U.S. Department of Housing and Urban Development
Office of Policy Development and Research

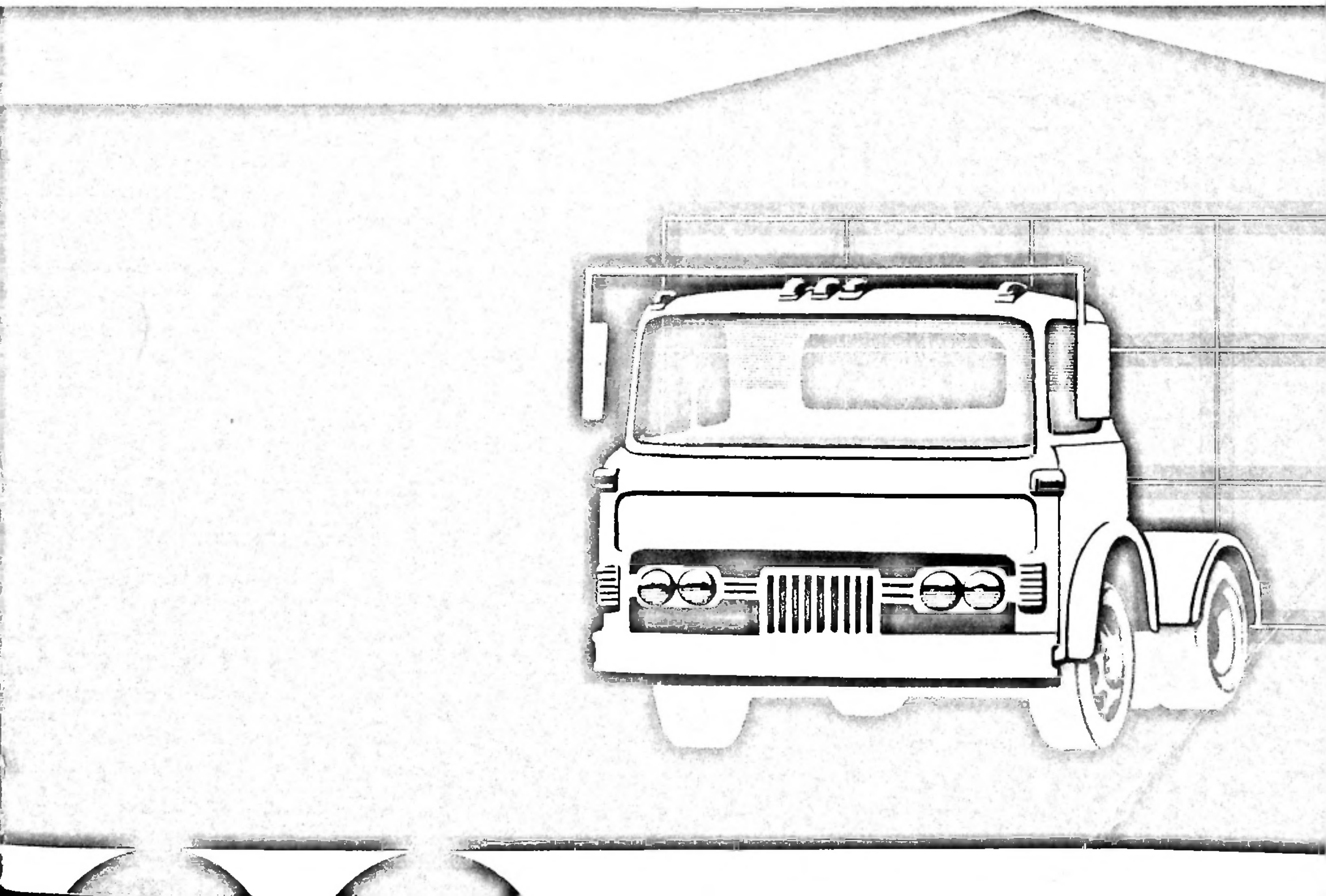
Mobile Home Research

Transportation and Site-Installation

Volume 1

Final Report

Analytical Evaluation of Transportation Effects on Mobile Homes



MOBILE HOME RESEARCH

TRANSPORTATION AND SITE-INSTALLATION

ANALYTICAL EVALUATION OF TRANSPORTATION EFFECTS ON MOBILE HOMES

VOLUME 1
FINAL REPORT

By

Southwest Research Institute

Prepared for

U.S. Development of Housing and Urban Development
Office of Policy Development and Research

