure conditions and assumes that it will perform equally well under entirely different circumstances. The schedule (par. 1–54*c*) shows at least one paint system which will give adequate and economical protection for most types of surface and exposure likely to be encountered in the painting of ferrous surface components of Corps of Engineers' structures. The surface preparation and paint systems specified in the schedule are the results of considerable experience in the Corps of Engineers and other agencies. It is believed that if the systems are used as indicated they will give economical protection. The assumption that they will be equally satisfactory when used under other than the specified conditions is entirely unwarranted.

The following paragraphs are intended to amplify the information contained in the schedule and to answer questions which will arise in the minds of those who have occasion to select a specific paint system for ferrous surfaces. It is believed, moreover, that some detailed knowledge concerning the systems will permit operating and inspecting personnel to obtain the maximum service from the coatings. Also some protective coatings will be discussed which, for reasons of brevity, incomplete evaluation, or other reasons, are not included in the schedule.

The information which follows attempts to cover by general paragraph headings the many exposure conditions which may be encountered on Corps of Engineers' projects. However, there will be numerous occasions when mixed exposure conditions and other circumstances, such as inaccessibility after erection and impracticability of blast cleaning in the field, will require that considerable judgment be exercised in selection of the coating systems. To serve as an example of the problems that may be encountered and also because considerable study has been given to the subject, the selection of coatings for several items of a hydroelectric project is discussed separately in the subparagraphs which follow.

a. **Penstocks, Draft Tube Liners, Spiral Cases, and Spiral Case Extensions.** In the paint schedule (par. 1–54*c*(4)), a hot-applied coal tar enamel system is specified for the interior surfaces of these items because it is the most durable coating known for the exposure condition involved. Since these surfaces are accessible for maintenance only at considerable cost and would involve shut down of vital equipment, it is considered from a long-range viewpoint that the hot-applied coal tar coating is the most economical system for these items. Although coal tar enamel is the first choice, based on long-term experience, for interior penstock surfaces, there may be occasions when consideration of some other type of protective coating may be indicated. A satisfactory enamelling job on penstock surfaces requires highly skilled workmen, the supply of which is quite limited. Coal tar enamel applied by unskilled workmen is certain to suffer in performance, when compared to enamel applied by skilled men. Where there is a likelihood that prospective enamel work will not be done by experienced crews consideration may be given to employing the vinyl type system shown in the schedule (par. 1–54*c*(2)), for interior surfaces of penstocks. If used for such surfaces, the total thickness of the vinyl system should be increased to an average of 7.5 mil by interposing one or more additional coats of the V–101 red lead paint.

Exterior surfaces of penstocks, depending upon the design of the structure, may be subjected to ordinary weathering or to high humidity conditions and moisture condensation (penstocks in tunnels). Also, some areas of steel may be protected as the result of being embedded in concrete. The surfaces exposed to ordinary outside weathering would normally be treated in the same manner as other exterior atmospheric exposed steel (par. 1–16*a*), unless climatic conditions and reservoir water temperatures are expected to be such as will cause frequent condensation on the penstock surfaces, in which event blast cleaning and one

of the phenolic or vinyl paint systems would be indicated. The exposure condition found in tunnels requires that a coating of high resistance to high humidity conditions and condensed water be selected for maximum protection of the penstocks exterior surfaces. Here the coal tar enamel system would also serve very well from a durability standpoint. However, since the restricted space available to workmen for cleaning and painting these surfaces increases the hazard of handling hot coal tar enamel, and since the exposure condition can be combatted successfully with a phenolic or vinyl paint system, the selection of a coating is narrowed to one of the latter. Because drying conditions normally will not be good in the space between the tunnel wall and the penstock, and since the phenolic paint system is much slower drying than the vinyl paint system, the latter should be selected as the more suitable. Also, the speed of drying and adaptability of vinyl lacquers to repainting will offer advantages for maintenance painting when it becomes necessary. Exterior penstock surfaces to be embedded in concrete require no painting. Blast cleaning, required for satisfactory performance of both the vinyl paint and coal tar enamel coating, is preferably done in the field after erection. However, in some instances it may be found to be more practicable to blast clean and apply one or more of the prescribed number of coats to the bulk of the surfaces in the field prior to erection, in which case, the riveted or welded joints would be cleaned, preferably by blasting, and coated after erection. Exterior surfaces of spiral (scroll) cases which are to be covered with cork-mastic prior to embedment in concrete should be cleaned of grease, loose scale, and rust by wire brushing or other mechanical methods. Blast cleaning, though desirable, is not considered mandatory for adequate adhesion of this type coating under the circumstances.

b. **Surge Tanks.** Interior surfaces of risers and surge tanks generally present a problem of mixed exposure conditions; one area being continuously under water, another area being exposed alternately to water and the atmosphere, and still another to atmosphere only. The vinyl system shown in paragraph 1–54*c*(2) is considered to be highly suitable for these surfaces, since the coating has excellent durability under all of the exposure conditions involved. Likewise, the phenolic systems shown in the same paragraph of the schedule would perform well on these surfaces, although for reasons related to coating application and maintenance, the vinyl system is preferred. The hot-applied coal tar enamel system might also be considered for the interior surfaces of risers and surge tanks, except that it would be suitable only for the continuously immersed areas, thus necessitating a different coating above the low water line. The difficulties stemming from applying two types of coatings to these surfaces are considered to outweigh any advantages in coating performance that might be gained from the coal tar enamel.

Exterior surfaces of surge tanks would normally be treated in the same manner as other exterior, atmospheric exposed surfaces (par. 1–16*a*), unless there is reason to believe, based on climatic conditions and reservoir water temperatures, that frequent and heavy moisture condensation on the tank exterior will be an exposure factor, in which case blast cleaning and one of the vinyl or phenolic paint systems would be indicated, with the vinyl type system preferred. If freezing of water in the surge tanks is a problem which will be encountered, consideration could be given to the use of a cork-mastic type of coating designed to provide both corrosion protection and insulation.

c. **Gates, Crest and Sluice (Tractor Type).** Although paragraph 1–54*c*(2) includes either phenolic or vinyl paints for blast cleaned surfaces of gates subject to immersion the vinyl system is generally preferred. In the case of gates of the tractor type, the problem of blast cleaning without damage to the stainless steel roller chain and track assembly is involved. Usually the gates or assembled sections thereof are shipped to the erection site with the track bolted in place but with the roller chains not installed. In such cases it is believed that, with the aid of temporary shields, the gate can be blasted and painted in the field without damage to the machined, stainless steel track. If the gate was shipped with the

roller chain installed it should be removed prior to blasting. In some cases it may be advisable, despite the general preference for field cleaning and painting, to permit blast cleaning and painting of these gates in the fabrication shop prior to installing the roller or track assembly. If all four coats of paint are applied in the shop with only minor touchup painting to be done in the field, either the phenolic or vinyl paint systems might be selected. However, if only one or two coats are applied in the shop, thought must be given to the adhesion of finish coats which will be applied months later in the field. Since the vinyl paints normally do not suffer from lack of intercoat adhesion and the time interval between application of succeeding coats is not critical (par. 1–17*b*(2) and (3)), and since some difficulty in adhesion of finish coats to weathered and hardened primers of the phenolic type may be experienced, it would be particularly advisable to select a vinyl system for gates of the tractor type.

It can be seen by the examples cited above that the specification writer must carefully balance all the factors involved, such as exposure conditions, relative durability of various coating systems, application characteristics of the coatings, accessibility for cleaning and painting after erection, accessibility after the structure has been placed in operation, replacement costs of the item to be protected, erection procedure or schedule, and facilities available to do the cleaning and painting work. Only by detailed study of all the items to be protected will the person responsible for this work arrive at a satisfactory and economical solution. The objective to be kept in mind is adequate protection for the least cost per unit area per unit period of exposure.

1–15. MANUFACTURERS' STANDARD COATINGS ON EQUIPMENT AND SIMILAR ITEMS INVOLVING MINOR AREAS

On fabricated and assembled items of minor area such as pumps, electrical equipment, and small floating plant items, paint systems conforming to the manufacturers' standard practice should be used in all practicable cases. Inflexible adherence to the customary specification requirements for such items, particularly where the number and surface area involved is small, is certain to disrupt manufacturing processes and result in unreasonably higher costs. However, specific instances may arise where there is need for conformance to a uniform color scheme or where exceptional corrosion conditions must be combatted. In the former case, all that is necessary is to accept the manufacturers' standard coating and finish paint the item with the desired color after installation. In the latter case, a suitable paint system for the exposure conditions involved may be specified despite the higher cost.

1–16. COATINGS FOR EXTERIOR AND INTERIOR FERROUS SURFACES SUBJECT ONLY TO NORMAL ATMOSPHERIC EXPOSURE

a. **Exterior Ferrous Surfaces.** It will be noted that the schedule herein (par. 1–54*c*(1)), does not prescribe blast cleaning for this type of exposure. It will also be noted that the vehicle of the specified primer (first coat), consists principally of linseed oil uncombined with resins. Experience has shown that structural steel surfaces, subject only to normal atmospheric exposure, which have been cleaned by solvents, power wire brushing, scraping, and similar superficial methods can be satisfactorily coated without recourse to blasting if linseed oil primers are used. Such slow drying oil type primers have the ability to thoroughly wet the underlying surfaces and penetrate to base metal beneath the edges of semi-adherent millscale as well as through residual and tightly bound rust which are always present when cleaning methods short of blasting or pickling are used. Blast cleaning to any of the degrees of surface cleanliness described in paragraph 1–12*c*(2) would, of course, be highly acceptable as a voluntarily selected method of surface preparation on contract work. Phenolic type aluminum topcoats P–2, P–3, or P–9, formulations of which are shown in paragraph 1–60 of the manual, complete the system for exterior atmospheric exposure. All three of the phenolic aluminum paints are believed to be of comparable durability. The system consisting of 1

coat of red lead primer similar to Fed. Spec. TT-P-86a, Type I, with aluminum phenolic topcoats has furnished good protection and appearance on service bridge structures in the upper Mississippi River for periods up to 13 years without appreciable maintenance or upkeep. If finish colors other than aluminum are desired, finish paints conforming to Fed. Specs. TT-P-81c (covering a wide variety of medium shades of gray, buff, green, etc.); TT-P-31b (dark red or brown); or TT-P-61b (black) may be substituted, although with some loss of durability of the system.

It will be seen that the schedule requires new steel, which is not to be blasted, to be primed in the shop as soon as practicable after fabrication. This provision is included to prevent the more or less common practice of allowing steel to weather to remove millscale. In the light of extensive experimental work, essentially intact millscale is a better surface for receiving paint than a rusted surface which has been superficially cleaned by methods short of blasting. The shop prime coat should be touched up as necessary to maintain it in good condition at all times prior to receiving the finish coats. In rare cases, the interval between shop coating and field application of the overall subsequent field coat may be so long as to result in deterioration of the shopcoat to a point where it becomes advisable to apply an additional overall field coat of primer of the same type as was used for the shop coat. Payment for such an additional prime coat would present a problem on contract construction work in the absence of an applicable provision in the specification. On the other hand, a provision in the construction specification which would provide that the contractor, at his expense, apply an additional coat of primer in the event of serious deterioration of the shop coat is undesirable for two reasons; first, it would be difficult to fairly determine when the additional coat was necessary and second the possibility of incurring the expense of an extra paint coat would discourage a contractor from getting his steel onto the job at the earliest opportunity, a practice which, particularly in times of short supply, is presumed to be encouraged.

Although the atmospheric exposure paint systems indicated in the schedule are generally intended for average conditions, it is considered that they will give satisfactory service even in exposures involving moderately severe conditions of humidity, industrial contamination of surfaces, etc. However, under such moderately severe exposure conditions, the inclusion of a second prime coat to make a 4-coat system is advisable. In circumstances where the atmospheric exposure conditions involve such extremes as prolonged condensation, heavy chemical and industrial contamination, or marine atmospheric conditions, consideration should be given to blast cleaning and use of one of the vinyl or phenolic type systems listed in the schedule (par. 1-54*c*(2)) normally employed for steel surfaces subject to immersion. It is to be noted, however, that even under such difficult exposure conditions the phenolic and vinyl systems will probably not perform any better than the systems based on an oil-type primer, *unless the surfaces are cleaned by blasting.* However, in the case of atmospheric exposure, the quality of the blasting, may be relaxed somewhat from that which is required for intermittent or continuously submerged surfaces.

b. **Interior Ferrous Surfaces.** In this category are included those surfaces which are protected from direct contact with destructive atmospheric elements (such as sunlight and rain) as the result of their being inclosed within weathertight structures. Structural framework of buildings and similar surfaces which will largely be inaccessible after construction are also included. As indicated in the schedule, two coats of primer conforming to Fed. Spec. TT-P-86a, Type I, are considered satisfactory for this type of exposure. As a matter of economy the paint system for steel in this type of exposure may well be limited to the shop coat if the enclosing surfaces are thoroughly and permanently weathertight and watertight and if the shop coat is in good condition at the time of enclosure of the steel surfaces. At any rate, in finished interior spaces, the second coat of primer may be omitted and the surfaces finish painted to conform to adjacent areas. It should be pointed out that the one- or two-coat system is adequate only if the interior ferrous surfaces are subject to the mild condi-

tions customarily associated with interior exposure. If there are possibilities that the exposure conditions will involve long periods of high humidity, condensation, or leakage water, the steel surfaces should receive additional coats or be painted with a system more adequately designed to combat the conditions. Ferrous surfaces within the walls of buildings particularly may need more adequate protection than the prescribed one- or two-coat system under certain circumstances of exposure and construction which may bring about a serious moisture condition within the walls stemming from condensation, wind-driven rain or water seepage. The inaccessibility of the enclosed surfaces for maintenance painting adds to the need for long-range protection or assurance that the exposure conditions are not seriously corrosive.

1–17. COATINGS FOR EXTERIOR AND INTERIOR FERROUS SURFACES SUBJECT TO CONTINUOUS OR INTERMITTENT IMMERSION AND ABRASION IN FRESH WATER (VINYL AND PHENOLIC TYPE PAINTS)

Included in this exposure category are surfaces which, in whole or in part, are exposed continuously or intermittently to immersion and frequently abrasion in fresh water (not sea water). Entire integral areas of structural components (sluice gates, crest gates, roller gates, etc.) are generally treated as submerged surfaces, even though exposed partly in the atmosphere, in order to avoid two different cleaning procedures and coating systems on one integral surface. Ferrous surfaces which are immersed for relatively short periods of time should be blast cleaned and coated with underwater paint systems, if the water exposure period, continuous or intermittent, is longer than about 3 weeks a year. The more economical systems (because blast cleaning is not required) listed for atmospheric exposure may be used if the water immersion period is less than this proportional amount of the total time. The systems based on phenolic or vinyl resins, shown in paragraph 1–54*c*(2) are the most versatile of the coatings used for submerged surfaces, since they are not only generally suitable either for continuous or intermittent exposure in quiet or flowing water, but also have excellent durability on those areas of submersible components which are exposed only to the atmosphere. They will perform satisfactorily on steel surfaces subject to water velocities and attendant abrasive conditions found in most hydraulic structures. Figures 3 and 4 illustrate steel dam gates subject to abrasion from ice and debris which have been successfully coated with phenolic and vinyl type paints. On surfaces involving very high velocities such as certain areas of high-head gates or on surfaces involving even a mild degree of cavitation erosion, the long-range effectiveness of these or any of the more common coating types is questionable. For these surfaces thick, heat-cured neoprene coatings, applied in liquid form appear to offer some promise (paragraph 1–23*d*). The cost and complexity of application and/or curing procedures for these materials, however, are such as to preclude their use except on relatively small surfaces which will be accessible only with great difficulty.

The phenolic and vinyl type paints prescribed for exterior and interior surfaces subject to immersion, are described in some detail in the following paragraphs.

a. **Phenolic Type Paints for Ferrous Surfaces Subject to Immersion.**

(1) *General.* The first five paint systems outlined in paragraph 1–54*c*(2) of the schedule are of the phenolic type, a brief discussion of which follows: The designation *phenolic type paints* springs from the fact that the vehicles for these paints consist of a varnish made with so-called phenolic resins. The resins themselves are clear, brittle, light to dark colored materials which are formed in a reaction between formaldehyde and certain phenol-like compounds. Although there are many resins of this general type made, those suitable for making varnishes must be soluble in drying oils when heated to a temperature somewhat above the melting point of the resins. This combining of resin and drying oil under a specific heating schedule is the process known as cooking. When the cooking is completed, the combined material is partially cooled, reduced to a workable consistency with suitable solvents and thinners, and driers added. There are a considerable number of phenolic resins suitable

for varnish making and most of the drying oils can be processed with these resins. It will be clear then that the possible combinations of resins with oils, together with the possibility of varying the oil to resin ratio (i.e., oil length), present a very large number of varnishes from which to make a selection.

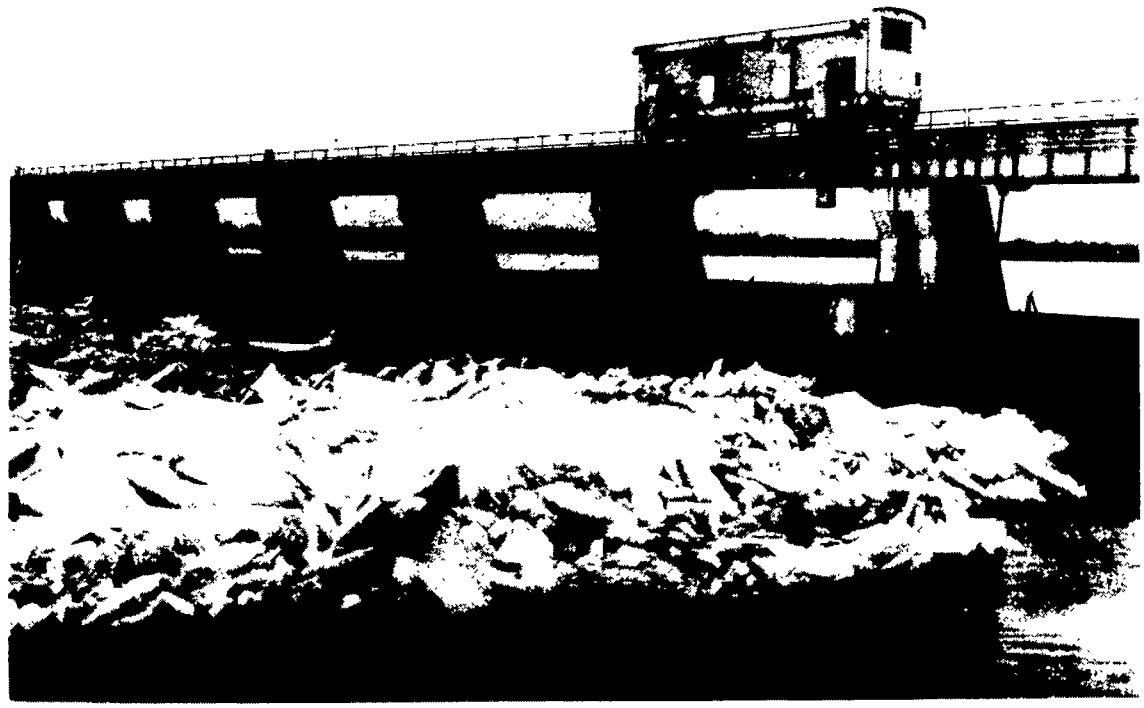

FIGURE 3. *Ice floes against upstream face of gate.*
(Mississippi River Navigation Dam)

Although there are certain considerations relating to compatibility of pigments and phenolic varnishes which must be taken into account, most of the phenolic varnishes are suitable for use with a large number of pigment types, concentrations, and combinations. It is apparent, therefore, that possible paint formulations composed of phenolic varnishes and pigments are almost infinite. Several thousand test panels coated with phenolic type paints have been made by the Rock Island District Paint Laboratory alone without beginning to exhaust the possibilities.

Phenolic varnish vehicles for underwater paints to be used on steel surfaces are generally formulated in the medium oil length range of 25 to 33 gallons of oil to 100 pounds of resin. For this exposure, the oil constituent of the varnish is usually all, or a large part, tung oil. However, other oils and combinations thereof, including linseed, oiticica, and dehydrated castor, have been used with fair to very good results. Phenolic varnishes formulated for this service are characterized by good flexibility and abrasion resistance, excellent water resistance, and excellent resistance to deterioration upon aging. These characteristics modified to greater or lesser degree by the addition of various types and quantities of pigments are retained by the mixed paint of which the phenolic vehicle is the binder or film-forming constituent.

(2) *Selection of Phenolic Type Paint System for Ferrous Surfaces Subject to Immersion.* With reference to the selection of one of the several phenolic systems shown



FIGURE 4. *Typical example of debris at face of gate.*
(Mississippi River Navigation Dam)

in paragraph 1–54*c*(2) of the schedule, no hard and fast rules can be given. The first system (P–4, P–4, P–2, P–2) has been used over the past twelve to fourteen years with good results in the near neutral waters of the upper Mississippi River, both with and without sand reinforcement (see following subparagraph) and in quiet and erosive water. The systems composed of four coats of formula P–5, four coats of P–6, or four coats of P–7 have been used with good results in the variable water of the Ohio River. The system composed of four coats of Fed. Spec. TT–P–86a, Type IV, Red Lead Paint, and similar systems have performed well in maintenance work and in several field tests in the Ohio and Mississippi Rivers. Where the red lead color of TT–P–86a as a finish coat is objectionable, the last two coats may be replaced by two coats of aluminum finish paint formula P–2. Similarly, the third and fourth coats of the P–6, and the P–7 multiplecoat systems may be replaced with two finish coats of formula P–3, if aluminum finish color is desired. In the absence of experience with a particular phenolic system in a given location, it is suggested that the system composed of four coats of TT–P–86a, Type IV, paint (or with substituted aluminum top coats as indicated above) is as likely as any to perform adequately. The system consisting of four coats of formula P–5 is particularly satisfactory for painting the interior of potable water tanks since its use does not bring up the frequently unfounded yet troublesome questions concerning the toxicity of paints pigmented with lead-containing pigments. Organizations charged with the maintenance of large areas of structural steel subject to immersion in fresh water may wish to conduct comparative tests of several of the phenolic systems in order to determine which is best adapted to the particular exposure conditions involved. It is to be noted that all of the phenolic systems, when applied to blast cleaned steel, will have excellent durability in exterior atmospheric exposure *but will not perform adequately on superficially cleaned surfaces.* However, when phenolic paints are used on

atmospheric exposed steel the quality of blast cleaning may be relaxed appreciably from the white metal classification (par. 1–12*c*).

(3) *Application of Phenolic Type Paints.* The application of the phenolic type paints shown in the schedule presents no particular difficulties. They may be applied by brush or spray and may be thinned where necessary with not more than one pint of mineral spirits to a gallon of paint except for formula P–5 which will require somewhat more. The formulations should be applied at a spreading rate 450 to 550 square feet per gallon to give a total dry film thickness for a 4-coat system averaging 5.0 to 6.0 mils as determined by a GE thickness gage. They dry hard enough for recoating in periods ranging from 6 to 16 hours. In 4-coat systems, for steel surfaces subject to immersion in water, a convenient coating schedule consists of applying one coat a day in normal drying weather. In poor drying weather a greater intercoat drying period should be permitted. However, extensive delays of several or more days, over and above that required to reach adequate hardness for recoating are inadvisable, since *such delays may be harmful to intercoat adhesion.* At least five days final drying (after the last coat is applied) should be allowed prior to submerging a painted component in water, but longer final drying periods, up to the maximum practicable, are desirable. It is particularly desirable that the longest practicable drying time be permitted for the last coat when the painted component is to be submerged in rapidly moving abrasive waters in order to avoid excessive mechanical damage during the early life of the coating. *All of the phenolic systems require thoroughly sandblasted surfaces for satisfactory results in submerged exposure.* Either of the postblasting pretreatments (chemical metal conditioner or vinyl type wash coat) will increase the durability of the phenolic coatings in underwater exposure, but good results would still be obtained by applying them to untreated blast cleaned surfaces. Paragraph 1–13, dealing with metal conditioning and pretreatment of sandblasted ferrous surfaces, should be consulted before selection of a pretreatment method is made.

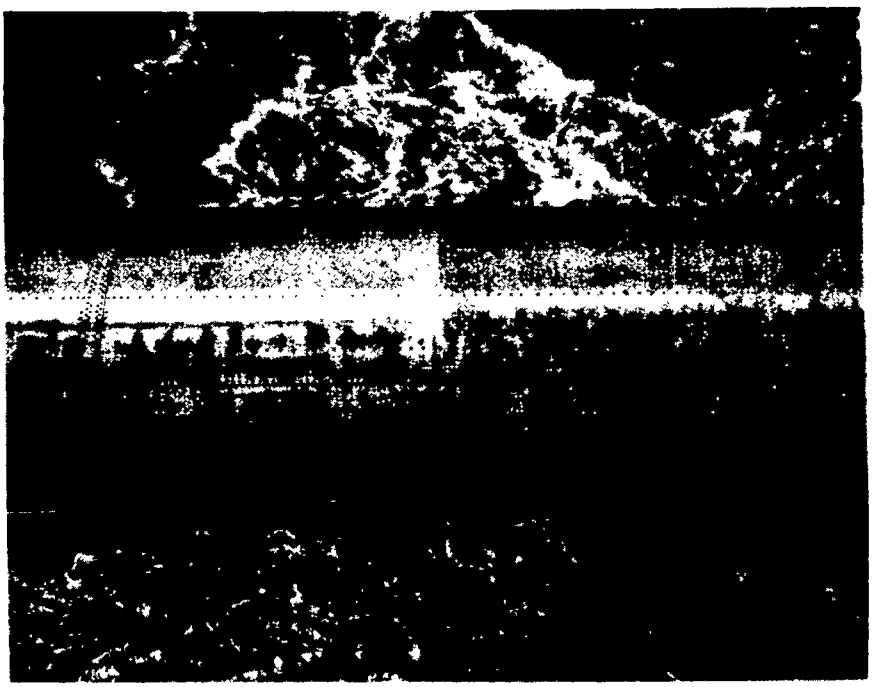

FIGURE 5. *Sand reinforced and unreinforced coatings.*

(4) *Sand-reinforcement of Phenolic Coatings for Abrasion Resistance in Submerged Exposure.* The abrasion resistance of the phenolic systems can be markedly improved by the use of sand-reinforcement. Although generally used only on steel surfaces subject to an underwater, abrasive exposure condition, the use of sand reinforcing also provides benefits over and above the increase in abrasion resistance, in that blistering tendencies and general durability in submerged exposure are improved to a considerable degree. Even in atmospheric exposures, the sand reinforcing brings about an increase in durability not entirely accounted for by the fact that the sand reinforced system employs about 25 percent more paint than a comparable unreinforced system. Figure 5 illustrates the benefit to be obtained on submergible steel surfaces by use of sand embedment. The right-hand half of the roller gate shown was sandblasted to bright metal, conditioned with a phosphoric acid solution, primed with a phenolic type paint, given a second coat of primer in which Ottawa silica sand was embedded and finally given two overall finish coats of phenolic type aluminum finish paint. Adequate periods of time were allowed for proper drying of each coat. The only difference between the coating on the left half and the right half of the gate surface is the sand reinforcement. The coating on the right is approximately three times the thickness of the coating on the left, but all except a very small portion of this increased thickness is provided by the sand particles themselves. At the time the photograph was taken, the approximate lower two-thirds of the painted gate surface shown in the picture had been exposed to continuous immersion and abrasion in the Mississippi River for ten years.

For the sand reinforced system, surfaces are blast cleaned, pretreated, and given a coat of primer in the usual manner. A second coat of primer is then applied about one-third more heavily than the customary 500 square feet per gallon. In this second coat, a uniform course of sand is thoroughly embedded promptly after application of the paint. The sand should be clean, dry, dust-free, particles graded so as to essentially pass a No. 30 and be retained on a No. 70 sieve. Ottawa sand conforming to paragraph 4.4.8 of Federal Specification SS–C–158c for making compressive strength tests of hydraulic cement is suitable for this use. The sand is applied, insofar as is practicable, within a few minutes after the paint coat is applied, but in any event before the paint has set sufficiently to prevent proper embedment of the sand. It has proven practical in the field to work a spray painter and helper together, with the latter applying the sand at such a rate that the newly applied paint coat is reinforced almost immediately. The building up of layers of imperfectly embedded sand is to be avoided. The sand should be applied in sufficient volume to provide an essentially continuous layer, one particle in thickness, without appreciable distance between sand grains. A two-day minimum drying time should be allowed for the sand reinforced paint coat in order for the particles of sand to become firmly anchored. After drying, the sand which is not firmly embedded should be removed by light brushing or air blast. The last two coats of the 4-coat system are then applied one or more days apart in order to lock in the embedded sand. The finish coats should be applied about one-third more heavily than for comparable coats of an unreinforced system, to take care of the increase in surface area occasioned by the sand. The completed sand reinforced system should present a rough granular appearance with each sand particle thoroughly coated but with valleys between grains only about one-third filled with paint. Film thickness gages similar to the type B, General Electric instrument may not be used for measuring the thickness of sand reinforced coatings, since their true thickness is distorted by the projecting sand granules.

The procedure for embedment of the sand need not be elaborate; it can consist of merely tossing the sand by hand onto freshly painted vertical surfaces and permitting the excess (that which will not be retained by the wet paint) to fall away. On horizontal surfaces the sand can be sprinkled on by hand. A method which has proven successful for large-scale surfaces is to use air pressure to blow the sand from a container through a hose onto the paint surface. The container, holding about 100 pounds of sand, feeds the sand by gravity

into an air line which ends in a flexible hose for distributing the sand on the surfaces. A valve on the gravity feed line and another on the air line permits the proper adjustment of sand and air. The pressure used should be only sufficient to carry the sand to the painted surface; a few pounds per square inch. The use of higher pressures may cause the sand particles to penetrate the hardened first coat.

River sand, properly graded and washed, has been used for embedment sand, but in view of the small quantities used (about 0.1 pound per square foot), Ottawa silica sand should be employed, principally because it is free of silt and other foreign matter.

It is somewhat difficult for the inexperienced to determine in the field the quantity of sand which should be applied. A practical method of determining this quantity is to coat a small flat steel panel with the paint at the prescribed coverage rate and, immediately after painting, hold the panel in a horizontal position and cover completely with about $\frac{1}{16}$-inch layer of sand. Tip the panel immediately to a vertical position and tap firmly with a hard object to remove the excess sand. The sand retained by the wet film is the proper amount which should be embedded.

The use of sand reinforcement in paint systems for new construction work performed under contract is not strongly advocated, since it may encourage unreasonably high bids from contractors inexperienced in the procedures involved. It is strongly recommended, however, that installations performing large-scale hired labor maintenance work on steel surfaces subject to immersion and abrasion, make a trial of a sand reinforced system and compare it with a similar unreinforced system to determine its effectiveness under the locally prevailing exposure conditions.

The vinyl type system for submerged exposure, i.e., the last system shown in paragraph 1–54*c*(2) of the schedule, is not adaptable for sand reinforcing because of its very rapid drying rate and low film-forming solids contents. The vinyl system, after it has reached full hardness, has shown better abrasion resistance in laboratory tests than unreinforced phenolic systems.

b. **Vinyl Type Paints for Surfaces Subject to Immersion**

(1) *General.* The paint system shown in paragraph 1–54*c*(2) of the schedule, made up of formulas V–101 and V–102, is of the vinyl type. The vinyl type wash coat which is used as a metal pretreatment of blast cleaned steel surfaces, not only for the all-vinyl system but as the preferred pretreatment for the phenolic type coatings also, has already been discussed in detail in paragraph 1–13*b*. Resins upon which the vinyl type coating is based are formed by polymerization of compounds which are characterized chemically by the vinyl group. They may further be divided on a chemical basis into several types but the two of most interest in paint work are the vinyl chloride-acetate copolymers and the polyvinyl butyral types. All of the vinyl coatings discussed herein are based on the vinyl acetate-chloride type of resin, except the Vinyl Type Wash Coat which is made with the butyral type of resin.

As will be seen from a study of the detailed formulations shown in paragraph 1–60, the vinyl paints (or more accurately, lacquers) are relatively simple in their makeup. They consist solely of pigments dispersed in a solution of the vinyl resins together with a small amount of added plasticizer to give greater flexibility and other properties. There are no drying oils or driers in the formulations. Moreover, there is no varnish cooking schedule such as is necessary with phenolic type coatings, variations in which can greatly modify the properties of finished products. A practical result of this simplicity of composition is that vinyl coatings are more likely to be uniform from batch to batch than are the phenolics.

Vinyl type paints are necessarily low in non-volatile content. In order to apply a given dry film thickness to a given area, approximately 2½ times as much liquid volume must be applied as is necessary with more conventional oil and varnish base materials. This

handling and spraying of proportionately large amounts of vinyl paints and attendant dissipation of large amount of rather costly solvents tend to make vinyl coatings relatively expensive. This tendency is generally more than compensated for, however, by certain inherent advantages of the vinyl coatings, stemming mainly from their rapid drying characteristics.

Although the experience with vinyl type coatings for underwater exposure is less than with phenolics, there is no evidence that the vinyl materials are inferior. Indeed, it would appear thus far that vinyl coatings lose their flexibility and degrade more slowly than conventional coatings which dry by oxidation and polymerization. On the basis of durability as determined to date, together with the advantages accruing from their rapid drying rate, it is considered that the vinyl paints are generally to be preferred over phenolics for underwater exposure. In addition to being suitable for submerged steel surfaces, vinyl paint systems have excellent durability in atmospheric exposure. Regardless of the contemplated service, vinyl paints should be applied only to blast cleaned surfaces; although the quality of cleaning can be relaxed from the white metal classification when the system is to be exposed only to normal exterior weathering.

(2) *Drying of Vinyl Paints.* Since there are no drying oils in the vinyl formulations, they form dry films by evaporation and when made up with solvents and diluents of low boiling point, do so with great rapidity. Successive coats can be applied, in general, with one or two hours drying of the undercoat. Freshly coated surfaces dry in a few minutes to tack-free which do not pick up dust from adjacent cleaning operations and which are not susceptible to damage from sudden adverse weather changes. After the last coat has been applied, a freshly coated structural component can be safely submerged in quiet water after 24 to 48 hours of drying without deleterious effect on the durability characteristics of the film. It should not be inferred, however, that the vinyl coatings reach their full hardness and ultimate abrasion resistance in such a short time. In view of their initial rapid dry to a tack-free, firm film, it is surprising to note that further increases in hardness take place slowly. This protracted softness of film is due to entrapment of residual solvent in the film and is particularly noticeable with aluminum pigmented vinyl lacquers. When vinyl coated structural components are submerged in quiet, non-abrasive water after painting, this slow achievement of ultimate hardness is not a major drawback, since mere immersion alone has little harmful effect on the relatively soft film and the hardening process will continue even though the surfaces are submerged. Where debris-laden, moving water of appreciable velocity is a factor, however, the vinyl coatings should be given as long a drying time as practicable to minimize the danger of mechanical damage to the film early in its life.

(3) *Intercoat Adhesion and Adhesion to Steel of Vinyl Paints.* Applied films of vinyl coatings (excepting the Vinyl Type Wash Coat) undergo practically no chemical change during drying or even after extended periods of time. Therefore, the dried films remain readily soluble in the solvents which were used in making the paint. The practical consequence is that succeeding applications of vinyl lacquers strike into the undercoat, no matter how long it has dried, and unite with it to form in effect, a single heavy coat. Intercoat adhesion, a troublesome factor generally in an abrasive, underwater environment with phenolic type paint systems is not a problem with vinyl coatings. A new coat may be applied over a vinyl system which has been exposed for long periods without danger of peeling or other evidence of poor intercoat adhesion. This is in direct contrast to conventional oil or varnish based paints which form dry films by chemical changes (i.e., oxidation and polymerization) and which soon reach a point where the hardened film is insoluble in the original formulating solvents, thus decreasing the effective adhesion of subsequently applied coats.

It should be kept in mind, however, that effective adhesion of certain vinyl coatings to even sandblasted steel requires special measures. In the case of the vinyl system (V–101 primer, V–102 topcoats) for fresh water immersion indicated in the schedule (as well as the

system for sea water immersion), the special measure consists of applying the Vinyl Type Wash Coat. The V–101 red lead vinyl primer will *not* itself adhere adequately to bare steel surfaces, i.e., a thin film of the Vinyl Type Wash Coat is necessary to establish adhesion of the V–101 primer to the steel. Once adhesion to the steel is established, succesive coats of the V–101 formulation will adhere to each other without difficulty. The V–102 vinyl type aluminum will adhere with tenacity to the V–101 red lead primer and to itself, but will not adhere properly to bare metal or to the wash coat. The V–766 vinyl formulation discussed in paragraph 1–23*b* will not adhere to the Vinyl Wash Coat but will adhere to bare steel and to itself.

(4) *Application of Vinyl Type Paints.* The application of the Vinyl Type Wash Coat has been discussed earlier in paragraph 1–13*b* dealing with cleaning and preparation of ferrous surfaces, and the information contained in this paragraph is not necessarily applicable to it. Other vinyl paints (e.g., formulas in paragraph 1–54*c*(2) of the schedule designated as V–101 and V–102), based on vinyl chloride-acetate copolymer resins, also require special precautions in application as follows. Generally, the vinyl paints as shown herein should be spray-applied only on large areas; although small areas can be brushed, using a flow-on technique and a minimum number of brush strokes. For spraying, the V–101 red lead vinyl primer should be very thoroughly mixed, thinned 25 to 35 percent by volume with a mixture (Thinner T–10) consisting of toluene containing at least 10 percent by weight of methyl isobutyl ketone. Ordinary thinners such as mineral spirits or solvent naphtha, containing no methyl isobutyl ketone (or other ketone), will be incompatible with the vinyl paints. The amount of thinner used should be varied to suit prevailing weather conditions, but must at all times be sufficient to provide a wet spray and avoid deposition of particles which are dry when they strike the surface. The aluminum powder for the V–102 finish paint is stirred thoroughly into the vehicle in small increments and the mixture is then thinned with 20 to 30 percent (by volume) of T–10 thinner.

Each coat required by the schedule consists of a double spray coat applied at a coverage rate of 150 to 200 square feet per gallon and, in any event, sufficient to obtain the dry film thickness required. A double spray coat consists of giving an area of 40 to 80 square feet a thin coat of paint in one pass, and then going over it again within a few minutes with a heavy coat, applied just short of sagging, in order to obtain an average dry film thickness of 1.2 to 1.5 mils. In order to obtain the maximum thickness of film from the double spray coat technique, it is important that the initial thin coat be given an opportunity to partially dry. Thus, in poor drying weather and at high spraying rates it may be necessary to enlarge the immediate work area to several hundred square feet instead of the 40 to 80 square feet mentioned above. Since the coverage rate of the vinyl type paints is low as a result of their relatively low non-volatile content, inexperienced workmen tend to apply this type of material too thinly. For this reason, it is necessary to make cumulative dry film thickness measurements prior to applying the two aluminum finish coats and after the system is completed with an instrument similar to the type B, General Electric film thickness gage. The wash coat and first coat of red lead primer should be gaged visually by observing whether the proper degree of hiding has been achieved, since the thickness gage is not accurate in measuring very thin films on blast roughened surfaces. A discussion of the use of the dry film thickness gage will be found in paragraph 1–49.

Care should be exercised to insure that the spray nozzle is held close enough to the surface to avoid excessive loss of volatile material in the spraying process. The reason for the above precautionary measure will be evident by spraying a vinyl coating onto a surface at a gradually increased distance. It will be seen that as the distance of nozzle to surface is increased, the material as deposited tends to become drier and eventually is laid down as a rough, porous appearing film or may even be so dry as to not adhere strongly to the surfaces. Failure to hold the spray gun perpendicular to the surfaces will also result in excessive "overspray"

and consequent deposition of particles which are dry when they strike the surface. Since the vinyl paints, upon deposition, possess poor after-flow characteristics, particular attention should be given to the thorough coating of pits, crevices, cracks, interior angles and similar surface irregularities. Rivets particularly will not be thoroughly coated unless the spray gun is pointed perpendicular to the sloping surfaces. Fluid and atomization pressure should be kept as low as practicable consistent with good spraying results. Alternate passes of the spray should be made at right angles to the preceding pass. DeVilbiss No. 704 or 765 air cap with E fluid tip, or its equivalent, has given good results in the spray application of vinyl type coatings. Equipment used for spraying formulas V–101 and V–102 must be cleaned with the T–10 thinner. Unlike the Vinyl Type Wash Coat material, unused quantities of thinned V–101 and V–102 formulations may be used after setting overnight. Undercoats should be permitted to dry at least two hours before recoating, and it is a good practice to allow an overnight dry between the second and third coats of the 4-coat system. Surfaces coated with vinyl type paints should be allowed as long a final dry as practicable before immersion in water *where abrasion and erosion* are exposure factors. A 48-hour final drying period, during normal drying weather, is sufficient for surfaces which are to be immersed in quiet, non-abrasive waters. The application of vinyl paints presents certain safety problems. See section in this manual devoted to safety. The information above on the application of Vinyl formulations V–101 and V–102 is also largely applicable to formulas V–766, V–103 and V–104 shown in paragraph 1–60.

(5) *Application of Vinyl Paints in Cold Weather.* The fact that vinyl type paints form dry films solely by solvent evaporation makes them more adaptable to cold weather painting than oil or varnish base paints which form dried films by oxidation and polymerization as well as solvent evaporation. Although solvent evaporation is greatly retarded in cold weather, the vinyl formulations still dry rapidly enough to permit reasonably recoating schedules. Observations over a 6-year period of vinyl systems applied on large-scale submersible steel surfaces at winter temperatures ranging down to 10° F. indicated that low application and drying temperatures do not appreciably affect the durability of the vinyl systems, provided the surfaces are free of moisture and frost at the time each coat of the system is applied, and provided the drying time between coats as well as the final drying period for the completed system is extended several-fold over what is normally allowed.