Contract Number H-2411

March 1979

FOREWORD

At the present time, 10 million Americans live in mobile homes. For them, and for the increasing numbers of people who will come to live in such homes in the future, HUD, at the request of the Congress, has undertaken research to improve mobile home safety and durability. Out of that research, HUD is to develop, promulgate, and enforce one nation-wide construction standard for the industry.

The six volumes that constitute this report should prove invaluable to those who develop standards as well as those architects and engineers who design both manufactured housing and mobile homes. That some of the research may be controversial is only to be expected. It is pioneering work that offers a new approach to resolving difficult problems.

The Division of Energy, Building Standards and Technology of HUD's Office of Policy Development and Research should be recognized for its contribution to this worthwhile project.

Moon Landrieu
Secretary

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NOTE: Since each part was originally written as a separate volume, each contains its own Table of Contents, List of Figures and Tables and Pagination.

SUMMARY

The research contained herein was undertaken to provide a basis for determining the adequacy of the Mobile Home Construction and Safety Standards, effective June 15, 1976. "Adequate" is defined as Standards that result in mobile homes with sufficient durability to provide the homeowner with an acceptable useful life; currently defined for purposes of this Study as a minimum of 15 years for a single-wide and as a minimum of 20 years for a double-wide unit. The research methodology to evaluate the standard included: (1) the development of analytical methods to determine transportation and site-installation induced loads and the resulting member stresses, joint-loads and deflections; (2) the development of a means to predict degradation caused by the aforementioned forces; (3) the conduct of a test program that compares analytically determined input loads and predicted degradation with actual physical test measurements and observations; (4) if required, proposed changes to the Standards; and (5) analytical or test methodology that could be used by enforcement agencies to evaluate proposed mobile home designs.

To determine mobile home structural member loads caused by in-transit conditions, computer modeling techniques were used. Critical in-transit conditions (i.e., road roughness and towing velocity) were analytically related to critical structural parameters (i.e., torsional stiffness, flexural stiffness, and damping) in order to calculate estimated

member loads. This analysis also related analytically predicted changes in structural parameters to degradation of the mobile home. Equations were developed that, in part, statistically compare structural parameters of any given mobile home to a home that is considered to be 100 percent degraded. Solution of these equations result in an estimation of mobile home degradation. These equations were modified as required to provide "best fit" estimates consistent with test data and are subject to further modification as additional data becomes available. This research activity is described in Volumes 1 and 4. A detailed rationale for analytical equations is not presented since emphasis was put on the "best fit" relationship of analytical computer simulations and test data.

Volumes 1 and 4 also includes a computer oriented methodology for the analysis of mobile home structures. This data provides a basis for future research oriented to the rapid analysis of mobile home member stresses, joint loads and structural deflections.

A test program was conducted to obtain data that could be compared to analytically derived data. Emphasis was placed on measured test data which resulted in equation modifications as necessary to "best fit" experimental data. Test data was obtained from single-wide and double-wide homes built per the current standard and from homes built prior to implementation of the current standard. Test homes were subjected to transportation and site-installation conditions to simulate years of actual use. Volume 2 describes the test program with supportive data sheets included in Volume 3.

The objective of proposed revisions to the Standards is to reduce the incremental degradation of mobile homes where current design practices result in predicted and observed degradation that exceeds acceptable levels. Volume 5 contains proposed changes to the current standard based on an analysis of data contained in Volumes 1 through 4. The proposed changes include increased design loads to resist in-transit and on-site forces; increased design criteria for attachment of joints as required to minimize loosening of joints during transportation; and a requirement for a minimum integrated structure stiffness criteria to ensure that degradation with respect to time is consistent with a reasonable useful life. Recommended design loads were based on actual measured test data multiplied by a factor selected to account for rough roads and highway speeds greater than 45 MPH. Minimum stiffness criteria were based on values obtained from the single-wide home built to the current standards.

Volume 6 contains a proposed field test method that could be used to measure the stiffness parameters of new or used mobile homes. These parameters are required to verify adherence to the proposed standard, and to perform calculations necessary to predict the remaining useful life of the mobile home.

Volume 7 (yet to be printed) will summarize the major results of the other six volumes and will provide a cohesive evaluation for the reader interested primarily in understanding the broader aspects rather than becoming technically involved in the specific technical aspects of the study.

The Southwest Research Institute's Study offers an innovative approach in terms of a concept and a model upon which to assess mobile home structural durability, or conversely, structural degradation. The Study's findings should offer a base upon which to develop proposed Standards.

The rationale of using degradation of torsional and flexural rigidity as a measure of mobile home durability is innovative for mobile home design and would appear to be basically sound. Changes in stiffness (torsional and flexural) and damping, have been used for several years in engineering practice as a measure of structural degradation in other applications. The concept of seeking a measurable parameter that is sensitive to degradation appears to have merit.

This Study's findings should therefore be considered in the whole context of the research effort rather than narrowly disected. Certain assumptions made upon the best available information from data, may later be modified as experience is gained in the use and application of the Study's results.

RELATED DOCUMENTATION

The research program, from which this volume and six others were derived, was originally organized into eight project tasks under each of which a varying number of reports were written; e.g., Task I consisted of Volumes I, II, III, and IV. In order to reduce the number of separate volumes produced from this research, certain reports that were considered related were combined into one volume.

Volume 1 consists of Task I, Vols I, II, III, IV;
Volume 2 consists of Task II and Task III, Vol I, Parts I & II;
Volume 3 consists of Task III, Vol I, Part II Raw Data;
Volume 4 consists of Task III, Vols II & III;
Volume 5 consists of Task IV, Vols I, II, & III;
Volume 6 consists of Tasks V, VI, & VII; and
Volume 7 consists of Task VIII.

The reader is made aware of this in order to understand the cross-references that occur throughout these documents as they were originally written. Thus, for example, references to Task I, Vols I and II can be found in the first two parts of what is now Volume 1. It is hoped that any confusion created by this compilation will be offset by the convenience of having fewer volumes of analogous material.

NOTE: Volume 3 is available through the national Technical Information Service; 5282 Port Royal Road, Springfield, Va. 22161. To order by phone call (703) 557-4610. This volume was not printed by the Government Printing Office since it is believed that the demand for Raw Data will be relatively small.

ACKNOWLEDGMENTS

The authors are indebted to many professionals for contributions and guidance that made this study possible. Our thanks include:

- Battelle Memorial Institute - for their earlier research study into mobile home flexural rigidity;
- U.S. National Bureau of Standards - for Dr. Robert Crist's evaluation of the predictive analysis theory;
- U.S. Department of Transportation - for their Federal Highway Administration and the Bureau of Motor Carrier Safety organizations for providing transportation insights;
- State of Texas Department of Labor and Standards; for the valuable assistance of Mr. Michael Alexander (Manufactured Housing Division) in evaluating the structural dynamics portions of the study;
- State of Texas Department of Public Safety; for Colonel Wilson Spear's assistance during the highway testing phase;
- Boeing Aerospace Company - for the quality of Mr. John Stevens penetrating assessments during the development of each of the several products of the research;
- American Association of State and Highway Transportation Officials - for the coordination of the highway safety survey;
- Manufactured Housing Institute - for coordinating the attendance of key engineering personnel at the several project status reviews and demonstrations conducted during the research.

DYNAMIC ANALYSIS
APPLIED ENGINEERING TEXT

DYNAMIC ANALYSIS
APPLIED ENGINEERING TEXT

Prepared by

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ABSTRACT

This volume summarizes the results of extensive computer modeling of intransit mobile homes. The study included a parametric investigation of the effect of changes in structural properties of mobile homes to probabilistic dynamic response and vice versa. In addition, the effect of road type and transport speed was also evaluated in terms of induced dynamic loadings. Results include regression equations that can be used by designers to define probable dynamic loadings of a mobile home during transit. Moreover, methodology is presented that can be used to gain insight into the anticipated remaining useful life of a particular unit. A detailed report of development and potential application is contained in Volume II of this Task.