In application of vinyl paints at low temperatures, the use of tarpaulin shelters over the structural components is advisable. If painting is to be done at extremely low temperatures, forced air heat from gasoline or fuel oil heaters should be provided within the shelters. Heaters should not be of the type that pass combustion products into the shelters. It should be pointed out, that intermittent heating entails some added danger in that, upon application of heat, the temperature of heavy masses of structural steel tends to lag behind the ambient air temperature, and a condition is produced which is conducive to condensation of moisture on the steel surface, particularly if the relative humidity of the heated air has an opportunity to rise. If heating within the inclosing shelter is to be carried on, particular care should be taken to insure that paint-receiving surfaces are free from moisture as determined by touch and visual observation. One District office which has had considerable experience in low temperature (winter work) application of vinyl type paints prefers the alternate vinyl system (V–766 primer with V–102 finish coats), described in paragraph 1–23*b*, to the system consisting of the Vinyl Type Wash Coat, V–101 red lead primer and V–102 finish coats. The reasons for this preference are: the former system does not require the wash coat pretreatment of the blasted surfaces, thus saving one operation; and the V–766 primer formulation does not increase as much in viscosity at reduced temperatures as the V–101 red lead primer. It is pointed out, however, that, aside from these advantages, the choice from the standpoint of adhesion and general performance tends somewhat to favor the system employing the wash coat, red lead primer, and V–102 aluminum finish coats. At quite low temperatures

(+25° F. or lower), the red lead formulation (V–101) will in a short time gel to a semi-solid condition which cannot be satisfactorily reduced by thinning with additional solvent. No permanent ill effects are brought about by the gelling and it can be reduced completely by warming the paint in the containers to approximately 110° F., followed by vigorous agitation. The gelling characteristic at low temperatures of the vinyl type red lead primer can be avoided to a large degree by omitting 15 of the 30 parts of methyl isobutyl ketone from the formula and substituting therefor methyl ethyl ketone. The substitution should be made only if the primer is to be used at painting temperatures considerably lower than normal, since the methyl ethyl ketone makes it more difficult to maintain a wet spray in warm, windy weather. The gelling difficulty experienced with the vinyl type red lead formulation in cold weather is avoided most easily, of course, by warming the paint prior to use and keeping the spray tank warm during spraying operations.

Although the V–101 formulation is the most troublesome in this respect, all of the vinyl formulations increase in viscosity as the temperature is lowered. In order to reduce thinning requirements and avoid excessive running and sagging of even thinly applied coats, it is advisable during application in cold weather to warm any of the vinyl paints to normal summer temperatures prior to mixing and keep the paint in the feed tank warm during actual spraying operations. Even though warmed in this manner the paint will require more than the normal amount of field thinning since there will be a very considerable drop in temperature in the fluid hose of the spray equipment.

Vinyl paints, as well as others, tend to sag more during cold weather application, particularly when thick coats are attempted. Therefore, it is difficult in low temperature applications to obtain the desired film thickness in the usual number of coats. It may be necessary under extreme conditions to apply an extra coat of the primer and an extra finish coat in order to build up the required total thickness unless the paints are warmed prior to use.

In the foregoing paragraphs the desirability of raising the temperature of the vinyl paints during cold weather operations to at least normal painting temperatures has been discussed. Logically, one would expect that additional increases in the paint temperature would be beneficial. The hot spray method which increases the temperature of the sprayed paint to 175° F. (or thereabouts) has demonstrated the effectiveness of further raising the paint temperature. The benefit gained stems primarily from the fact that the viscosity of the vinyl paints is reduced by heat to a point where little or no field thinning is required in order to spray the material. The unthinned, hot sprayed paint during atomization and travel to the receiving surface loses considerable solvent and cools to near-normal temperatures. Thus, although it is atomized at the usual spraying viscosity, the paint reaches the surface at a higher viscosity than when normal temperature spray is used and hence has greater resistance to sagging and running. The equipment for hot spraying consists of electrically heated coils through which the paint is passed for heating, a pump for circulating the paint, a double-fluid hose to carry the paint to and from the spray gun and appurtenant valves, gages and fittings. A conventional pressure pot may be used in conjunction with the circulating pump and its use presents certain advantages. The spray gun used with the hot spray equipment is exactly the same as is used for normal temperature spraying. Generally only one spray gun can be successfully used off of a heater-pump setup. In operation the pump draws paint out of the supply container, passes it through the heating coils to the spray gun and back again through the return hose to the pump for reheating and recirculation. When the paint required to initially fill the system is brought up to the optimum operating temperature of about 175° F. the spraying operations may be started. As long as no paint is being sprayed the pump merely circulates the paint through the double-fluid hose and the heater merely keeps the paint up to temperature. As soon as spraying begins the pump draws more paint from the supply container and passes it through the heater to replenish the material in the circulating system. All operations of the pump and heater are automatic. The purpose

of recirculation is to maintain a supply of hot paint at the gun at all times, even during intermittent spraying operations. The capacity of the heaters should be sufficient to heat the new paint brought into the system and to take care of loss of heat from the fluid lines. Obviously, low initial paint temperatures, long fluid lines and low ambient temperatures put a greater load on the heaters and may exceed their capacity. When painting with hot spray at normal summer temperatures the temperature drop of the paint between heater and gun can be kept to about 15° F. with 75 feet of hose. When using the equipment in winter weather it is necessary to insulate the fluid lines in order to limit the temperature drop to this amount. Although the hot spray system in which the paint is circulated directly through electrically heated coils and through a double-passage fluid hose is the more common setup, at least one manufacturer makes hot spray equipment in which hot water circulating through a heat exchanger, raises the paint temperature. Also, the hot water is circulated through two passages of a 3-passage fluid hose, thus eliminating entirely the need for circulating the paint.

The hot spray technique was initiated primarily for indoor, industrial spraying of nitrocellulose lacquers. Its adaptation to outside painting of structural steel with Vinyl type paints is quite recent. To a considerable degree the advantages claimed for inside industrial painting (i.e., less thinning, thicker coats without sagging and running, better appearance of dried film, and less overspray) seem to be realizable in exterior work. However, in outside painting work the hot spray method presents problems not completely solved at this time as follows. Length of lines must be limited to prevent exorbitant heat loss and to keep fluid pressures down to a reasonable working level. Also, moderate wind conditions which are prevalent during exterior painting have a more adverse effect on hot spray than on cold spray in that distortions and disturbances of the spray fan by the wind tend to produce troublesome quantities of atomized paint particles, which are dry before they reach the receiving surface and which tend to settle on the upper surfaces of rivets and similar projections. Finally, the application of thick, hot sprayed films tends to cause more than the normal amount of difficulty with solvent blistering, i.e., blistering of the film, while drying, as the result of rapid evaporation of solvent. Although the solvent blistering can be eliminated to a large degree by decreasing the amount of solvent in the paint and thus depositing the paint onto the surfaces in a less fluid condition, this corrective action increases the likelihood that natural wind conditions will whip off portions of the spray fan and deposit completely dry paint particles on the surfaces some distance outside of the spray pattern. It may be said that improved spraying techniques together with reformulation of the solvent portion of the vinyl paints present a favorable prospect of solution of these difficulties.

1–18. FERROUS SURFACES SUBJECT TO IMMERSION IN QUIET, FRESH WATER OR TO FREQUENT CONDENSATION BUT PROTECTED FROM ABRASION AND FROM EXTENDED EXPOSURE IN SUNLIGHT (COLD APPLIED COAL TAR PAINT)

In fresh, essentially neutral waters, pH of 5.0 to approximately 9.0, it is possible to protect immersed ferrous surfaces adequately with a number of coating systems. The phenolic systems discussed in paragraph 1–17*a* will give satisfactory protection for periods of at least twelve years in this exposure. The vinyl system shown in paragraph 1–54*c*(2) as an alternate to the phenolic paints will be found to be at least equal in durability and additionally possess more favorable drying characteristics. Hot-applied coal tar enamel, discussed in detail in the following paragraph, should give adequate protection under continuous immersion conditions for twenty years or more. Paragraph 1–54*c*(3) also lists cold-applied coal tar paint conforming to Military Specification MIL–C–18480 (docks) for possible use in this type of exposure. This coating has good durability when it is not subjected to abrasion or extended periods of sunlight, but it is considered inferior to phenolic paints, hot-applied coal tar enamel, and vinyl systems previously mentioned. It is generally advisable to

prepare the surfaces of major structural components by blast cleaning when cold-applied coal tar paints are used. However, materials of this general type are used quite extensively without blast cleaning by manufacturers as coatings for standard items of equipment, such as pumps, pipe, tanks, flap gates, etc., in which case, it is frequently advisable to accept the manufacturers' standard coating, because insistence upon another type of coating might result in a disproportionately higher price for such items of equipment. The cold-applied coal tar material in normal weather dries to touch in 24 hours by evaporation of solvents but at the end of this time the film is still soft and easily indented. In poor drying weather several days between coats is necessary. The material as supplied is very heavy bodied and should be brush applied in heavy coats *without thinning*, unless instructed otherwise by the manufacturer, at a coverage rate per coat of not more than 100 square feet per gallon. Cold-applied coal tar materials of the type under discussion will appear so viscous, prior to mixing of newly opened containers, as to preclude application unless thinned, but upon being vigorously stirred will be reduced to a workable consistency. For maximum life, the coating should be built up to $\frac{1}{32}$ of an inch dry film thickness in multiple coats, each applied with brush strokes at right angle to those used for preceding coat. Completed systems, built up of multiple coats applied one or two days apart, remain soft for an extended period of time and even after several weeks or months can be indented by pressure with a fingernail. The relative softness of the applied coal tar system makes it unsuitable for abrasive conditions. It should not be used where anticipated temperatures fall outside the range of —10° to +140° F.

If specific experience within an operating organizations has proven that the cold-applied coal tar material is a more economical coating (cost per year of protection) than other coatings mentioned herein, it should, of course, be used. Such experience, however, is valid only if actual side by side comparisons have been made with other systems described for underwater surfaces. There are many grades of this material, some of which are of poor quality. Users should assure themselves that coal tar products conforms with the specifications.

The coal tar paint is not applicable to tanks and pipe lines used for military operations.

1–19. FERROUS SURFACES SUBJECT TO CONTINUOUS FRESH WATER IMMERSION WITH OR WITHOUT MODERATE ABRASION, BUT PROTECTED FROM SUNLIGHT AND EXCESSIVE TEMPERATURES (HOT-APPLIED COAL TAR ENAMEL)

Examples involving the essential elements of this type of exposure are interior ferrous surfaces of penstocks, spiral cases, draft tube liners and large diameter steel water pipe; exterior surfaces of pipe where immersed or buried; interior surfaces of buoyancy chambers; exterior surfaces of buried tanks, and continuously submerged dam gates (for discussion of cleaning and painting of penstocks and spiral cases see paragraph 1–14*a*). This exposure category overlaps to a certain extent that indicated in the paragraph immediately above. However, the cold-applied coal tar material discussed above is considered to be an alternate only for use where maximum coating life is not necessary or where other reasons make its use advisable. Hot-applied coal tar enamel, conforming to AWWA Spec. C203–51 for "Coal Tar Enamel Protective Coatings for Steel Water Pipe of Sizes 30 Inches and Over," provides a coating which will give many years of protection in this exposure condition. Service records of this material used in many different localities indicate satisfactory protection of steel surfaces after twenty-five or even forty years, in situations where mechanical damage, exposure to sunlight, and extreme temperature conditions have been avoided. On the other hand, hot-applied coal tar coatings on surfaces which were alternately subjected to immersion in water and exterior atmospheric exposure showed poor durability as compared with the best paint coatings. Similarly, coal tar enamel coatings have not been outstandingly durable

in continuous exterior atmospheric exposure, on exterior waterline areas, under icing or freezing and thawing condition, or at temperatures outside the range of —20° to +140° F. At temperatures below —20° F., the enamel may spontaneously crack and disbond from the surfaces. In the low temperature range of —20° up to +20° F., the applied enamel will have greatly reduced resistance to damage from handling, mechanical impact, and shock. It is pointed out also that the enamel which remains, after having degraded to the point where a complete recoating job is advisable, is very costly to remove, because blasting sand tends to become embedded in the enamel instead of removing the coating from the steel. If the cleaning work can be accomplished during winter weather when the enamel is hard and brittle, it can be more easily removed.

Coal tar enamel is the name commonly applied to "processed coal tar pitch" to which has been added mica, talc, or other finely divided inert mineral pigments. The enamel is melted and applied by hand daubing or flow-on methods over a relatively thin coat of coal tar pitch, cold-applied primer. When properly applied, the enamel produces a thick, fairly hard coating which is highly impervious to moisture and is fairly elastic except at low temperatures. Enamel of two different penetration ranges (10 to 25 and 15 to 20 at 77° F.) are included in the AWWA specification. The enamel of 15 to 20 penetration should be used generally for work of the Corps of Engineers, and particularly where the anticipated minimum temperatures to which the coated surfaces will be exposed is below 20° F. Also, if the coated surfaces will be handled or worked on during cold weather only the higher penetration enamel should be used.

Blast cleaning of surfaces and application of coal tar primer and enamel should generally be done in the field and preferably after erection of the component being coated. For most Corps of Engineers' work, application of the enamel will necessarily be by hand daubing, though flow-on methods are preferable if practicable. Spray application is not satisfactory at the present time although some progress has been made in this direction. Shop enameled surfaces are susceptible to extensive damage in transit and at the construction site prior to and during erection. Cleaning and priming in the shop with the intention of applying the enamel later in the field is a poor practice, since the thin prime coat, which in itself has little weather resistance, would be without the protective enamel coating for an extended period of time.

Areas which have been primed should receive the hot-applied coal tar enamel coating within the minimum and maximum drying time limits recommended by the manufacturer of the materials. If the maximum drying time (3 to 5 days, depending on the manufacturer) is exceeded, the surfaces must be re-primed with an additional light coat of primer. However, if the original prime coat has rusted through, or if the originally primed surface has stood two or more weeks without receiving the enamel, the primer should be removed by blasting prior to re-priming. The coal tar primer may be applied by brush or spray, in accordance with the manufacturer's instructions. Primer and coal tar enamel must be the products of the same manufacturer.

Satisfactory field application of coal tar enamel by hand daubing requires that it be accomplished only by experienced crews. It cannot be emphasized too strongly that all of the applicable requirement of the AWWA Spec. C–203–51, together with supplementary special instructions of the primer and enamel manufacturer, must be strictly observed if the inherent durability of the coal tar coating is to be realized. In particular, the requirements relative to priming of the surfaces and heating of the enamel should be followed without permitting the slightest deviation. Excessive temperatures and prolonged heating of the enamel can easily reduce its serviceable life to a fraction of what it should be. It is important that a periodic sample from the last of the enamel in a kettle batch be tested for penetration at 77° F. to insure that the penetration value has not been decreased more than 6 points when compared with that of the original enamel. On sizeable jobs the use of recording thermometers in the

heating kettles should be made mandatory. Heating kettles should be kept covered at all times and fumes therefrom should not be permitted to condense on blasted, primed, or previously enameled surfaces. Installations contemplating the application by hired labor of coal tar enamel for the first time, should engage at least a few experienced men or should send inexperienced personnel to visit a site where the material is being properly applied. One enamel manufacturer has contract crews for applying enamel; most manufacturers will send representatives to assist new users. Thorough inspection of the coating for holidays, insufficient thickness, and inadequate bond is absolutely necessary. An electrical flaw detector operating at 8 to 10 thousand volts and low amperage is indispensable for revealing small holidays and each square foot of surface must be so tested. General Electric film thickness gage is valuable in determining the thickness of the applied coating. Tests in the field for bond should be made 24 hours or more after the coating has been applied by gradually warming an area with a heat lamp to a temperature of 80° to 160° F., making a small ¾-inch by 4-inch rectangular cut completely through the enamel with a knife and attempting to lift or peel the coating from the metal. Adhesion should be such as to prevent peeling, stripping, or lifting of the enamel, that is the strip should break rather than be removed in one piece from the surface. The Bureau of Reclamation "Paint Manual *(For the Control of Paints and Painting)*," April 1951, Chapter V, describes field inspection procedures for coal tar enamel in considerable detail and should be consulted by inexperienced personnel. The manual is available from the U. S. Government Printing Office.

Where the coal tar enameled surface is to be buried in the ground and the coating is subject to mechanical damage by certain soil conditions, the appendix to the American Water Works Association specification should be specifically made a part of the contract specifications and one of the methods described therein for mitigating soil stresses selected. Damage to the enamel coating may result from a backfill containing sizeable rocks or hard clods which under pressure of the superimposed load may distort and even penetrate the enamel. Also clay backfills which are subject to drying may set up shrinkage stresses which can distort the enamel or entirely remove it from the surfaces. The alternate preventive measures to counteract such damage are described in the aforementioned appendix and consist, briefly, of using selected sand backfill, asbestos felt wrapping, or a gunite shield.

Where spiral (scroll) cases, spiral case extensions, and other components of hydroelectric structures must be blasted in proximity to generators and other easily damaged equipment, already in place, suitable protective measures such as dust barriers and exhaust fans should be provided for the prevention of damage by spent abrasive and dust. The use of steel grit rather than sand would also be advisable, provided that the steel grit can be reclaimed, since less blasting dust would be generated.

The application of coal tar enamel, as well as other coating materials, to penstock surfaces present many special problems related to ventilation, condensation, materials handling and scheduling of work. OCE Civil Works Bulletin 54–23, 8 October 1954, discusses these problems and suggests corrective measures. The North Pacific Division has issued an informative report covering penstock coating operations at Detroit Dam, and the Omaha District has issued a similar report for the Fort Randall project. These reports were distributed to all Districts.

1–20. COATINGS FOR FERROUS SURFACES SUBJECT TO IMMERSION IN SEA WATER AND FOULING FROM SEA WATER ORGANISMS

a. **General.** The selection of coatings for hulls of vessels and steel structures exposed to sea water presents problems differing greatly from those described in preceding paragraphs for fresh water exposure. The protection of steel in salt water has been studied for many years, but an entirely satisfactory solution to the problem of fouling organisms and the corrosive nature of sea water has not been found. An added problem in ship painting is the

maintenance practice in drydock of rushing all operations to get the ships waterborne as soon as practicable. The high cost of drydocking is the principal cause for this practice. For this and other reasons, the cleaning of exterior hull surfaces is frequently a superficial process, making use of scrapers, chipping hammers, wire brushes, and similar tools which are incapable of producing completely clean surfaces. Blasting methods are employed in some drydocks for the removal of fouling organisms, rust, scale, and paint. Dry blasting is frequently objected to in drydock work because the dust created is harmful to machinery if it is permitted to get into working parts. Moreover, the dust is a nuisance and is a health hazard unless personnel working in the area are properly protected. Therefore, wet blasting procedures are more commonly used. The wet blasting method cleans the surfaces satisfactorily, but, when conducted under the hurried conditions normally present, there is strong likelihood that paints will be applied to surfaces which are not dry and which have rusted appreciably subsequent to wet blast cleaning. In view of the additional variables which may be introduced by wet blasting, every effort should be made to overcome the difficulties and objections commonly associated with dry blasting so that the latter cleaning method may be used. With reference to preventing rust on wet-blasted surfaces, the Navy uses a 4:1 mixture (non-toxic), by weight, of diamonium phosphate and sodium nitrite in sufficient amount, in the sand-water slurry, to furnish approximately a 1.5 to 2.0 percent (based on mixing water) solution. When washing down of the cleaned surfaces immediately follows sandblasting, the use of the rust inhibitive compounds may be restricted to the rinse water and is used in sufficient amount to furnish approximately a 0.6 percent solution. Reportedly, this measure will prevent rusting of surfaces for periods up to 48 hours in humid weather. Another complicating factor present in the painting of ships is the more or less common thought that, since the ship will probably be back in drydock for repairs within one year, the paint coating need not be exceptionally durable. The circumstances surrounding ship painting, described above, in addition to the difficult exposure conditions, have, no doubt, contributed appreciably to retarding the development and use of coatings of long life on hulls of ships exposed to sea water. The information furnished herein, on painting of vessels operating in salt water, should be supplemented by reference to "Instructions for Painting," Appendix 6 to General Specificatons for Building Vessels of the U. S. Navy (Bureau of Ships) and to "Painting Ships in Service," Chapter 19 of Bureau of Ships Manual, U. S. Navy. It is also suggested that contact be made with Naval shipyards in those instances where a district is confronted with appreciable and important work of this nature and previous experience is lacking or unsatisfactory.

The removal of millscale, corrosion products, and all other soil, preparatory to painting surfaces subject to sea water immersion is of the utmost importance. The complete removal of millscale is doubly important, since it has been shown repeatedly that millscale is cathodic with respect to bare steel and therefore the scale tends to intensify pitting action on the scale-free areas which inevitably will be present. Operating conditions which tend to discourage blast cleaning should be studied carefully before decision is made to forego this method of cleaning prior to painting. Certainly, it does not appear economical to sacrifice from 50 to 90 percent of the potential life of a coating in order to save some additional cleaning and drydocking expense. Dry blasting is much to be preferred but if wet blast cleaning must be used work should be scheduled so as to provide an opportunity for surfaces to dry thoroughly prior to painting, supplemented if need be by artificial drying procedures. Similarly, work should be programmed so that freshly painted areas are not subjected to water from adjacent wet blasting operations until they have reached a degree of hardness where permanent ill effects are not brought about.

b. **Anti-Fouling Paint System for Sea Water Exposure.** The schedule, paragraph 1–54*c*(5), shows a vinyl coating system for sea water exposure. Extensive investigation and use by the Navy and other Governmental agencies indicate that this system is among

the best available. The system is intended primarily for protection of hulls of vessels operating in sea water and subject to fouling organisms. However, its use on fixed structures may under certain circumstances be indicated. In this connection, it is to be noted that while the primary purpose of anti-fouling topcoats in a marine system is to prevent loss of vessel speed resulting from the drag of fouling organisms, a secondary purpose is to prevent possible damage to the underlying anti-corrosive paint coats by penetrating type organisms. Vinyl Type Wash Coat (Specification MIL–C–15328A) offers an advantage in connection with wet sandblasting in that cleaned and dried areas receiving the wash coat are protected for a brief period from the water spray and high humidity caused by the cleaning of adjacent areas. Since the period during which the wash coat will protect is brief, subsequent paint coats should be applied as soon as practicable. The wash coat dries to a tack-free film within 15 minutes in good drying weather. It is probable that after two hours of drying the film will be hard enough to withstand a brief exposure to water spray and splashing without deleterious effects, although this condition should be avoided, if possible. Where the dried wash coat film has to withstand moderately prolonged exposure before subsequent coats are applied, it should be put on at a dry film thickness approaching the maximum of 0.5 mils. The red lead-vinyl paint (Specification MIL–P–15929A) and the anti-fouling paint (Specification MIL–P–15931A) also dry very rapidly and successive coats may be applied at 2-hour intervals, although longer drying periods are preferable. Inadvertent splashing or spraying applied coats with water should be avoided, if possible, although the vinyl type paints harden in a few hours to a sufficient extent to preclude ill effects resulting from this incidental exposure.

The anti-fouling paint is heavily loaded with toxic cuprous oxide which becomes available upon immersion in sea water to combat fouling organisms. It is pointed out that the anti-fouling paint was formulated specifically for exposure in sea water. In sea water, diluted to varying degrees with fresh water, it may not have satisfactory anti-fouling properties. Hull areas above the water line of floating plant which must conform to certain color requirements (O & R, Chapter IV, Operations, Part II, Civil Works, par. 4228.15) should be painted in the same manner as the underwater hull areas except, that in place of the anti-fouling coats, there would be substituted two double-spray coats of a black vinyl type finish such as formula V–103 shown in paragraph 1–60*m*, or two coats of black vinyl-alkyd paint conforming to Military Specification MIL–P–15932A.

It will be noted that the pretreatment component of the anti-fouling paint system (i.e., Vinyl Type Wash Coat) is identical to the corresponding component of the vinyl system for fresh water immersion. Also, the second component (MIL–P–15931A red lead vinyl paint) is very similar to the corresponding material (Formula V–101) used in the fresh water system except that a greater thickness is employed for sea water exposure. Application instructions for these two materials have been given in paragraphs 1–13*b* and 1–17*b*(4). The anti-fouling paint is also of the vinyl type and its application characteristics are similar in some respect to those of the red vinyl paint. The anti-fouling may be thinned for spray application with thinner T–10 which is a solvent mixture consisting of 10 percent (by weight) of methyl isobutyl ketone and 90 percent toluene. The amount of thinning should be sufficient to insure that a wet spray is maintained at all times and that no dry particles are deposited on the surface. The amount of thinner which must be added will vary with weather conditions, but will probably be in the neighborhood of 10 to 20 percent of the base paint by volume. The anti-fouling paint has a high solids content compared to the other vinyl formulations and, therefore, spray applications of the former tend to build up the dry film thickness of the system quite rapidly. *Care must be taken to clean spray equipment thoroughly when changing over to the Vinyl Type Wash Coat, after applying the anti-fouling paint,* because contamination of the pretreatment solution with cuprous oxide may cause it to gel and be unusable. If desired, one of the two prescribed coats of MIL–P–15931A anti-fouling paint may be omitted. This omission may be particularly desirable in the case of

vessels which are expected to be drydocked for inspection and repairs within a year, since touchup painting can be accomplished, and, if necessary, a supplementary overall coat of anti-fouling paint applied during the latter docking period. The anti-fouling formulation should not be used over old or new coatings which are not of the vinyl type, since the solvents used in the formulation may soften and lift coatings which are not of the vinyl type.

In connection with the procurement of paint materials for the anti-fouling system, attention is invited to Orders and Regulations, paragraph 4228.16, Chapter IV, Operations, Civil Works, which indicates that Corps of Engineers' agencies may obtain marine supplies from U. S. Naval shipyards. Thus it appears that the shipyards may be a convenient source of the paints which make up the anti-fouling vinyl system. In this connection it may be noted that as an alternate to the MIL–P–15929A red lead vinyl primer component of the system the Navy also makes use of a zinc chromate-vinyl primer conforming to Military Specification MIL–P–15930A.

1–21. PAINTING OF STEEL SURFACES SUBJECT TO EXTERIOR EXPOSURE UNDER MARINE ATMOSPHERIC CONDITIONS

a. **Floating Plant.** The general maintenance practice in painting the exterior, above-water surfaces of major items of floating plant operating in sea water is to conduct a more or less continuous painting program by members of the crew. Where this practice is followed, random areas are cleaned and repainted as the protective coating breaks down and corrosion becomes evident. Cleaning is accomplished with hand or power-driven chipping hammers, wire brushes, and scrapers. The paint-receptive characteristics of the cleaned surfaces are, at best, considerably inferior to those achieved by blast cleaning. The paints used are seldom standardized and are frequently purchased under a trade name without knowledge of their composition or characteristics. Brush application is usually the only feasible method.

As to whether the above method of maintaining above-water surfaces is an economical one is difficult to determine. If the painting work is accomplished principally in the spare time of crew members who must be in attendance as a result of other duties, then the economy of the painting work can hardly be improved upon. On the other hand, if additional members of the crew are hired solely for maintenance painting work, the question may be asked as to whether a more economical and thorough job might not be obtained if the painting of above-water surfaces were to be accomplished during periodic overhaul and repair periods by professional painting crews. In either event, it would appear profitable to give greater consideration to the selection of paint systems which are compatible with the exposure conditions and the quality of surface preparation.

With reference to the question as to what types of paint are most satisfactory in marine atmospheric exposure, it is clear that the answer is, in large part, dependent upon the type of surface preparation available. Also, the discussion in the following paragraphs which has to do with the protection of steel decks and other atmospheric exposed surfaces of floating plant operating in fresh water is also generally applicable to similar surfaces of floating plant operating in sea water. Decks in marine atmospheric exposure can be painted in a manner identical to that recommended for decks of fresh water floating plant. With reference to above-water surfaces (other than decks), the systems discussed in paragraph 1–22*d*, based on red lead primer, Fed. Spec. TT–P–86a, Type I or Type II, and alkyd finish coats conforming to Fed. Spec. TT–E–489b or TT–E–529, are reasonably durable in marine exposure and should be used when blast cleaning is impracticable. It is recommended for marine atmosphere exposure that two coats of primer and two finish coats be applied. The quality of surface preparation should be the best obtainable short of blast-cleaning.

The employment of blast cleaning is more advisable for surfaces of floating plant subject to atmospheric marine exposure than for comparable surfaces of plant operating in fresh

water. Blast cleaning may be justified not only because of the added durability imparted to all paint systems, irrespective of their type, under these relatively severe exposure conditions, but also because this thorough cleaning method permits the use of more durable priming materials which, because of their poor wetting characteristics, are suitable only for application to very clean surfaces. Despite the difficulties and objections often encountered in blast cleaning the superstructure of floating plant, consideration should be given to this method of surface preparation, particularly for new construction.

Once the surfaces have been completely cleaned of millscale and rust, by blasting or other equally effective means, several alternative systems can be used with very good results on surfaces subject to marine atmosphere. A system consisting of vinyl wash coat pretreatment, 2 coats of alkyd type red lead primer (Fed. Spec. TT–P–86a, Type III) and 2 finish coats of gloss (Fed. Spec. TT–E–489b, Class A) or semi-gloss (TT–E–529, Class A) alkyd type enamel of the proper color should perform very well. Based on Navy experience, good results may be anticipated on thoroughly cleaned surfaces in atmospheric marine exposure with a vinyl system similar to that described in the schedule, paragraph 1–54*c*(5), except that the number of coats of red lead vinyl paint is reduced to give a thickness of 4 mils and the anti-fouling top coats are replaced with two or three mils of a gray paint (MIL–P–15934A, MIL–P–15935A, or MIL–P–15936A) based on a blended vehicle combination of vinyl and alkyd resins. Additional vinyl-alkyd paints pigmented to conform with the Corps of Engineers' color scheme for floating plant could be formulated. The use of straight vinyl finish coats in place of the vinyl-alkyd topcoats, formulated to give the proper colors, should also be highly durable in atmospheric marine exposure. Finally, it is considered that phenolic type systems employing a primer similar to Fed. Spec. TT–P–86a, type IV, or Fed. Spec. TT–P–57, type III, should provide excellent durability on blast-cleaned surfaces when finish-coated with phenolic paints pigmented to meet the prescribed color requirements.

b. **Fixed Structures.** In the painting of steel surfaces of fixed structures subject to marine atmospheric exposure, it is believed that the practicability of blast cleaning should be considered in order to obtain long, trouble-free paint life. In order to reduce costs, the quality of blast cleaning could be relaxed somewhat in comparison with that required for steel surfaces subject to immersion in fresh or sea water. The blasted surfaces would be coated with the vinyl type paint system or one of the phenolic systems prescribed for surfaces subject to immersion in fresh water (par. 1–54*c*(2)). If blast cleaning is not practicable, the paint systems based on primers with good wetting properties should be used. Such systems are shown in paragraph 1–54*c*(1) and have been discussed in paragraph 1–16*a* herein; for marine atmospheric exposure it is recommended that an additional coat of primer be used, thus making a 4-coat system.

1–22. PAINTING OF FLOATING PLANT (STEEL CONSTRUCTION) OPERATING IN FRESH WATER

Paragraph 4228.15, Chapter IV, Operations, Part II, Civil Works, of Orders and Regulations, prescribes a certain color scheme for the exterior painting of floating plant. Skiffs, rowboats, launches, speed boats, scows, and other similar craft are excepted from the color scheme requirements. Where painting of such items involves only small quantities of paints, not normally stocked, consideration should be given to the acceptance of satisfactory proprietary types of paints. None of the following suggestions should be construed as superseding the instructions pertaining to color contained in the above reference.

a. **Exterior Surfaces of Steel Hulls.** The painting of exterior submerged areas of hulls, operating in inland (fresh) water, does not present a problem greatly different from that of painting structural steel components of fixed structures which are subject to immersion in flowing water. An important exception, however, may be encountered in the case of certain floating plant operating in shallow waters where the bottoms of hulls may be abraded by

frequent running aground. The likelihood of maintaining a coating in a reasonably intact condition on areas subject to such destructive action is somewhat remote. Since the color of paint for exterior steel hull surfaces below the water line is not specified in the Orders and Regulations, it is considered that any of the phenolic or vinyl type paint systems outlined in paragraph 1–54*c*(2) may be used with good results provided the surfaces are thoroughly cleaned by sandblasting. Moreover, any of these systems are recommended for use on the entire hull surfaces (including areas above the water line) of those floating plant items: e.g., barges, skiffs, etc., which are not subject to the O & R color requirements provided the finish coat color is not objectionable to the using agency. In this connection, the finish coat color of the P–4, P–4, P–2, P–2 system is aluminum, the color of the multiple coat P–5 system is light gray; and that of the multiple coat P–6 and P–7 systems is dark red to maroon, depending on the shade of iron oxide pigment used. The system composed of four coats of Fed. Spec. TT–P–86a, type IV, paint is, of course, red lead in color. The final color of the vinyl type system (two coats of V–101, two coats of V–102) is aluminum, but by substituting additional applications of Formula V–101 in place of the prescribed coats of Formula V–102, a red lead color would be obtained.

In the painting of floating plant where conformance with the O & R color scheme is required, the black color prescribed for hull surfaces above the water line may be accomplished as follows:

(1) When the underwater hull section has been painted with one of the phenolic systems (See schedule, paragraph 1–54*c*(2)) the first two coats may be extended to include the hull surfaces above the water line. These upper hull surfaces could then be finished off with two coats of a durable, abrasion-resisting, black paint such as that conforming to Military Specification JAN–P–698, "Paint, Deck, Black," or to U. S. Maritime Administration Specification 52–MA–151A, "Paint; Deck, Black, Oil Resisting."

(2) When the underwater hull section has been painted with the vinyl type system (Vinyl Wash Coat and two coats each of formulas V–101 and V–102) the first two coats of vinyl red lead primer could be extended upward to include the surfaces above the water line and finished off with two coats of formula V–103, "Vinyl type Black Finish," shown in paragraph 1–60m, or two coats of black vinyl-alkyd paint conforming to Military Specification MIL–P–15932A.

b. **Interior Surfaces of Steel Hulls.** Those interior surfaces of steel hulls which are subject to high humidity, moisture condensation and contact with accumulated water should be sandblasted and painted with one of the systems suggested for exterior underwater surfaces of hulls. Since no abrasion problem is involved, the quality of blasting may be relaxed somewhat in comparison with that required for exterior surfaces. As an alternative to the above suggestion, it is believed that two or three heavy coats of cold-applied coal tar material (Mil. Spec. MIL–C–18480) applied in conformance with the coating manufacturer's recommendations, will offer good protection on interior hull surfaces subject to severe moisture conditions. Surface should be cleaned thoroughly to bare metal preparatory to receiving the cold-applied coal tar coating although methods short of blasting may prove reasonably satisfactory under these exposure conditions, particularly on new steel. Although not considered as effective as the above alternates, consideration may be given to coating interior hull surfaces subject to condensation or contact with accumulated water with a hot-applied, petrolatum-base, rust-preventive compound of the hard-film type such as is prescribed in MIL–C–11796A, Class 1 and 1A. Surface cleaning measures preparatory to applying this type of coating will generally be limited to wire brushing, scraping, and other methods short of sandblasting, because the coating does not require or justify more elaborate cleaning methods. Attention is invited to the fact that these relatively soft, grease-type coatings should be used only on surfaces which will not be contacted by maintenance or operating personnel.

c. **Painting of Steel Decks.** Steel decks, as prescribed by the referenced paragraph of Orders and Regulations, are to be painted deck red. A system consisting of three coats of Formula P–6 (paragraph 1–60*e*) will perform adequately on these surfaces. Three coats of MIL–P–1232A, "Paint, Deck, Red" will also provide a durable, wear-resistant protective coating. It is emphasized that a considerable variation in the color shade can be obtained with either of the paint formulations suggested and that the manufacturer should be furnished a color standard if a definite shade is desired by the user. In this connection, it is considered that a deck red color is exemplified by color spot No. 10076 of Federal Specification TT–C–595 and similar reddish-brown shades. The P–6 formulation and the MIL–P–1232A paint cannot be obtained in the brighter red colors. For satisfactory results with either of the above systems the surfaces should be sandblasted, although the quality of blasting may be relaxed somewhat in comparison with that required for exterior submerged surfaces. Sand reinforcement of the above systems, as described in paragraph 1–17*a*(4) is recommended where a nonskid, traffic-bearing surface is required.

Vinyl type paints make an excellent coating for steel decks. A vinyl system of the proper finish color would consist of blast cleaning the surfaces, applying the vinyl type wash coat, two coats of V–101 vinyl red lead paint, and two finish coats of the V–104 vinyl-iron oxide paint, the composition of which is shown in paragraph 1–60*n*. The total dry-film thickness of the entire system should be not less than 5.0 mils at any point. It would be difficult to sand reinforce the vinyl system because of the rapid drying characteristics of this type of paint. As will be recognized, this system is the same as the vinyl system shown in the schedule, paragraph 1–54*c*(2), except for the change in finish coats.

d. **Exterior Surfaces of Floating Plant (Steel Construction), Except Hulls and Decks.** The color scheme for the painting of these surfaces is prescribed in Orders and Regulations, but the specific methods and paints to be used are not. Since the surfaces involved are subject only to atmospheric exposure it would appear that blast cleaning, although beneficial, may not be justified. However, if wire brushing, scraping, and other methods short of blasting are employed the surfaces will be incompletely cleaned of corrosion products and millscale. For such incompletely cleaned surfaces one or two coats of a primer with good wetting properties such as red lead-linseed oil paint conforming to Fed. Spec. TT–P–86a, Type I, would be advisable. The primed surfaces could then be finish coated with one or two coats of high gloss enamel conforming to Fed. Spec. TT–E–489b, Class A. If a finished surface of lower gloss is desired, semi-gloss enamel conforming to Fed. Spec. TT–E–529, Class A, should be used. Both of these specifications include a range of gray, ivory, black, and red colors from which those suited to the floating plant color scheme may be selected. It is to be noted that the finish coat enamels are relatively fast drying materials and that they should not be applied to the surfaces primed with the slow-drying, linseed oil, red lead paint without an extended drying period of one week or more for the primer. As a compromise between the two desirable but conflicting characteristics (good wetting properties and fast drying properties) type II paint of Fed. Spec. TT–P–86a may be used in place of type I. Type II paint is based on a vehicle which is a blend of linseed oil and alkyd resin. Thus, the type II paint dries considerably faster than type I, but is somewhat inferior in ability to wet the incompletely cleaned surfaces.

If the surfaces subject to atmospheric exposure are cleaned to base metal by blasting or pickling, it is suggested that two coats of an alkyd vehicle primer, conforming to Fed. Spec. TT–P–86a, type III, be applied. The cleaned surfaces may be treated with Vinyl Type Wash Coat prior to receiving the primer, but good results will be obtained in this type of exposure even though the wash coat is not employed. Finish coats of enamel, conforming to Fed. Spec. TT–E–489 or TT–E–529, as discussed above, could then be used to comply with the required color scheme.

Stacks and other surfaces subject to high temperatures should not be primed with the red lead oil paint but should be given two or more coats of black heat-resisting enamel, conforming to Fed. Spec. TT-E-496, type I or II, as applicable, directly over the bare metal. Dried film of this material will withstand temperatures up to 400° F. If higher temperatures (400° to 850° F.) are involved, the use of heat-resisting paints based on silicone resins is suggested. No standard specifications are available for the silicone resin paints, but they are produced by a considerable number of paint manufacturers. Military Specification MIL-P-20087 covers the procurement of paint with the ability to resist temperatures up to 850° F. and although no specific type of material is required, it is presumed that paints based on silicone resins are contemplated. The Engineer Research and Development Laboratories have developed a heat resistant paint capable of withstanding temperatures as high as 1200° F. and is based on a combination of silicone and other resins, ceramic frits and pigments. A Military Specification covering the coating is being prepared.

1-23. MISCELLANEOUS MATERIALS AND METHODS FOR THE PROTECTION OF FERROUS SURFACES SUBJECT TO FRESH WATER IMMERSION

The following materials and methods for the protection of ferrous surfaces are not included in the painting schedule because of limited usefulness, incomplete evaluation, the need for brevity, or other reasons. These methods and materials are discussed in some detail here because they represent considerable experience by certain Corps of Enginers' installations and because they show results which are at least favorable enough to warrant their limited use under some circumstances.

a. **Metallized Coatings.** The metallizing process consists of feeding a metal, usually in the form of a wire, through an oxygen-gas flame where it is melted. A strong current of air surrounding the flame atomizes and projects the molten metal in a fine spray against the surface being coated. Adhesion is obtained principally by mechanical means, i.e., there is welding action between the deposited metal and the substrate metal. The receiving surface must be thoroughly roughened by blast cleaning in order to obtain good adherence of the coating. For protective coatings, it is common practice to use relatively soft, corrosion-resisting metals, such as zinc and aluminum, in this process. Commercial metallizing guns are available for application of these metals. Several district offices in the Corps of Engineers have used the metallizing process on an experimental basis, during the past twelve to fifteen years, for surfaces subject to continuous or intermittent immersion in fresh water. Exterior surfaces of lock miter gates, broome type sluice gates, and tainter and roller dam gates were metallized in these tests. In addition, a considerable number of laboratory scale tests were made to obtain information on such items as: Spraying characteristics of various metallizing guns; relative effectiveness of various sprayed metals; surface preparation necessary for adequate adhesion; correct application procedure; effect of fineness of atomization; and supplementary surface treatment of the metallized coating. The details of the field and laboratory tests are contained in a report entitled "Report on Metallized Coatings," 25 January 1950, prepared by the Rock Island District Paint Laboratory. General conclusions based on the results from these tests follow:

(1) Durable metallized coatings of aluminum on steel surfaces subject to immersion can be obtained but at costs considerably greater than those of paint coatings. Whether the cost of metallizing to a thickness of 15 mils is much greater on a percentage-wise basis than the best 4-coat paint systems is dependent upon job conditions. Where fixed expenses incurred in mobilization, handling of equipment, bulkheading, unwatering, and demobilization for a relatively small area to be coated (lock miter gates, for example) are large, irrespective of the type of coating used, the cost of metallizing may amount to only about one-third more. However, where extensive mobilization and similiar preparatory operations are not involved, metallizing costs may be 75 to 100 percent greater than paint coatings. The greater

costs lie principally in slow application compared to spray painting; and the meticulous care needed in surface preparation in order to obtain satisfactory adhesion and a continuous uniform coating. On a unit area basis, the increase in cost is estimated to be 30 to 40 cents per square foot, but it can be much greater unless metallizing operations are organized very efficiently.