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DEFINITIONS

The following pages contain definitions of physical words or terms used within the context of the TASK I effort.

CONSUMED LIFE: This is defined using the structural system of the mobile home as the basis for progressive degradation that eventually deteriorates the unit to the point that the useful life has been used up or consumed rendering the home unfit for:

- Transportation Modes
- Live-ability or occupancy
- Mortgage, Financial or Insurance Risk (See RUL, Remaining Useful Life and Structural Degradation)

STRUCTURAL DEGRADATION: Degradation measured in the form of structural stiffness and integrity with a factory new mobile home noted as "un-degraded". The reduction in structural stiffness is measured in two forms: (1) vertical stiffness designated as EI and (2) torsional stiffness designated as GJ. Other indicators of structural degradation are: increased deflections with decreased accelerations indicating a "softening" or loosening of the structure.

REMAINING USEFUL LIFE (RUL): TASK I utilizes this percent of useful life that is used up due to the transportation, setup and takedown cycle with a new/un-used mobile home designated as a unit of 1.0 or has 100 percent of its useful life left. Any operation will degrade the mobile home to some degree there-on. A zero percent RUL indicates the unit (or part of the unit) has been totally degraded.

DYNAMIC ANALYSIS MODEL: In order to totally analyze the mobile home, it was necessary to separate the TASK I predictive analysis into two modes: dynamic and static. The dynamic model evaluates the dynamic loads (or accelerations) generated by the mobile home during the transportation mode. The dynamic model is of the lump mass-beam element configuration with the key masses placed at the proper distance from the centerline of the system. During highway operations, this configuration generates the various accelerations,velocities and displacements as a result of induced excitations from the road surface. From their data, loads can be generated for use in the static finite element model in order to develop the various stress patterns in designated components of the mobile home.

FINITE ELEMENT STATIC ANALYSIS/MODEL: The finite element model consists of dividing the various components of the mobile home into a fine mesh system that is compatible with the actual structural system. All nodal points of the mesh on each component interconnect in order that the program can complete individual element analysis as well as the overall component and mobile home analyses. The finite element method analysis can be used with various basic computer programs such as STARDYNE, STRUDAL or ANSYS. The analysis output can provide stresses at selected points or junctions under various loadings that are usually obtained from the dynamic model. In this analysis, the mobile home structure was divided into major components such as chassis, floor, left wall, right wall, front end wall, rear end wall, roof and individual partitions within the mobile home.

VERTICAL STIFFNESS: The average mobile home can be considered a long box-like structure that has a certain structural stiffness with respect to bending in the vertical plane. Usually the longer the mobile home, the less the vertical stiffness and conversely the shorter the mobile home the greater the stiffness. Vertical stiffness is the ability of the mobile home structure to resist vertical loads/deflection and is synonymous with "flexural rigidity" and "EI". The mobile home can have two basic EI's, one forward of the running gear and one aft of the running gear.

TORSIONAL STIFFNESS: The average mobile home can be considered a long box-like structure that has a certain structural stiffness with respect to torsion about the fore and aft longitudinal axis. The torsional rigidity, like the flexural rigidity is higher in the shorter length mobile homes and lower in the longer mobile homes. Also, the torsional rigidity is a function of the "completeness" of the box structure with respect to the cross section of the mobile home. If there is no plywood structure on the roof under the metal to complete the structural torque box, the torsional rigidity or stiffness is lower than the mobile home with the maximum section properties.