(2) If properly applied, it is estimated that 15 mils of aluminum metallizing will provide fifteen to eighteen years of trouble-free protection for steel in fresh, neutral water carrying considerable debris, ice, and other abrading materials at low velocity. For comparison, the best paint coatings tested in the same environment will give about twelve years of protection. Zinc metallizing at 10 to 12 mils thickness appears to be not as durable as the best paint coatings in the same exposure. When subjected to sustained water velocities in the neighborhood of 20 feet per second, there are some indications that the effective life of both zinc and aluminum metallized coatings is reduced proportionately more than for paint coatings. The life of a metallized coating can be increased appreciably by applying a vinyl or other type sealer over it, but aluminum metallizing, applied to a thickness of 12 to 15 mils and subject to immersion in fresh water, is not generally considered to require a seal coat. In fresh, quiet, non-abrasive water, it is conjectured that 15 mils of aluminum metallizing on steel may provide adequate protection for twenty or more years, and it is known that certain paint coatings will provide adequate protection for fifteen years.

(3) It is expected that when metallizing is found to have an advantage over other protective coatings, the areas to be coated will be relatively small. Metallizing probably will not be found to be the most economical coating for tainter, sluice, and roller gates where a large number of units and very extensive surface areas are involved. It might be found suitable for relatively small structural components where trouble-free protection for many years justifies the additional cost. It is not considered suitable for items such as trash racks or grating because of the difficulty of obtaining satisfactory adhesion on the large number of sharp edges.

(4) It is established that variations in the quantity and type of soluble constituents in water may greatly affect the corrosion rate of metals and the characteristics of galvanic couples immersed therein. Recognition of this factor should, it is believed, serve as a caution signal in the use of metallized coatings on large-scale structural surfaces subject to immersion. The initial field application of metallized coatings on metal work subject to immersion in waters of an unusual or unknown nature should be limited to small areas. Considering the expected life of such coatings, it is, of course, not generally feasible to determine their ultimate durability prior to use on a larger scale. It is considered advisable, however, to observe the trial application for at least a year or two before adoption of metallizing on a large scale.

(5) It is emphasized again that satisfactory performance of metallized coatings in fresh water immersion requires blast cleaning of the very highest quality obtainable in the field. Finger marks, dust, oil films, and all other soiling contaminants must be completely absent. Surfaces must be thoroughly roughened in order to obtain a good bond. The coating must be applied with meticulous care to obtain uniform thickness and proper characteristics of the deposited metal. Inadequate adhesion, originating from concave surfaces, sharp edges, overheated surfaces, excessively heavy coating application, as well as poor surface preparation must be carefully guarded against. These precautionary measures become increasingly difficult to enforce as the surfaces involved become larger and/or more irregular.

b. **Alternate Vinyl System for Underwater Ferrous Surfaces.** Although not shown in the schedule, an alternate vinyl type paint system has been used extensively in the field and appears to be about as durable in fresh water exposure as the system in the schedule consisting of the Vinyl Type Wash Coat (Mil. Spec. MIL-C-15328A), V-101 red lead primer, and V-102 vinyl aluminum paint. There are some indications, however, that the alternate system requires a more thoroughly blasted surface for effective results and that the adhesion

to steel upon prolonged immersion, while satisfactory, is not as good. The alternate system consists of two double spray coats of V–766 Vinyl Type White Primer (paragraph 1–60) over bare sandblasted steel, followed by two double spray coats of V–102 Vinyl Aluminum. The total dry film thickness of the applied system should be not less than 5.0 mils and additional coats should be applied if necessary to obtain the minimum thickness. Instructions for the application of the alternate system are the same as were indicated in paragraph 1–17*b*(4) for other vinyl paints. This alternate vinyl system requires a thorough sandblast job for best results. It is emphasized that the Vinyl Type Wash Coat *should not* be used in conjunction with this particular vinyl system.

c. **Dispersion Resin Paint System.** A paint system for ferrous metal surfaces subject to fresh water immersion which has performed very satisfactorily is one based on a phenolic type dispersion resin. The resin consists of highly polymerized oil-resin particles redispersed in volatile solvent. The dispersed solids, having already passed through the oxidizing and polymerizing process customary for phenolic type paints, form dry films by evaporation of solvent only, and when made up with highly volatile solvents do so very rapidly. The dispersion resin formulations, described herein, are modified to provide greater flexibility and certain other desirable properties by the addition of a fixed amount of conventional phenolic varnish.

The dispersion resin system which has shown excellent durability on steel surfaces subject to fresh water immersion consists of a sufficient number of spray coats of formula D–301, Dispersion Resin Red Lead Primer (paragraph 1–60*h*) to build up a dry film thickness of 5 to 6 mils. In normal painting weather this thickness can be achieved in four heavy coats. The paint, as packaged, should be thinned with toluene or xylene in the proportion of three volumes of base paint to one of solvent. In good drying weather, successive coats may be applied an hour or two apart, though longer drying periods are permissible and, up to a certain point, desirable. A structural component painted with the system has, in test applications, been submerged with only 24 hours drying of the last coat without apparent ill effects, although longer final drying periods are considered advisable. If the red lead as a finish color is not acceptable, the last two coats of red lead paint may be replaced with two coats of formula D–302, Dispersion Resin Aluminum Paint (paragraph 1–60*i*).

Precautions in the use of the dispersion resin paint system follow:

(1) Steel surfaces must be blast cleaned to obtain satisfactory performance of the coating. Pretreatment of the sandblasted surfaces, prior to receiving the first coat of dispersion resin paint, may consist of the vinyl type wash coat, or chemical metal conditioner, or no pretreatment. The vinyl wash coat alternate is considered preferable.

(2) When used on immersed surfaces, subject to considerable erosion and abrasion, there are positive indications that the dispersion resin coating *does not* possess a high degree of underwater abrasion resistance.

d. **Neoprene Coatings.** Neoprene KNR, a synthetic rubber, can be dissolved in solvents and in solution form becomes the basis for brushable and sprayable protective coatings. The Neoprene coating is pigmented with a medium thermal carbon black which is preferably dispersed by milling the dry Neoprene, carbon black and a small amount of process (mineral) oil together on a differential speed, 2-roll mill of the type used in the rubber industry. The Neoprene into which the carbon black has been dispersed, in proportions varying between 1 and 2 parts by weight to 1 part of Neoprene, is dissolved in xylene and a small amount of anti-oxidants and peptizing agents added. This base paint is accelerated (catalyzed) at the time of use with agents which cause the applied coating to vulcanize or cure. Curing is greatly hastened by heating to 170° or 180° F., but the coating will cure at room temperature if given enough time. Neoprene formulations made up with a high carbon black content cure at normal temperatures faster than those with less carbon black. Also, within limits,

additional accelerators help curing at lower temperatures. Even at best, however, the Neoprene coatings cure rather slowly at room temperature and require a week or more to attain sufficient toughness and resiliency to withstand abrasion. When fully cured, the coatings have most of the characteristics associated with Neoprene sheet linings, i.e., excellent strength and resiliency and unsurpassed abrasion resistance.

In order to attain greatest effectiveness, particularly in abrasion resistance, the Neoprene paint is applied in 8 or more heavy coats to a total dry film thickness of 50 to 60 mils. The material is preferably applied by brush, but can be sprayed with a fair degree of success. The Neoprene coats are applied at intervals of several hours which permit the bulk of the solvent to escape, but little actual curing of the film. Curing is accomplished in the extended period following the application of the last coat. To obtain good adhesion to steel surfaces, a primer or tie-coat must be used under the Neoprene. Blast cleaning is the only satisfactory means of surface preparation.

The material described above, applied to thickness of 50 to 60 mils, results in a very expensive coating, costing 50 to 75 cents a square foot for materials alone. Thus, it would be used only in exposures involving immersion and severe abrasion where other coatings failed to perform satisfactorily, and then only on a trial basis until its merits have been established under the specific conditions contemplated.

Heavy duty Neoprene coatings of the type discussed above are available commercially. So-called maintenance type Neoprene coatings which are applied much thinner and which have much less resistance to abrasion and corrosion are also commercially available but would be of little value in an underwater exposure involving severe abrasion. It is suggested that the Rock Island District Paint Laboratory be contacted prior to trial of Neoprene coatings on Civil Works projects.

e. **Epoxy Resin Paints.** Epoxy resins are relatively new, but have evoked much interest in the paint industry because of their excellent chemical resistance and other properties. The epoxy resins are the basis of some very interesting coatings in which the resin is the sole binder; that is, no significant amounts of drying oils or other film forming materials are used in conjunction with the resin. In this respect these epoxy coatings are similar to vinyl paints. The epoxy paints of the type under discussion, however, do not, as is true of vinyls, harden only by evaporation of solvent. Instead, after the solvent has been released, they continue to harden by polymerization induced by curing agents in the form of chemical compounds of the amine class. A practical consequence of their ability to cure or harden in this manner, is that epoxy resin paints can be formulated at a high solids (non-volatile) content and yet be of workable viscosity. These paints of high solids content would, in this absence of the catalytic curing reaction, provide soft films of inferior corrosion resistance and durability but the post-application curing mechanism converts them into hard, durable coatings.

In view of their excellent abrasion resistance, hardness, general durability and superior application characteristics, the amine-cured epoxy coatings would appear to be excellent for steel surfaces subject to immersion and abrasion. Unfortunately these coatings have so far shown a tendency toward blistering in prolonged immersion. It is hoped that the blistering tendency can be overcome by formulation changes. Until such improvement is made, it would seem that the amine-cured epoxy coatings must be used with caution on submerged steelwork.

f. **Cathodic Protection of Ferrous Surfaces.** Anyone concerned with the control of corrosion of ferrous surfaces in submerged or underground exposure should consider the feasibility of protecting those surfaces by means of cathodic protection in lieu of, or as a supplement to, the use of organic coatings. A considerable degree of success has been attained with cathodic protection on the Panama Canal lock gates which are exposed to brackish and salt water and on Mississippi River lock gates in the Rock Island District. Cathodic

protection is being used extensively for protection of underground or underwater steel surfaces of pipe lines and water storage tanks. Although new uses of cathodic protection may require considerable experimental work for successful application, it may be found to be the most economical protection yet developed for certain types of structures and exposure conditions.

Cathodic protection of underground or underwater surfaces involves the use of an external source of electrical potential to drive a direct current from an anode through the ground or water to the protected surfaces. This applied current counteracts or represses the electrochemical process of corrosion. The direct current can be obtained from batteries, a rectified alternating current, or it may under some circumstances be supplied by a galvanic cell consisting of a sacrificial metal, such as magnesium or zinc, coupled with the steel being protected. The equipment required is relatively simple and inexpensive, but the successful application of cathodic protection generally involves many problems. It is beyond the scope of this manual to discuss the details of cathodic protection.

MAINTENANCE PAINTING OF FERROUS SURFACES

1-24. GENERAL

In view of the fact that maintenance painting of ferrous metals is a recurring item of work in each district and very likely will be a larger item in the long run than the inital constructon painting, it is considered desirable to discuss it in some detail in this section. Even though the most durable protective coatings can be expected to afford adequate protection to metal for long periods, it is an accepted fact that an organic coating will deteriorate and fail eventually. It is important that planning be done sufficiently far in advance so that maintenance painting can be accomplished at the proper time and by the most efficient means. The maintenance painting program should include the recording of all pertinent data, as described in paragraph 1-52. Without a dependable historical record of what has been done, evaluation of results will be difficult.

1-25. WHEN TO REPAINT

Specific rules for determining the point of coating deterioration at which maintenance painting work should be started on metal surfaces can not be given. Some of the factors which must be considered are: cost of repainting; emphasis placed on appearance; accessibility for repainting; coordination of painting activities with mechanical repairs where expensive dewatering operations are involved; hazards to life and property should a failure occur because of a delay in maintenance; cost of replacement of corroded metal; rate of metal loss; exposure conditions; relative importance of the component to the operating efficiency of the structure; and the question of whether obsolescence may precede actual deterioration. It is obvious that metal in normal atmospheric exposure can be left unprotected for a longer period of time than metal in an environment that causes more rapid corrosion. Heavy structural steel which could safely undergo years of moderately severe exposure without danger of failure does not require the continuous degree of protection needed by thin metal surfaces which would corrode to failure in a relatively short time if not protected. Also, metal contained in certain non-critical structural features may not be considered as needful of protection as that contained in highly important structural components. It may be considered more important to protect a miter gate in a navigation system composed of single locks than to protect a tainter gate which is one of several and which can be bulk-headed in the event of structural weakening without serious interruption of project operation. It is seldom if ever justified to allow corrosion to proceed uncontrolled with the idea that the metal will be replaced with new when required. More specific information as to when to

repaint for various conditions of exposure and type of coating is given in the following paragraphs.

1–26. MAINTENANCE PAINTING OF FERROUS SURFACES SUBJECT TO EXTERIOR ATMOSPHERIC EXPOSURE

Metal in service bridges of dams and in other superstructure work exposed only to the atmosphere should be repainted before appreciable deterioration of the existing coating has taken place. In general, when a few percent of the total surface area shows blistering, corrosion and weathering away of finish coats it is time to wire brush and scrape the badly deteriorated areas, spot prime, and apply one or two overall coats of paint. Many weather-exposed steel structures coated at the time of construction with red lead-oil primer and phenolic type aluminum finish coats have been economically maintained by scraping and power wire brushing any blistered, rusted, or other unsatisfactorily protected areas and spot priming the prepared areas with the Fed. Spec. TT–P–86a, type I, primer (red lead–in–oil paint). A second spot coat of the primer is applied to the cleaned and primed areas, or the second coat may consist of formulas P–2, P–3, or P–9, Phenolic Aluminum Paint. The entire structure is then given an overall coat of the aluminum finish paint. Such a repainting practice has satisfactorily postponed further maintenance painting for periods of six to ten years.

If touchup work and repainting are delayed indefinitely, a point will be reached where the painted surfaces as a whole are in such poor condition that a complete cleaning and painting job is required. Except in the more extreme cases of corrosion and coating deterioration, cleaning will take the form of power wire brushing, scraping, and solvent cleaning. In some instances, however, it is expected that districts will encounter heavily rusted bridge structures, equipment, and other surfaces which have been unprotected for many years and which cannot be satisfactorily cleaned by any means other than blasting. In such cases the brushoff method of blast cleaning should be sufficient. In either event, whether brushoff blast cleaning (par. 1–12*c*(2)) or power wire brushing is employed, a complete new system similar to one of the alternates shown in the schedule for exterior atmospheric exposed ferrous surfaces should be applied.

1–27. MAINTENANCE PAINTING OF FERROUS SURFACES SUBJECT TO WATER IMMERSION

Metal surfaces of floating plant, dam gates, and similar items that are in underwater exposure, and metal which is subject to appreciable condensed moisture must be considered in a considerably different light than that which is in atmospheric exposure. In the coating of underwater steel surfaces, paints which are unadapted for any but scrupulously cleaned surfaces must be used for adequate durability. In short, these paints require blasting of steel surfaces to obtain good adhesion.

a. **Maintenance of Phenolic Type Coatings.** In some districts, phenolic coatings, on structural steel surfaces in this type exposure, are successfully maintained by a very prompt schedule of repainting prior to appreciable coating deterioration or formation of more than a negligible amount of corrosion. Maintenance usually takes the form of cleaning abraded, rusted areas by spot blasting preferably, and applying to the cleaned areas a system equivalent to that originally employed. At more infrequent intervals the entire surfaces may be cleaned of mud, grease, etc., by suitable means, and an overall finish coat of paint applied. Only a small amount of cleaning and priming at any one time is required when this schedule is followed, but under severe abrasion conditions almost yearly attention must be given to certain of the surfaces to maintain the coating in good condition.

In other districts this procedure has not been found very successful, principally because the prompt touchup schedule was not followed consistently, because the spot-painting

procedures themselves were ineffective, or because the surfaces involved were accessible only at considerable expense. Some districts have particularly found it difficult to maintain good adhesion, in an abrasive, underwater environment, between new paint coats and old weathered phenolic paint films. Consequently, in these cases a delayed schedule was adopted which allowed deterioration of the coating to progress until 20 to 30 percent of the area was unprotected. At this stage of the coating life, which may be about 10 years for a sand reinforced, phenolic system in a moderately abrasive, fresh water exposure, the entire structural component is blast cleaned and given a complete underwater coating system as described in the schedule. Although this maintenance plan may seem to permit undue deterioration of the structural steel component, it should be kept in mind that on steel of relatively heavy cross section, perfect protection is not necessary. Instead, the preservation of the components function during the foreseeable useful life of the structure as a whole is the important consideration. With this in mind it will be clear that highly corrosive exposure conditions and/or thin metal sections would make the delayed maintenance schedule inadvisable.

The relative economies of the two procedures (prompt and delayed maintenance schedules) is not known. The success of either method depends greatly upon the organization, plant, and personnel available to accomplish the work and the amount of surface area to be maintained.

b. **Maintenance of Vinyl Type Coatings.** The question of how and when to repaint steel surfaces subject to water immersion which were previously sandblasted and painted with the vinyl type systems involves much the same consideration as are mentioned above for phenolic type coatings. There are important differences, however. Aged films of the vinyl type remain soluble in the solvents which were originally used in making up the formulations and consequently, effective adhesion can be established between the old weathered film and any new coats which are applied. Also, the rapid drying characteristics of the vinyl paints make them much more adaptable to touchup painting procedures, than the phenolic paints. With these advantages in mind, it would appear that the vinyl system is more adaptable to a touchup program of year by year maintenance than the phenolic systems. By use of this method it is believed that the need for complete removal of old vinyl coatings and overall repainting of the surfaces possibly may be postponed indefinitely.

c. **Maintenance of Coal Tar Coatings.** Insofar as the cold-applied coal tar base system and the hot-applied coal tar enamel, shown in the schedule, are concerned, every effort should be made to maintain these coatings in good condition immediately as the need arises, instead of letting them deteriorate to the point where complete removal and recoating is necessary. Extensive preparatory work and large mobilization costs may, of course, prohibit repair of these coatings except at extended intervals. The maintenance of the cold-applied coal tar system should be accomplished by cleaning abraded, rusted, or otherwise deteriorated areas to base metal by spot-blasting (preferably) or by scraping and power wire brushing, and then coating the cleaned areas in a manner similar to that used for the original coating. Cleaning the old coating of dirt, grease, and other surface contaminants, and applying a new coat of cold-applied coal tar paint overall may be attempted, but this procedure may not secure good adhesion of the new application to the old, particularly on areas where the latter has been weathered for several years in exterior atmospheric exposure. The maintenance of hot-applied coal tar for enameled surfaces should take the form of cleaning abraded, rusted, or otherwise deteriorated areas to base metal by spot-blasting preferably, and coating the cleaned area in a manner similar to that used originally. Renewal of the old coal tar enamel by adding a new coat of enamel is not feasible. If deterioration of coal tar coatings progresses to the point where their complete removal is necessary, it should be accomplished by scraping and blasting in cold weather when the residual coating becomes more brittle and thus more easily removed.

1–28. PERFORMANCE OF WORK

Maintenance painting may be accomplished either by contract or by hired labor. The method to be used for greatest economy is often not easily determined. River and harbor structures present conditions which are generally quite different from that in which the contract painter is experienced. Floating plant may be required which few, if any, contractors in the locality would have; the structures may be located long distances from industrial centers where skilled craftsmen are recruited; the duration of work normally would not extend over long periods of time, resulting in proportionately high mobilization and demobilization costs to the contractor. All of these factors tend to restrict competitive bidding and result in high costs. They are present in hired labor painting also, but their effect can be minimized by training local personnel, utilizing the maintenance personnel which are part of the regular organization, and utilization of existing Corps of Engineers' floating plant. The flexibility of operations inherent in hired labor offers the opportunity of shifting personnel to entirely unrelated work during periods of inclement weather when painting operations must be delayed. In those instances where other work can be provided for the painting personnel during the winter season, thus offering year-around employment to skilled employees, the hired labor method of performing the work becomes even more attractive. A trained and skilled crew is extremely important in obtaining the quality of workmanship contemplated by this manual, particularly for steel surfaces exposed to immersion. Experience has shown that the cost of the work done by a highly trained crew is very much lower than that done by an inexperienced crew.

1–29. COST DATA FOR MAINTENANCE PAINTING OF STRUCTURAL STEEL SURFACES

The cost of maintenance painting of metal components of river and harbor structures varies considerably from one location to another and from one season to another. It is believed that a large variation in costs quite often results from differences in cost accounting. However, such factors as weather, wage rates, accessibility of work, quality of workmanship, and condition of metal play a very large part in determining the cost of a cleaning and painting job. For these reasons the following cost data do not have much value, except as a basis for estimates in districts that have no other available information. *The data should not be used as a target goal or as a justification of costs in any district.* The roller and tainter gate surfaces included in the cost data were made accessible by inexpensive bulkheading procedures and were cleaned and painted by equipment mounted on floating plant. All surface areas indicated were sandblasted to a degree of surface cleanliness just short of white metal and given a four-coat vinyl system totalling 5 mils or more in thickness. About half of the surfaces was rather severely corroded and pitted while the other half was relatively smooth and corrosion-free.

MAINTENANCE PAINTING COSTS OF STRUCTURAL STEEL

1952 SEASON

	Labor	Material	Plant	Non-personnel	Total	Percent of Total	$/sq. ft.
LOCK and DAM No. 17 (MISSISSIPPI RIVER)—Sandblast and paint interior & exterior 3 rollers & 8 tainter gates—177,570 sq. ft.							
Mob. and demob. 321-431A	2,711.82	137.43	2,255.42	1,950.26	7,054.93	10.0	$0.039
Sandblasting 321-431B	11,358.15	2,016.18	10,188.69	4,159.85	27,722.87	39.2	0.154
Painting 321-431C	8,535.75	9,386.90	4,568.18	2,601.99	25,092.82	36.8	0.145
Inspect. and superv. 321-433	1,131.59		72.50	116.74	1,320.83	1.8	0.007
Direct costs	23,737.31	11,540.51	17,084.79	8,828.84	61,191.45		
Overhead—Div. and Dist. (14.1 percent)					8,643.00	12.2	0.048
Total cost of job					69,834.45		0.393 per sq. ft.
LOCK and DAM No. 17 (MISSISSIPPI RIVER)—Sandblast and paint 6 roller gate bulkheads & 5 tainter gate bulkheads—43,765 sq. ft.							
Mob. and demob. 321-411	371.06	13.18	113.72	519.30	1,017.26	7.0	0.023
Sandblasting 321-412	2,265.02	774.21	2,042.33	504.87	5,586.43	38.2	0.128
Painting 321-413	1,489.47	3,299.71	943.94	364.36	6,097.48	41.6	0.139
Inspect. and superv. 321-43	101.85		33.00		134.85	.9	0.003
Direct costs	4,227.40	4,087.10	3,132.99	1,388.53	12,836.02		
Overhead—Div. and Dist. (14.1 percent)					1,797.00	12.3	0.041
Total cost of job					14,633.02		0.334 per sq. ft.

SURFACE PREPARATION AND PAINTING OF WOOD SURFACES

1-30. GENERAL

The primary purpose of painting exterior wood is protection. Without the protection of paint, varnish, or other coating exterior woodwork undergoes weathering, which roughens its surface, turns it drab gray in color, causes cupping and warping unless the boards are very firmly held in place, and wears away about one-fourth inch of thickness a century. A secondary purpose of painting wood, except for interior surfaces, is to obtain a more pleasing appearance. Paint not only provides a wide choice of color effects and decorative schemes, but, if properly maintained, it gives an appearance of style and prideful occupancy.

Indirectly painting makes for economy of maintenance because each renewal of paint provides a reminder and a suitable occasion for making any needed minor repairs that otherwise might be neglected until they become major repairs. Painting, therefore, stimulates inexpensive preventative maintenance which forestalls eventual expensive remedial maintenance.

1-31. PAINT RETAINING CHARACTERISTICS OF WOODS

Woods vary greatly in their ability to retain paint according to the density of the wood and the texture of the surface painted. Among softwoods, paint coatings remain sound longest on wood of light weight, with narrow growth rings, on edge-grain surfaces, on the bark side rather than the pith side of flat-grain boards, and on high grade lumber free from knots and other defects. The growth rings in softwoods consist of a dense, horny, darker colored part called the summerwood and a less dense, soft, lighter colored part called the springwood. When paint coatings begin to disintegrate they do so first and continue most rapidly on the widest streaks of summerwood in the paint surfaces; hence the importance of low density and narrow growth rings for good paintability. Average shipments of the select grades of properly dried softwoods commonly used for building may be classified as follows with reference to ability to retain paint coatings and ability to withstand weathering:

Group 1—Woods that retain paint longest and withstand weathering best.
- Western red cedar
- Other cedars except eastern red cedar
- Southern cypress
- Redwood

Group 2—Woods that retain paint well if properly primed and withstand weathering well.
- Northern white pine
- Western white pine
- Sugar pine

Group 3—Woods that retain paint only moderately well and withstand weathering moderately well to poorly.
- Commercial white fir
- Eastern hemlock
- Western hemlock
- Ponderosa pine
- Eastern spruce
- Western spruce
- Lodge pole pine
- Angleman spruce
- Sitka spruce

Group 4—Woods that retain paint poorly and withstand weathering poorly.
Douglas-fir
Western larch
Southern yellow pine
Norway pine
Tamarack

Hardwoods are used much less frequently than softwoods in building construction especially on exterior surfaces. Besides the wood properties already mentioned, size of pores is an important factor in the painting and finishing of hardwoods. Hardwoods with pores larger than those in birch, such as ash, chestnut, elm, hickory, oak, and walnut, are unsuitable for ordinary exterior painting with house paints because smooth, durable coatings are not attainable without an extra operation to fill the pores. Hardwoods with small pores and moderate density, such as basswood, cottonwood, and poplar, hold paints about as well as softwoods of *Group 3*. Heavier hardwoods with small pores, such as beech, birch, gum, and maple, hold paint about as well as softwoods of *Group 4*.

1–32. PAINTS FOR EXTERIOR WOODWORK

House paint is most often chosen for the main exterior surfaces of buildings and most other woodwork out of doors. House paints are opaque coatings of moderate gloss designed for ease of spreading by brush or spray, for building up the thickness of dried coating necessary for best durability with the minimum number of coats, for forming a moderately smooth surface despite the imperfections in commercial lumber, and for withstanding exposure to the weather as long as possible without leaving too difficult a surface to prepare for further painting.

a. **House Paint Finish Coats.** The schedule, paragraph 1–54*c*(8), provides three kinds of house paint where white or light color is desired as follows:

(1) *Titanium-Lead-Zinc Paint.* Paint conforming to Fed. Spec. TT–P–102 is of the mixed-pigment type made with titanium dioxide, white lead, and zinc oxide. It is recommended for general exterior painting. Paint of Fed. Spec. TT–P–102 resists discoloration by dirt and by mildew well, normally remains free from checking and cracking until it becomes due for repainting, does not chalk too freely, and performs well near the seacoast or other places where there is much damp weather.

Users of such paints should note particularly that Fed. Spec. TT–P–102 provides two classes of paint, class A for use as white paint only, and class B for tinted colors made up by the paint manufacturer or for white base paint to be tinted by the painter on the job. Purchase orders should indicate clearly which class is desired. The class A paint is made to resist discoloration by dirt but it is unsuitable for tinting because the color will soon fade badly. The class B paint is made to resist fading of color reasonably well but it will become more seriously soiled by dirt than class A paint.

(2) *Titanium-Zinc Paint.* Paint conforming to Fed. Spec. TT–P–103 is a lead-free paint made with titanium dioxide and zinc oxide for use in places where paints containing white lead might become blackened by fumes of hydrogen sulfide. There are a few places where atmospheric contamination with hydrogen sulfide is to be feared; sulfur dioxide, which is of more frequent occurrence, does not blacken paints containing white lead. Paint of Fed. Spec. TT–P–103 resists discoloration by dirt and by mildew, normally remains free from checking and cracking until it becomes due for repainting, may chalk somewhat too freely, and performs well near the seacoast or in other damp places. Paint conforming to Fed. Spec. TT–P–103 is for use as white paint only; if tinted it would fade badly and in most tints would lose its resistance to hydrogen sulfide.

(3) *Pure White Lead Paint.* Paint conforming to Fed. Spec. TT–P–104 is pure white lead paint in ready-to-use form. Pure white lead is only moderately resistant to dis-

coloration by dirt and by mildew, chalks moderately, normally develops an inconspicuous pattern of checking long before it is time for repainting, finally breaks up by fine crumbling, is highly resistant to cracking and scaling, and normally leaves an easy surface to prepare for repainting. This type of paint may become mildewed and chalk away too rapidly near the seacoast or other damp places. Pure white lead paint may be used for white paint or it may be tinted; it holds tints well.

(4) *Deep and Medium Colors.* Paints of deep colors cannot be made by tinting white paints. The deep colors are used chiefly for trim and other minor areas of buildings, less often for large areas such as siding. Deep colored paints suitable for wood surfaces may make use of the following Federal Specification materials: for red or brown, paint conforming to Fed. Spec. TT–P–31b; for green, Fed. Spec. TT–P–71b; for black, Fed. Spec. TT–P–61b. Medium shades of gray, buff and green may be obtained under Fed. Spec. TT–P–81c.

b. **House-Paint Primers.** Most house paints, including whites, tints, and deep colors, are made primarily for use as finish coats. White and tinted paints and some deep colors may serve well as priming coats for painting woods of *Group 1* in paragraph 1–31, if the paints are thinned moderately with linseed oil, or linseed oil and a little thinner, but better work can be done by using priming paints made especially for that purpose. Special priming paints are particularly desirable when painting woods of *Groups 2, 3, or 4.* Pure white lead paint, however, is a good paint for priming as well as for finish coats and may, therefore, be used for all coats on wood of any kind.

(1) *Titanium-Lead Primer.* The schedule herein, paragraph 1–54*c*(8), provides house paint primer conforming to Fed. Spec. TT–P–25a for the first coat on exterior woodwork. It is a paint made with titanium dioxide, white lead and extender pigments without zinc oxide, in a vehicle of raw and bodied linseed oil so adjusted that the oils do not penetrate unduly into wood. The house paint primer, however, should be used only for priming or undercoating, never for the finish coat, because it is not designed to take the direct impact of the weather. Priming paint TT–P–25a comes in white or in light colors as specified by the Contracting Officer, or as tinted by the painter on the job. When the finish paint is to be white the primer also is usually white, though some prefer a pale gray. When the finish paint is a light color the primer usually should be the same color or a slightly darker tint of similar color. When the finish paint is a deep color the primer should be gray or a tint as close to the finish color as can be made by tinting the white priming paint.

House paint primer Fed. Spec. TT–P–25a should always be used whenever previously unpainted wood of any group is to be painted with but two coats, one of primer and one of finish paint. Such two-coat painting, however, requires close supervision to insure that enough paint is applied.

Primer conforming to Fed. Spec. TT–P–25a should not be used under fume-resistant titanium-zinc paint of Fed. Spec. TT–P–103 when the exposure is to hydrogen sulfide, since fully reliable resistance to such fumes requires that a lead-free primer be chosen. The finish paint of Fed. Spec. TT–P–103 itself, reduced with one pint of linseed oil per gallon, makes a satisfactory primer.

When repainting without completely removing the previous paint with blow torch or paint remover, house paint primer conforming to Fed. Spec. TT–P–25a should always be used for spot priming those places where the wood is bare and for undercoating if a coat of titanium-lead-zinc paint of Fed. Spec. TT–P–102 is to follow promptly. If the final coat is to be pure white lead paint, Fed. Spec. TT–P–104, the spot priming and undercoating may be done equally well with either the white lead paint itself or with the TT–P–25a house paint primer.

(2) *Aluminum Primer.* Aluminum priming paint for wood is not generally recommended because it is difficult to hide with subsequent finish coats and because adhesion of

finish coats to the aluminum primer may be poor. Under special conditions, discussed below, aluminum primer may be useful. The aluminum paints provided herein (for finish coating of metal surfaces) are unsuitable for use on wood. There are, however, Federal Specifications for the necessary ingredients, which are best mixed by the painter on the job just before use. The best choice as a rule is 2 pounds of aluminum paste (Fed. Spec. TT–A–468a, type II, class C) to be added to 1 gallon of aluminum mixing varnish according to Fed. Spec. TT–V–81b, type I, class B. Another choice is 1½ pounds of dry aluminum powder, Fed. Spec. TT–A–468a, type I, class C, to be added to 1 gallon of varnish, Fed. Spec. TT–V–81b, type I, class A.

Aluminum priming paint is useful for priming previously unpainted surfaces of any of the wood in *Group 4* of paragraph 1–31 when the primer is to be followed by two coats of finish house paint of any of the various types previously discussed. Aluminum primer may also be useful on woods of *Groups 2, 3,* and *4* when the finish paint is to be titanium-zinc paint Fed. Spec. TT–P–103 for resistance to severe fumes of hydrogen sulfide. Aluminum primer, however, is not recommended for use in repainting and spot painting except under unusual circumstances.

c. **Porch and Deck Paints.** Exterior wood steps, platforms, floors of open porches, and other surfaces that must stand traffic require paints that harden much more rapidly than house paints do. Paints for such traffic-bearing surfaces are made with varnish rather than oil vehicles. As a rule they are worn out by the pounding and scraping of the traffic rather than by the slower action of the weather. For that reason, paints can safely be used that harden rapidly even though, if they lasted as long as house paints do, they would become very brittle and crack and scale badly. It is to be expected that a practicable porch paint, after several repaintings, will reach a condition of breakdown on the less trafficked areas such that complete removal of old paint will be necessary before repainting.

The schedule, paragraph 1–54*c*(9), provides varnish base floor enamel conforming to Fed. Spec. TT–E–487 for this purpose. This is an enamel made with a vehicle of floor varnish and is intended for use either indoors or outdoors and on either wood or aged (at least six months) concrete. Since the paint is usually worn out by traffic rather than by weathering, efforts to improve weather resistance by using special primers are considered unrewarding; the paint is, therefore, used as its own primer.

d. **Stains for Shingles and Rough Woodwork.** Stains for exterior use, particularly on shingles and other woodwork with rough surfaces, are prescribed in Fed. Spec. TT–S–706 for "Stain, Opaque, Wood, Exterior, Oil."

1–33. PAINTS AND VARNISHES FOR INTERIOR WOODWORK

House paints for exterior woodwork should not be used on interior surfaces of wood or other materials. For such uses the exterior paints may dry unnecessarily slowly, may never harden as much as is desired, and may gradually turn yellow.

a. **Paints for Interior Woodwork Other Than Floors.** The following instructions relative to painting of interior woodwork are also applicable to general interior painting except that plaster, wallboard and similar surfaces should, prior to the desired finish coat, receive a prime coat of Fed. Spec. TT–P–56b primer-sealer followed by a coat of Fed. Spec. TT–E–543 enamel undercoat in place of the two coats of Fed. Spec. TT–E–543 prescribed for wood surfaces.

(1) *Priming Paint for Interior Woodwork.* For interior woodwork other than floors, the paint finishes prescribed in the schedule, paragraph 1–54*c*(17), consist of three coats of which the first and second are enamel undercoats conforming to Fed. Spec. TT–E–543. Although not particularly designed for priming wood, the undercoat material serves very well for that purpose on most interior woodwork. The undercoater should approximate the color of the final finish coat material which is to be used.

(2) *Eggshell-Finish Paint.* Three different finish paints are provided for interior woodwork according to the degree of gloss required. Paint conforming to Fed. Spec. TT–P–51d is a flat paint that dries with little gloss to give a so-called eggshell surface from which light is reflected diffusely. For large areas such as plywood panels on walls and ceilings such eggshell or flat paint presents the most pleasing appearance and most comfortable distribution of light. The eggshell paint can be washed from time to time to keep it clean but it will not stand as many or such vigorous washings as the semigloss or gloss paints. One coat of the Fed. Spec. TT–P–51d paint applied over the two coats of Fed. Spec. TT–E–543, should be sufficient for new woodwork.

(3) *Semigloss Finish Paint.* For wood trim in general and for walls and ceilings in service rooms such as kitchen and bathrooms, where good washability is important and moderately glossy surfaces are customary, the best choice for finish paint is usually semigloss enamel conforming to Fed. Spec. TT–E–508. The enamel is made with a varnish vehicle and a relatively high level of pigments to produce a semigloss appearance and a coating that stands wear and washing well. One coat of the semigloss enamel, applied over the two coats of Fed. Spec. TT–E–543 enamel undercoater, should be sufficient for new work.

(4) *Gloss-Finish Paint.* When a highly glossy finish is desired, the finish coat over the Fed. Spec. TT–E–543 undercoats should be enamel conforming to Fed. Spec. TT–E–506c. This is an enamel of good hiding power but moderate level of total pigment in a varnish vehicle. It has high gloss and stands washing well but it should be remembered that highly glossy coatings accentuate any defects or irregularities in the wood surfaces, such as planer marks, hammer marks, rough grain, knots or raised grain, unless the wood has been carefully smoothed before finishing and the finishing system includes a surfacer that has been sanded smooth before the finish coat of glossy enamel is applied. Semigloss finish is ordinarily to be preferred for moderate-priced interior finishing because it does not render such imperfections as conspicuous as high gloss finish does.

b. **Natural Finish for Woodwork Other Than Floors.** Natural finishes for interior woodwork are of great variety. Only a simple varnish finish with or without stain and filler, is prescribed in the schedule, paragraph 1–54*c*(19).

(1) *Stain.* When the color of the wood is to be changed, stain conforming to Fed. Spec. TT–S–711a should be used. The color desired should be specified when the stain is purchased. Normally, the stain is one made of pigments in oils or varnish together with necessary thinners. The stain may be diluted with mineral spirits to make a lighter color. On softwoods with wide bands of summerwood, such as flat-grain southern yellow pine or Douglas-fir, a more nearly uniform coloring can be produced by applying a thin, penetrating coat of shellac (Fed. Spec. TT–V–91b, type 1, grade A) as a sealer *before* the stain is applied. It is not necessary or desirable to seal with shellac after the stain has been applied unless, for some unusual reason, the stain is one containing an oil-soluble dye.

(2) *Filler.* After staining, if stain is used, hardwoods with pores larger than those in birch should have the pores filled with wood filler conforming to Fed. Spec. TT–F–336a. The filler may be either *natural* wood filler, which is essentially colorless, or it may be colored. Colored filler accentuates the grain pattern of the wood whereas natural filler does not. The filler comes in the form of a paste which is thinned to brushing consistency with mineral spirits, using a somewhat stiffer mixture for woods with very large pores than for woods with pores of moderate size. The mixture is brushed well into the wood and allowed to stand a few minutes for much of the thinner to evaporate and for the coating to turn dull. Before it has time to set or harden, however, the excess filler is wiped off with rags, burlap, or other suitable material. The first wiping strokes should be in a direction at right angles to the grain of the wood and should include a padding or pounding action to pack filler into the wood pores. Final strokes should be done with clean rags in the direction of the wood

grain. It is very important from the standpoint of appearance, that all excess filler be removed from the surfaces.

(3) *Varnish.* After staining and filling, when necessary, the wood should be coated with three coats of varnish conforming to Fed. Spec. TT-V-121c. Each coat should stand at least overnight to dry and, when practicable, should be sandpapered lightly before the next coat is applied. The final coat may be left in its natural gloss or it may be rubbed to the desired finish.

c. **Floor Finishes.** Wood floors may be painted or they may be finished with natural wood sealer and wax according to the appearance desired.

(1) *Paint.* For painted interior wood floors, dadoes, etc., the same material (Federal Specification Floor Enamel, Fed. Spec. TT-E-487) and procedure are followed as for exterior wood porches and steps. Paint finishes are apt to be chosen more often for softwood than for hardwood floors. It would be unusual to paint oak or other hardwood with large pores, but if it were done the pores should first be filled with wood filler.

(2) *Natural Floor Finish.* For natural finish on floors of oak or other hardwood with large pores, the first operation, after necessary sanding, is filling the pores with wood filler (Fed. Spec. TT-F-336a). Maple, other hardwoods with small pores, and softwoods do not require filling.

Next, two coats of sealer conforming to Fed. Spec. TT-S-176b are applied. The sealer is a form of varnish made to penetrate into wood surfaces rather than to coat them over. It comes in two classes. Class 1 contains 40 percent nonvolatile by weight for use on very absorptive surfaces such as cork and woods of low density. Class 1 sealer may be adjusted for less absorptive surfaces by thinning it as needed with mineral spirits. Sealer of Class 2 contains 25 percent nonvolatile for use on less absorptive surfaces such as maple and oak that has been filled. Class 2 should not be thinned for use.

Sealer is usually mopped on the floor with a suitable applicator and allowed to stand a few minutes for much of the volatile thinner to escape, after which it is buffed with steel wool, preferably with a power buffing machine. Next day, a second application is made in the same way. The buffing operation is necessary for best appearance and longest wear. It makes sure that all of the material left is held within the wood near the surface and that no appreciable coating is formed over the wood. It is practicable, however, to apply the sealer finish without buffing, provided care is taken to avoid leaving too much excess material on the wood surface.

Sealer finishes are commonly maintained by waxing. Emulsion wax conforming to Fed. Spec. P-W-155 should be used for that purpose. The last coat of sealer should be allowed to dry for a week or more before the wax is first applied.

1-34. PREPARATION OF WOOD SURFACES FOR PAINTING

a. **General.** New woodwork when painted or otherwise finished should be at a moisture content well within the range within which it presumably will stay while in service. For exterior woodwork a moisture content of 9 to 14 percent is preferred. Interior woodwork may be between 5 and 10 percent and flooring between 6 and 9 percent. If outside woodwork has been brought to suitable moisture content but its surface has been made temporarily wet by rain or dew, painting may be started as soon as the surface again becomes dry to the touch. New woodwork should be painted or otherwise finished as soon as practicable after erection. All plastering should be completed and dried out before the woodwork to be painted is erected.

b. **Preparation of Exterior Wood Surfaces**

(1) *New Woodwork.* Normally new woodwork in building requires little preparation for painting. If the surfaces are dirty or contaminated by oil, asphalt, or lumber marking

crayon, they should be cleaned by suitable methods. Any loose grain or splinters in low grade or poorly manufactured lumber should be removed and the surface made as smooth as practicable with plane, scraper, or sandpaper provided the need for good appearance justifies the extra expense. Any resin (pitch) exudations on the surface should be removed by scraper and sandpaper or, if the resin is soft, by cleaning with mineral spirits or turpentine. If the importance of the work justifies it, pitchy areas may be heated by a blowtorch to encourage bleeding of the resin before the resin is cleaned off.

Except as already provided, it is not customary to sandpaper exterior woodwork before painting it.

Knots should be sealed with a thin coat of knot sealer conforming to Military Specification MIL–S–12935A, "Sealer, Surface, Knot," prior to painting. Knot sealers may prevent early discoloration of the paint over knots in pine and make it easier to avoid loss of gloss over knots in flat-grained boards. On the other hand, sealers do not always make it possible to conceal knots entirely and do not always keep the paint from flaking off the knots or the sealed areas well before it breaks down elsewhere. See figure 6. Decision about use of sealer on knots should be made clear in the painting specifications before bids for the painting work are invited. Treating the knot with the MIL–S–12935A sealer is considered better than shellac.

Nail holes or other imperfections should be puttied, but not until the priming coat of paint has been applied and has dried thoroughly.

House paints to be used on new wood in areas where mildewing is known to be prevalent should contain fungicidal agents as will be discussed later in connection with repainting

(2) *Previously Painted Wood.* When paint is maintained in accordance with a well-planned program, the preparation of the surface for repainting normally is relatively easy and inexpensive. Haphazard maintenance, poor choice of paints, or the abnormal conditions discussed subsequently herein, however, may give rise to difficult surfaces to prepare for repainting. In extreme cases, it may become necessary to remove all of the old paint before repainting.

(a) When Removal of Old Paint Is Unnecessary. If there is no loose, curling, or blistered paint, adequate preparation of the surface consists merely in seeing that it is reasonably clean, dry, and free from serious contamination. Brushing with a painters' duster may suffice for most of the area. Very dirty parts should be washed, particularly if the dirt is of an oily or greasy nature. The parts of the building most heavily shaded, such as the ceiling of the roof overhang, are usually dirtiest and most likely to need washing. Contamination, as with asphalt spilled in roof repairs, or resin exuded from the wood should be removed with scrapers, solvents, or other suitable means.

If there is any loose, curling, or blistered paint, it should be taken off by scraper, wire brush, or sandpaper. A chalkiness or dusting of the paint surface is to be expected and calls for no special precautions. Likewise, checking or cracking of the paint if there is no loosening or curling at the edges of the fissures is not considered loose paint. On dense woods that show conspicuous growth rings, such as southern yellow pine or Douglas-fir, some of the bands of summerwood may have been laid bare by fine crumbling or flaking of the paint without giving occasion for undue concern. If a few boards on a building are conspicuously worse than the rest in this respect, it may be wise to replace them with boards of more representative density and grain pattern. Blistering or scaling of the old paint in pieces large enough to lay bare springwood and summerwood indiscriminately give warning of abnormal conditions, discussed hereinafter, which should be studied carefully and corrected, if possible, before proceeding with repainting.

(b) When Old Paint Must Be Removed. Complete removal of old paint is expensive, usually costing more than the subsequent repainting. For that reason complete

removal is a last resort adopted only when no cheaper procedure offers reasonable change of acceptable results. Circumstances under which complete removal may be necessary are discussed later.

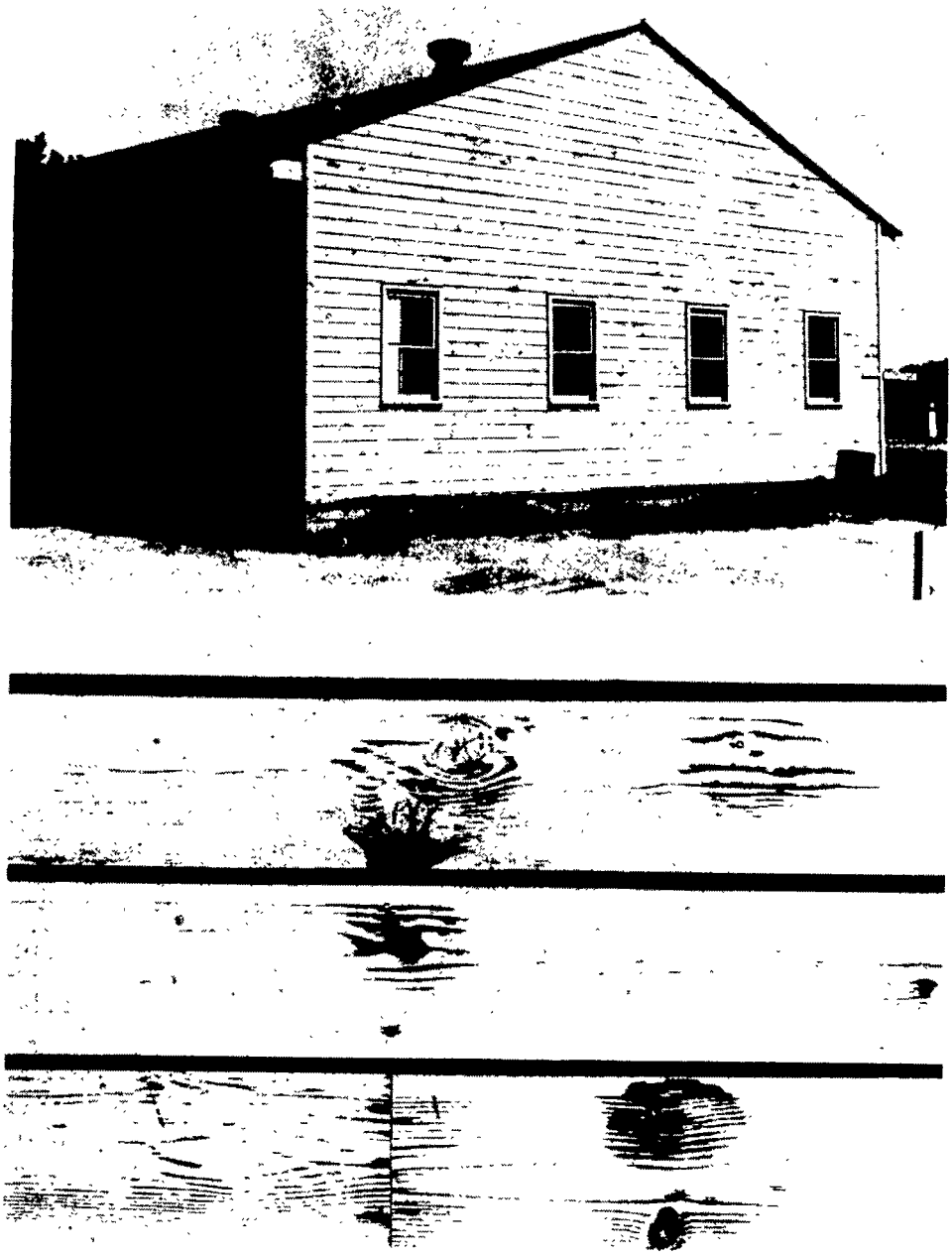

FIGURE 6. *Effects of knots on paint coatings.*

(Knots in low-grade lumber impair the service of paint, whether or not they are covered with knot sealer. On this building the knots were carefully shellacked before painting.)

When it is practicable to do so, old paint should be removed by scraping and sandpapering. Usually, however, much of the old paint adheres too firmly to come off readily by scraping. In such cases, the old paint must be softened either by heat or by solvents before it can be scraped off. Heat may be used in the form of the painter's blowtorch. Care must

be taken to avoid charring the wood. There must also be constant watchfulness to see that the building is not set afire; badly neglected buildings on which siding has cupped badly offer opportunity for flame from the torch to get into the sheathing or stud space where fire may make headway before it is detected. Where electric outlets are conveniently available, electric torches are now available that afford less hazard of charring the wood or starting fire. House paint removers contain solvents that are absorbed by and soften paint. The more viscous types which can be spread on thickly are recommended where the surfaces to be cleaned are largely sidewalls or ceilings, e.g., Type III, class B, of Fed. Spec. TT–R–251d.

With either heat or solvents, application should be continued until the old paint is softened sufficiently for one stroke of the scraper to take off everything down to the bare wood. Ordinarily a clean wood surface, entirely free from old paint, should be left. When aluminum paint is used for the priming coat of the first paint job, however, it may not be possible to remove all of it either by heat or by solvents but the aluminum so left behind may safely be left. When house paint remover is used, the bared surface should be washed with paint thinner if necessary to remove any wax left from the remover. Type III, class B, Fed. Spec. TT–R–251d is supposed to provide a remover which does not require solvent washing after scraping. Finally, it is wise to sandpaper the surface lightly before starting to repaint.

(c) When Old Paint Has Mildewed. Where paint is warm and damp much of the time, as in southern coastal areas, it may become discolored by an overgrowth of the fungi of mildew. Unless mildewed paint is scrubbed clean before repainting, the infection may come through the new paint. Mildew should be thoroughly washed off with strong soap and warm water or with a solution of one-fourth pound of trisodium phosphate to a gallon of water (wear rubber gloves to protect the hands) and then rinsed with clean water. It should be pointed out that the positive identification of mildew is very difficult for any except the most experienced observer, and is frequently confused with surface soil in various forms.

Paints vary in resistance to mildew. House paints that contain zinc oxide are moderately resistant, provided that they are not thinned excessively with linseed oil. Pure white lead paint is somewhat more susceptible. Trim paints in dark colors such as green, brown, or black are still more easily attacked, though they do better if they are made with enough varnish in the vehicle to dry fairly rapidly. For places where mildew infestation is *known* to be severe, it may be necessary to use paints in which suitable fungicides have been incorporated. Mercuric chloride in proportions of 1 part by weight to 500 parts of paint has been widely used in the past but is a poisonous material that should not come in contact with the skin.

Note: According to data of the Engineer Research and Development Laboratories, mercuric chloride is not effective unless it is used in concentrations many times that indicated above. Phenyl mercuric salicylate, acetate, chloride, nitrate, and other phenyl mercuric compounds were much more efficient than mercuric chloride in control of mildewing. The phenyl mercuric compounds, when used in concentrations ranging from 0.5 to 1.0 per cent of the weight of the paint, controlled mildewing and were as effective as 6 per cent of mercuric chloride. The phenyl mercuric compounds are toxic to humans. A practical or technical grade of phenyl mercuric compounds should be used in paints in order to reduce cost; in pure forms these compounds are quite expensive. Pentachlorophenol to the extent of 3 to 5 per cent of the weight of paint is safer to use because it is relatively nontoxic to man; tetrachlorophenol is slightly more efficient than pentachlorophenol.

c. Preparation of Interior Surfaces

(1) *New Woodwork.* Surfaces of new, interior woodwork should be clean and free from resin (pitch) exudations. Imperfections should be smoothed. Where glossy enamel or varnish finishes are to be applied and the need for best appearance justifies the expense, the woodwork may be sandpapered until free from raised grain or planer marks. If there are knots in woodwork in rooms where fine appearance is required, which should rarely

be the case, the knots should be thoroughly cleaned and scraped then sealed with the MIL–S–12935A knot sealer. In rooms of rough usage where painting is done chiefly for improved illumination, for marking hazards to safety, or for ease of cleaning, it may not be necessary to seal knots before painting or otherwise finishing. Nail holes or other imperfections should be puttied after the priming coat of paint or varnish has been applied.

(2) *Previously Coated Woodwork.* Usually interior coatings need renewal because they become soiled, dull, or faded although they remain intact. If they are badly soiled or if the dirt is of a greasy nature, as is often the case in kitchens, the surface should be washed thoroughly before refinishing. Any damaged spots where the coating has been scratched off or worn through to the wood should be spotprimed and then sandpapered lightly after the primer has dried.

If woodwork that has previously been varnished is to be changed to a paint or enamel finish, all of the old varnish should first be taken off with varnish remover and the surface mopped with paint solvents to take off any wax left from the remover. Paint or enamel applied over varnish is apt to fail by alligatoring.

(3) *Floors.* New wood floors should be well sandpapered before finishing them. The sanding is best done with a power sanding machine, working in the direction of the grain of the wood as far as possible. Use No. 3 sandpaper for the first rough sanding followed by No. 1½ sandpaper and finally by No. 0 sandpaper. If the floor is unusually rough or uneven, the first strokes with No. 3 sandpaper may be at 45° to the grain of the wood working from left to right, then working from right to left, and finally working with the grain of the wood. The final sanding with No. 0 paper should be done just before the finish is to be applied. No traffic on the floor should be permitted after the last sanding, before the finishing has been completed.

In refinishing floors when resanding is unnecessary, any wax that may have been used for maintenance must first be removed. Solvents such as paint thinner may be used to wash off most of the wax but the floor should then be washed thoroughly with soap and warm water and then dried as promptly as possible. The washing may also be necessary to remove dirt. New finish of the kind used previously may then be applied.

If a change in type of finish, as from varnish or paint to sealer finish, is desired, the old finish must be removed. As a rule this is best done by power sanding as already described for new floors. With varnish or paint finishes that have been renewed two or three times, it may also become necessary to resand the floor before applying the same type of finish again satisfactorily.

1–35. MAINTENANCE PAINTING OF WOOD SURFACES

a. **General.** Coatings of paint and other finishes wear out within a few years and require periodic renewal. For most surfaces, especially exterior surfaces, the frequency of needed renewal can be estimated in advance on the basis of past experience. To make such estimates as reliable as possible, records should be kept at each installation for all large surfaces requiring paint maintenance. Painting should then be planned and programmed ahead of time rather than left to hasty decisions made after coatings have broken down unexpectedly. Properly planned maintenance gives better performance of paint, avoids the compromises usually necessary in haphazard painting and permits scheduling work to keep crews steadily at work. In northern climates exterior painting can be planned for warm seasons and interior painting for cold weather.

b. **Frequency of Painting with Normal Deterioration of Exterior Coatings.** Normally exterior walls that are painted white or in light tints need repainting about once in four to five years. Even light tints prove more durable than white paint. For the deeper tints, repainting every five to six years should suffice. Some dark colors, such as iron oxide red,

may safely go eight to ten years before renewal. The surfaces most directly exposed to sunshine deteriorate most rapidly; thus paint wears out first as a rule on south sides of buildings in the northern hemisphere. Unshaded gable ends of buildings show faster paint wear than the walls under overhanging eaves. Porch railings or other horizontal or sloping surfaces wear very rapidly and need repainting every two to three years.

On interior surfaces, painting rarely should be done more often than once in four years. If the surfaces become soiled meantime they should be washed rather than repainted.

Finishes on floors or porches wear out quickly, the time depending on the kind and amount of traffic they bear. Where records of finishing are kept, however, it soon becomes possible to plan the maintenance in advance.

Unduly frequent repainting is undesirable for purely technical reasons as well as for economy. Paints for wood are designed for best performance when the total thickness of coating is 4 to 5 mils (0.004 to 0.005 inch). Thicker coatings are too brittle and eventually crack and scale badly, thus necessitating complete removal. If the paint is not given time to waste away materially between paintings and if too much paint is applied each time, the coating soon becomes too thick and must be removed.

c. **Stages in Normal Deterioration of Exterior Coatings.**—House paints and other exterior finishes for wood undergo slow and gradual changes from the time they are applied. Those responsible for their maintenance should know what the changes are so that they will not be misled into hasty and unwise early repainting and so that the normal deterioration can be promptly distinguished from abnormal developments for which corrective measures other than repainting are needed. Normal deterioration takes place in six recognizable stages. The more serious of these are shown in figure 7.

(1) *Soiling.* Coatings normally gather dirt and become increasingly soiled during most of the first year on sunny areas and for a longer time in shaded areas. Pure white lead paint becomes more seriously grayed by dirt than either titanium-lead-zinc or titanium-zinc paint does. Dirty paint may be washed, but, on exterior surfaces should never be repainted until deterioration has gone much further than mere soiling.

(2) *Flatting.* The coating gradually loses its initial gloss and becomes flat (glossless), usually within a year on sunny areas but less rapidly on shaded areas.

(3) *Chalking.* The pigment at the surface becomes loose and may be rubbed off like chalk. Dirt also becomes dislodged in the chalking stage and gradually sloughs off. In tinted paints, however, the colors appear to fade as chalking progresses. Usually fading is less marked with pure white lead paint than with titanium-lead-zinc paint. Normally, exterior paint is in the chalking condition during the greater portion of its useful life except in heavily shaded areas that may retain gloss for several years. Chalking does not offer sufficient grounds for repainting exterior surfaces. Interior paints seldom, if ever, reach the chalking stage within their useful lives.

(4) *Fissures.* Significant differences among the kinds of paint appear first in the stage of fissures. Under some conditions, not always realized, titanium-lead-zinc paint and titanium-zinc paint may skip the stage of fissures and pass directly into the stage of disintegration. Fissures are of two kinds, checking and cracking.

In checking, the fissures are at first superficial but later penetrate entirely through the coating. When checking occurs, it usually begins well within the first half of the normal life of the paint, say within the first two years on the sunny areas, somewhat later in the shady areas. Pure white lead paint always develops checking in a finely reticulated pattern that is usually inconspicuous. Titanium-lead-zinc paint may or may not develop checking and titanium-zinc paint seldom does.

In cracking, the fissures pass entirely through the coating. Cracking seldom occurs under normal conditions before the midpoint in paint life, say the beginning of the third

year. The cracking may or may not have been preceded by checking. The fissures in cracking are larger and more conspicuous than those in checking. After cracking sets in, the paint may loosen and curl up at the edges of the cracks.

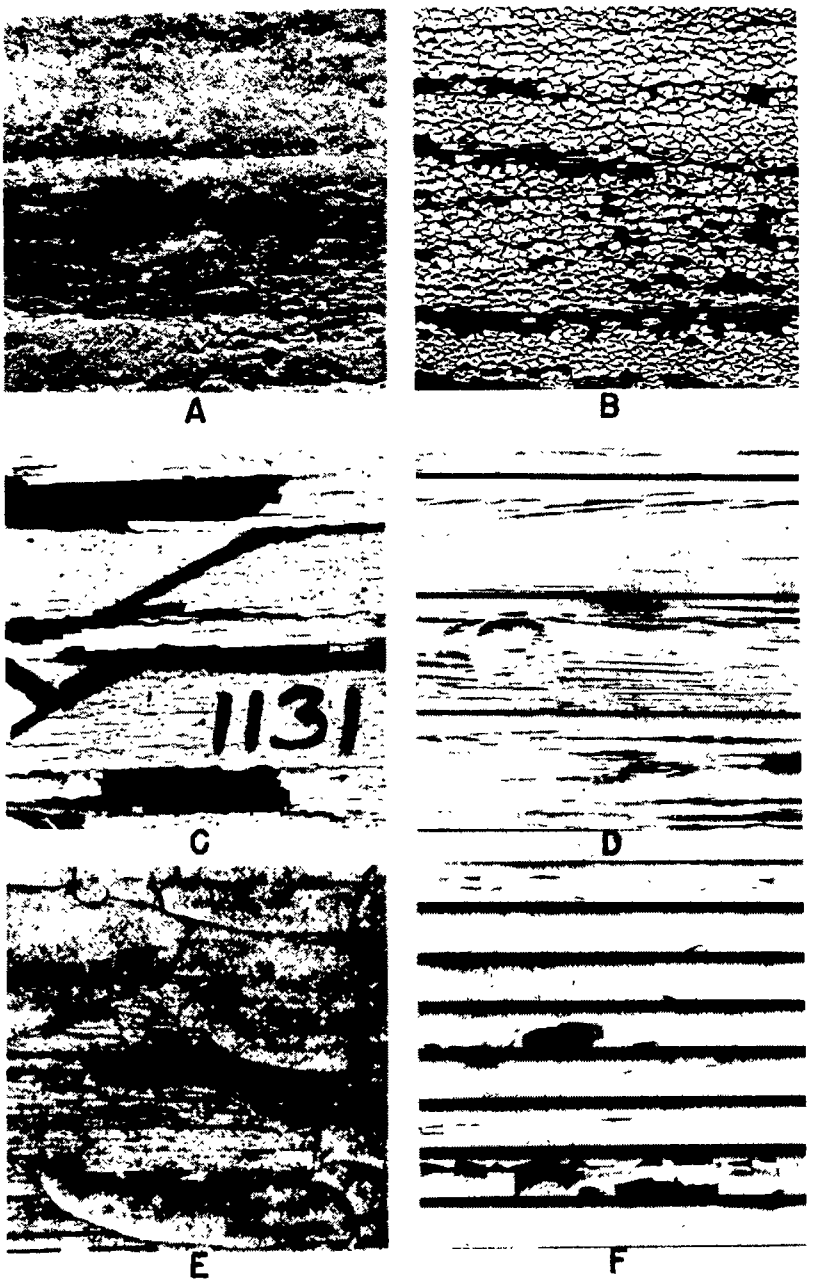

FIGURE 7. *Examples of different forms of normal deterioration of paint.*

A — deterioration by erosion; B — deterioration by checking and crumbling; C and D — deterioration by cracking, curling, and flaking; E and F — deterioration by cracking and scaling. Note carefully that the areas shown in A and B were actually ½ by ½ inch in size, those in C and E were 1 inch by 1 inch, that in D was 17 by 17 inches, and that in F was 36 by 36 inches.

(5) *Disintegration.* The disintegration or wasting away of the paint depends upon whether it passes through the stage of fissures, and if so, the kind of fissures. The

effect on paint life of the kind of wood painted first becomes noticeable during the stage of disintegration.

(a) Erosion. When those paints that do not suffer checking waste away by chalking or erosion fast enough to escape cracking, the coating finally becomes too thin to hide the wood and then patches of the wood begin to be laid bare. Disintegration by erosion occurs with some rapidly chalking paints, in climates that are generally moist and free from extremely dry periods, and with coatings that are not allowed to exceed 5 mils total thickness. The surface should be repainted when the coating becomes thin enough to begin to show the grain of the wood while the coating is wet with rain or when patches of bare wood begin to appear.

(b) Crumbling. When coatings develop checking, and cracking does not intervene, disintegration occurs by crumbling. Tiny fragments of coating fall off when the checking becomes interwoven and penetrates through the coating; the size and shape of the loosened crumbs of paint correspond to the dimensions of the checking pattern. Normally the paint crumbles from the bands of summerwood much sooner than it does from the springwood, so that the grain pattern of the wood becomes revealed by the disintegration of the paint. See figure 8. Disintegration by checking and crumbling leaves a surface that needs little preparation for reliable repainting. Repainting may be done at any time during the stage of disintegration by crumbling.

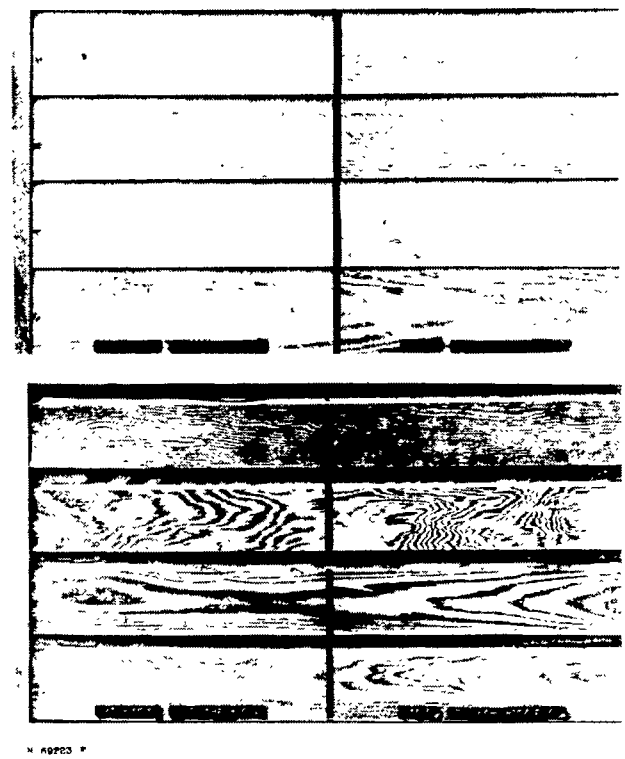

FIGURE 8. *Effect of grain density on durability of paints.*

(Paint normally wears away sooner over the bands of dense, hard summerwood than over the lighter softer springwood. The upper view shows an earlier stage in such deterioration of paint than the lower view. Both views show the same two paints at the same age, 8 years, on woods of group IV but the upper view shows the milder exposure facing North and the lower the more severe southern exposure at Madison, Wisconsin. The upper two boards of each panel were Douglas-fir, the lower two boards southern yellow pine.)

(c) Flaking. When cracking occurs and leads to curling, disintegration is by flaking. The loosened and curled edges of the coating break off. The dimensions of the cracking determine the fineness or coarseness of the flaking; numerous small cracks lead to

fine flaking and large cracks to coarse flaking. Fine or moderate flaking, at first lays bare the summerwood only so that the disintegration follows the grain pattern of the wood. Coarse flaking, properly called scaling, uncovers both summerwood and springwood at the same time. Flaking paint needs careful preparation for repainting to see that all loose paint is removed. Scaling paint needs still more careful preparation and leaves an uncertain foundation for the new paint. Repainting should be done soon after the most exposed parts of the building have reached the stage of disintegration by flaking or scaling.

(6) *Advanced Breakup or Neglect.* When disintegration lays bare enough wood for the boards to begin to show distress from wood weathering, the coating has reached the stage of advanced breakup and is in a stage of neglect. Signs of wood weathering are development of a gray color and numerous fine checks in the exposed wood, and tendencies for the boards to cup or pull loose at their fastenings. Badly neglected surfaces become increasingly difficult to prepare for repainting, consume more than normal quantities of new paint, and fail to produce a fully satisfactory appearance of the renewed paint job.

d. **Abnormal Deterioration of Exterior Coatings.** When paints deteriorate unduly rapidly or in an abnormal manner, the conditions responsible should be determined and corrected before further painting is done. In the more serious cases, repainting before the fault is set right will simply add to the difficulty.

(1) *Inferior Paints.* Paints procured under federal specifications are materials of high quality that will give normal performance when used properly for the purposes recommended. If shipments received are tested for conformity to the specifications and the paints are used for their intended purposes, any abnormality in service will result from some cause other than the quality of the paint.

(2) *Abnormal Deterioration of Coatings Resulting from Peculiarities of Wood.*

(a) Dense Species. Strength, availability, or economy often dictates the use of the woods of group 4 for structures that are to be kept painted. On such woods paint in a given stage of disintegration reveals its condition more conspicuously because of the larger patches of summerwood laid bare than is the case on woods of groups 1 and 2. See figures 9 and 10. Repainting, however, should not be hastened on that account, for to do so makes each successive paint job worse than the previous one. A lower standard of appearance before repainting is done should be considered the normal expectation on the less satisfactory woods for painting.

(b) Knots. Whether or not a sealer is applied, knots will cause blemishes in painted surfaces well before the paint wears out over the clear wood. A lower standard of appearance for paint on knotty grades of lumber should be accepted and repainting should be done no sooner than would be expected on high-grade wood free from knots.

(c) Discolorations. Occasionally a yellow to brown discoloration appears in paint either in streaks or more or less uniformly over the heartwood only of white pine, sugar pine, or ponderosa pine. Usually it appears only on a few boards. In new construction the trouble may be more widespread if the wood is unduly moist at the time of painting, possibly by reason of erection before the plaster has dried thoroughly. On exterior surfaces the discoloration generally bleaches out after a few weeks of strong sunshine but it may persist for a long time on interior surfaces. Where the importance of appearance justifies the expense, the troublesome boards may be replaced with well-dried wood because, in severe cases, the discoloration may reappear on repainting.

Reddish-brown to black discoloration of paint on red cedar or redwood occurs when the wood becomes wet under the paint. This is nearly always a minor complication of the faulty structural conditions discussed subsequently.

Blue to black discoloration of paint that penetrates also into sapwood beneath the coating is bluestain caused by growth of certain fungi in damp sapwood. Appearance of

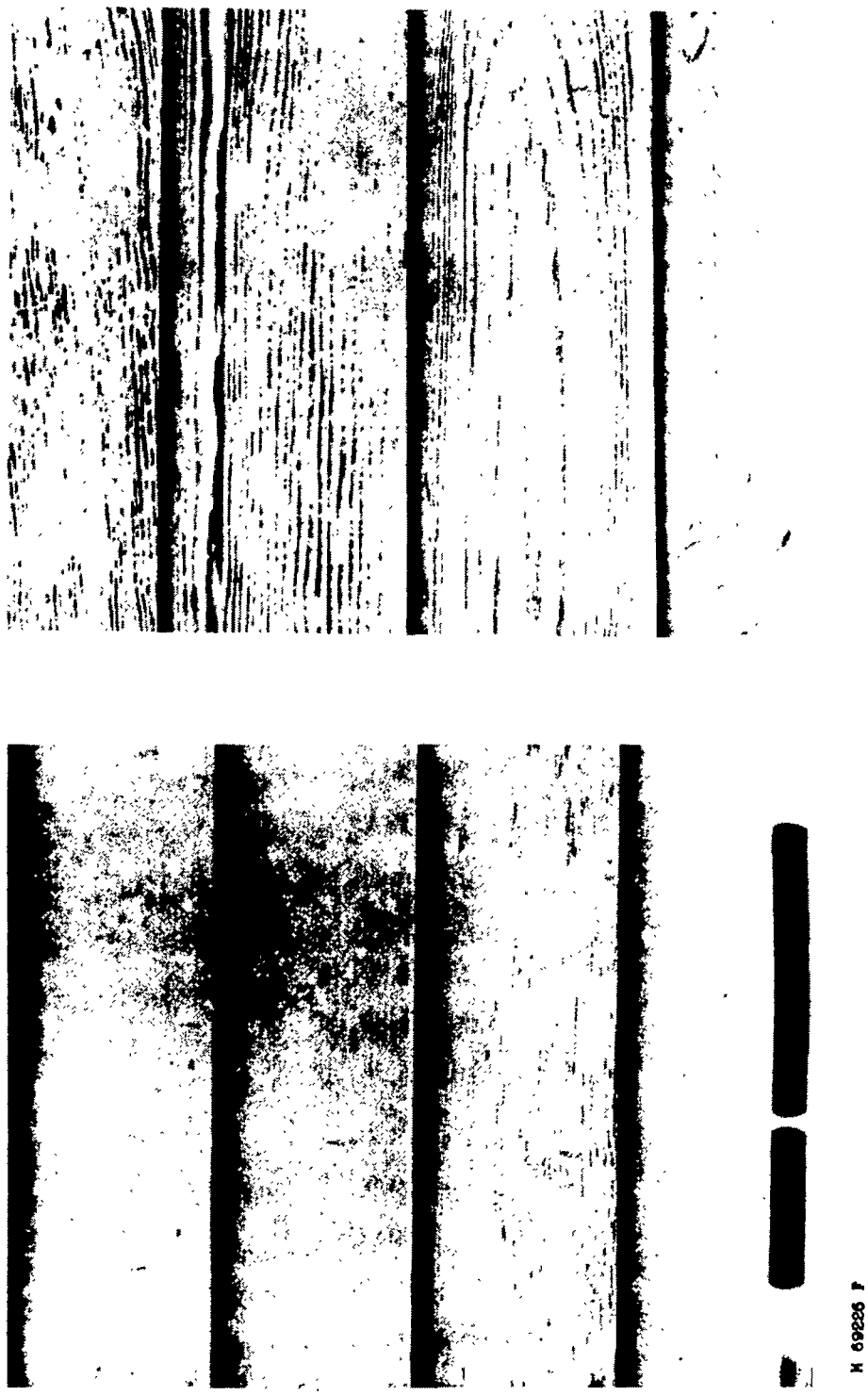

FIGURE 9. *Comparison of paint durability on woods of different species.*

(Paint lasts longer on woods of groups I and II, shown at the left, than on woods of group IV, shown at the right. The paint, period, and direction of exposure were the same for both panels. At the left the upper two boards were western red cedar, the lower two boards eastern white pine. At the right the upper two boards were Douglas-fir, the lower two boards southern yellow pine.)



FIGURE 10. *Example of paint durability on different species of wood.*

(Replacement of four boards of greater than average density, the four boards that can be seen to be nearly bare of paint, would make the next paint job on this building last much longer with reasonably satisfactory appearance.)

bluestain through paint furnishes positive evidence that the wood becomes damp (over 20 percent moisture content) for substantial periods of time. If the wood can be kept dry the next painting will permanently hide the stain, though the stained wood must be replaced to restore a natural varnish finish. When bluestained wood is replaced the new wood should be treated with a suitable preservative unless it is certain that it will not again become damp. Bluestain sometimes occurs on windows subject to much condensation, at the bases of wood columns or posts under which rain seeps, and near unprotected joints in fences, railings, stoops, shutters, and trim. See figure 11.

(d) Decay. Whether painted or not, wood decays only if it remains wet for considerable periods of time. In buildings, wood remains wet because of faulty structural conditions such as those discussed later.

(3) *Abnormal Deterioration of Coatings Resulting from Trouble in Application.* See figure 12.

(a) Crawling. When the new paint refuses to wet the old paint and, after it has been spread, tries to draw back into drops as water does on a greasy surface, the paint is said to be crawling. The condition may arise because the surface was not cleaned of oily or greasy contaminants. It may also arise because the previous paint is not yet old enough to be in a suitable condition for repainting or because the old and new paints are too dissimilar in composition.

(b) Poor Drying. Enamels, varnishes, and some paints may suffer loss in ability to dry promptly if they are held too long in storage. Drying should be checked before using old shipment of paint and a little liquid paint drier added when necessary to restore prompt drying. In cold, damp, and cloudy weather paints and varnishes may be expected to take longer than usual to dry but in such cases the drying cannot be safely speeded by adding more drier.

Wax, such as floor wax from polishes or paint removers, may retard or destroy the drying of paints or varnishes that otherwise dry promptly. Such contaminants must be cleaned off with solvents or by washing with soap and water before refinishing.

On damp redwood, red cedar, cypress, or on wood that has been treated with water-repellent preservative drying may be slower than usual but the retardation is not serious if the priming paint is one designated for use on wood.

(c) Wrinkling. If the paint, instead of drying with a smooth surface, draws up into ridges or folds while drying it is said to have wrinkles. If the pattern of wrinkling is fine enough the effect may seem to be merely a loss of gloss. Paint mixed with too much oil and applied in too thick a coating may wrinkle at any season of the year but wrinkling is most troublesome when painting during cold weather. A sharp drop in temperature of 20° F. or more a few hours after applying the paint often causes wrinkling that would not otherwise take place. Avoid painting in such weather if possible. Although wrinkling mars appearance it does not impair the durability of the coating.

(d) Uneven Gloss and Color. If paint is thinned excessively or is spread too lightly too much of its oil may be absorbed by the wood or by the previous paint and it may dry with less than its normal gloss and, if colored, a faded color. The defect may be uniform over the whole surface but is more often spotty. This is particularly to be guarded against in two-coat painting on bare wood or in one-coat repainting or in repainting badly neglected surfaces, where the painter might easily fail to gage the absorptiveness of the surface correctly. In repainting over old paint in reasonable good condition, however, it is better to put up with slight defects of uneven gloss and color, which will soon disappear as the new paint ages, than to add unduly to the total thickness of coating on the surface.

Uneven gloss and color may come also from adverse weather conditions while the paint is drying or during its first few weeks. Fog, dew, rain or frost repeatedly deposited

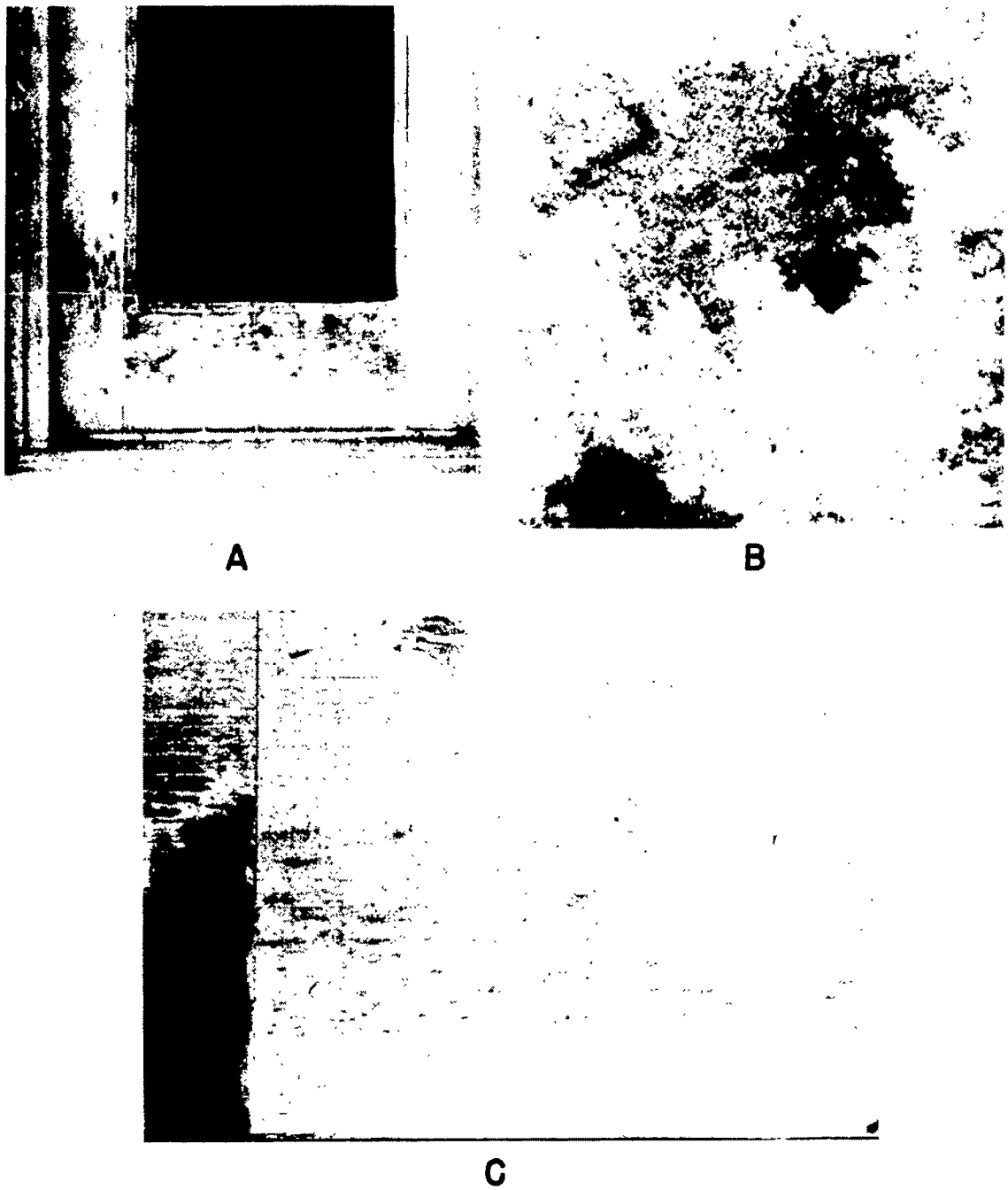

FIGURE 11. *Examples of discoloration of paint by substances in the wood.*

A — Blue to black color produced by growth of the fungi of bluestain in the sapwood of a window on which there was much condensation during the winter season; B — Reddish brown to black exudation of water-soluble colored material in redwood; C — Yellow to brown discoloration of paint over the heartwood of ponderosa pine but not over the sapwood. The area shown in B is 1.2 by 1.3 inches; in C about 4 by 5.5 inches.

on fresh paint may thus damage it. Sometimes the defect follows the pattern of framing in the walls of heated buildings because of difference in thermal transmission through studs and the spaces between studs. The defects are not serious and will soon disappear as the paint ages.

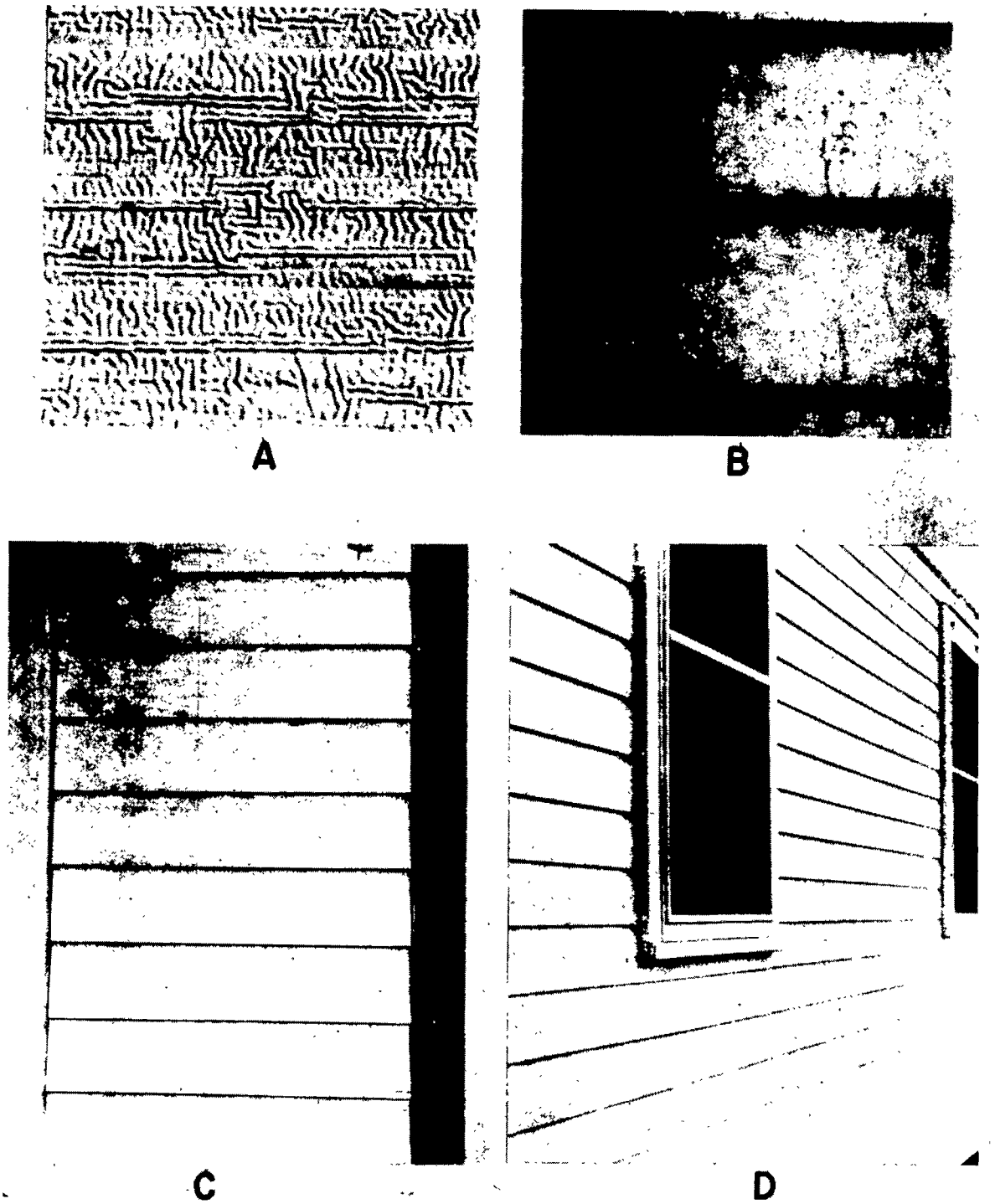

FIGURE 12. *Defects caused by faulty practices of hazards of weather during application of paint.*

A — Wrinkling; B — Exudation of zinc salts of acid decomposition products of the linseed oil in paint; C — Uneven gloss from stingy application of paint; D — Uneven gloss revealing the location of studs in the sidewall, resulting from nightly dews during the first few weeks after painting.

(4) *Abnormal Deterioration Resulting from Unusual Exposure Conditions.* Certain atmospheric conditions may seriously alter paint performance. When the conditions cannot be altered it becomes necessary to choose the paints most resistant to the particular conditions and then rest content with the defects that develop.

(a) Excessive Dirt Collection. Smoky air in industrial environments and air heavily laden with plant pollen make for excessive collection of firmly adherent dirt on painted surfaces. The soiling becomes still worse when the buildings are erected close enough together to shade one another heavily. Further, the soiling is aggravated by painting just before the cold, cloudy winter season sets in or by adding more oil to the paint than is necessary. Siliceous dirts do not cling firmly to paint, once it has dried, and seldom remain there very long.

When rain water drains off roofs and runs down over sidewalks it usually leaves vertical streaks of adherent dirt, particularly when the paint is only a few weeks old. Buildings with the edge of the roof cut flush with the sidewalks are bad offenders in this respect. Even if eaves troughs are provided there may be such streaking from rains that overload the troughs, from clogging of the troughs, or from freezing of ice in the troughs in cold weather. Substantial overhang at roofs is very effective in preventing streaking of paint and making the paint last longer.

(b) Mildew. In warm, damp climates mildew may be a normal development on painted surfaces. Elsewhere it may occur as an abnormality in local areas that are kept damp for some reason. If at all practicable, the best remedy on these local areas is to remove the sources of dampness. Mildew is often difficult to distinguish from excessive dirt; by examination with a good magnifying glass or a microscope it can be seen that mildew is characterized by thread-like mycelia when it is in its growing stage, by numerous egg-shaped spores when it is dry and dormant. (See fig. 13.) Dirt, in contrast, is usually composed of granular particles of irregular size and shape. The use of anti-mildew agents has been previously discussed.

(c) Excessive Chalking or Washing. Although federal specification paints do not generally chalk or wash excessively, they may do so in atmospheres contaminated by sulfur dioxide or other acid gases from industrial operations or the combustion of sulfur-containing fuel. The defect shows up not only in unduly rapid disintegration of the paint but in a smearing of neighboring surfaces with white pigments or salts leached from the paint by rain. Thus the dark-painted trim or the stucco, cement, or brick surfaces under woodwork painted in white or tints may be marred by white deposits, often in streaks.

Another form of paint washing stimulated by sulfur dioxide is the development of yellow to brown patches of discoloration on the paint that subsequently are leached out by heavy rain. Under some conditions the brown substance collects in circular deposits along the under edge of bevel siding or trim boards where rain drips off after storms. Occasionally gummy drops form on the faces of siding boards much like resin exuded from wood except that the substance, unlike resin, is easily dissolved in water.

(d) Hydrogen Sulfide. Paints containing lead or other metals that form black sulfides become discolored in air contaminated by hydrogen sulfide. The hydrogen sulfide blackening usually has a metallic luster and can be bleached by application of ordinary hydrogen peroxide solution, characteristics that distinguish it from dirt and mildew. Contamination of the air with hydrogen sulfide is not of common occurrence. Combustion of sulfur-bearing fuels does not ordinarily produce hydrogen sulfide. The gas can come, however, from certain industrial processes such as the refining of petroleum and a few other industries. It can come also from some mineral springs, swamps, and streams that are badly overloaded with sewage.

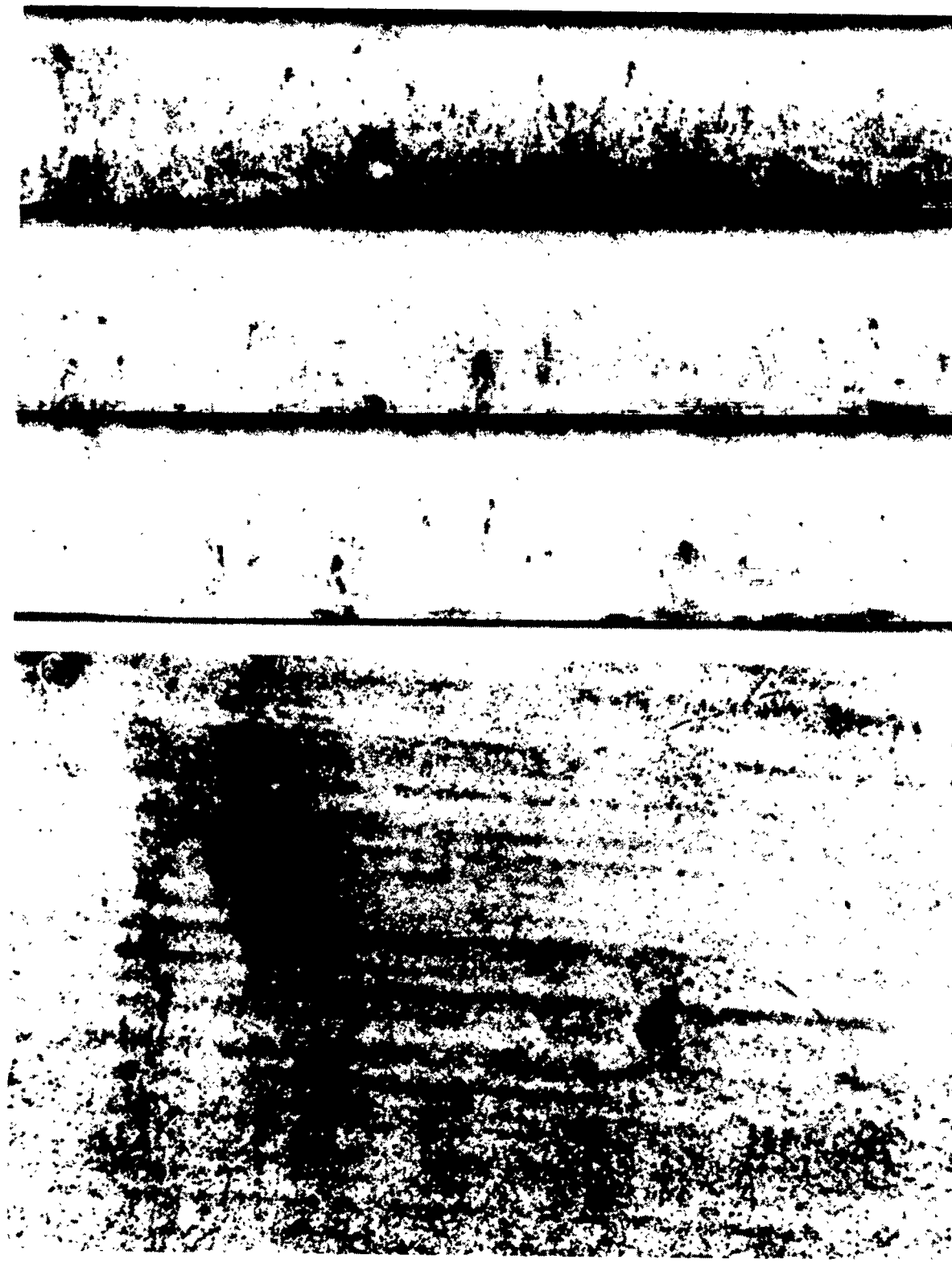

FIGURE 13. *Growth of mildew on white paint on a house in a damp location.*

(5) *Abnormal Deterioration Resulting from Incompatible Paints.* It is always safest to repaint surfaces with the same kind of paint used previously unless experience shows that a new and different paint under consideration is compatible with the old. Use only recommended combinations of primers and finish paints. Dissimilar paints may cause unduly rapid deterioration following the normal defects. See figure 14.

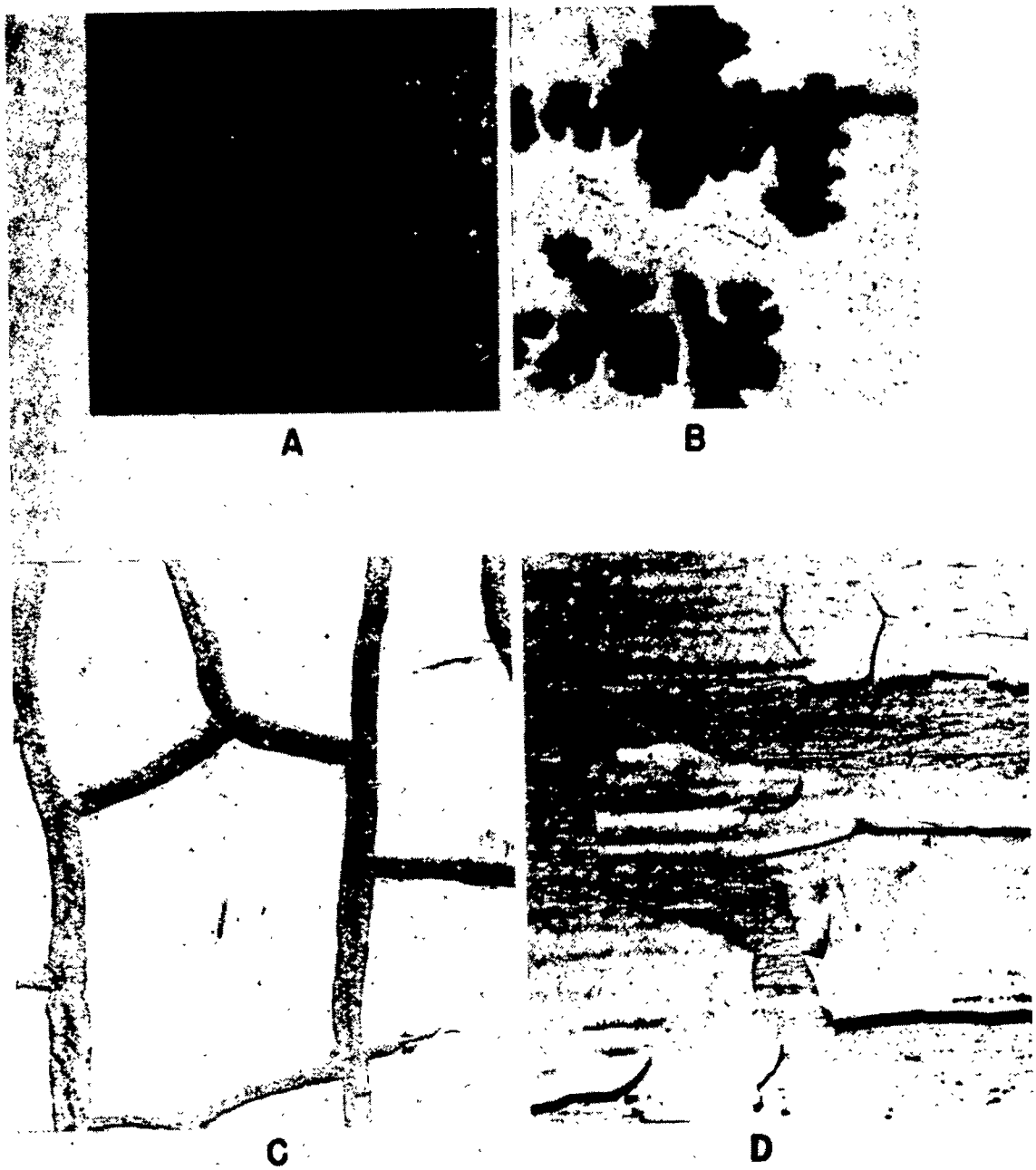

FIGURE 14. *Defects caused by incompatibilities between paints used successively.*

A — Lifting of an old oil paint when white lacquer was applied over it; B — Crawling of a white enamel over a previous gray enamel of very different composition; C — Alligatoring of a house paint over an older house paint of a different kind; D — Intercoat scaling of the most recently applied house paint from a previous house paint of a different kind. The areas shown in A and B are 1 inch by 1 inch; those shown in C and D are 1.25 inch by 1.4 inch.

(a) Lifting. Lifting is a softening, loosening, or wrinkling of the old coating by strong solvents in a new paint. Crawling and impaired drying are also at times consequences of incompatibility.

(b) Alligatoring. Alligatoring, the normal pattern of checking or cracking to which the new paint is subject is modified, often by a hastening of the development and coarsening of its pattern, and characteristically with a slipping of the new coating over the old one so that the old one can be seen through the fissures. Some combinations which often result in alligatoring are—

1. House paint applied over spillings of roofing tar that had not been cleaned off, over old lettering or numbering that had been applied with dark-colored stenciling ink or enamel, over old signs of sheet metal coated with baked enamel, or over pitch that had exuded from the wood.

2. Paint or enamel applied over varnish, shellac, or lacquer.

3. White or light-colored house paint over dark-colored trim paints or over red barn paint, and sometimes, though less often, dark-colored paints applied over white paint.

4. White paint applied over a dissimilar white paint, such as pure lead paint over a previous paint containing zinc oxide that had not yet been weathered for at least three or four years.

If alligatoring is not severe enough to seriously impair appearance it may not prove too harmful, for it does not necessarily hasten coating disintegration.

(c) Intercoat Scaling. Normally disintegration of coatings by crumbling, flaking, or scaling goes right down to bare wood even though the surface may have been repainted a number of times and the coating may have become excessively thick. With dissimilar paints, however, the disintegration may take the form of scaling at one or more intermediate points within the coating, usually at the interfaces of greatest difference between successive paints. When intercoat scaling is encountered, the last repainting is generally falling short of the life reasonably to be expected under normal conditions.

(6) *Abnormal Deterioration from Excessive Coating Thickness.* When too frequent repainting or application of too much paint at a time builds the total thickness of coating much beyond 5 mils, abnormal deterioration usually sets in and the coating becomes increasingly unsatisfactory as the coating thickness mounts. Paints that do not crack conspicuously in thickness of 5 mils or less often develop large, conspicuous cracks, and do so at an earlier date, when the thickness becomes 8 mils or more. (See fig. 15.) Whereas the normal cracking occurs predominantly parallel to the grain of the boards, in thick coatings the cracking often begins and becomes most marked in a direction at right angles to the grain of the wood. With increasing coating thickness flaking deteriorates into scaling and the disintegration of the coating loses all relation to the grain pattern of the wood. Thick coatings that are scaling badly present a difficult surface to prepare for repainting; moreover, unless the old coating is removed entirely, the new coating lacks the desired smoothness because the scaled places in the old coating still show through.

Unduly thick coatings sometimes become blistered especially if one of the older paints in the lower part of the coating was a paint of dark color. In blistering a circular or oval patch of paint becomes loose and becomes raised in a hollow dome. If broken open, blisters of this kind are usually found empty and free of water, though they can fill with water during rains. The inside surface of the broken blister or the exposed surface under it is covered with a glossy, sometimes wrinkled film of clear material that may easily be mistaken for varnish. When the blister has been freshly formed the glossy material may be soft and gummy. The clear material is at least partly soluble in warm water. Dry blistering of this kind comes from chemical changes, not yet fully understood, in old layers of paint that have been shut off from



FIGURE 15. *Effects of excessive thickness of accumulative coatings.*

(Paint in the condition shown should be completely removed from all parts of the surfaces before further painting can be done reliably. The coating, after 15 paintings during 60 years, was 0.029 inch thick, was cracking badly, and in places not shown in the photograph was scaling badly in consequence of the excessive film thickness.)

light and oxygen by later layers of paint applied in repainting. Such blistering should not be confused with moisture blisters discussed in the paragraph following.

e. **Effects of Faulty Structural Conditions on Paint Coatings.**—Abnormally early failures of paint coatings may occur when too much water gets behind painted woodwork. See figures 16, 17, and 18. Moreover, if the condition persists very long, sapwood may become bluestained and eventually the wood may decay. When such conditions occur they can usually be traced to faults in the design, construction, or occupation of the building, though the paint failures may be aggravated by poor practices in applying and maintaining paints. Those responsible for painting should learn to recognize such *moisture failures* so that they can defer further painting until the faulty conditions have been corrected. Characteristic paint defects which point toward the effects of moisture acting behind painted woodwork follow:

(1) *Blistering.* If the coating is not unduly thick or too well aged, blistering is apt to occur. Unlike the dry blistering described in the previous paragraph, moisture blisters generally become filled with water soon after they form and when subsequently they dry out they usually collapse, often leaving the blistered paint wrinkled. Moisture blisters alone, however, are not positive proof that there was water behind the boards because occasionally they can come from water acting through the exposed surface of the paint just as paint may blister on metal. As a rule, bare wood is uncovered when the blisters are opened,



FIGURE 16. *Paint failure due to faulty structural details—example 1.*

(Unequal distribution of the early paint scaling on this building, obviously related to its structural details, gives warning of the existence of abnormal conditions that need correction before further painting is done. The difficulty may come from storm water penetrating some joints or it may come from condensation in the sidewalls during cold weather. Probably both are involved in this case.)

though a priming coat may remain intact beneath blisters if considerable time elapsed between applying the priming and the following coats; and blistering may occur between layers of incompatible paints.

(2) *Peeling.* Peeling may follow if blisters break open or are broken open. If a loose edge of the coating can be grasped and can be torn off progressively well beyond the



FIGURE 17. *Paint failure due to faulty structural details—example 2.*

Blistering, left, and peeling, right, of paint on wet siding. The man was holding a strip of paint that had just been peeled from a place under the window. He was showing the back of the strip of paint which was stained by the water-soluble colored material in redwood siding.

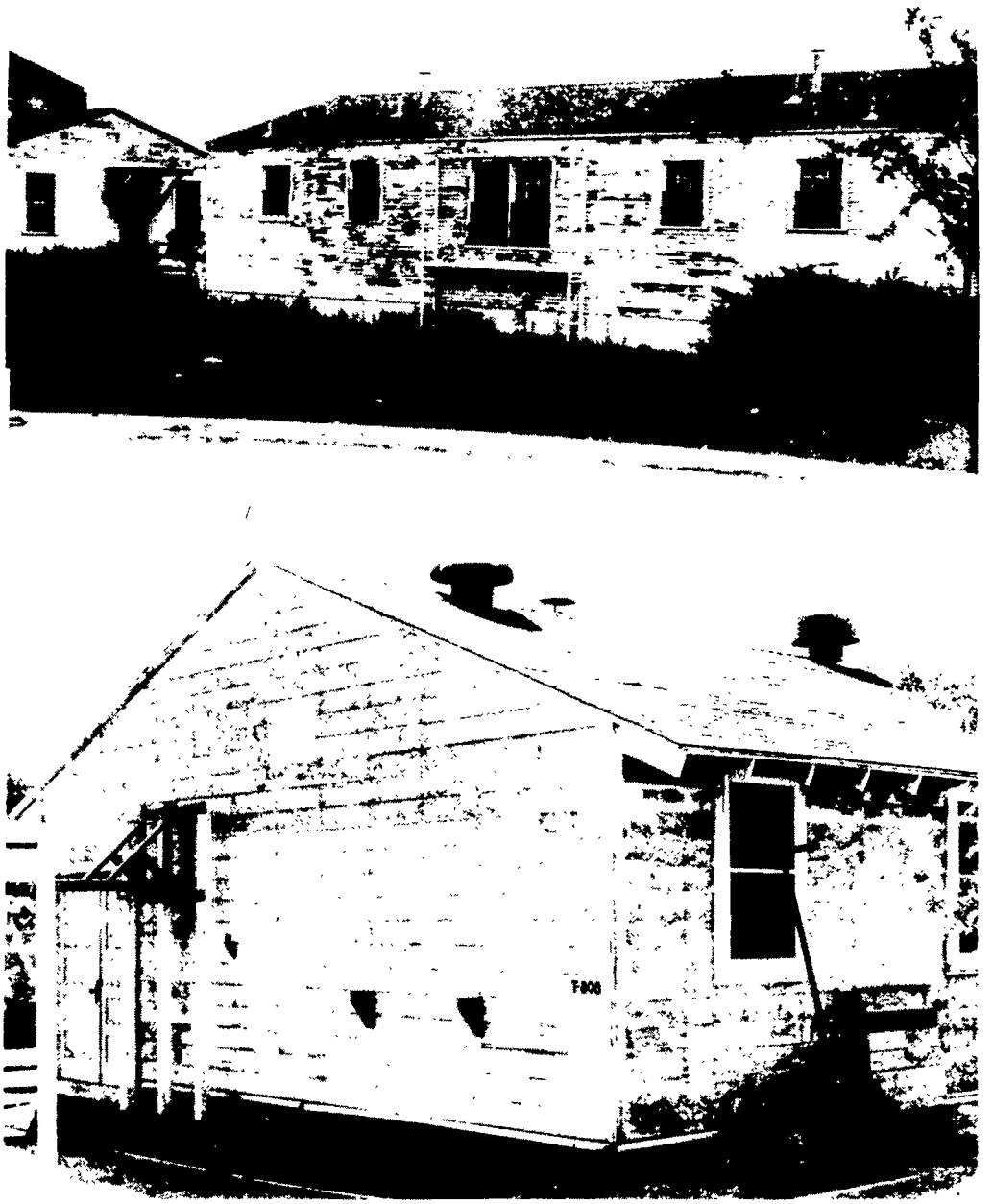

FIGURE 18. *Paint failure due to faulty structural details—example 3.*

Paint may fail early if sidewalls become wet. In the upper view, water got in from outside, largely from lack of overhang at the eaves. In the lower view, water from inside the building condensed in the sidewalls during cold weather except behind the area where the paint remains good. The area that held paint was closed off by a header in the framework to furnish support for a sheet metal wall covering behind a row of shower baths inside the building.

periphery of the blister, the condition is called peeling. Cases have been seen in which a strip of coating could be torn off in one piece extending the full length of a 16-foot board. As a rule, paint remains in a peeling condition only as long as the wood and the coating remain damp. As soon as they dry out the coating becomes too brittle to be stripped off beyond the limits of the blister. Nevertheless, on weathering it may continue to curl up at the edges and break off but at that stage it is properly called scaling rather than peeling.

(3) *Discoloration.* On redwood or red cedar too much water behind the painted wood often causes discoloration of the paint with the water-soluble colored materials in those woods. The discoloration may occur in streaks where water runs out at joints to drain down over the painted surface, it may exude from paint blisters or run out of broken blisters, or it may exude much like resin from a painted surface on which the paint apparently remains sound. Such discoloration, however, is positive evidence of excessive water behind the wood.

(4) *Scaling.* If blistering occurs but the blisters remain unbroken until wood and coating dry out again, the blisters may flatten out and seem to disappear for some time but during subsequent dry weather they usually crack, curl, and begin to scale. Often the blistering stage escapes unobserved and realization that something is wrong begins only when the disintegration sets in unexpectedly early and in the form of scaling where the normal expectation may have been flaking or erosion. Moreover, the disintegration may be confined to local areas of the building while other areas of similar weather exposure but unreached by the harmful water still show paint following its normal course of behavior. Perhaps the north wall, on which normally paint deterioration lags far behind the south wall, is found to be failing much more rapidly.

Although the above abnormalities in the progress of paint wear should always lend to careful examination of the building for faults that might let too much water behind the wood, they should not be considered adequate evidence that the trouble is in fact caused by water. Direct evidence of too much water should be sought before attributing the paint difficulty to it. If the trouble does come from water, the mode of entry into the structure must be found and cut off before the faulty paint condition can be corrected.

f. **Mode of Entry of Moisture Behind Paint Coatings and Corrective Measures**

(1) *Penetration of Water from Outside.* The exterior of a wood building necessarily presents many joints through which there is more or less possibility of rain or melting snow and ice gaining entrance and finding lodgement behind painted boards. From long experience principles of design have been worked out that minimize such penetration of water in various ways. Neglect of these principles by designers, poor workmanship in erection, or failure to maintain properly may lead to enough admission of water to damage paint and eventually let the wood decay.

(a) Joints. Most horizontal joints are made to overlap or overhang the board below. Thus shingles and bevel siding overlap generously and the butts overhang for prompt shedding of water. Nevertheless, strong winds may blow rain up and under the overlap in siding, especially if the overlap was skimped by the builders. Generous application of paint at the junction helps to minimize such penetration. Drop siding provides either shiplap or tongue-and-groove joints but both overlap and overhang are less than with bevel siding. Flush siding, which provides no overhang, is unduly easy for rain to penetrate. Trim is best laid overlapping and overhanging the siding below it. Vertical joint in horizontal siding should be made only over studs for firm nailing and should be well staggered in the successive courses. Siding erected vertically needs battens to cover the long vertical joints. Corners necessarily present long vertical joints that, if mitered, should be very carefully fitted or should be covered with corner pieces or corner boards. Window and door cases need to be carefully fitted into sidewalls to avoid admitting more water than necessary at the junctions with the siding.

Building paper behind siding should be water-resistant but should not be too vapor-resistant. It should pass at least 5 grains of water vapor per square foot, per hour, per inch of mercury when tested by a dry method. Under the best of conditions some water will get through siding at times and when it does the capacity of the sheathing and framing and the opportunity of drying toward the inside are needed to keep the siding from becoming wet enough for paint to be damaged.

Free standing woodwork such as columns, posts, and railings offer numerous

joints that are difficult to keep from admitting water. By painting, the subsequent drying of the wood near the joints is retarded. Presence of sapwood at such joints makes matters worse because sapwood takes up water more rapidly than heartwood does and the sapwood is readily subject to bluestain and decay. Construction involving susceptible joints needs shelter by projecting roofs wherever possible. When practicable, the members should be made of heartwood of naturally durable woods or of wood well impregnated with preservatives that do not interfere with painting. If none of these precautions can be taken better paint life and longer service of the wood will be obtained if, during construction or replacements, all end-grain ends of pieces are dipped in water-repellent preservative after they have been cut and fitted but before they are fastened in place.

(b) Flashing. Omission or skimping of flashing where it is needed or damage to flashing by poor maintenance or repair may let much water get behind painted woodwork. Roof valleys, edges of roofs, junctions of roofs with chimneys or with dormers, headers over windows or doors, water tables, and junctions of siding with shingles, stucco, or masonry may need adequate flashing. Further, where ends of siding on dormers meet the roof the siding should not be tightly scribed but should be cut short by three-fourths of an inch or more to minimize seepage under it and to permit prompt drying after water runs off.

The adequacy of flashing must be considered in the light of winter conditions when melting and freezing of snow may clog the normal paths of run-off with ice. Ice dams at the edges of roofs, particularly when aggravated by ice-filled eaves troughs, back up melting snow well past the point to which flashing is needed for summer run-off.

(c) Ground Contact. Painted wood in buildings must not be brought in contact with the ground. Although that mistake is seldom made when buildings are erected, it may be brought about by unwise regrading later. Wood skirting around crawl spaces under basementless buildings should be cut off well short of the ground and the boards should be spaced apart sufficiently for good circulation of air between them.

(d) Protection of Sidewalls by Overhang. The best of sidewalls is subject to some penetration of water. For that reason the less water that flows over it the less chance there will be of enough penetration to damage paint. A sidewall may reasonably be expected to remain tight enough to shed the rain that falls directly upon it without permitting undue penetration, but if in addition it must carry the run-off from a large area of roof cut flush with the top of the wall the chances that too much water will penetrate the wall are greatly increased. When gutters are not provided to handle the roof drainage the need for generous overhang is urgent.

(2) *Condensation.* Cold-weather condensation behind painted exterior woodwork can occur when the temperature out of doors is well below the dewpoint of the air indoors in heated buildings and the exterior walls or ceilings are too permeable to moisture vapor. If enough water, or frost that melts later on, collects in that manner, the paint may be damaged by blistering, peeling, discoloration and scaling as previously described. The amount of water condensed is governed by the difference between indoor and outdoor temperature, the amount of water vapor in the air indoors, and the permeability of the walls to moisture vapor. The water vapor in the air indoors depends in turn on the amount of water evaporated in the building or admitted from outside and the extent to which it is carried away harmlessly by ventilation through windows, doors, chimneys, or other openings. Thermal insulation in the sidewalls adds to the problem by making the outside woodwork colder than it would be otherwise.

For controlling condensation one or more of the following general procedures is necessary: reduce the amount of water evaporated within the building during cold weather, improve ventilation in order to carry off more of the moisture vapor harmlessly, avoid higher indoor temperatures than are necessary, and render the sidewalls less permeable by installing vapor barriers on the warm sides of the walls.

(a) Building Moisture. New buildings completed in cold weather may condense water in the sidewalls and damage paint if the building moisture, particularly the plaster moisture, is not dried out chiefly by good ventilation at moderate temperatures.

(b) Stagnant Air Spaces. Unventilated air spaces behind exterior walls that may be warmed by heat from the building and humidified from the soil or from the living quarters often condense water and cause paint failures. Tight skirting inclosing crawl spaces under basementless buildings or under porches, little used closets, rooms, or storage places, and unused attics or closed-off spaces under roofs require adequate ventilation to prevent condensation. Likewise hollow columns or outside walls into which rain water can gain entrance need good ventilation.

(c) Soil Moisture. Failure to secure a watertight basement and poor drainage of soil may result in over humidification of the building and condensation in the sidewalls. Buildings erected over crawl spaces require particular care. Grading should direct surface water, including roof run-off, safely away from the building. In places where the water table at times is close to the bottom of the crawl space, a vapor-resistant soil cover may be needed.

(d) Activities Within the Building. Normal use of a building involves more or less humidification if only from the breathing of the occupants but some activities, such as laundering, dishwashing, bathing, and cooking evaporate much water. Such humidification generally increases with the number of occupants. The kitchen of a mess-hall or restaurant, for example, generates more moisture per cubic foot of volume than the kitchen of a residence housing only one family. The need for ventilation increases proportionately to the evaporation of water. Intentional humidification through the heating system is justifiable in cold weather only when there is unusually little evaporation water from other sources.

When danger of condensation cannot be avoided by minimizing evaporation, avoiding higher temperatures than are necessary, and improving ventilation, the walls and ceilings under the attic or roof must be made less permeable by installing vapor barriers on the warm sides. Vapor barriers are commonly essential where sidewalls contain thermal insulation against cold weather and they are usually a wise precaution where winters are cold even when no extra insulation is added.

Methods of preventing cold-weather condensation are discussed in detail with illustrations in a booklet on "Condensation Control in Dwelling Construction" by the Housing and Home Finance Agency, Washington, D. C.

g. **Abnormal Deterioration Requiring Removal of Old Paint.** Complete removal of old paint with blowtorch or house paint remover is so expensive that it is seldom done; yet under some circumstances no other procedure offers reasonable prospect of at least moderately durable repainting with acceptable appearance. To avoid the expense of complete removal considerable sacrifices in appearance are often accepted. No hard and fast rule can be given, for each case should be decided on its own merits, taking into account the price that can properly be paid for first-class appearance, the frequency of repainting that might be necessary without removal of the old coating, and the estimated future life of the building.

The following abnormal conditions are apt to justify removal of the old coating:

(1) Serious incompatibility between paints that has caused unsightly alligatoring or scaling. Equally conspicuous scaling caused by water in sidewalls, however, does not require removal unless the coating has become too thick for further satisfactory painting.

(2) Excessive thickness of coating that has caused dry blistering or conspicuous scaling. Coatings more than 10 mils thick may well be removed and coatings 20 mils or more thick certainly should be removed. The thickness of coating can be estimated fairly simply by placing the edge of a chip of loose paint in alinement with the edges of a dollar bill and

examining the two edges simultaneously with a good magnifying glass. The dollar bill is 4 to 5 mils thick.

Few other conditions, if any, justify the expense of completely removing old paint.

h. **Application of Paints.** Painting should be adequately planned before the work is started and then should be completed promptly as planned. It is bad practice to make important changes in procedure once the work is under way. As a rule repainting should be done with paint of essentially the same kind as that used previously. Conformity to the same Federal Specification assures sufficient similarity even though the specification may have been revised in the meantime.

(1) *Thinning Paints.* Excessive reduction of paints with oil and volatile thinners is a common and harmful failing of the painting craft. The note section of many Federal Specifications for paint contains directions for thinning which should be followed carefully. Most Federal Specification paints are supplied in the proper consistency for application as finish coats during good painting weather. In cold weather, which thickens paint, they may be restored to proper consistency by adding volatile thinner but not beyond 1 pint to the gallon. Oil must not be added for cold-weather painting. Moderate thinning with volatile thinner is also permissible when the painting plan calls for thinner coats than normal, as may be desirable in repainting the heavily shaded parts of buildings or on buildings on which the coating is tending to become too thick.

When a finish paint is used for priming bare wood or for the first of two coats over old paint in a thoroughly chalky or checked condition, one gallon of the paint may be thinned with not more than 1 pint of linseed oil and enough volatile thinner, not to exceed 1 pint, to give suitable consistency for application at the desired spreading rate on the surface to which it is to be applied.

House-paint primer, Fed. Spec. TT–P–25a, should be applied without any addition when it is used for the first of a two-coat system to be applied on previously unpainted wood or wood from which all previous paint has been removed. For the first of a three-coat job, however, or for the first of two coats in repainting, volatile thinner, not to exceed 1½ pints to the gallon, may be added to the primer if necessary. No linseed oil should be added to the primer under any circumstances.

Enamels and interior paints may be thinned moderately with volatile thinner when necessary but no oil or varnish should be added to them.

Inexpensive mineral spirits conforming to Fed. Spec. TT–T–291a, grade 1, is suitable for thinning practically all paints used for interior and exterior wood surfaces.

(2) *Number of Coats and Spreading Rates.* The number and thickness of coats to be applied should be adjusted according to the thickness of new coating it is desired to place on the surface. For exterior woodwork a thickness of 4 to 5 mils is about right. The Federal Specification house paints are designed to build 4 to 5 mils of coating thickness on new wood either with two heavy coats or with three lighter ones, provided the spreading rates are gaged correctly.

(a) Previously Unpainted Wood. For painting new exterior wood with two coats only, the priming paint should be spread so that 1 gallon covers no more than 450 square feet of surface and 1 gallon of finish paint covers no more than 550 square feet. Only skilled painters working in favorable weather can safely apply paint so heavily. The schedule herein, therefore, does not include two-coat work on new wood and requires instead three coats.

For painting new wood with three coats, the priming paint (Fed. Spec. TT–P–25a) should be spread so that 1 gallon covers about 450 square feet of surface. The second coat (first coat of finish paint), thinned with not more than one pint of thinner to the gallon, should be spread at the rate of 1 gallon for about 700 square feet and the third coat at 1 gallon for about 600 square feet of surface.

In lieu of the 3-coat system for new wood consisting of one coat of priming paint and two finish coats, a system composed of two coats of primer (450 square feet per gallon) and one coat of unthinned finish paint (600 square feet per gallon) may be used.

(b) Repainting. In repainting, the number of coats to be applied and their spreading rates should be governed by the thickness of the old coating and its condition. If practicable, the addition of new paint should not bring the total thickness after repainting too much over 6 mils. The thicker the old coating the less new paint should be added. Often, repainting should be confined to one coat to avoid excessive addition to coating thickness even though some minor sacrifices in initial appearance of the repaint job must be accepted. The paint in one-coat work may dry with less than its full degree of gloss; it may be somewhat variable in gloss according to the absorptiveness of the old paint under it; it may show flat spots where the old paint flaked away or even over deep cracks in the old paint. These, however, are all minor blemishes that disappear as soon as the new paint reaches its chalking stage. They are a small price to pay for longer life of the job and lessened danger of conspicuous cracking and scaling.

If the old paint is merely chalky, checked, or cracked but is not seriously crumbling, flaking, or scaling and little or no wood has been laid bare, repainting should be done with one coat only unless there is less than 3 mils thickness of coating left on the surface. The new paint coat should be spread at approximately 550 square feet a gallon.

If most of the old coating is suitable for one coat repainting but there are scattered patches of flaking or scaling exposing bare wood, the bare places should be spot-primed and then one full coat of paint applied over the whole building. Sometimes, of course, the sheltered sides of a building need only one coat but the more exposed parts need spot-priming or need two full coats. The very sheltered areas such as the ceiling under an overhanging roof seldom require more than one coat of new paint.

When the old coating is less than 3 mils thick or when there is enough crumbling, flaking, or scaling to expose some bare wood on nearly all parts of a wall, two coats of new paint are usually needed. The first coat generally should be house-paint primer and the second coat finish paint. The primer should be applied at 450 square feet a gallon. The finish coat should go on at 600 square feet a gallon.

(c) Enamels, Floor Paints and Varnishes. Enamels, floor paints, and varnishes contain more volatile and less nonvolatile ingredients than exterior house paints. Because of their lower nonvolatile content, the enamels, floor paints, and varnishes tend to provide a dry film thickness which is considerably less for each coat than is obtained with the exterior house paints. Enamels, floor paints, and varnishes should be flowed on the surface and not brushed out in the manner recommended for the application of exterior primers and house paints.

(d) Interior Paints. Since interior paints do not wear away appreciably between paintings they are bound eventually to build up too much thickness of coating. Interior painting, therefore, should always be done with the minimum number of coats and maximum spreading rates consistent with satisfactory appearance.

(3) *Atmospheric Conditions for Painting.* In northern latitudes exterior painting should be scheduled insofar as practicable for the warm part of the year, from midspring to midautumn. Spring and early summer painting has the advantage of minimizing the amount of dirt the paint will collect subsequently and hastening its arrival at the chalking stage when the dirt begins to slough off. In southern latitudes the local rainy season, if there is one, may wisely be avoided. Interior painting in buildings that are kept warm can be done at any season of the year except that, in new or remodeled buildings, time should elapse for the building moisture to be eliminated before painting is started.

It must be recognized, however, that there may be emergencies in which exterior painting may have to be done in weather that is not ideal for the purpose. The chief hazards are rain, dew, or frost striking freshly applied paint and a sharp drop in temperature while fresh paint is drying. The defects that may result are slow drying, wrinkling, and uneven gloss, as discussed in previous paragraphs. Although these defects mar the appearance of new paint jobs they become less noticeable as the paint ages and usually do not impair the durability. When necessary, good oil paint can stand any temperature in which the painters can do acceptable work. In cold-weather painting, work should not be started in the morning until dew or frost has dried off; outside work should be postponed for the day when a drop of 20° F. or more temperature is predicted for the night, and outside work is best stopped at least 2 hours before sunset. Outside paint should not be applied while it is raining or foggy.

Where there is loose soil around buildings it may be necessary to postpone outside painting on windy days. Sand or soil blown onto fresh paint becomes embedded in the paint and gives it a rough, sandy appearance that remains for the life of the paint, though it does not impair the durability.

(4) *Time for Drying Between Coats.* Painting once started should progress promptly to completion. In reasonably dry air at 70° F. or more, Federal Specification exterior paints should be allowed to dry for a minimum period of 48 hours prior to recoating. Interior paints, enamels, and varnishes usually will dry satisfactory for recoating within 24 hours. Dampness or low temperatures may delay thorough drying for an additional day or two. The next coat of paint should be applied as soon as practicable after thorough drying of the undercoat has been achieved. Delay of more than a week between coats should be avoided, if practicable.

New construction finished in winter presents a different problem. The exterior wood cannot safely be left unprotected through the winter because its surface will roughen, there may be some wood checking and cupping, and nails may corrode. A priming coat can be applied in cold weather without much danger of wrinkling, for much of it is absorbed by the wood, but a priming coat furnishes little protection and by the time spring comes is not the best condition for recoating. It is best, therefore, to complete the exterior painting as promptly as the hazards of winter painting permit.

(5) *Brush and Spray Applications.* Painting can be done more neatly by the brush method than with spray guns. Spraying of paint requires troublesome masking or use of shields to cut in sharply, and produces mist and over-spray. Spreading rates of paint are more easily gaged by brush painters, who are guided by feel, sight, and length of brush strokes, than by spray painters, who must rely on sight and timing. On rough surfaces where old paint has flaked or scaled or the wood has checked, the brush can do a better job than the spray in depositing extra paint in the hollows without overloading the high places. On the other hand, the spray can reach rather wide, deep cavities that the brush cannot enter. In general, skilled spray operators can paint wood fully as durably as the best brush hands can do.

On buildings that present large wall areas unbroken by windows and doors much labor can be saved by spraying paint. Buildings with many windows and doors, however, afford far less opportunity for labor saving, especially if the trim is to be cut in with a color differing from that on the body. Spraying may offer little economy for painting ordinary dwellings, for example, unless the following short cuts are acceptable; limit the paint to one color for body and trim alike; cover window glass with masking compound and spray paint over sash and glass alike, then strip the dried paint and masking compound from the glass.

Fly screens admit considerable saving in labor by spray application even when the rest of the painting is done by brushing provided frame and screen wire may both be coated with the same paint. The screens should be taken to a place set apart for the purpose and

piled on top of one another. When the wire of the topmost screen is being sprayed much of the overspray passing through is caught and utilized on the wire of screens lower in the pile.

i. **Special Problems**

(1) *Shingles and Rough Woodwork.* The rough surfaces of shingles, boards with unplaned surfaces, or wood that has become weather-beaten are expensive to paint because they take excessive quantities of the paint and the coating fails to hide the surface irregularities or to produce the smooth appearance expected of paint. Such wood, however, takes shingle stain well and, if the stain is of reasonably dark color, should go seven or eight years before needing renewal of the stain. Two coats of stain should always be applied because of the low nonvolatile vehicle content of stains and the high porosity of shingles and most rough woodwork. If only one coat of stain is used, the vehicle solids of the stain are usually absorbed and result in none or little of the binder left on the surface to hold the pigment which will then wash away easily. The spreading rate is low, often no more than 100 square feet a gallon, depending on the roughness of the wood. When shingles or wood shakes are being used, the first application of stain is best made by dipping the shingles, butt end down, before they are placed in position on the building. Bevel siding is sometimes used where stained finish is desired, in which case the siding is best erected with the sawed side rather than the planed side out. The smooth side of siding can be stained if desired but it will take up less stain and will need renewal several years earlier than the rough side will.

(2) *Preservative Treatments Before Painting.* In a previous paragraph the damage to paint caused by water penetrating structures through various joints was pointed out. Where enough water gets in and stays long enough the wood may decay, particularly if it contains sapwood or other wood of little natural resistance. The best way to prevent such difficulties is to keep the wood always dry by improved design or construction or by keeping water away from the joints. Most of the joints involved in customary practices of wood construction can be adequately protected in such ways. There are, however, some places that experience shows to be chronically troublesome where treatment of wood with preservatives is advisable. Preservative treatments must be applied before any painting is done and the best of them before the wood is fastened in position.

Windows subject to condensation in cold weather often become wet enough for sapwood to become bluestained and then to decay. The condensation can usually be kept within safe limits by installing storm windows unless the indoor humidification is exceptionally great. Treatment of windows with water-repellent preservatives is now widely practiced and is generally worthwhile. Such treatment probably aids in keeping the windows freely running by furnishing some protection for the contact surfaces that cannot well be painted. The treatment is commonly applied by the millwork manufacturer by dipping in preservative for at least 3 minutes. Exterior doors, storm windows, fly screens and shutters are other items for which treatment with water-repellent preservatives may be well worth while to prevent decay and improve the performance of paints. Care should be taken to select a preservative which does not contain any wax which would be injurious to subsequent painting.

The posts, stringers, and balusters of porch or stair railing and the bases of columns when directly exposed to rain present joints that seldom can be kept watertight. Such woodwork, unless made wholly of heartwood of naturally resistant woods, commonly needs preservative treatment before painting. The most effective treatment for the purpose is by thorough impregnation with water-borne preservatives according to Int. Fed. Spec. TT-W-00571d when such treated wood can be conveniently purchased. Water-borne preservatives cannot be properly applied superficially at the building site. Where the treated wood has been cut for fitting the cut ends should be dipped in water-repellent preservative before the pieces are fastened in place. If treated wood cannot be obtained, water-repellent preservative may be applied at the site after all cutting and fitting has been done. End-grain sur-

faces at least should be dipped before fastening in place after which the remaining surfaces may be treated by brushing. Wood sealer, conforming to Military Specification MIL–S–13518A, type I, is recommended when sealer is applied at the work site.

(3) *Painting Creosoted Wood.* Wood in contact with the ground or other source of prolonged dampness is commonly preserved by impregnation with creosote or other oil-borne preservative that leaves the wood with a surface difficult to paint. Parts of wood close to the ground cannot be kept reliably painted anyway because the wood gets too wet. It may sometimes be desired, however, to paint the upper parts of creosoted posts set in the ground. Ordinary oil paints or enamels soon become discolored by creosote from the wood. Two coats of exterior aluminum paint, however, will make a bright coating that will not be discolored, unless creosote bleeds from the wood and comes through the coating. The aluminum paint remains bright because the very opaque aluminum particles float on top of the paint vehicle. Application of a white oil paint over the aluminum paint may still result in discoloration.

If the creosoted wood has rough surfaces, it can often be painted white without discoloration by using a water-thinned paint such as exterior casein paint, exterior resin-emulsion paint, exterior latex-emulsion paint, or even ordinary whitewash. A reasonable degree of whiteness may be retained for as much as two years before repainting is necessary.

SURFACE PREPARATION AND PAINTING OF MISCELLANEOUS SURFACES

1–36. PREPARATION AND PAINTING OF GALVANIZED SURFACES

Galvanized surfaces are generally left unpainted at least during their early life, since the purpose of galvanizing itself is protection of the base metal. However, for the sake of appearance or additional protection, painting is rather frequently done. In any event, painting should be initiated at the first signs that the galvanizing is not adequately protecting the underlying base metal. The largest problem in connection with painting of new galvanized surfaces is in obtaining and maintaining good adhesion, since most paints do not adhere well to this type of surface. However, the Vinyl Type Wash Coat (see par. 1–13*b*) adheres well if oil, grease, and other contaminants are first removed from the galvanized surface by washing with solvents and wiping dry. For use over the vinyl wash coat, zinc dust paint conforming to Fed. Spec. TT–P–641b, type II (Alkyd Type), is prescribed in the schedule herein for exterior galvanized surfaces, although other types covered by the specification may be used if the exposure conditions appear to warrant a change (see note section of Fed. Spec. TT–P–641b). Zinc dust pigmented paint is suggested since it performs quite well on galvanized surfaces, even without the vinyl wash coat. However, once adhesion to the galvanizing is established by means of the vinyl wash coat almost any type or color of paint suitable for the exposure conditions may be employed in place of the zinc dust paint with good results. For example, in interior exposure, painting of galvanizing would normally be done only for appearance and in such cases the vinyl wash coat might well be followed by whatever paint is being used on adjacent surfaces.

1–37. PREPARATION AND PAINTING OF ALUMINUM AND ALUMINUM ALLOY SURFACES

Aluminum surfaces will normally be left unpainted. However, where such surfaces are to be exposed for prolonged periods to moisture, concentrated chemical fumes or industrial gases, painting is generally advisable. Gutters subject to collection of debris, flashing in contact with concrete, contacting surfaces with other metals and contacting surfaces with

damp wood are also situations in which the protection of aluminum is indicated. The surfaces should be cleaned with solvents to remove heavy grease and oil accumulations and then treated with the Vinyl Type Wash Coat (see par. 1–13*b*).

There are other satisfactory methods of preparing aluminum surfaces, such as anodizing, hot dip phosphate treatment, and hot dip chromic acid treatments but they are for the most part not adaptable to field use.

The system prescribed in the paint schedule for exterior aluminum surfaces consists of the vinyl wash coat, two coats of a phenolic type zinc chromate aluminum primer followed by a phenolic type, aluminum finish coat. One of the two coats of primer may be omitted, if desired, where the exposure conditions are not severe. This system was not specifically designed for aluminum surfaces but was selected as being one which might be on hand as a result of procurement for other applications. In the absence of the paints for the suggested system any high quality primer, the pigment content of which consists of 50 percent or more of zinc chromate (zinc yellow), such as primer conforming to Military Specification JAN–P–735 may be used either over bare metal or over the vinyl wash coat, followed by one or more finish coats of high quality aluminum paint or other finish color as required. In general, paints containing lead pigments should not be used for the first coat on aluminum surfaces. Exterior lead-free house paints may be used in painting aluminum siding subject to normal exterior exposure with good results. High quality bituminous paints may be used to advantage in painting aluminum flashing which is in contact with concrete or mortar and in painting the inside of gutters. Aluminum surfaces in contact with dissimilar metals should be cleaned and given two or more coats of a zinc chromate-containing primer such as that conforming to Military Specification JAN–P–735.

1–38. PREPARATION AND PAINTING OF CONCRETE AND MASONRY SURFACES

The painting of concrete and other masonry is complicated by several factors which are generally associated with such surfaces, particularly when they are new. The first factor is that new concrete structures and the mortar joints of other masonry structures contain a large amount of moisture which was introduced at the time of construction. Secondly, there are considerable amounts of soluble, alkaline substances in new concrete and mortar. Those soluble alkaline substances which are distributed on or near the surface of the concrete or masonry are gradually neutralized or insolubilized but those which lie more deeply in the masonry or concrete may, in conjunction with the leaching action of water, be carried to the surface over a very extended period of time and cause painting difficulties. Additionally, new concrete surfaces are likely to be soiled with oil from forms and may be glazed as the result of having been cast against smooth, nonabsorbent forms. All of these conditions are inimical to the satisfactory performance of paint coatings.

Various paint systems have been advanced for use of these surfaces, many of them purporting to be unaffected by the above conditions. The fact remains that adequate surface preparation is still an important factor in satisfactorily coating concrete and other masonry surfaces. No matter what type of paint coating is used, the surfaces must be rough enough to establish a good mechanical bond with the coating and must be cleaned of soiling substances, particularly oil, grease, and efflorescence. Extended exterior weathering will generally remove oil films but heavy grease deposits should be removed with solvents, steel brushes, abrasive stones or preferably light sandblasting. Reduction of surface smoothness or glaze and removal of efflorescence should be accomplished by blasting or by other mechanical means whenever practicable. There may, however, be some dense, hard efflorescent deposits which will require treatment with acid as will be discussed later. The removal of oil, efflorescence, and other contaminants, together with any necessary reduction of surface

smoothness, would be the only surface preparation necessary for the application of water-cement paints such as are covered by Fed. Spec. TT–P–21, since water-cement coatings are relatively unaffected by unneutralized alkalies and by moisture.

Most paints, excluding those of the cement-water type, cannot safely be applied to new concrete surfaces until the concrete surfaces have thoroughly dried and/or the active alkalies have been effectively neutralized. The easiest way to relieve these difficulties is to allow the concrete to age and weather for three to twelve months; the length of elapsed time depending on the thickness and porosity of the concrete sections and atmospheric conditions. Aging not only permits the concrete to dry out but, by a carbonation process, decreases alkalinity at the surface and within the thin shell of outer concrete. The presence of objectionable alkalinity can be determined with some degree of success by wetting the surfaces and applying a few drops of phenolphthalein indicator solution. A pink color indicates an alkaline surface condition. This test, however, is so beset with variables and sources of error that in inexperienced hands it is of little practical value. It is to be remembered that even after extended aging and drying of the surfaces there still are soluble materials, including alkalies, within the concrete mass and these may be carried to the surface if there is an outward movement through the concrete during subsequent exposure.

The reduction of surface alkalinity where prolonged aging is impracticable, has frequently been accomplished by brushing a solution of zinc sulphate (2 pounds to a gallon of water) on the surfaces. After drying, the loose particles are brushed off prior to paint application. The application of a dilute solution of muriatic (hydrochloric) acid, followed by thorough flushing with water, has also been used for neutralization of alkalinity and to an even larger extent for etching and roughening of excessively smooth or glazed surfaces. The acid application supplemented by a scrubbing treatment with stiff fiber brushes is also used to remove hard, adherent deposits of efflorescence. Experimental work by the Bureau of Reclamation, reported by Messrs. Burnett and Fowler in a paper "Painting Concrete Surfaces," in the June 1947 issue of the Journal of the American Concrete Institute, indicated that treatment of 3-week-old concrete surfaces with a water solution containing 3 percent phosphoric acid and 2 percent zinc chloride followed by a 24 hour or more drying period resulted in greater paint durability than treatment with muriaic acid or zinc sulphate solution. The last two methods, according to the report, were completely ineffective in increasing paint durability when compared with no pretreatment. The authors state that the superiority of the proposed phosphoric acid-zinc chloride solution lies in the formation of insoluble compounds during the neutralizing action, whereas the muriatic acid or zinc sulphate solution form soluble salts. These soluble materials lying on the concrete surfaces tend to produce an osmotic effect which draws moisture to the paint-concrete interface with resulting blistering of the paint film. On the basis of this information, the use of zinc sulphate or muriatic acid solutions to neutralize the alkalinity of masonry surfaces should be abandoned in favor of the phosphoric acid-zinc chloride solution, although it is to be recognized that any of the neutralizing solutions are probably less effective than permitting the surfaces to age for an extended period. The use of muriatic acid for such purposes as etching of masonry surfaces and removal of efflorescence should also be discontinued in favor of the phosphoric acid mixture.

Once the conditions which make new concrete and masonry difficult to paint (i.e., high moisture content and movement of moisture through the mass, alkalinity, surface glaze and surface contaminants) have been remedied, there are a large number of paint materials which can be used satisfactorily on these surfaces. The use of Portland cement-water paints (Fed. Spec. TT–P–21) has already been mentioned. This paint serves well for open-textured, exterior surfaces, such as concrete building block and may be used on interior surfaces as well where good washability is not required. When Portland cement paints are being used proper surface preparation and paint application are of the greatest importance and are

described in detail in paragraph 1-54c (13) and in the Report of ACI Committee 616, Journal of the American Concrete Institute, September 1949. In the painting schedule, paragraph 1-54*c*(13), an alternate to the water-cement paint system for exterior concrete and masonry surfaces (except floors) is prescribed and is based on a paint (Fed. Spec. TT-P-24a) made up with a conventional drying oil-varnish vehicle. TT-P-24a paint is adapted only to concrete and masonry which has been allowed to thoroughly age and dry out. Moreover, the concrete or masonry mass should not have an opportunity, after painting with TT-P-24a paint, to regain a high moisture content. Paints of the water-thinned, latex base type, particularly those made up with polyvinyl acetate emulsions, have been reported as being excellent for *exterior* concrete and masonry surfaces but it is believed, despite promising results to date, that to widely prescribe the use of this type paint at this time would be somewhat premature.

For *interior* concrete or masonry surfaces, two alternate systems are prescribed in the schedule (par. 1-54c(22)), the first consisting of an oil-base primer-sealer (Fed. Spec. TT-P-56b), followed by an undercoater (Fed. Spec. TT-E-543) and a conventional interior flat, gloss, or semigloss finish coat, and the second system consisting of two coats of water-thinned, latex base, interior flat paint (Fed. Spec. TT-P-29). The conventional oil-base system should be used only on concrete and masonry which is well aged and which, in service, is not subject to entrance of water into the wall behind the paint. With respect to open textured surfaces, such as concrete block, it should be noted that it is difficult to apply conventional oil or varnish base paints in such a manner as to fill all of the surface voids and that consequently a satisfactory appearance may require a preliminary filling treatment of the surfaces with class B cement-water paint or cement-sand grout. Latex paints are more adaptable to painting open textured concrete block without a preliminary filling or grouting treatment since they can be worked into the surface voids with a whitewash brush by using a light scrubbing action. Because of their excellent alkali resistance and greater permeability to moisture vapor, latex paints require a lesser aging period of concrete and masonry surfaces than do varnish or oil-base paints although an aging period of less than three or four weeks is not recommended. For interior concrete floors, two systems are indicated in the schedule; one consisting of multiple coats of a rubber base paint (Fed. Spec. TT-P-91a) and the second consisting of two coats of a varnish base enamel (Fed. Spec. TT-E-487). The latter paint can also be used on *exterior* traffic bearing concrete surfaces. However, painting of concrete floors for decoration is not recommended, because in a short time the appearance will be worse than that of an unpainted floor, unless the user is prepared to incur the expense of frequent repainting. For additional information relative to the painting of concrete and masonry surfaces, attention is invited to the note section of the referenced federal specification which contain information as to the proper application and the range of usage of these materials.

Before leaving the subject of painting concrete and masonry it would seem worthwhile to deal briefly with the frequently raised questions concerning the sealing of such surfaces against moisture penetration. Poured, monolithic concrete of good quality and of a thickness greater than an inch or two is considered to be highly impermeable and in no need of sealing treatments for the purpose of reducing moisture penetration, provided that the concrete is free from cracks. Concrete blocks, on the other hand, are highly porous as a result, it is presumed, of being made with a relatively dry, very stiff concrete mixture which does not consolidate completely during block manufacturing processes. Concrete block therefore has poor ability to resist penetration by wind-driven rain and water stemming from other sources. Any attempts toward sealing concrete block should obviously be directed toward the surfaces facing the water source rather than the dry side. It would appear also that the sealing material, to be successful, should be applied heavily enough to fill the many small voids in the block surface. Cement-water-sand paints (class B, Fed. Spec. TT-P-21), when applied at a thick consistency and scrubbed into the surfaces with a stiff-bristle brush do a good

sealing job but are troublesome to apply and water-cure and they leave something to be desired in the way of appearance. On the other hand in order to fill the surface voids of concrete block with conventional oil or varnish base paint would require abnormally large amounts of paint. Moreover the oil or varnish base paints are hardly adaptable to the scrubbing action necessary to work the paint into the surface voids. Thus if one wishes to obtain the better appearance and other advantages of oil or varnish base paint and wishes also to seal the concrete block surfaces it is advisable to apply the cement-sand-water mixture first in order to fill the surface voids. The process of filling surface voids can be accomplished by "sacking," in which a Portland cement grout is put in a sack made of loosely woven material and the sack rubbed over the surfaces to be filled.

1–39. PREPARATION AND PAINTING OF PLASTER SURFACES

New plaster should be aged prior to painting with oil-base paints for a period of 60 days in order to remove moisture and, in the case of lime plaster, to decrease the surface alkalinity. Under good drying conditions it is considered that the aging period may be safely reduced to a minimum of 30 days. Plaster is sometimes tested for objectionable alkalinity by wetting small representative areas and applying a few drops of phenolphthalein indicator solution. A pink color developing in and around the test drop indicates an alkaline condition of the surface. There are so many sources of error in the test however that it is of little practical value in inexperienced hands.

Once the surfaces have been permitted to thoroughly dry they may be painted by first coating with primer-sealer conforming to Fed. Spec. TT–P–56b, second coating with enamel undercoater, and finishing with interior flat, semigloss or gloss paint, all as indicated in paragraph 1–54*c*(22) of the schedule. Primer and/or undercoater should be tinted to a color approximating that of the final coat. If a two-coat paint system is satisfactory from an appearance standpoint, the enamel undercoater may be omitted as an economy measure. Alternatively, two or more coats of a water-thinned, latex base emulsion paint conforming to Fed. Spec. TT–P–29 may be applied. With the latter system, no special primer need be applied unless the surfaces are extremely porous. Although the latter system, based on the latex emulsion paint, may be applied to new plaster surfaces which are less thoroughly dried out than when conventional wall paints are used, at least 2 weeks, or as long a drying period as is practicable, is recommended.

If it is desired to limit the painting to one coat work, paint conforming to Fed. Spec. TT–P–47a, "Paint, Oil, Interior (Nonpenetrating-Flat, Ready-mixed, Tints and White)" should be used. This material is designed for direct application over porous surfaces such as wallboard, wallpaper, plaster, or other absorptive materials, to give a uniform finish without the use of a primer or sealer. It is a ready-mixed flat wall paint of the combined-primer-sealer-finish type. It is to be anticipated that the one-coat paint system for interior surfaces will not present an appearance equal to multiple-coat systems.

It is to be noted that considerable similarity exists between painting interior woodwork and interior plaster work except when resin emulsion (latex) paints are used. Therefore, much of the information in paragraph 1–33*a* is applicable here.

PAINT APPLICATION, STORAGE, INSPECTION, AND SAFETY

1–40. GENERAL

The following paragraphs are intended to be general only, describing workmanship, equipment, methods of application, mixing and thinning, atmospheric conditions, protection against inclement weather, coating progress inspection, safety, etc. Information relative

to special procedures in the application of particular types of paint are included in the foregoing sections of the manual dealing with the preparation and painting of ferrous, wood and miscellaneous surfaces.

1–41. WORKMANSHIP

Workmen employed in painting operations should be thoroughly experienced. Inexperience produces unsatisfactory jobs not only from an appearance standpoint but because of higher costs stemming from unreasonable wastage of material and effort. In hired labor work it is frequently necessary to employ painters whose experience and training are inadequate. Such employees can profitably be given a short training course with emphasis on application of paint materials which may be strange to them. Even thoroughly experienced personnel may profit greatly by a short course of instruction in the application of some of the relatively new materials which appear in this manual. In such training periods, a major objective should be to impress upon the workmen that, with the exception of necessary thinners and in some cases metallic pigments, the paints are formulated to be used as furnished and are not to be reformulated by adding oils, pigments, varnishes, driers, etc., according to the personal opinions of the applicator. A neat appearance of the finished surfaces, with an absence of ridges, sags, runs, drops, laps and unnecessary brush marks, is one obvious criterion of good workmanship. There are other criteria which although less obvious are of even greater significance in obtaining a satisfactory paint job. Thorough mixing of paint, limited use of thinners, uniformity of film thickness, removal of dust, grease and other foreign matter on the surface to be painted, conservation of paint materials, proper drying between coats, and protection of surfaces not to be painted are only a few of the important trademarks of a skillful and conscientious painter.

As a general rule, it is believed that the first coat of paint on new wood, plaster, concrete, and other nonmetallic substrates should be applied by brush although roller coating may be used to advantage on many broad, smooth surfaces. Subsequent coats on these surfaces may be applied by whichever method is the more economical or practicable. On hot-rolled structural steel surfaces which have been only incompletely and superficially cleaned by methods short of pickling or sandblasting, the first prime coat should be brushed in order to obtain more intimate contact with the surfaces and work the paint into pits, crevices, and beneath the edges of semiadherent rust and scale. The oil-type primers generally prescribed for nonblast-cleaned structural steel surfaces are much more adaptable to obtaining a thoroughly brushed-on coat than varnish type paints which must be more or less flowed on with a minimum of brushing. Subsequent (to the first) coats on brush primed structural steel surfaces may well be either brushed or sprayed, depending on which is the cheaper or more practicable. On *thoroughly* cleaned surfaces of nonferrous metals, cold-rolled steel, and on sandblasted or pickled structural (hot-rolled) steel, all coats of paint may be applied by brush or spray, whichever is more economical. In applying the first coat of paint to structural steel surfaces, at least one district in the Corps of Engineers found it worthwhile and practicable to use a combination of the two methods: spraying, followed immediately by brushing out of the paint. Roller coating of structural steel is now rather extensively used and works well on large smooth areas. When rollers are used care must be exercised to insure that welds, rivets, edges and corners are thoroughly coated. It is not believed that roller coating should be permitted for application of the first coat on non-blast cleaned structural steel. Dipping has been found to be an effective and economical method of coating such items as subway type grating which are difficult to spray or brush. There are several other methods of paint application which will not be discussed herein, since they are adaptable only to industrial or shop finishing.

Every effort should be made to avoid the deposition of dust from blasting operations onto wet paint films. Prevention of dust contamination can best be done by scheduling work so

that the blasting operations can be delayed until the film has dried. After the paint has dried, unavoidably collected dust should be blown away or, if adherent, should be immediately wiped off lightly with solvent soaked rags.

1–42. EQUIPMENT FOR PAINT APPLICATION

The equipment to be selected for paint application depends entirely upon the requirements of the job. The quantity of work, the condition and type of surface, the personnel organization, the rate of production, and the type of coating materials all have an important bearing upon the selection of the equipment to be used. For this reason, only information of a general nature can be furnished herein.

a. **Brushes.** Most good brushes are made from genuine Chinese hog bristles, because only they are naturally split at the outer end into two or more branches. This characteristic means, for practical purposes, 2 or 3 times as many contact points as with other types of bristles, and results in finer brushmarks and greater paint-holding ability. Low quality brushes are frequently characterized by short bristles and/or a center plug which prevents the cross-sectional area of the brush from being completely filled with bristles. Nylon bristle brushes have been produced with split bristle ends and they have shown considerable promise. For most painting operations brushes are either rectangular, oval, or round in shape. The rectangular brushes are suitable for applying paint on flat surfaces, while the round and oval shaped brushes are adapted to the application of paint in constricted areas, such as in corners and on window sash. The experienced painter recognized the necessity for clean painting equipment and makes it a cardinal principle to keep his brushes and other painting tools free from dirt and accumulations of dried paint.

b. **Spray Equipment.** This equipment consists essentially of spray gun, air and fluid hoses, pressure feed tank, a compressor to supply air pressure to the gun and to the paint tank, and a pressure regulator or air transformer to maintain constant pressure and to filter out moisture, oil, and other impurities from the air supply. Low capacity spray apparatus of the suction feed type is used principally in shop work and will not be discussed herein. Pressure tanks of spray equipment used for the application of paints which tend to settle after being thinned to spraying consistency should be fitted with an air-driven mechanical agitator. Spray equipment is available in many different sizes and types for all kinds of work. It is important that the proper types and sizes be selected for the work to be done. Equally important is to have a proper balance of the combination of items that make up the spray equipment. The hoses must be of such diameter with relation to length as to supply ample air and paint to the gun without the use of abnormal pressure, the compressor must have sufficient capacity to operate not only the paint guns, but all other air tools which might be used simultaneously, and the gun must have the proper air cap and fluid tip. Normally, the air hose to the spray gun will not be less than $\frac{5}{16}$-inch inside diameter and from compressor to feed tank $\frac{7}{16}$-inch. A production type spray gun is used for most work since it is capable of high performance and can be fitted with a variety of air caps and fluid tips which make it adaptable to most types of paint. It is important that all spray equipment be kept clean and parts replaced when they become worn.

1–43. APPLICATION PROCEDURE

a. **Brush.** The paint should be applied so as to form a uniform film of such thickness as to be in accordance with the specified spreading rate for the particular paint being applied. The brush should be held lightly but firmly. The paint should be spread over the surface with a moderate, even pressure and finished off with a light, even pressure. Care should be taken to brush out oil-type paints thoroughly, so as to completely coat all irregularities on the surface. Rapid drying paints should be brushed only enough to spread the paint evenly and to avoid excessive thickness. On flat surfaces, the paint should be first applied by brushing

parallel to the length of the work, then cross brushed at right angles, and finished off by brushing lightly in the original direction. It is a desirable practice to cross brush succeeding coats. For brushing rivet heads, badly pitted areas, corners and similar surfaces, a round or oval brush should be used. Here the initial movement of the brush should be a series of small circles completely covering the area, following which the coating should be smoothed and thinned by a series of parallel strokes.

b. **Spray.** In spray painting the flow of air and fluid at the gun must first be adjusted or balanced so that proper atomization and other spraying characteristics are obtained. The first consideration in obtaining this balance is the proper selection of air cap and fluid tip, for the particular material being sprayed, according to the equipment manufacturer's recommendations. After the air cap and fluid tip have been selected, there are several adjustments which may be made in order to properly balance the air and fluid relationship. The fluid-adjusting screw on the gun permits restriction of fluid flow in proportion to the volume of air being used, but this method is not the best, since it puts additional tension on the trigger and discourages "feathering" of each stroke. Adjustment of tank pressure and adjustment of the atomization air supply to the gun can more effectively be employed to obtain the proper air-fluid balance for a specific combination of air cap and fluid tip. Also the pattern adjustment screw can be changed to spread the atomized fluid out over a greater area which, in combination with the increased air flow, is equivalent to reducing the flow of fluid. A very common method of adjustment, which is definitely not recommended is to thin the paint excessively in order to increase the flow of fluid. The atomizing pressure to be used is dependent upon the type of paint and the length and diameter of air line from regulator to gun, but it should be just sufficient to completely atomize the paint. With 100 feet of $\frac{5}{16}$-inch air hose and enamel paint of rather heavy viscosity, a pressure of 40 to 60 p.s.i. at the regulator usually gives satisfactory results. An excessive concentration of air may give a split pattern or one which is *light* in the center insofar as deposited material is concerned. Too little air may give a heavy-centered pattern. Pressure on the paint pot is usually adjusted between 25 and 40 pounds, but may vary more widely depending on the unit weight of the paint and the height above the pressure tank it is to be raised. Air hose from spray gun to pressure feed tank should be not less in diameter than $\frac{5}{16}$-inch. Hose from compressor to feed tank should be $\frac{7}{16}$-inch. The gun and paint are designed for a certain spraying technique which includes holding the gun six to eight inches from the surfaces being coated, and proper stroking and triggering the gun. Inexperienced painters have a tendency to arc or wave the gun on each stroke. This practice should be avoided by flexing the wrist at the ends of the stroke so that the spray remains perpendicular to the surfaces and the nozzle remains at a constant distance of 6 to 8 inches. One of the more difficult techniques to learn is the proper triggering of the gun. The operator should pull the trigger just before he commences his stroke and release it just before he stops his stroke. In this way, adjacent areas will be coated uniformly and the overlapped areas at the ends of the stroke will not be visible. In the parallel direction, each stroke should be aimed so that the middle of the spray strikes the bottom of the preceding stroke. Frequent check with a film thickness gage should be made to ascertain the thickness and uniformity of the coating in view of the fact that there is a tendency to increase the spreading rate with spray application, particularly with paints having good hiding power. Special care must be taken, particularly with paints of poor flow characteristics (such as vinyl paints described herein) that the gun is pointed perpendicularly at all surfaces as they are passed. For example, rivet heads present a surface that requires facing the gun in several directions before they are completely painted. Surfaces inaccessible to the spray gun should be coated by brushing or daubing as the occasion requires. It should be noted that *overspray* (paint not deposited on the intended surfaces) can drift relatively long distances when the exteriors of tall structures are being painted and particularly so on windy days. Such particles, if deposited on adjoining property, may cause

numerous complaints. Due to the toxic and combustible properties of paint, when spray operations are performed in confined places, it is necessary to provide adequate ventilation and initiate such action as is necessary to control or eliminate sources of ignition.

1–44. MIXING AND THINNING OF PAINTS

The mixing of paints seems elementary and a subject that need not be discussed at length, but it is a very common source of trouble either through negligence or lack of knowledge. All paints, whether ready-mixed or paste type, require field preparation prior to application. On standing, the pigments of ready-mixed paints generally tend to settle to the bottom of the container, forming a layer of paste, the firmness of which depends on the period of storage and the components of the paint. Some paints, such as the vinyl type wash coat, cannot be stored satisfactorily for more than a few months and judgment should be exercised in their procurement. After long standing, the settled material may become so hard and dry that mixing by field methods is impossible. All paints should be stored in full, tightly sealed containers. These precautions serve to reduce oxidation and prevent loss of volatile constituents.

Ready-mixed paints should be prepared for use in places that are well ventilated, away from open flame and free from direct sunlight. All motors of electrically-driven equipment must be explosion-proof. Mechanical mixers of the types that vibrate containers ranging in size from a pint can to a 55-gallon drum, and the stirring type that consist of a motor-driven propeller on a shaft may be useful where large volumes of paint are being used, but for much field work, the hand paddle and boxing will normally be found more economical. The latter method consists of the following: (1) Into a clean container of approximately equal size of the paint container, pour most of the liquid from the paint without previous stirring, (2) stir any settled material remaining in the original container until a uniform paste is obtained, thoroughly loosening all pigment that may have accumulated on the sides and bottom, (3) pour the liquid portion from the second container into the paste, a little at a time, stirring thoroughly all the while, until most of the paint is in the original container, (4) box (pour) the paint from one container to the other until a smooth homogeneous mixture is obtained: any lumps or skins should be removed before use by screening.

Paste type pigments, such as aluminum, to be incorporated into vehicles are mixed in much the same manner as described immediately above. An accurate balance must be used for weighing the proper amount of pigment to be used. Care must be taken to add the vehicle to the paste in small increments, rather than paste to the vehicle. Paints made up with powdered metallic pigments are often supplied in two containers, one containing the base paint or vehicle and the other the metallic pigment; for example, the zinc dust-zinc oxide paint (formula P–5) shown in paragraph 1–60*d*. In preparing such a paint, the base paint must first be mixed as described above. Then the correct amount of metallic pigment is added in small increments to about one-third of the base paint, stirring continuously until a smooth paste is obtained. The remainder of the base paint is then thoroughly stirred and boxed in.

Thinners and solvents have a definite function in the formulation of paints, but their excessive use in the field must be scrupulously avoided. Painters are very prone to add thinner beyond that required by any particular paint formula, primarily to make easier the application of the paint. Such practices should not be tolerated because the resulting film will be applied too thinly and will be inferior in durability. The use of the proper thinner is also of great importance, but one which is often treated with carelessness. If a thinner is needed for addition in the field it should have the following properties; it must be completely compatible (at least in the quantities to be used) with the components of the paint vehicle in order to avoid precipitation or throwing out of solution any of the constituents; it must have suitable solvency power to effect the reduction in viscosity desired without the use of an excessive quantity; its evaporation rate must be such as to allow proper flow and

leveling of the film; and it must be free of harmful impurities which would remain in the film. Unless otherwise specifically prescribed, inexpensive mineral spirits may be generally considered suitable for the paints indicated in this manual. However, any tendency of mineral spirits to cause curdling, precipitation or other signs of incompatibility during thinning operations should result in its discontinuance and the substitution of a stronger solvent such as covered by Fed. Spec. TT–T–306, "Thinner, Synthetic Enamel." Because many different grades of mineral spirits, some of which are entirely unsuitable, are marketed, it is important that it conform to the requirements of Fed. Spec. TT–T–291a "Thinner; Paint, Volatile Mineral Spirits (petroleum spirits)" Grade 1. Thinner should be added to paints only in small increments with constant stirring. Both paint and thinner should be raised, if necessary, to normal room temperature. Accurate measures must be available for measuring thinners into the paint. The thinning of vinyl and other paints requiring special thinners is covered in detail in the sections devoted to these materials.

1–45. ATMOSPHERIC CONDITIONS AND PROTECTION AGAINST INCLEMENT WEATHER

In general, paints should be applied only to surfaces that are thoroughly dry and under such combination of humidity and temperatures of atmosphere and surfaces to be painted as will cause evaporation rather than condensation. A practical test is to wipe a damp cloth on the surface to be painted. If the moist streak dries within a few minutes, it indicates that favorable drying conditions prevail. Even those few paints prescribed in the manual which are thinned or mixed with water should be applied to reasonably dry surfaces. The only material discussed in the manual which is suitable for application over damp or moist surfaces is cement-water paint (Fed. Spec. TT–P–21).

In no case should any paints be applied to surfaces upon which there is frost or droplets of water. Where exterior painting is permitted during damp, rainy weather, the surfaces should be sheltered and/or heated to provide a warm, dry surface upon which moisture will not condense. Metal surfaces may be considered dry enough to paint when no moisture can be detected by sight or touch but this criterion may not be sufficient in the case of wood and other porous substrates.

In general, while any painting is being done and during at least the initial drying period, the temperature of surfaces being painted and the air in contact therewith should be maintained at or above 40° F. However, the vinyl type paints (including the Vinyl Type Wash Coat) may be applied successfully with the surfaces and ambient air at temperatures as low as 25° F. These lower temperatures are permissible because the vinyl type paints dry by evaporation only and the solvents used in making them up are sufficiently volatile to leave the applied film fairly rapidly even at relatively low temperatures. As a matter of interest, this type of paint has been applied with both surface and ambient air temperatures as low as 10° F. This extreme is, however, not recommended as a general painting practice with vinyl type coatings. It should not be inferred that the lower temperatures permitted for application of vinyl paints are generally desirable. Although probably not harmful in itself to the paint film being applied, the lower temperatures do increase the possibility of there being frost and condensation on the surfaces, with attendant poor adhesion. Moreover, the viscosity, amount of required thinning, drying time, tendency to sag and run, and other application characteristics of any paint are adversely affected by low temperatures. Painting at reduced temperatures, even with vinyl type paints, should be permitted only when it can be done under no other circumstances. Lock gates, lock chamber valves, and other component parts of navigation projects which cannot be immobilized during the navigation season are examples of surfaces which must be painted during cold weather. Although such structural components can generally be inclosed by temporary canvas shelter, and heat

applied, it may be impracticable in cold climates to maintain the temperature of air and surfaces at the generally required minimum of 40° F. Under such conditions, consideration should be given to permitting a lower application temperature and the use of the more adaptable vinyl paints. When protection is provided for painted surfaces, such protection should be left in place until the paint film has dried firm.

It is frequently stipulated that paint being applied should be at a temperature at least as high as that of the surface on which it is applied. Although it is probably a good safe rule, the reasons for such a requirement are not too obvious. One valid reason, of course, is that the viscosity of the paint and, therefore, the amount of required thinner are increased by lowering the temperature of the paint. Also, low temperature of the paint tends to increase running and sagging difficulties.

No upper temperature limit for surfaces receiving paint is considered necessary except that the surfaces shall not be so warm as to cause blistering or porosity of the film during the drying period.

1–46. COATING PROGRESS

Surfaces which have been cleaned, pretreated, and/or otherwise prepared for painting should be primed as soon as practicable, as a precaution against deterioration of the prepared surfaces. *Structural steel for service in atmospheric exposure (i.e., not requiring blast cleaning) should be cleaned and shop primed prior to breakdown of millscale,* insofar as practicable. Shop coated steel should be stored at the permanent erection site out of contact with the ground in such a manner as to minimize the formation of water-holding pockets and in such a location as will minimize soiling of the surfaces from adjacent construction operations. The shop coat should be touched up in the field as necessary to maintain its integrity. If field painting is greatly delayed the shop coat may need to be completely renewed with an additional coat of primer identical to that originally applied. After field painting has been commenced on any surfaces, the complete painting operation, including all coats to be applied, should be completed without prolonged delays. It is apparent that the avoidance of long delays will reduce the possibility of chalking or marring of the undercoats and the collection of grease, dust, and other soil. Obviously, any chalk or soil of the undercoats which might have an adverse effect on intercoat adhesion should be removed by air blast, solvent wiping, or other means, prior to applying a succeeding coat, and the integrity and continuity of all undercoats should be re-established whenever necessary by touch-up painting. *Structural steel subject to underwater exposure should normally be blast cleaned, surface treated, and painted entirely in the field,* after erection, in order to avoid long delays between the beginning and finishing of coating operations. In addition to the probability of ill effects resulting from soiling and marring of undercoats, where excessive time between coats elapses, there is the possibility that such delays will result in a decrease of intercoat adhesion, where the phenolic type paint systems in underwater exposure are concerned. This can be explained perhaps by the fact that these paint films, which dry by oxidation and polymerization, tend to progressively harden and become more insoluble in the original formulating solvents. Therefore, successive new coats have less of a dissolving and amalgamating effect as the undercoat becomes older and harder and this inability to strike into the previous coat tends to promote deficiencies in intercoat adhesion, particularly in underwater exposure. Needless to say, considerable latitude should be allowed in requirements for any maximum drying period between coats, lest unreasonable restraint be placed upon operators; a few extra days of drying time should not be generally a source of great concern. It will be noted that shop primed steel work which will ultimately be subjected only to atmospheric exposure (not blast cleaned) may have to stand for a considerable period of time before receiving another coat. It is believed that the long delay in this particular case is preferable to the alternative, i.e., permitting the steel to weather and rust for an indefinite period prior to

priming. Moreover, the problem of intercoat adhesion in atmospheric exposure is much less serious than in submerged exposure.

The desirability of quickly completing the application of a multiple coat paint system should not obscure the fact that there is a minimum hardness which each coat should achieve before it is recoated. It is difficult to set up minimum time periods for intercoat drying of a given paint formulation. It is obvious that there are many different degrees of drying. Dust free, tack free, dry through, full hardness, and dry for recoating are those defined in Fed. Spec. TT–P–141b. Dry for recoating is defined in the referenced federal specification as the point at which a second coat (of the same material) can be applied without the development of any film irregularities, such as lifting or loss of adhesion of the first coat, and the drying time of the second coat does not exceed the maximum specified for the first coat. Such a definition is useful, but its general nature indicates the difficulties inherent in attempting to stipulate just when a given coat of paint is hard enough to recoat. The issue is further complicated by the probability that the minimum degree of intercoat drying should be revised if a 4-coat paint system is to be applied instead of a 2-coat system, or if the surfaces being coated are to be submerged in water instead of being exposed to the atmosphere. Also, everyone is familiar with the need for long drying time during periods of high humidity, low temperatures, or in restricted areas where there is poor air circulation. It is clear that it would be unrealistic to set up dry for recoating time intervals and expect them to be applicable under all conditions. Indeed, it is hard to say more than that undercoats should be permitted to dry for recoating as defined above.

It is preferable to put on paint coats to be applied in the field after erection of a structural component, rather than before, since the applied film has much less chance of being damaged. Surfaces which need protection, however, and which will be inaccessible after erection are necessarily painted prior to erection.

When successive paint coats of the same color have been specified it is good practice to require tinting of alternate coats to insure complete coverage. Coats should be sequenced so that the final coat is untinted if the tinted color is objectionable. Most conventional paints based on linseed oil vehicles, alkyd vehicles, phenolics and other oleo-resinous varnish vehicles may be tinted with colors-in-oil. Pigments with high tinting strength, such as lampblack, should be employed and only in the amount needed to provide a color differential. Aluminum paints are very difficult to tint because the leafing of the aluminum pigment obscures the tinting material. Prussian blue is commonly used to tint aluminum paints but it is far from being completely satisfactory. Vinyl type paints and any others which are incompatible with colors-in-oil should be tinted only with pigments which have been ground in the same vehicle as was used in making up the paint itself.

1–47. PAINTING OF CONTACTING SURFACES

Contacting surfaces formed by a riveted or bolted joint may be painted or left unpainted where both surfaces are steel and of essentially similar chemical composition.

In construction specifications it is considered advisable to permit the contractor the option of either painting or not painting such contacting surfaces. To illustrate the desirability of such an option, consider first steel which is to be in atmospheric exposure, i.e., that which will not be blast cleaned and which will receive a shop coat at the fabricator's plant. If the contacting surfaces are specified to be unpainted the fabricator would have to locate and mask off the contact surfaces which would be formed in the field or if the entire surfaces were shop coated the contractor would have to remove the paint from the contacting surfaces prior to erection. On the other hand consider steel which is to be in submerged exposure, i.e., that which will be shipped to the construction site without paint and erected prior to painting. If painting of the contacting surfaces were required in this case, the contractor would have to

locate and paint the contact areas before erection — a very troublesome and time consuming operation. Where an electrical potential is apt to exist between metal surfaces of unlike chemical composition in riveted or bolted contact, each of the contacting surfaces should be cleaned, pretreated and given one coat of primer, all as prescribed for the particular metals involved. Where a nonmetal surface is to be in bolted or riveted contact with a metal surface, the contacting surface of the metal should be cleaned, pretreated and given three coats of the prescribed primer or the complete paint system otherwise specified.

1-48. DRYING TIME OF PAINT COATINGS PRIOR TO IMMERSION

Surfaces to be in underwater service which have been painted with phenolic type paints (those formulations designated in the schedule with a number preceded by a "P," and also paint conforming to Fed. Spec. TT-P-86a, type IV) should not be immersed until the last coat has dried for several days. Even in good drying weather this final drying period should be not less than 5 days and it should be increased to a minimum of 9 or 10 days during poor drying weather. Paint systems based on vinyl type coatings (those formulations designated in the schedule by a number preceded by a "V") may be immersed after a minimum of 48 hours of drying for the last coat. It is pointed out that even after these minimum drying times have been observed the phenolic and vinyl coatings will by no means have reached their maximum or full hardness. The time required for the coatings to reach full hardness is further increased by the fact that they are applied in four coats to a fairly thick film. Therefore, the drying periods for the last coat of completed phenolic and vinyl films should always be extended to the fullest extent practicable prior to immersion. It should be noted also, that immersion in water of these films prior to reaching maximum hardness does not appear in itself to have a deleterious effect on their intrinsic durability. However, the soft films are very susceptible to mechanical damage if the water is moving at considerable velocity and carrying suspended material or floating debris. For this reason, where time is an important element, coated surfaces may be immersed in quiet water after a somewhat shorter final drying time than when the immersing environment involves abrasion.

The other class of organic coatings shown in the schedule for immersed surfaces, i.e., cold- and hot-applied coal tar materials, differ widely in drying requirements. The cold-applied coal tar system is applied as a very heavy film in multiple coats. The completed system, even under good drying conditions, takes weeks to harden fully and at best, does not have outstanding abrasion resistance. It logically follows then that cold-applied coatings are best adapted to immersion in quiet, nonabrasive waters. On the other hand, surfaces coated with hot-applied coal tar enamel could be immersed at once, since the enamel sets to almost full hardness as soon as it has been applied and cooled. Since coal tar coatings are not outstandingly durable in atmospheric exposure, surfaces coated therewith should not be permitted to stand indefinitely out of doors. For example, it is not considered good practice to coat structural components with coal tar materials and leave them exposed for several months prior to erection.

1-49. COVERAGE AND FILM THICKNESS

Coverage and film thickness requirements are covered in the schedule or in those sections of the manual dealing with specific types of paint systems. The importance of adhering to the prescribed requirements with respect to coverage and film thickness is obvious, since it is generally true, within reasonable limits imposed by the nature of the paint used, that the thicker the coating the greater will be the protective life of the applied system. If the total cost of mobilization, surface preparation, and paint application are considered, the short-sightedness of skimping on number of coats and coverage will be quite evident. A word should be said, however, concerning the fact that paint coatings can be applied too heavily. In the first place, there are some paints which appear to perform better at relatively low

thickness than when applied more heavily. Moreover, it is possible in long years of maintenance painting where the old paint is not removed, to build up a very heavy film which may crack and flake off as a result of stresses set up within the heavy film. These exceptions, however, should not invalidate the general concept that greater film thickness means longer protection. Prescribed coverage (or spreading) rates in square feet per gallon of the phenolic paints and the suggested spreading rates of the vinyl type formulations for metal surfaces are based on spray application, but take into account only normal losses in application. On windy days, the loss of paint into the air, particularly in the case of vinyl formulations, may be very appreciable and allowance should be made for this loss. Spray applications to irregular, complex surfaces and narrow members will also result in abnormal overspray losses.

In the painting of ferrous metal surfaces, a convenient way to check dry film thickness is through the use of an instrument such as the General Electric, type B, film thickness gage which can measure the thickness of a nonmagnetic coating when applied to a magnetic substrate. The instrument does not deleteriously affect the coating in any way. It is more accurate on smooth surfaces than rough and is more accurate at ranges above 1 mil than below. In general its accuracy is about plus or minus 10 percent provided the instrument is properly calibrated and used in accordance with the manufacturer's instructions. A small pocket size thickness gage called the Elcometer, available from Henry A. Gardner Laboratory, Bethesda, Md., is convenient for field use but its dependability and accuracy are not considered to be of as high an order as the GE gage. The use of instruments of the type described is very simple but certain precautions need to be exercised if misleading results are to be avoided. The instrument should be calibrated with a standard which is approximately the same thickness as the coating to be measured and, if possible, on metal identical both in composition and surface texture to that underlying the coating. Calibration consists simply of placing a standard of known thickness on a bare metal surface and adjusting the instrument till it reads the correct thickness. On a smooth machined surface, the instrument should also read zero when the standard is removed as the gage contacts the surface. The user must be careful that the gage head does not indent the coating being measured, thus giving readings which are lower than actual. The thickness measurements of films on relatively rough surfaces (such as are obtained by blast cleaning) may be very misleading.

Even with coating thicknesses of several mils, the instrument may not read accurately if the base metal is roughened by blast coating. However, if the instrument is calibrated on blasted or rough surfaces identical to the base metal being painted, the results should be reasonably accurate. It should be pointed out that on such surfaces the thickness of the paint films varies between the peaks and valleys. If the instrument is calibrated on a blast cleaned surface, the test measurements subsequently obtained will generally be the thickness of coating *above the average high points of the blast pattern* and will not be the same as the reading which would have been obtained if the same amount of liquid paint had been applied to a smooth, nonblasted surface. The actual thickness over some of the highest peaks may be much less than is read on the instrument.

The instrument should not be used to check the thickness of coating nearer than one-half inch from an edge, on sharp interior angles, or on rough pitted or welded surfaces. Enough measurements should be made to enable the observer to determine the general uniformity of thickness of the coating and to determine whether the minimum and maximum thickness prescribed have been complied with. Since a measurement takes only a brief interval once the instrument is set up, there is no reason why hundreds of measurements on a single component cannot be made. It should be noted that ordinary red rust underlying a paint film is nonmagnetic and will be included in the coating thickness unless the calibration method takes the rust layer into account. On the other hand, mill scale is generally magnetic and will not be included in the coating thickness, although it may effect the zero point of the instrument.

In such cases, a reading may be made and the paint cut away to expose the metal: a new reading is made and the difference in the thickness determined. The observer should always be aware that if the use of the instrument deviates from the manufacturer's instructions there is an opportunity for error. In *any doubtful cases* the measurements obtained should be verified by another method such as scraping away the coating to the underlying base and checking with a micrometer depth gage. Even when inaccuracy exists for one reason or another, the instrument may possibly be used to advantage if a correction curve is made which takes into account the extent of the deviation between actual and measured thicknesses.

1–50. STORAGE OF PAINTS

The storage characteristics of paints and other coating materials vary widely, as might be expected. One of the more common forms of deterioration during storage is settling of pigment to the bottom of the container. If the settled pigment can be redispersed with relative ease, no serious harm is done. However, if the settled pigment forms a hard cake which cannot be redispersed by ordinary stirring methods, the harmful effect is obvious. The paints discussed in the manual can, in general, be stored for six months to a year without excessive settling, except that the Vinyl Type Wash Coat Base Solution and the V–101 vinyl red lead paint may settle objectionably after a few months. The commonly recommended practice of periodically turning containers may be helpful in preventing pigment settlement although it is more common as a recommendation than as an actual practice. If carried out, the containers should be turned by laying them on their sides and rotated 180°, since periodic storage in the upside down position may lead to settled pigment on the inside surface of the lid which is quite objectionable to users.

Thickening of paints because of chemical reactions between certain of the constituents is another form of deterioration during extended storage. In general, the paints discussed in the manual should not deteriorate in this manner for a year, although faulty processing methods and improper selection of raw materials may introduce unexpectedly rapid deterioration. Stored paints which show even minor thickening should be issued and applied as quickly as practicable, since the condition may worsen to the point of making the paint unusable. Increases in viscosity as a result of storage at low temperature are temporary only and should not be confused with viscosity increases resulting from reaction processes. Paints, particularly those which have a tendency to deteriorate as a result of chemical reactions, should be stored in a cool rather than a warm place.

Storage of paints in unheated warehouses subject to temperatures as low as zero Fahrenheit is, in most cases, not harmful except for an increase in viscosity which can be corrected by removal to a heated space, a few days before application. The effect of low temperature storage on certain vinyl type paints was discussed in paragraph 1–17*b*(5) together with corrective measures. In general, water thinned, emulsion-type paints should not be stored in warehouses where freezing temperatures are likely to prevail. Some of the modern resin emulsion paints will withstand a limited number of freezing and thawing cycles without the material itself being ruined, although the container might be ruptured during freezing. Paints may be generally stored outside temporarily but should be sheltered by canvas to protect containers from direct rays of the sun and prevent deterioration of labels.

As a general rule, paints should not be purchased more than six months in advance of their anticipated use. Storage practice should include provisions to issue the oldest paints first. Cognizance should be taken of the combustible nature of paint materials in complying with safety requirements. Paint storage space should consist of a separate building or room and should be well ventilated to relieve possible concentration of solvent vapors. Care should be taken to insure that all stored material is properly identified and that identifying marks will still be affixed and legible at the time the material is used.

1–51. SAND REINFORCEMENT OF PAINT COATS FOR UNDERWATER STEEL SURFACES

The practice of including sand in the coating system was started in some districts of the Corps of Engineers approximately 15 years ago. A large amount of experimental work has subsequently been done. It included embedding the sand in the first prime coat, in the second prime coat, varying the amount of sand embedded, changing the vehicle characteristics, varying the pigment-vehicle ratio of the paints used with sand reinforcement, varying the quantity of paint applied, and changing the type and gradation of the sand. The value of sand reinforcement in materially increasing the durability of phenolic type paint subject to immersion and abrasion has been well substantiated by this test work and extensive field experience. Not only is abrasion resistance of the coatings improved, but the tendency of the coatings to blister in prolonged water immersion is markedly decreased by sand reinforcement. Details of the sand reinforcing procedure are included in the section of the manual devoted to the painting of ferrous metal surfaces, paragraph 1–17*a*(4).

1–52. INSPECTION OF PAINT APPLICATION AND COATED SURFACES

On construction projects the majority of work on the preparation of metal surfaces and application of coatings normally occurs near the end of the construction period. The general contractor is looking towards the commencement of a new project elsewhere and many of the Corps of Engineer's inspection personnel have moved on to other work. Under these circumstances, it is quite likely that the painting work will be neglected. The employees assigned to the inspection of this work are very often not given any training and are not made to feel the importance of their work. Consequently, many failures of protective coatings can be attributed to unsatisfactory inspection and supervision. Employees are trained for inspection work on concrete, soils, steel erection, and other phases of construction, but the training of inspectors for painting work has been omitted in too many instances. The painting inspector should have an adequate knowledge of the painting materials with which he is required to work. He should know what constitutes an acceptable cleaning and protective coating job. It is important, obviously, that he be conscientious and energetic and be able to recognize inadequacies in equipment, materials, and methods. Employees with education and experience necssary to meet these general qualifications will not be available in many offices and resort must be made to a training course, including actual field experience of a week or more, to develop the inspectors needed. At least one district has found it profitable to train its resident lockmasters as inspectors for maintenance painting. Since the lockmasters will have to live for a long time with the paint coatings applied, close inspection and resultant high quality work are usually obtained.

Although visual observation is the most important part of paint inspection, it is advisable to furnish the inspector with a few mechanical aids. These tools include suitable thermometers for measuring the air temperature as well as the temperature of metal surfaces and paint materials; a psychrometer for measuring relative humidity; a simple cup type viscosimeter to insure that thinning of paints is not excessive; and a dry film thickness gage to insure that films of adequate and uniform thickness are obtained. For some inspection work, particularly Military equipment painting, a 60° glossmeter will be useful. If facilities for laboratory testing are available, it is considered good practice to occasionally take a sample of paint from the painter's spray tank or paint pot and determine the pigment-vehicle ratio and total nonvolatile content, especially if the material is suspect.

The inspector must keep complete records of painting operations. Recorded daily information concerning the paint used, number of coats, coverage, weather conditions, surface preparation, and other variable factors, are indispensable if the value of the coating is to be assessed in succeeding years. Permanent painting records for any major painting work on

Civil Works projects should be kept on the Paint Service Record, ENG Form 144 (see Civil Works Engineer Bulletin 55–12).

For a more complete discussion of paint inspection practices reference is made to chapter 5, volume 1 of the Steel Structures Painting Manual, available from The Steel Structures Painting Council, 4400 Fifth Avenue, Pittsburgh 13, Pa.

1–53. SAFETY MEASURES FOR PAINTING OPERATIONS

The materials and methods described in the manual require few safety precautions other than those normally found necessary for painting operations and construction work. As is true for handling any materials, it is necessary to recognize the inherent hazards involved and exercise suitable precautions against accident. In painting work, the following hazards are commonly present; (1) falls from scaffolds and ladders; (2) poisoning from toxic paint materials; (3) fires from inflammable volatiles; (4) carbon monoxide poisoning from engine exhaust gases; (5) silicosis from blast cleaning dust; (6) temporary illness resulting from high concentrations of vapors from solvents and thinners; and (7) burns from handling hot-applied coal tar enamel.

On large scale field painting work, it is generally necessary that the blast nozzle operators wear gloves and air-fed hoods, and other workmen in the vicinity wear respirators and goggles. Painters, and particularly those using spray equipment should wear air-fed respirators where conditions are such that it is not practical to provide good ventilation. A carbon monoxide alarm device should be included in the air lines feeding the air-fed hoods and respirators whenever internal combustion engines are used on the job.

It should be noted that the solvents and/or thinners used in vinyl paints are highly volatile and have a flash point lower than normal ambient painting temperatures. With respect to volatile, flammable solvents it is pointed out that the flash point of a solvent is determined by a standard laboratory test and furnishes an approximate indication of the critical ambient temperature, below which working conditions may, with reservations, be considered safe from explosions and above which working conditions must be considered unsafe. In actual practice the safe ambient temperature should be considered to be considerably below the flash point since barometric changes and temperature changes may rather quickly change a safe condition to an unsafe one. Moreover, in inclosed spaces artificial lights and other equipment may locally raise the surface and ambient temperature beyond the danger point. It is generally recognized that a certain minimum concentration of solvent vapor must be present in the air before a flash fire or explosion can take place; however, it is not so well known that, with most solvents, if the vapor concentration exceeds a certain amount an explosion can not occur. For example, the commonly used solvent, mineral spirits has lower and upper explosive limits of about 1 percent and 6 percent, respectively, by volume in the air. Many of the other common solvents such as xylene, toluene and coal tar naphtha have explosive limits of this same general magnitude. Operating personnel should be well aware that the solvents with low flash points are generally those which volatilize most easily and therefore are most likely to bring about high vapor concentrations in inclosed spaces. They should also be aware that one spray gun putting out a pint to a quart of fluid paint per minute will bring about a greater concentration of solvent vapors in the air of an inclosed space than a dozen or more brush painters, and that every gallon of liquid solvent in the paint furnishes 100 or more gallons of potentially dangerous gas, or vapor. In the painting of exterior surfaces the danger of building up explosive concentrations of vapor except in small, local areas (e.g., in the immediate vicinity of a spray nozzle) is considered nil. However, when interior surfaces of inclosed spaces are to be painted immediate consideration should be given to safety. Although steps to prevent sparks and other sources of ignition by using nonsparking tools, explosion proof fixtures, etc., are encouraged by supplemental safety

measures *the primary safeguard against flash fires and explosions must be the maintenance of vapor concentrations below the danger point by means of adequate ventilation.* If vinyl paints and other low flash point materials are to be applied in confined spaces by spray methods adequate ventilation, approved by a qualified ventilating engineer, must be provided and the adequacy of the ventilating system should be checked both initially and periodically by means of an instrument such as the "Explosimeter," manufactured by the Mine Safety Appliance Company. Particular care must be exercised to insure that all portions of the space to be ventilated are included in the moving air stream. Ventilation must be carried on not only during paint application but also must be continued until the paint film has lost most of the solvent through evaporation, i.e., dried to touch.

The odor characteristic of the Vinyl Type Wash Coat, and to a lesser extent of other vinyl paints, may be found to be penetrating and disagreeable in poorly ventilated locations. The vapors from these materials are not poisonous, in the ordinary sense, but, like most solvent vapors in high concentrations, can cause hydrocarbon intoxications with temporary impairment of muscular control, dizziness and other discomforts. Even where concentrations as low as 100 parts per million are present in the air, these solvents can be a health hazard if they are breathed over extended periods of time. In any cases of doubt air-fed respirators should be used. It is also worth mentioning that the vapors from hot-applied coal-tar enamel are strongly irritant to the skin of workmen. Suitable salves and creams should be used to cover the skin prior to commencement of work with the enamel.

It is frequently desirable in cold weather to warm containers of paint prior to using. In such cases the paint should be in original, unopened containers during warming operations. Warming should not be done with any kind of open flame. Instead the containers and contents should be brought up to the desired temperature by placing them a day or two prior to use in a space heated by hot air, steam or hot water. Also, the paint may be safely heated by partially immersing the containers in warm water, maintained at a temperature not exceeding 150° to 160° F.

The Safety Requirements Handbook, Office, Chief of Engineers, War Department Technical Manual 5–618, Painting; Repairs and Utilities, October, 1946, and Civil Works Engineer Bulletin 55–6, 10 May 1955, furnish additional information on safety precautions which should be taken on painting work. In addition to the information to be obtained from these sources, the safety program shown below is included as an example of a plan which was put into effect on hired labor painting units operating from floating plant while painting the steelwork of hydraulic structures of navigation projects on the Mississippi River.

a. **Training.** All personnel were given physical examinations stressing their capability to perform work of an arduous nature. Chest X-rays of all paint crews employees were taken on the date of starting employment and again upon completion of the season. Interpretive notes of each X-ray by qualified physicians were made a part of each employee's 201 file. Prior to doing the first productive day's work at each of the paint jobs, the foreman in charge of the unit conducted a safety meeting to impress upon the crew (a large percentage of which were new men) the need for alertness against fire, falling, drowning, gassing, and silicosis hazards. The signal system for fire and man-overboard drills was explained and the station for each member of the crew was designated. Drills were conducted as a windup of the safety meeting and were repeated at least once each month thereafter, without benefit of briefing beforehand. Safety meetings were held twice each month with emphasis, in the discussion, on crew members' suggestions for safer and more efficient operation of the units.

b. **Protective equipment and apparel.** The programs included the following requirements relative to protective equipment and apparel. When phenolic type paints were being sprayed, the painter was required to wear a sponge-type respirator. When vinyl type paints

were being applied, the painter used an air-fed respirator. The air was supplied by a compressor to air-fed respirators through a Mine Safety Appliance Company combination filter and air pressure regulator which filtered the air and reduced the pressure from approximately 100 to 14 pounds. Adequate walkways with handrail on both sides were provided between pier noses and barges to permit safe and efficient movement of personnel boarding or leaving the units. All personnel were required to wear life jackets except when working in areas inclosed with handrail, safety chain, or when the side of the barge from which work was being performed was lying against a pier face or a tainter or roller gate. The sandblast barge was secured to the piers and bulkheads by a sufficient number of lines to preclude any upstream, downstream, or outward movement which would permit a workman to become caught between the barge and the pier or gate. All personnel were required to wear air-fed sandblast hoods, gloves, and heavy clothing while they were sandblasting. All other members of the crew were required to wear sponge type respirators and goggles when they were working in the general area of sandblasting. During sandblasting operations on roller gates, safety lines were tied from one end of the gate to the other for topside blasting. The sandblast nozzlemen were secured to the safety lines by means of a safety belt and line. Nozzlemen were required to use safety belts while sandblasting underneath the aprons of roller gates.

c. **Painting from swinging platform.** For painting from a platform suspended from a crane, the following procedure was used. With a signalman standing in a position where he could see both the crane operator and the service platform, the painters and their equipment were placed on a platform at the downstream nose of the pier. The platform was swung in toward one end of the gate and checked by the painters with snubbing lines secured to the gate arms. The crane then traveled from one end of the gate to the other and the platform raised approximately 6 feet with each change in direction.

d. **Medical facilities, sanitation, and health.** One 16-unit first aid kit was available on the sandblast barge and another in the office of the unit. Both paint crew and lock supervisory personnel were qualified to administer first aid. Blankets and stretchers were provided. One truck was kept on the job during working hours and was available in the event of an emergency. Names and addresses of designated physicians and the names and locations of hospitals nearest the job sites were posted at each first-aid kit. Adequate toilet and shower facilities with water-carriage disposal systems were provided on the barge. Paper cups and salt tablet dispenser were placed adjacent to each drinking fountain.

e. **Fire protection.** Smoking was forbidden in areas where paint was stored or in areas where paint was being sprayed. The paint storage bunker was equipped with built-in CO_2 fire extinguisher system and adequate ventilation. The paint units were equipped with fire pumps with capacity of 100 gpm at 100-foot head. Carbon dioxide and Pyrene extinguishers were located in the engine room, the locker room, the sandblasters' and painters' storage supply rooms, and in the office.

f. **General comments.** Causes of accidents and measures to prevent their occurrence were discussed at semi-monthly safety meetings of each paint unit. All supervisory employees completed refresher studies in Corps of Engineers' safety regulations prior to placing the units into operation and were required to attain a thorough understanding of their responsibilities in effectively carrying out the safety program.

PAINTING SCHEDULE

1–54. PAINT SCHEDULE FOR STRUCTURES OF CORPS OF ENGINEERS

a. **General.** The form in which the following painting schedule appears is essentially the same as in the Guide Specification CE–1409, modified as necessary to suit the purpose and format of this manual. The coatings specified for various surfaces and exposure con-

ditions are not necessarily the only ones which could be used, but they represent a class or type on which a large amount of satisfactory performance data has been collected. In using the schedule, it will be necessary to refer to the subsequent section on paint formulations for detailed data concerning certain of the paints prescribed. Also, in a following section is listed the full title of Federal, Military, and other standard specifications for materials mentioned in the schedule and elsewhere in the manual. The reader should also refer to the preceding paragraphs which discuss in greater detail the surface preparation and coating systems for specific surfaces and exposure conditions. In many instances, the schedule will list more than one system for a particular surface and exposure condition. The directions and remarks in the schedule and the text will often give some guidance for the selection of one of the alternate systems. If such guidance is not given, the reader's selection may be governed by his own preference.

b. **Colors and Tints.** It should be noted that in the case of formulations in which the type and amount of pigment is definitely fixed, the paint manufacturer is *limited* in the latitude of shades and colors which can be obtained. Those formulations covered by Federal Specifications which in the title contain the clause "white and tints" or a similar phrase, may be tinted to obtain various shades of gray, ivory, buff, light green, etc. Such specifications should not be used where dark shades or deep colors are desired. On the other hand, where Federal Specifications for mixed paints do not specify the type of pigment to be used and do not specifically mention the color in the title, almost any color may be procured under the specification. Insofar as possible, colors should be designated by making use of Fed. Spec. TT-C-595, "Colors for Ready Mixed Paint."

c. **Painting Schedule (Exterior and Interior Surfaces).**

(1) *Exterior Ferrous Surfaces Subject to Atmospheric Exposures*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Exterior ferrous surfaces subject only to normal atmospheric exposure, as follows: (bridges, light standards, corner wall protection and other weather-exposed structural steel surfaces.)	Solvent cleaning, scraping, and power wire brush (or equivalent); no pretreatment.	Fed. Spec. TT-P-86a, Type I.	P-2	P-2	None.
		Fed. Spec. TT-P-86a, Type I.	P-3	P-3	None.
		Fed. Spec. TT-P-86a, Type I.	P-9	P-9	None.

Directions and Remarks: In the above systems, intended as alternates, the first coat should be brush-applied in the shop as soon as possible after fabrication of the metal and touched up as required in the field. Exterior ferrous surfaces are intended to include all structural steel exposed to the atmosphere except that inclosed within weathertight structures. Apply priming coat by brushing at a coverage rate of not more than 600 square feet per gallon and second and third coats at a coverage rate not greater than 500 square feet per gallon. See paragraphs 1–12 and 1–16 for more detailed information on the surface preparation and painting of exterior atmospheric exposed steel.

(2) *Ferrous Surfaces Subject to Immersion (Phenolic System) (Alternate 1)*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Exterior and interior surfaces of ferrous components which are in whole or in part subject for extended periods of time to moisture condensation or immersion and abrasion in fresh water, as follows: (crest gates, roller gates, miter gates, sluice gates, tainter valves, trash racks, stoplogs, interior surfaces of water tanks and surge tanks, exposed structural steel in pumping stations below pump room floor, etc.)	Blast clean and treat with Mil. Spec. MIL-C-15328A Vinyl Type Wash Coat or MIL-M-10578A, Type II chemical metal conditioner.	P–4	P–4	P–2	P–2
		*P–5	*P–5	*P–5	*P–5
		P–7	P–7	P–7	P–7
		P–6	P–6	P–6	P–6
		Fed. Spec. TT–P–86a, Type IV	Fed. Spec. TT–P–86a, Type IV	Fed. Spec. TT–P–86a, Type IV	Fed. Spec. TT–P–86a, Type IV.

*Recommended for interior of potable water tanks.

Directions and Remarks: In the above phenolic type systems, intended as alternates, all coats (except for pretreatment) may be brush or spray applied. *Blast cleaning and painting should normally be done in the field* (see par. 1–12*c* for discussion). Entire areas of structural components should generally be treated as though subject to immersion even though a part of area will be in atmospheric exposure. When conditions warrant, such surfaces as the downstream portions of tainter gates, if not subject to immersion, may be cleaned and painted as specified for atmospheric exposed steel. At least one day of drying between field coats should be permitted, but prolonged periods which would produce a very hard surface, harmful to intercoat adhesion, should be avoided. Paint formulas P–5 and P–7 dry quickly to form very hard films, and undercoats should, therefore, be recoated as soon as possible after they have dried to a firm film, in order to avoid possible adhesion difficulties; in very warm weather, the drying period for formulas P–5 and P–7 should be limited to a maximum of 8 hours. Paints should be applied at a coverage rate of approximately 500 square feet per gallon to give a total dry film thickness of at least 6 mils for the 4-coat system. The paint systems shown above are intended to offer a fairly large group from which one or more may be selected. Either of the pretreatment methods may be used in conjunction with the above paint systems but the Vinyl Type Wash Coat is generally to be preferred. See paragraphs 1–17*a* and 1–13 for more detailed information on the selection and application of phenolic type coatings and pretreatment materials. See paragraph 1–22 for a discussion relative to the painting of underwater steel surfaces of floating plant operating in fresh water. Any of the above phenolic systems may be sand reinforced for greater abrasion resistance (see par. 1–17*a*(4)).

(2) *Ferrous Surfaces Subject to Immersion (Vinyl System) (Alternate 2)*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Exterior and interior surfaces of ferrous components which are in whole or in part subject for extended periods of time to moisture condensation or immersion and abrasion in fresh water, as follows: (crest gates, roller gates, miter gates, sluice gates, tainter valves, trash racks, stoplogs, interior surfaces of water tanks and surge tanks, exposed structural steel in pumping stations below pump room floor, exterior surfaces of penstocks in tunnels, etc.)	Blast clean and treat with Vinyl-Type Wash Coat (Mil. Spec. MIL-C-15328A).	V–101 Double-spray coat.	V–101 Double-spray coat.	V–102 Double-spray coat.	V–102 Double-spray coat.

Directions and Remarks: The above vinyl type system is to be spray-applied only to an average thickness of at least 5.5 mils for the completed system and the minimum thickness at any point should be not less than 5.0 mils. At least 3.5 mils of the total thickness should be built up before applying the first coat of V–102 finish paint. Additional coats shall be used, if necessary, to obtain the required thickness. It is recommended that the total film thickness of the vinyl system be increased to an average of 7.0 mils by interposing one or more additional coats of V–101 red lead paint in those cases where: (1) Surfaces are accessible only with difficulty and at great expense; (2) surfaces are subject to considerable erosion and abrasion as a result of being exposed to rapidly moving water carrying debris, ice, and suspended material; (3) where waters are considered to be more than ordinarily corrosive as the result of industrial contamination, low pH high dissolved solids content, etc. Entire areas of structural components should generally be treated as though subject to immersion even though part of area will be in atmospheric exposure, although when conditions warrant such surfaces as the downstream portions of tainter gates, if not subject to immersion, may be cleaned and painted as specified for atmospheric exposed steel. This system is intended as an alternate to the phenolic type systems shown in the preceding subparagraph. In general, if selection of a coating for immersed steel surfaces cannot be made on the basis of specific past experience, the vinyl system is to be preferred to the phenolic systems. See paragraph 1–17*b* for more detailed information concerning vinyl type coatings, and paragraphs 1–53 for safety information.

(3) *Ferrous Surfaces Subject to Immersion, Protected From Abrasion and Sunlight*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Ferrous surfaces subject to immersion in fresh water, protected from abrasion and from extended exposure in sunlight, as follows: (interiors of submergible gates, interior ferrous surfaces in galleries where moisture condensation is severe, exterior of underground tanks, short runs of underground pipe, exposed structural steel and equipment below pump room floor in small pumping stations; small slide gates and flapgates in drainage systems).	Blast clean. No pretreatment.	Cold-applied coal tar base paint.	Same as first.	Same as first.	None, unless needed to build up prescribed total film thickness.

Directions and Remarks: Materials should conform to Military Spec. MIL–C–18480 (Docks) for: Coating Compound, Bituminous, Solvent, Coal Tar Base. A special primer should be used only if/as recommended by the manufacturer of the coating. Apply heavily by brush, at a coverage rate of not more than 100 sq. ft./gal. to give a total film thickness in three coats (or more if necessary) of one thirty-second of an inch. Brush each coat at right angles to strokes of preceding coat. Spray application may be permissible, provided results equivalent to brushing are produced and provided special spray equipment suitable for handling the viscous material is employed. Drying time between coats should be as recommended by manufacturer of coating. The above system should not be used where anticipated temperatures are outside the range of —10° to +140° F. Cold applied coal tar paints are considered to be far less durable in submerged exposure than hot-applied coal tar enamel and much less adaptable to a variety of exposure conditions than vinyl or phenolic type paints. Once applied, this type of coating is difficult to remove. See paragraph 1–18 for further information on cold-applied coal tar coatings, including surface preparation.

(4) *Ferrous Surfaces Subject to Continuous Immersion or Underground Exposure*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Ferrous surfaces subject to abrasion, continuous fresh water immersion, and/or otherwise protected from sunlight and excessive temperatures, as follows: (interior steel surfaces of penstocks, spiral cases, draft tube liners, large diameter steel water pipe; exterior surfaces of pipe where immersed or buried; inside of buoyancy chambers; exterior of buried tanks, etc.)	Blast clean. No pretreatment.	Coal tar enamel primer.	Hot-applied coal tar enamel.	None.	None.

Directions and Remarks: Materials, test procedures, and methods of application should be in accordance with the following indicated sections of the AWWA Spec. C203–51 for "Coal Tar Enamel Protective Coatings for Steel Water Pipe (sizes 30-inch and over)." Coal tar primer and enamel should be supplied by the same manufacturer and should conform to sections 5–2.1 and 5–2.2 respectively, as determined by the test procedures described in section 5–2.4. The penetration of the enamel as furnished should be 15 to 20 at 77° F. Samples and detailed application instructions should be supplied by the contractor in accordance with section 5–2.3. Preparation of surfaces should be in accordance with section 5–3.2 except that removal of oil, grease, and other foreign matter by solvents or mechanical means, prior to blast cleaning, need not be required, provided that blasting alone accomplishes the complete removal of *all* scale, rust, oil, grease, and other surface contaminant. Blast cleaning should thoroughly etch the surface, and render it suitable for firm adhesion of the coating. Priming, heating, and application of enamel, inspection and care of coating should be in accordance with sections 5–1.8, 5–1.9, 5–3.3, 5–3.5, 5–3.6.1, 5–3.6.4, 5–3.10.1, 5–3.12, 5–3.13, 5–3.14, 5–4.2.4, and any other applicable portions of the AWWA specification. *Primed surfaces which have not received enamel within the maximum drying period stipulated by the manufacturer should be reprimed in accordance with section 5–3.3.6 of the AWWA specifications, except that if any rust is in evidence or if more than two weeks elapse after application of the original primer, it should be removed by blasting prior to repriming.* The total thickness of the primer and enamel should be $\frac{1}{32}$-inch, plus or minus $\frac{1}{32}$-inch. Enamel should not be applied to metal of a temperature less than 45° F. The penetration (at 77° F.) of the applied enamel, as indicated by tests on samples taken from the last of the enamel in a kettle batch, should be not more than 6 penetration units lower than the original penetration value. Heating kettle for large jobs should be provided with thermostatic controls capable of automatically controlling the temperatures of the enamel at the desired level; a built-in stirrer which will permit agitation of the enamel without lifting the cover; and a recording type thermometer capable of making a continuous, permanent time-temperature record. Thermostatic control of heating may be waived if a competent kettleman is in constant attendance. Heating kettles, if placed anywhere except in a completely unrestricted outdoor location, should be positively vented by means of a forced ventilating system. The general working area, if in-

doors should be ventilated to the extent necessary to provide safe working conditions. Hand enameling should be done by men specifically experienced in the application of coal tar enamel. The bond of the enamel on the actual structure being coated should be such that, after 24 hours or more of curing, there is no evidence of peeling, stripping, or lifting when the coating is gradually raised to a temperature between 80° and 160° F. (by heat lamps or other means) and subjected to the peel test described in section 5–2.4.4(5) (a) of the AWWA specifications. Surfaces which are adaptable to application of coal tar enamel only by hand application methods should be cleaned and coated in the field rather than in the shop, and, insofar as practicable, all work should be performed after erection of the structural components. Where the shape and size of the surfaces permit the use of mechanical methods of application, as opposed to hand application, the components may be enamelled in the shop provided proper precautions are taken to prevent deterioration and damage of the coating during shipment, storage, and erection. See referenced AWWA specification and paragraph 1–19 herein for further information on hot-applied coal tar enamel. See paragraph 1–14*a* for a discussion of cleaning and painting of penstocks, spiral cases, surge tanks, etc.

(5) *Ferrous Surfaces Subject to Immersion in Sea Water*

Surface	Surface preparation and pretreatment	Paint formulas to be applied
Ferrous surfaces subject to immersion in sea water and fouling from sea water organisms.	Blast clean and treat with Vinyl Type Wash Coat Military Spec. MIL–C–15328A.	Four double-spray coats of Red Lead Vinyl Primer Mil. Spec. MIL–P–15929A and two double-spray coats of Vinyl Anti-Fouling paint MIL–P–15931A.

Directions and Remarks: The 4 double-spray coats of MIL–P–15929A primer should be applied heavily enough to total at least 7.0 mils (average) dry film thickness, including the wash coat, and additional coats shall be applied, if necessary, to obtain this thickness. The total thickness of the system after application of the antifouling coats shall be not less than 10 mils at any point. See paragraph 1–20*b* for additional information on this system and paragraph 1–17*b*(4) for information on application of vinyl paints.

(6) *Open Type (Subway) Grating*

Surface	Surface preparation and pretreatment	Paint formulas to be applied
Open type (subway) grating and similar surfaces (exterior or interior).	As required for galvanizing operations.	Hot dip galvanize after fabrication in accordance with ASTM Spec. A123–53 to give at least 2 ounces of zinc per square foot of actual metal surface.

Directions and Remarks: Galvanizing is considered to be the best means of protection for new subway grating which can be coated at the time of fabrication. Old, previously painted grating may also be galvanized if commercial facilities are available for stripping of paint films and galvanizing. In lieu of galvanizing any of the alternate phenolic or vinyl systems specified in paragraph 1–54*c*(2) of the schedule are satisfactory for grating except that the second coat may be omitted to give a 3-coat system. Blasting is considered the best means of cleaning, but in view of cost on such difficult surfaces, less expensive methods should be considered. The use of the chemical metal conditioner or Vinyl Type Wash Coat pretreatment is considered unnecessary in this exposure, except that the vinyl system consisting of V–101 primer and V–102 finish coats, if selected, requires the use of the vinyl wash coat treatment for purposes of obtaining adhesion. Apply pretreatment materials, if any, and paint by dipping. Paint should be thinned not more than necessary for satisfactory dipping consistency. After removal from the dipping pan the grating should be allowed to drain with

traffic bearing surfaces uppermost. Drips and runs should be brushed out after draining but before appreciable drying has taken place.

(7) *Ferrous Surfaces Subject to High Temperatures*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Exterior or interior metal surfaces subject to high temperatures as follows: (stacks, steam pipes, etc.)	Solvent cleaning and wire brush. No pretreatment.	TT–E–496 (*Type I) (*Type II).	Same as first.	None.	None.

Directions and Remarks: *Alternate types. Type II, in addition to being heat resistant, is also resistant to gasoline and water. Either of the two types are resistant to temperatures only of 400° F. maximum. Where higher temperatures are involved, the use of heat resistant paint conforming to Military Spec. MIL–P–20087 is suggested.

(8) *Exterior Woodwork*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Exterior woodwork on buildings, not otherwise specified.	Solvent cleaning, scraping, sandpapering as required.	Fed. Spec. TT–P–25a.	Fed. Spec. *TT–P–102 (Class A for white; Class B for tints) *TT–P–103 *TT–P–104.	Same as 2d.	None.

Directions and Remarks: *Alternates. When fume resistant paint, Fed. Spec. TT–P–103, is selected for use, it should be used for all three coats. See paragraph 1–32*b*(1). A system composed of two coats of Fed. Spec. TT–P–25*a* primer and one finish coat of Fed. Spec. TT–P–102 or TT–P–104 may be used in lieu of the systems shown in the schedule, consisting of one coat of primer and two coats of finish paint. See paragraphs 1–32*a* and 1–32*b* for detailed information on painting of exterior wood surfaces and selection of paints from the alternates. See also the "Notes" section in the rear of Fed. Specification TT–P–102, TT–P–103, and TT–P–104.

(9) *Exterior Wood Steps, Platforms, Floors*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Exterior painted wood as follows: (steps, platforms, floors of open porches, etc.)	Solvents, scraping and sandpapering as required.	Fed. Spec. TT–E–487.	Same as first.	None.	None.

Directions and Remarks: See paragraph 1–32*c* for further information on painting of wood surfaces of this type.

(10) *Exterior Cement-asbestos Board*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Exterior asbestos cement board.	Clean, remove stains.	Fed. Spec. TT–P–25a.	Fed. Spec. *TT–P–102 *TT–P–103 *TT–P–104.	None.	None.

Directions and Remarks: Cement-asbestos board does not require painting except from an appearance standpoint. The prescribed specification materials are the same as those indicated for exterior wood surfaces. See paragraphs 1–32*a* and 1–32*b* which discuss the characteristics of the alternately (*) specified materials.

(11) *Exterior Galvanized Surfaces*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Exterior galvanized metal surfaces.	Wash with solvents and treat with Vinyl Type Wash Coat (Mil. Spec. MIL–C–15328A).	Fed. Spec. TT–P–641b, Type II.	Same as first.	None.	None.

Directions and Remarks: Painting of galvanized surfaces is not generally required, although it may be desirable for additional protection or from an appearance standpoint. See paragraph 1–36 for additional information on the painting of galvanizing.

(12) *Exterior Aluminum and Aluminum Alloy Surfaces*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Exterior aluminum and aluminum alloy surfaces.	Wash with solvents and treat with Vinyl Type Wash Coat Mil. Spec. MIL–C–15328A.	P–4	P–4	P–2	None.

Directions and Remarks: At least 1 day of drying shall elapse between coats. See paragraph 1–37 for further information on painting of aluminum surfaces.

(13) *Exterior Concrete Block and Monolithic Concrete Surfaces (Alternate 1)*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Exterior concrete block and monolithic concrete surfaces (except concrete floors).	Remove foreign matter and loose particles and roughen glazed surfaces.	TT–P–24a, Type I or II as required.	Same as first.	None.	None.

Directions and Remarks: The paint for first coat shall be reduced with Fed. Spec.

TT–V–121c spar varnish in the proportion of 1 quart to a gallon of the base paint. New surfaces shall be permitted to dry at least 3 months prior to painting. See paragraph 1–38 for further information concerning the painting of concrete surfaces.

(13) *Exterior Concrete Block and Monolithic Concrete Surfaces (Alternate 2)*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Exterior concrete block and monolithic concrete surfaces (except floors).	Remove foreign matter and loose particles and roughen glazed surfaces.	Fed. Spec. TT–P–21, Type II, Class A or B.	Same as first.	None.	None.

Directions and Remarks: Use class A for fine textured surfaces and class B for open textured surfaces. Mix the cement-water paint with sufficient water to give a thick creamy consistency and allow to stand for 15 to 30 minutes. Remix prior to use and stir frequently during application. Dampen surfaces prior to paint application with fine water spray and allow water to penetrate a few minutes. Apply paint with stiff bristle brush and scrub thoroughly into surface voids. Cure the first coat 24 hours by means of fine water-spray, initiating curing as soon as paint is hardened sufficiently to resist damage. Allow free film of curing water to disappear. Apply second coat of paint and damp cure for 2 days with fine water spray. See paragraph 1–38 for further information on painting of concrete and masonry surfaces.

(14) *Interior Ferrous Surfaces*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Interior ferrous surfaces such as structural steel framing, roof trusses, etc.	Solvent cleaning and wire brush. No pretreatment.	Fed. Spec. TT–P–86a, Type I.	Same as first.	None.	None.

Directions and Remarks: The first coat shall be applied in the shop as soon as practicable after fabrication of the metal and its integrity maintained prior to field application of the second coat. Structural steel and miscellaneous ferrous surfaces in finished spaces shall, in lieu of the required second coat, be finish painted to match adjacent surfaces. Under favorable circumstances the paint system for interior steel surfaces may be limited to the single shop coat. See paragraph 1–16*b* for further information on the painting of interior ferrous surfaces.

(15) *Interior Galvanized Surfaces*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Interior galvanized surfaces.	Treat with Vinyl Type Wash Coat (Mil. Spec. MIL–C–15328A).	Same as for adjacent surfaces.			

Directions and Remarks: Interior galvanized surfaces will generally be painted for

appearance only. Once good adhesion to the galvanized surfaces is established by means of the vinyl wash coat, the surfaces can be coated with the same paints as are used on adjacent surfaces.

(16) *Machinery, Equipment, Piping Systems (Interior or Exterior)*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Permanently installed machinery. Equipment, steel and iron piping systems (interior or exterior atmospheric exposure).	Solvent cleaning and wire brush.	Fed. Spec. TT-P-86a, Type III.	Fed. Spec. TT-E-489b, Class A.	Same as 2d.	None.

Directions and Remarks: Finish coats shall be of color as selected. In lieu of the above system, new machinery and equipment may be coated in accordance with the manufacturer's standard practice. Exterior machinery may, for simplicity, be painted as prescribed in paragraph 1–54*c*(1) of the schedule for ferrous surfaces subject to normal atmospheric exposure. Piping systems for hydroelectric power stations shall be identified by means of printed adhesive markers in accordance with Civil Works Engineer Bulletin 56–3, 20 Feb. 1956, Guide for Identification of Piping Systems, Hydroelectric Power Stations. MIL–T–704B will govern the treatment and painting of equipment used in construction and engineering work. For military equipment, applicable military specifications will be used, since military requirements for metal preparation and painting are greatly different from above.

(17) *Interior Wood Surfaces (Painted)*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Interior painted wood surfaces except floors.	Remove foreign matter, sandpaper as required.	Fed. Spec. TT-E-543.	Fed. Spec. TT-E-543.	*Fed. Spec. TT-P-51d.	None.
		Fed. Spec. TT-E-543.	Fed. Spec. TT-E-543.	*Fed. Spec. TT-E-506c.	None.
		Fed. Spec. TT-E-543.	Fed. Spec. TT-E-543.	*Fed. Spec. TT-E-508.	None.

Directions and Remarks: *The above 3d coat alternate paints provide finished surfaces with varying degrees of gloss. See paragraph 1–33*a* for additional information. When only two coats are required or justified, omit one of the TT–E–543 coats. Undercoats should be tinted to the approximate color of the finish coat.

(18) *Interior Radiators, Heating Ducts*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Interior radiators, heating ducts, and similar miscellaneous ferrous items in finished spaces.	Remove foreign matter. Wire brush as required.	Fed. Spec. TT–P–51d.	Fed. Spec. TT–P–51d.	None.	None.
		Fed. Spec. TT–E–508.	Fed. Spec. TT–E–506c.	None.	None.
		Fed. Spec. TT–E–508.	Fed. Spec. TT–E–508.	None.	None.

Directions and Remarks: Color to match adjacent wall or ceiling surfaces. Undercoat should be tinted to approximate color of finish coat. On radiators, better radiation is obtained with a flat finish paint. Galvanized ductwork should be pre-treated with Vinyl Wash Coat (Mil. Spec. MIL–C–15328A) before applying first coat of paint.

(19) *Interior Wood Surfaces, Except Floors (Natural Finish)*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Interior wood surfaces, except floors (natural finish).	Clean and sandpaper as required.	Treat with Fed. Spec. TT–S–711a Stain, fill and seal as necessary.	Fed. Spec. TT–V–121c Varnish.	Fed. Spec. TT–V–121c Varnish.	Fed. Spec. TT–V–121c Varnish.

Directions and Remarks: Filling, Fed. Spec. TT–F–336a, after stain coat required only on open grain woods. Intermediate coats should be lightly sanded. See paragraph 1–33*b* for further information on this type of wood finish.

(20) *Interior Wood Floors (Painted)*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Interior wood floors (painted).	Clean and sandpaper as required.	Fed. Spec. TT–E–487.	Fed. Spec. TT–E–487.	None.	None.

Directions and Remarks: Reduce paint for first coat only, in the proportion of 1 pint to a gallon of base paint with mineral spirits conforming to Fed. Spec. TT–T–291a, Grade 1. Use unreduced paint for second coat. Generally, only softwood floors are painted in the above manner.

(21) *Interior Wood Floors (Natural Finish)*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Interior wood floors (natural finish).	Clean, sandpaper and fill as required.	Int. Fed. Spec. TT–S–176b Sealer.	Int. Fed. Spec. TT–S–176b Sealer.	Fed. Spec. P–W–155 Floor wax.	None.

Directions and Remarks: Open grain wood should be filled with Fed. Spec. TT–F–336a wood filler before application of sealer. Sealer should be class 1 or 2 as required by the type of wood. Each application of material should be followed by suitable wiping, buffing, and polishing operations to give a high quality finish. See paragraph 1–33*c*(2) for additional information.

(22) *Interior Walls (Alternate 1)*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Interior walls as follows: (plasterwork, gypsum board, concrete, concrete block, asbestos-cement board, composition wallboard, etc.)	As previously required for each type of surface.	Fed. Spec. TT–P–56b.	Fed. Spec. TT–E–543.	Fed. Spec. TT–P–51d.	None.
		Fed. Spec. TT–P–56b.	Fed. Spec. TT–E–543.	Fed. Spec. TT–E–506c.	None.
		Fed. Spec. TT–P–56b.	Fed. Spec. TT–E–543.	Fed. Spec. TT–E–508.	None.

Directions and Remarks: Use additional touch-up coats of Fed. Spec. TT–P–56b as necessary for complete sealing. Allow new concrete surfaces to dry and age at least 60 days before painting. New plaster surfaces may be painted after an ageing period of 30 to 60 days, depending on drying conditions. The alternate finish coats shown differ principally in the degree of gloss obtained. Finish coats of Fed. Spec. TT–P–51d give a flat texture, Fed. Spec. TT–E–508 a semigloss finish, and Fed. Spec. TT–E–506c gives a full gloss effect. The need for washability and other factors should be considered in selection of the type of finish. Wall and ceiling surfaces are generally coated with low-gloss paint except where high washability requirements point toward the use of semigloss or high gloss enamels. Where appearance requirements do not justify the use of a 3-coat system, the TT–E–543 undercoat may be omitted to make a 2-coat system. Where it is required to improve the fire rating of insulating fiberboard or acoustical tile used for interior finish, a paint conforming to Fed. Spec. TT–P–26a, may be used following the manufacturer's instructions and recommendations for coverage rates.

A system for interior walls and ceilings based on a water-thinned latex emulsion paint is shown in the following subparagraph.

(22) *Interior Walls (Alternate 2)*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Interior walls (plasterwork, gypsum board, concrete, concrete block, asbestos-cement board, composition wall-board, etc.).	As previously specified.	Fed. Spec. TT-P-29.	Fed. Spec. TT-P-29.	None.	None.

Directions and Remarks: All new concrete and concrete block surfaces shall be permitted to age at least 4 weeks and new plaster shall be permitted to age at least 2 weeks prior to painting with the above system. The above system is based on a water-thinned, latex emulsion type of paint which serves both as a primer-sealer and finish paint. The TT-P-29 paint furnishes a low-gloss finish which has good washability characteristics. The TT-P-29 paint may be applied over old oil or varnish-base paints provided the latter are of low gloss. Some light-colored latex paints of poor hiding power may require 3 coats, particularly where a high order of appearance is required.

(23) *Interior Concrete Floors (Alternate 1)*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Interior concrete floors.	Allow to age 90 days minimum.	Fed. Spec. TT-P-91a.	Fed. Spec. TT-P-91a.	Fed. Spec. TT-P-91a.	None.

Directions and Remarks: The above system consisting of successive coats of rubber-base paint is more suitable for floors which are subject to dampness than the following alternate. It should not be used, however, over other types of floor paint. Paint systems for concrete floors should not be applied to an excessive thickness. See paragraph 1-38 for further information on preparation and painting of concrete surfaces.

(23) *Interior Concrete Floors (Alternate 2)*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Interior concrete floors.	Allow to age 90 days minimum.	Fed. Spec. TT-E-487.	Fed. Spec. TT-E-487.	None.	None.

Directions and Remarks: The first coat only of Fed. Spec. TT-E-487 enamel should be thinned in the ratio of 1 quart per gallon of base paint with mineral spirits conforming to Fed. Spec. TT-T-291A, Grade I. The second coat should be applied without thinning. Paint systems for concrete floors should not be applied to an excessive thickness. See paragraph 1-38 for further information on painting of concrete.

(24) *Ferrous Surfaces Subject to Gasoline and Fuel Oil*

Surface	Surface preparation and pretreatment	Paint formulas to be applied			
		1st coat	2d coat	3d coat	4th coat
Ferrous surfaces subject to immersion in gasoline (including aviation gasoline) and fuel oil.	Blast clean only—no pretreatment.	MIL–L–2638B Type I, primer coat.	MIL–L–2638B Type II, body coat.	MIL–L–2638B Type III, seal coat.	None.

Directions and Remarks: The materials for the above vinyl type coating system should be supplied by one manufacturer. The first and third coats should be white and the intermediate coat should be gray in color to facilitate inspection of application. The vinyl lacquers should be thinned as necessary for application with a mixture containing equal volumes of methyl isobutyl ketone (Fed. Spec. TT–M–268) and normal butyl acetate (Fed. Spec. TT–B–838). The dry film thickness of the applied system should be not less than 4.0 mils at any point. Special application instructions by the manufacturer of the coating should be closely followed. See safety instructions, paragraph 1–53.

1–55. DESIGNATED TITLES OF FEDERAL SPECIFICATIONS AND OTHER STANDARD SPECIFICATIONS

The designated titles of Federal specifications and other standard specifications identified by number or abbreviated name in the painting schedule or elsewhere in the manual are listed below: *(Suffix letters to the numbers are shown where applicable to indicate more specifically what material was in mind when this manual was prepared. These specifications are the latest revisions only at the time of writing this manual and are, of course, subject to change at any time.)*

FEDERAL SPECIFICATIONS

Number	*Title*
P–W–155	Wax, Floor, Water-Emulsion, Slip Resistant
TT–A–468a	Aluminum-Pigment; Powder and Paste for Paint
TT–B–838	Butyl Acetate; Normal (for use in organic coatings)
TT–B–846	Butyl Alcohol; Normal (for use in organic coatings)
TT–C–595	Colors (for) Ready-Mixed paints
TT–E–487	Enamel; Floor and Deck
TT–E–489b	Enamel; Gloss, Synthetic (for exterior and interior surfaces)
TT–E–496	Enamel; Heat-Resisting (400° F.), Black
TT–E–485c	Enamel; Semi-Gloss, Rust-Inhibiting
TT–E–506c	Enamel, Tints and White, Gloss, Interior
TT–E–508	Enamel; Interior, Semi-Gloss, Tints and White
TT–E–529	Enamel; Synthetic, Semi-Gloss
TT–E–543	Enamel-Undercoat; Interior, Tints and White
TT–F–336a	Filler; Wood, Paste
TT–M–268	Methyl Isobutyl Ketone (for use in organic coatings)
TT–P–21	Paint; Cement-Water, White and Tints (for interior and exterior use)
TT–P–24a	Paint, Oil, Concrete and Masonry, Exterior, Eggshell Finish, Ready-Mixed, White and Tints
TT–P–25a	Primer, Paint, Exterior (undercoat for wood) Ready-Mixed, White and Tints
TT–P–26a	Paint; Interior, White and Tints, Fire Retardant
TT–P–29	Paint, Latex Base, Interior, Flat White and Tints
TT–P–31b	Paint; Iron-Oxide, Ready-Mixed, Red and Brown
TT–P–47a	Paint, Oil, Interior (Nonpenetrating-Flat, Ready-Mixed, Tints and White)
TT–P–51d	Paint, Oil, Interior, Flat, White and Tints
TT–P–56b	Primer Coating (Primer-Sealer), Pigmented Oil, Plaster and Wallboard

FEDERAL SPECIFICATIONS (Continued)

	TT-P-57	Paint, Zinc, Yellow — Iron Oxide — Base, Ready-Mixed
	TT-P-61b	Paint; Ready-Mixed, Black
	TT-P-71b	Paint; Ready-Mixed, Exterior, Chrome-Green
	TT-P-81c	Paint; Ready-Mixed, Exterior, Medium Shades on a Lead-Zinc Base
	TT-P-86a	Paint; Red-Lead-Base, Ready-Mixed
	TT-P-91a	Paint, Rubber-Base (for) Concrete Floors
	TT-P-102	Paint (Titanium-Lead-Zinc and Oil, Exterior, Ready-Mixed, White and Light Tints)
	TT-P-103	Paint (Titanium-Zinc and Oil, Exterior, Fume Resistant, Ready-Mixed, White)
	TT-P-104	Paint (White Lead and Oil, Exterior, Ready-Mixed, White and Light Tints)
	TT-P-141b	Paint Varnish, Lacquer, and Related Materials; Methods of Inspection, Sampling and Testing
	TT-P-636b	Primer Coating, Synthetic Wood and Ferrous Metals
	TT-P-641b	Primer, Paint; Zinc Dust-Zinc Oxide (for galvanized surfaces)
	TT-P-781a	Putty and Elastic-Compound; (for) Metal-Sash-Glazing
	TT-P-791a	Putty; Pure-Linseed-Oil, (for) Wood-Sash-Glazing
	TT-R-251d	Remover; Paint (Organic Solvent Type)
	TT-S-176b	Sealer, Floor; Varnish-Type (for wood and cork)
	TT-S-706	Stain, Opaque, Wood, Exterior, Oil
	TT-S-711a	Stain; Oil Type, Wood, Interior
	TT-T-291a	Thinner; Paint, Volatile Mineral Spirits (Petroleum Spirits)
	TT-T-306	Thinner; Synthetic-Enamel
	TT-V 51a	Varnish; Asphalt
	TT-V-71d	Varnish, Interior, Floor and Trim
	TT-V-81b	Varnish; Mixing for Aluminum Paint
	TT-V-91b	Varnish, Shellac
	TT-V-119	Varnish, Spar, Phenolic Resin
	TT-V-121c	Varnish, Spar, Water-Resisting
(Interim)	TT-W-00571d	Wood Preservative; Recommended Treating Practice

U. S. Maritime Administration Specification

	52-MA-151a	Paint; Deck, Black, Oil-Resisting

Military Specifications

	MIL-P-1232A	Paint, Deck, Red
	MIL-B-2638B	Lacquer, Vinyl Resin, Gasoline and Water Resistant
	MIL-M-10578A	Metal Conditioner and Rust Remover (Phosphoric acid base)
	MIL-C-11796a	Corrosion Preventive, Petrolatum, Hot Application
	MIL-S-12935A	Sealer, Surface, Knot
	MIL-S-13518A	Sealer, Surface, Wood Preservative
	MIL-C-15328A	Coating, Pretreatment (Formula 117 for Metals)
	MIL-P-15929A	Primer, Paint, Vinyl-Red Lead Type (Formula 119)
	MIL-P-15930A	Primer Paint, Vinyl-Zinc Chromate Type, Formula 120
	MIL-P-15931A	Paint, Anti-Fouling Vinyl-Red (Formula 121)
	MIL-P-15932A	Paint, Outside, Gloss-Black, Vinyl-Alkyd (Formula 122-1)
	MIL-P-15934A	Paint, Outside, Gray, No. 7 (Vinyl-Alkyd) (Formula 122-7)
	MIL-P-15935A	Paint, Outside, Gray, No. 11 (Vinyl-Alkyd) (Formula 122-11)
	MIL-P-15936A	Paint, Outside, Gray, No. 27 (Vinyl-Alkyd) (Formula 122-27)
	MIL-P-20087	Paint, Heat Resisting
	JAN-P-698	Paint, Deck, Black
	JAN-P-735	Primer, Paint, Zinc-Chromate, Alkyd Type
	MIL-C-18480 (Docks)	Coating Compound, Bituminous, Solvent, Coal Tar Base
	MIL-T-704B	Treatments and Painting of Material

SPECIAL FORMULATIONS

1-56. GENERAL

Paints shall have the composition as indicated in the formulas listed herein. Except

where otherwise specified or authorized, all paint shall be made by grinding together dry pigments and a liquid vehicle to form a smooth paint that will flow freely and will not settle or react deleteriously in containers. Where so specified, special pigments shall be packed in separate containers for mixing on the job. Unless otherwise specified, grinding shall produce a fineness such that coarse particles and skins will not exceed 1.5 percent (total residue left on No. 325-mesh screen) based on pigment. The grinding, unless otherwise specified, shall be done in a roller, pebble, or steel ball mill at a temperature that will not cause polymerization. Stone mills shall not be used unless specifically authorized. All paints shall be so processed as to insure that they will not gel, liver, or thicken deleteriously or form gas in the closed container within a period of one year from date of manufacture. Packaging of pigmented paints shall be in containers not larger than 5 gallons. The provisions and specified raw materials in this section are applicable only to the special paint formulations shown herein in detail and not to those finished product formulations governed by Federal Specifications or other standard specifications.

1-57. INSPECTION AND TESTS

Except as otherwise indicated, testing will be performed in accordance with the applicable provisions of the current revision of Fed. Spec. TT-P-141b, "Paint, Varnish, Lacquer, and Related Materials; Methods of Inspection, Sampling and Testing." In addition, special tests shall be made as follows:

Water resistance of clear phenolic vehicles V-1 and V-2 shall be determined in accordance with method No. 601.1 of Fed. Spec. TT-P-141b. Tin panels prepared in accordance with method 201.2 shall be dipped in the material to be tested, drained, and allowed to dry 72 hours prior to immersion. Immersion shall be in distilled water at 100° C. (212° F.) for the hot water resistance, and at 20° C. (68° F.) for the cold water resistance, for the specified number of hours. The panels during immersion shall be in a vertical position. A recovery period of 2 hours shall be allowed before examination of the panel under test. Acceptable specimens shall show no whitening, dulling, or blistering.

Alkali and acid resistance of clear phenolic vehicles V-1 and V-2.—Dip the closed end of well-cleaned 1 by 6 inch test tubes to a depth of 4 inches into the coating material to be tested and allow to dry for 72 hours in an inverted position; that is, with the mouth of the test tube down. Place the end of test tube, which was uppermost during the drying period, 2 inches below the surface of a 5 percent caustic soda (NaOH) solution or a 50 percent solution (by weight) of sulfuric acid at 20° C. (68° F.), for the specified period of time when testing for alkali and acid resistance, respectively. After removal, immediately rinse under gently running tap water, holding near the mouth of the tube and being careful not to touch the treated film. Dry for 2 hours and examine under suitable light. Acceptable specimens shall show no visible dulling, checking, or blistering. Defects at the extreme bottom of the test tube shall be disregarded.

Reactivity of phenolic vehicles V-1 and V-2 shall be determined in accordance with ASTM D154-53, "Standard Methods of Testing Varnishes," paragraph 33 to 37, inclusive.

1-58. PAINT PROPERTIES

a. **Skinning.** Skinning of phenolic type paints shall be negligible after exposing 6 ounces of paint in a tightly closed 8-ounce glass container for 48 hours in the dark.

b. **Brushing and leveling.** The paints shall have satisfactory brushing and leveling properties (except for vinyl and dispersion resin formulations), shall set to touch within the specified time limits, and shall provide a satisfactory film and a smooth even surface without undue gloss, suitable for proper application and adhesion of subsequent paint coats. Where the type of paint so requires, sufficient approved driers shall be added to paints to insure good top drying without wrinkling, satisfactory through drying, and to make the paint dry

through within the time specified. Driers shall be of such concentration that the viscosity of vehicles or mixed paints will not be appreciably changed by addition of the necessary amount of driers.

c. **Drying time.** Unless otherwise specified, mixed paints based on phenolic type vehicles shall set to touch in 1 to 4 hours and dry through, suitable for recoating, in not more than 12 hours. Mixed paint formulations based on vinyl and dispersion resins shall dry for recoating within 1 hour.

1-59. COLORS AND TINTS

Colors where specified shall conform to the listed chip in Fed. Spec. TT-C-595, "Colors for Ready-Mixed Paints." If not specified, the color shall be that naturally obtained from the required pigmentation.

1-60. PAINT FORMULATIONS

a. Formula P-2; Aluminum Paint; 100 Percent Tung Oil, Phenolic Vehicle

Ingredient	*Gallons*	*Pounds*	*Percent by Weight*
Finish aluminum paste	14.1	172.0	21.0
Vehicle V-1	85.9	649.5	79.0
	100.0	821.5	100.0

Aluminum pigment shall be packaged separately and mixed with vehicle immediately prior to use. Each vehicle container shall be labeled to the latter effect together with instructions showing correct proportions of vehicle and aluminum pigment.

b. Formula P-3; Aluminum Paint; Linseed-Tung Oil, Phenolic Vehicle

Ingredient	*Gallons*	*Pounds*	*Percent by Weight*
Finish aluminum paste	14.1	172.0	20.7
Vehicle V-2	85.9	660.0	79.3
	100.0	832.0	100.0

Aluminum pigment shall be packaged separately and mixed with vehicle immediately prior to use. Each container of vehicle shall be labeled to the latter effect together with instructions showing correct proportions of vehicle and aluminum pigment.

c. Formula P-4; Aluminum-Zinc Chromate Paint, Phenolic Type

Ingredient	*Gallons*	*Pounds*	*Percent by Weight*
Zinc chromate	4.2	123	13.5
Priming aluminum paste	13.5	165	18.1
Vehicle V-1	82.3	622	68.4
	100.0	910	100.0

Aluminum pigment shall be packaged separately and mixed with base paint immediately prior to use. Each container of base paint shall be labeled to the latter effect together with instructions showing correct proportions of base paint and aluminum pigment. The P-4 formulation is predominantly aluminum in color.

d. Formula P-5; Zinc Dust-Zinc Oxide Paint, Phenolic Type

Ingredient	*Gallons*	*Pounds*	*Percent by Weight*
Zinc Dust	27.1	1,590	64.0
Zinc Oxide	8.4	396	16.0
Vehicle V-2	64.5	495	20.0
	100.0	2,481	100.0

The consistency of the base paint (excluding zinc dust pigment) shall be 75 Krebs units plus or minus 15. The fineness of grind (method 441.1, Fed. Spec. TT-P-141b) of the base

paint shall be not less than 5. Zinc dust for this formula shall be packaged separately and mixed with base paint immediately prior to use. Each container of base paint shall be labeled to the latter effect together with directions showing correct proportions of base paint and zinc dust and instructions to thin with the minimum amount of mineral spirits for correct application characteristics. The natural color of this paint is light grey. The P–5 formulation dries to a very hard film; therefore, the drying time between successive coats of the material should be not more than that required to produce a firm film, in order to avoid poor intercoat adhesion; in very warm weather, 4 to 6 hours of drying between coats should be sufficient. If more than a 24-hour drying period elapses in warm weather, the paint used for the succeeding coat may be thinned from 1 to 3 percent by volume with a strong solvent such as "Butyl Cellosolve" (Ethylene glycol monobutyl ether) in order to improve intercoat adhesion.

e. **Formula P–6; Red Lead — Iron Oxide Paint, Phenolic Type**

Ingredient	*Gallons*	*Pounds*	*Percent by Weight*
Red iron oxide (85 percent grade)	14.9	573	40.5
Red lead (97 percent)	2.8	206	14.6
Diatomaceous silica	3.8	73	5.2
Mineral spirits	30.0	195	13.8
Pine oil	1.8	14.1	1.0
Butanol	0.4	2.8	0.2
Vehicle V–2	46.3	349	24.7
	100.0	1,412.9	100.0

The consistency of the paint shall be 75 Krebs units, plus or minus 15. The fineness of grind (method 441.1, Fed. Spec. TT–P–141b) shall be not less than 5. The natural color of this paint is dull red to maroon, depending on the shade of iron oxide pigment used.

f. **Formula P–7; Zinc Dust-Zinc Oxide — Iron Oxide Paint, Phenolic Type**

Ingredient	*Gallons*	*Pounds*	*Percent by Weight*
Zinc dust	9.5	556	32.5
Red iron oxide (85 percent grade)	7.8	334	19.5
Zinc oxide	4.7	222	13.0
Vehicle V–2	78.0	600	35.0
	100.0	1,712	100.0

The consistency of the paint shall be 75 Krebs units, plus or minus 15. The fineness of grind of the base paint (excluding zinc dust) shall be not less than 5. Zinc dust for this formula shall be packaged separately and mixed with base paint immediately prior to use. Each container of base paint shall be labeled to the latter effect together with directions, showing correct proportions of base paint and zinc dust and instructions to thin with the minimum amount of mineral spirits necessary for correct application characteristics. The natural color of this paint is maroon with a grey cast. The paint dries to a very hard film; therefore, the drying time between successive coats of the formulation should be not more than that required to produce a firm film, in order to avoid poor intercoat adhesion. In very warm weather, 4 to 6 hours between coats should be sufficient. If more than a 24-hour drying period elapses in warm weather, the paint used for the succeeding coat should be thinned from 1 to 3 percent with a strong solvent such as "Butyl Cellosolve" (Ethylene Glycol Monobutyl Ether) in order to improve intercoat adhesion.

g. **Formula P–9; Aluminum Paint, Linseed-Tung Oil, Phenolic Varnish**

Ingredient	*Gallons*	*Pounds*	*Percent by Weight*
Finish aluminum paste	14.1	172.0	21.0
Varnish (Fed. Spec. TT–V–119)	85.9	649.5	79.0
	100.0	821.5	100.0

Aluminum pigment shall be packaged separately and mixed with vehicle immediately prior to use. Each vehicle container shall be labeled to the latter effect together with instructions showing correct proportions of vehicle and aluminum pigment.

h. Formula D–301; Dispersion Resin Red Lead Primer

Ingredient	*Pounds*	*Gallons*
Red lead (97 percent grade)	170.0	
Zinc chromate	34.0	
Magnesium silicate (fibrous type)	68.0	
Mica (water ground)	66.4	
Aluminum stearate	1.7	
Dispersion resin	249.0	29.5
Vehicle V–3	134.0	17.3
Xylene	315.0	43.7
Lead drier (24 percent)	0.68	
Cobalt drier (6 percent)	0.27	

Grind formula D–301 in pebble or ball mill with all ingredients added to a fineness of grind (method 441.1, Fed. Spec. TT–P–141b) of not less than 5. The paint should be reduced in the field for spray application in the proportion of one quart of Xylene to one gallon of base paint and each container should bear these thinning instructions. The natural color of formula D–301 approximates that of red lead pigment.

i. Formula D–302; Dispersion Resin Aluminum Finish Paint

Ingredient	*Pounds*	*Gallons*
Dispersion resin	249.0	29.5
Vehicle V–3	134.0	17.3
Xylene	315.0	43.7
Lead drier (24 percent)	0.68	
Cobalt drier (6 percent)	0.27	
Finish aluminum paste	100.0	

Aluminum paste should be packaged in separate containers and added in the field in the ratio of 1.1 pounds per gallon of vehicle. Mixed paint should be thinned with sufficient Xylene to obtain correct spraying characteristics. Each container should bear the above mixing and thinning instructions.

j. Formula V–101; Red Lead Paint, Vinyl Type

Ingredient	*Percent by wt.*
Vinyl resin, type 2	15.0
Red lead (97 percent grade)	22.0
Tricresyl phosphate plasticizer	3.0
Toluene	30.0
Methyl isobutyl ketone (See note below)	30.0
	100.0

The pigment in this formula shall be dispersed by means of a pebble or ball mill, or other approved method to produce a fineness of grind (Fed. Spec. TT–P–141b, method 441.1) of not less than 7. The viscosity of the paint shall be between 65 and 80 Krebs units. No wetting or grinding agents will be permitted in the processing of the formulation. A 1.0 mil film of the vinyl type red lead primer when applied over a 0.5 mil dry film of Vinyl Type Wash Coat shall show good adhesion to the latter after a 24-hour drying period at 68° F. The above paint is predominantly the color of red lead pigment. The V–101 formulation will not adhere to bare steel; it must be applied to surfaces pretreated with Vinyl Wash Coat (MIL–C–15328A).

Note: If formula V–101 is to be applied at relatively low (20° to 40° F.) temperature, 15 of the 30 parts of methyl isobutyl ketone should be omitted and methyl ethyl ketone substituted therefor.

k. Formula V–102; Aluminum Paint, Vinyl Type

Ingredient	*Percent by wt.*
Vinyl resin, type 3	16.5
Tricresyl phosphate plasticizer	4.1
Aluminum powder	13.0
Toluene	33.2
Methyl isobutyl ketone	33.2
	100.0

The aluminum pigment shall be packaged separately and mixed with the liquid immediately prior to use. Each container of liquid shall be labeled to this effect together with instructions showing the correct proportions of the vehicle and aluminum pigment (one part of aluminum powder to 6.7 parts of liquid, by weight). Formula V–102 is intended for topcoats over Formulas V–101 and V–766; it will not adhere to bare steel or Vinyl Wash Coat.

l. Formula V–766, Vinyl Type White Primer

Ingredient	*Percent by wt.*
Vinyl resin, type 3	8.0
Vinyl resin, type 4	8.0
Titanium dioxide (type III)	12.0
Tricresyl phosphate plasticizer	3.0
Toluene	34.5
Methyl isobutyl ketone	34.5
	100.0

The pigment shall be dispersed in the V–766 formulation preferably by preparing resin-pigment "chips" on a differential speed 2-roll mill of the type used in rubber mixing. The mill stock shall not include the No. 4 vinyl resin because of its reactive characteristics. The formulation may be processed in a pebble or ball mill only if a dispersion is obtained which is approximately equal to the preferred method. The fineness of grind in any event shall be not less than 7 (Fed. Spec. TT–P–141b, method 441.1). The viscosity of the paint shall be between 60 and 72 Krebs units. No wetting or grinding aids will be permitted in the processing of the formulation. The above paint is white in color but may be tinted to various shades of gray by the manufacturer, if desired by the purchaser. Formula V–766 will adhere to bare steel but not to Vinyl Type Wash Coat.

m. Formula V–103, Vinyl Type Black Finish

Ingredient	*Percent by wt.*
Vinyl resin, type 3	16.0
Carbon black	1.2
"Flexol" DOP plasticizer	3.8
Methyl isobutyl ketone	39.5
Toluene	39.5
	100.0

The carbon black shall be dispersed preferably by preparing resin pigment chips on a differential speed 2-roll mill of the type used in rubber mixing or alternately by any other means which will produce a dispersion equal to the preferred method. All necessary measures shall be taken to produce a material which is free from seeding, gelling, and other deleterious effects. The fineness of grind (Fed. Spec. TT–P–141b, method 441.1) shall be not less than 7. The viscosity of the paint shall be between 60 and 72 Krebs units. Formula V–103 is intended for topcoats over Formula V–101 or V–766; it will not adhere to bare steel or to Vinyl Type Wash Coat.

n. Formula V–104, Vinyl Maroon Finish Paint

Ingredient	*Percent by wt.*
Vinyl resin, type 3	16.2
Synthetic iron oxide (red)	14.4
Tricresyl phosphate plasticizer	4.0
Toluene	32.7
Methyl isobutyl ketone	32.7
	100.0

The pigment in Formula V–104 shall be dispersed by means of a pebble or ball mill, or other approved method to produce a fineness of grind (Fed. Spec. TT–P–141b, method 441.1) of not less than 7. The viscosity of the paint shall be between 60 and 72 Krebs units. The vinyl maroon paint is suitable for use as topcoats over the V–101 red lead paint and the V–766 white vinyl paint. The vinyl maroon paint will not adhere to bare steel or to the vinyl type wash coat.

1–61. PHENOLIC VARNISH VEHICLES

a. Vehicle V–1, Phenolic Resin-Tung Oil Vehicle

COMPOSITION

Tung oil	25 gallons
R–1S phenolic resin	75 pounds
R–2 para-phenyl phenol-formaldehyde resin	25 pounds
Hi-flash solvent naphtha	7 gallons

Mineral spirits — sufficient to give specified viscosity and nonvolatile.

Procedure: (The following procedure is intended as a guide only.) Heat 12½ gallons of tung oil and 100 pounds of the resins to 560° F. in 35 minutes. Hold 15 minutes for body and add the remaining 12½ gallons of tung oil (T. 420° F.) Heat to 450° in 5 minutes and hold about 25 minutes for body. Thin to specified nonvolatile and viscosity and centrifuge or filter to remove foreign particles. Add naphthenate driers to give 0.15 percent lead, 0.015 percent cobalt, and 0.008 percent manganese, as metals, based on the weight of oil present.

REQUIRED PROPERTIES AND PERFORMANCE:

Viscosity (Gardner)	D–F
Wt. per gallon	7.4 to 7.6
Nonvolatile	55±1.0 percent
Kauri reduction	Pass 100 percent
Skinning	None in 48 hours
Cold water resistance	OK – 96 hours
Boiling water resistance	OK – 7 hours
Alkali resistance (5 percent NaOH)	OK – 24 hours
Acid resistance (50 percent H_2SO_4)	OK – 24 hours
Drying time (dust free)	1 to 4 hours
Dry through	12 hours (max.)
Reactivity (ASTM D 154–53)	Not more than slightly reactive
Appearance	Clear and free from sediment

b. Vehicle V–2, Phenolic Resin, Tung-Linseed Oil Varnish

COMPOSITION:

R–2 Para-phenyl phenol — formaldehyde resin	100 pounds
Tung oil	20 gallons
Alkali refined linseed oil	13 gallons
Mineral spirits	26 gallons
Dipentene	4 gallons
Ethylene glycol monoethyl ether	3 gallons
Hi-flash naphtha	1 gallon
Toluene	2 gallons

Procedure: (The following procedure is intended as a guide only.) Heat all of the resin and all of the linseed oil to approximately 565° F. and hold for about 20 minutes. Add the tung oil, heat to 465° F., hold for 5 minutes and then allow the batch to cool to 420° F. Add the thinners in the order shown and filter or centrifuge to remove foreign solid particles. Add naphthenate driers to give 0.15 percent lead, 0.015 percent cobalt and 0.0075 percent manganese based on the weight of oil or otherwise as necessary for proper drying.

REQUIRED PROPERTIES AND PERFORMANCE:

Viscosity (Gardner)	C–D
Wt. per gallon	7.55 to 7.75
Color (Gardner Standards 1953)	10 to 12
Nonvolatile	59±1.0 percent
Kauri reduction	Pass 120 percent
Skinning	None in 48 hours
Cold water resistance	OK – 96 hours
Boiling water resistance	OK – 7 hours
Alkali resistance (5 percent NaOH)	OK – 5 hours
Reactivity (ASTM D 154–53)	Nonreactive
Dry dust free	4 hours (max.)
Dry through	12 hours (max.)

c. Vehicle V–3, Phenolic Resin—Dehydrated Castor-Tung Oil Varnish

COMPOSITION:

R–2 para-phenyl phenol-formaldehyde resin	100 pounds
Dehydrated castor oil (visc. G–H)	12.5 gallons
Tung oil	12.5 gallons
Xylol	14.0 gallons
Dipentene	4.0 gallons
Mineral spirits	10.5 gallons

Procedure: (The following procedure is intended as a guide only.) Heat the dehydrated castor oil and half the resin to 560° F. in 30 minutes and hold 30 minutes. Add the remaining resin and when this is melted add the tung oil (temperature 340° F.) Gain 465° F. and hold for body. Thin.

REQUIRED PROPERTIES:

Nonvolatile	60 percent
Viscosity	L–N (Gardner)
Specific gravity	0.945 (approx.)
Appearance	Clear and free of sediment

1–62. PIGMENTS

Aluminum powder shall conform to Fed. Spec. TT–A–468a "Aluminum-Pigment; Powder and Paste, for Paint," type I, class B.

Aluminum paste (finish) shall conform to Fed. Spec. TT–A–468a for "Aluminum Pigment; Powder and Paste, for Paint," type II, class B.

Aluminum paste (priming) shall conform to the applicable provisions of Fed. Spec. TT–A–468a, "Aluminum-Pigment; Powder and Paste, for Paint," type II, class C, except that (1) nonvolatile matter shall be not less than 62 percent; and (2) gradation shall be within the following percentage limits, calculated by dividing the total weight of all particles retained on, or passing the specified mesh number by the total weight of the original sample of paste.

	Percent	
	Maximum	*Minimum*
Retained on No. 50 mesh sieve	0.1	
Retained on No. 100 mesh sieve	1.0	
Retained on No. 200 mesh sieve	10.0	3.0
Passing No. 325 mesh sieve	90.0	80.0

Diatomaceous silica shall conform to Military Spec. MIL–S–15191A "Silica, Diatomaceous (flatting-extender pigment)."

Magnesium silicate shall conform to Fed. Spec. TT–M–90 "Magnesium-Silicate; Dry (paint pigment)."

Red Lead shall conform to Fed. Spec. TT–R–191b "Red-Lead; Dry and Paste-in-oil," type I, grade 97.

Red Iron Oxide (synthetic) shall conform to Fed. Spec. TT–I–511a "Indian-red and Bright Red (Iron-oxide); Dry (paint pigment)" type I or II.

Red Iron oxide (85 percent grade) shall be a natural pigment containing at least 85 percent Fe_2O_3 and shall contain not more than 5 percent of lime and sulfur in any form. It shall contain no organic coloring matter.

Zinc chromate shall conform to Fed. Spec. TT–Z–415 "Zinc-Yellow (zinc chromate); Dry (paint pigment)," type I.

Zinc dust shall conform to Fed. Spec. TT–Z–291 "Zinc-Dust (Metallic-Zinc Powder); Dry (paint pigment)," type I, except that type II shall be used for compounding paints to be used on the interior of potable water tanks.

Zinc oxide shall conform to Fed. Spec. TT–Z–301a "Zinc Oxide; Dry and Paste-in-oil" Dry, American or French process.

Mica (waterground) shall conform to Military Spec. MIL–M–15176a, "Mica (extender pigment)" type I.

Titanium dioxide shall conform to Fed. Spec. TT–T–425a entitled "Titanium Dioxide; Dry (paint pigment)," type as required.

Carbon black shall conform to Fed. Spec. TT–C–120, "Carbon-Black; Dry (Paint Pigment)," form I, class A.

1–63. OILS AND PLASTICIZERS

Tung oil shall conform to Fed. Spec. TT–O–395, "Oil, Tung (Chinawood), Raw (for use in organic coatings)."

Alkali refined linseed oil shall conform to Military Spec. MIL–L–15180a entitled "Linseed Oil, Alkali-refined."

Boiled linseed oil shall conform to Fed. Spec. TT–O–364, "Oil Linseed, Boiled (for use in organic coatings)."

Raw linseed oil shall conform to Fed. Spec. TT–O–369, "Oil, Linseed, Raw (for use in organic coatings)."

Tricresyl phosphate plasticizer shall conform to Fed. Spec. TT–T–656a entitled "Tricresyl phosphate."

1–64. RESINS

R–1S phenolic resin shall conform to Military Spec. MIL–R–15189a, "Resin, Phenolic (Alkyl Phenol, Oil-Soluble)."

R–2 Para-phenyl phenol-formaldehyde resin shall conform to Fed. Spec. TT–R–271, "Resin, Phenol-formaldehyde, para-phenyl."

Dispersion resin shall consist of a dispersion of highly polymerized oil-resin particles in solvent and shall be similar and equal to BK–3962 resin as manufactured by the Bakelite Division, Union Carbide and Carbon Company.

Vinyl resin, type 2 shall be a hydroxyl containing vinyl chloride-acetate copolymer. It shall contain 89.5 to 91.5 percent (by weight) vinyl chloride, 2.0 to 5.5 percent vinyl acetate and 5.3 to 7.0 percent vinyl alcohol. The resin shall, in the specified formulations, produce results equal to "Vinylite" resin VAGH.

Vinyl resin, type 3 shall be a vinyl chloride-acetate copolymer of medium average molecular weight and shall contain 85 to 88 percent vinyl chloride and 12 to 15 percent vinyl acetate

by weight. The resin shall, in the specified formulations, produce results equal to "Vinylite" resin VYHH.

Vinyl resin, type 4 shall be a copolymer of the vinyl chloride-acetate type, shall contain (by wt.) one percent interpolymerized dibasic acid, 84 to 87 percent vinyl chloride and 12 to 15 percent vinyl acetate. It shall, in the specified formulations, produce results equal to "Vinylite" resin VMCH.

1-65. SOLVENTS, THINNERS, DRIERS, AND ACIDS

Mineral spirits shall conform to Fed. Spec. TT-T-291a, "Thinner; Paint Volatile Mineral Spirits (petroleum spirits)" grade I.

Toluene shall conform to Fed. Spec. TT-T-548a, "Toluol (for use in organic coatings)."

Butanol shall conform to Fed. Spec. TT-B-846 for "Butyl Alcohol; Normal (for use in organic coatings)."

Isopropanol (99 percent) shall conform to ASTM D770-46 for "Isopropyl Alcohol."

Methyl ethyl-ketone shall conform to Fed. Spec. TT-M-261 "Methyl-Ethyl Ketone (For use in organic coatings)."

Methyl isobutyl ketone (MIK) shall conform to Fed. Spec. TT-M-268, "Methyl Isobutyl-Ketone (for use in organic coatings)."

Thinner T-10 for vinyl coatings shall consist of 10 percent methyl isobutyl ketone (by weight) and the balance of toluene.

Hi-flash solvent naphtha shall conform to the following requirements:

Specific gravity	0.855 to 0.875
Flash point	35° C. (min.)
Distillation:	
Initial	145° to 156° C.
95 percent	190° C. (max.)
End	220° C. (max.)
Naphthalene	None
Kauri-butanol solvency value	78 cc (min.)

Turpentine shall conform to Fed. Spec. TT-T-801 "Turpentine; Gum Spirits and Wood (steam distilled and sulfate) (for use in organic coatings)," type I, II, or III at the option of the contractor.

Dipentene shall conform to Fed. Spec. TT-D-376a, "Dipentene; for use in organic coatings."

Ethylene glycol monoethyl ether shall conform to Fed. Spec. TT-E-781, "Ethylene Glycol Monoethyl Ether."

Driers shall conform to Fed. Spec. TT-D-643b, "Drier, Paint, Naphlenate, Liquid, Concentrated," type as required.

Ortho-phosphoric acid (85 percent) shall be U.S.P. (or better) grade and its concentration shall be 85 percent by weight.

Pine oil shall conform to Fed. Spec. LLL-O-358, "Oil, Pine."

Normal butyl acetate shall conform to Fed. Spec. TT-B-838, "Butyl Acetate, Normal (for use in organic coatings)."

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