DYNAMIC LOADS AND DYNAMIC RESPONSE: During development of the RUL and dynamic model, it was anticipated that the TASK I program would be divided into the:

–Dynamic lump mass model

–Predictive, (RUL) remaining useful life formula

–Finite element static analysis model

–Exploded isometrics of detailed points on the mobile home for stress analysis

The finite element static analysis model requires inputs other than the static one "g" loadings. These inputs simulate the actual road condition excitations induced in the mobile home during transit. Accordingly, the acceleration levels from the dynamic model are input to the finite element as "equivalent" G (inertial) loads. The repetitive roadrun dynamic response, even if at a low G level, can be very damaging in terms of accumulative degradation.

STRUCTURAL INTEGRITY VERSUS DEGRADATION: The predictive analysis contained in Volumes I and II of TASK I, is based on the assumption that there exists a direct correlation between the structural integrity of the mobile home and the degree to which it has been or can be degraded. This degradation is attributable to–:

–Transportation modes

–Setup

–Take down

–Occupancy periods of high traffic and poor maintenance.

The structural integrity of a mobile home is measured as a function of the flexural rigidity and torsional stiffness; both of which may change significantly during transit as well as setup-takedown procedures. The mobile home can have a varying stiffness, both in flexural rigidity and torsional rigidity from the front of a mobile home to the rear. However, for the purpose of this report, the mobile home structural rigidity has been analyzed in two areas only: hitch to front axle and front axle to rear wall.

BEAM ELEMENTS: These elements are referred to in two areas:

–Dynamic model

–Finite element model

These elements predominently refer to elements used in the finite element analysis/model because the chassis acts as a beam; the floor acts as a beam and the side walls act as a beam. Also, the dynamic analysis utilizes a simplified lump/mass model with the various eccentric beam elements taken off the longitudinal beam (or axis) for the various dynamic responses generated by designated road conditions and velocities as inputs.

As an example, the sidewall or beams are divided into various elements or a grid mesh of approximately 32-inch centers (to match the 16-in. stud spacing). Each element of this side wall beam is specifically designated or located by the nodal points connecting each corner of the element to the adjacent element. Each beam element has the capacity of determining the stress at any point around the periphery of the element. Therefore, the finer the mesh, the finer the stress points. But, the finer the mesh, the more costly the program to run and analyze or interpret.

POWER SPECTRAL DENSITY (PSD): In terms of physical reality, the spectral density at any particular frequency may be regarded as the average power passing when a random signal is filtered by a narrow band pass filter centered at that frequency.

EFFECTIVE FLEXURAL RIGIDITY (EI): This is the equivalent bending (vertical) stiffness of a mobile home if the *a priori* assumption is made that the unit in flexure can be modeled as an Euler beam.

EFFECTIVE TORSIONAL RIGIDITY (GJ OR J): This is the mobile home's equivalent structural resistance to torsion if the *a priori* assumption is made that the unit in torsion responds as a closed channeled rectangular tube.

MOBILE HOME TEST UNITS: The mobile home test units are designated by the following prefixes:

T-1 1976 14 X 64–Single wide (new)
T-2A 1976 Double wide 24 X 56–Wet half (new)
T-2B 1976 Double wide 24 X 56–Dry half (new)
*T-3 1971 14 X 64–Single wide (used)
*T-4A 1974 Double Wide 24 X 56–Wet half (used)
*T-4B 1974 Double Wide 24 X 56–Dry half (used)

ATTACHMENTS OR FASTENERS: Refers to mechanical devices such as tacks, nails, bolts, screws or staples used to assemble the various joints or structural components. This does not include glue or welding.

JOINTS: Comprises the interface between two pieces of structure or components that are assembled using the attachments noted above. Examples of joints are stud to plate; header to stud; shear wall to side wall; side wall to end wall and roof to wall.

EXPLODED ISOMETRICS: The test mobile homes are shown in an overall exploded isometric configuration with a breakdown of the major components. The critical joints of each model are then detailed in an enlarged/exploded isometric drawing showing the load/stress input, transfer or flow. The exploded isometrics offer a pictorial presentation of the output from the finite element analysis.

RANDOM LOAD INPUT: Induced dynamic inertial loads incurred by the mobile home during transit due to the random excitations from the road surface.

TRANSPORTATION MODE: The mobile home transportation mode is divided into two sections as follows: Condition I covers the transportation from the manufacturer to the dealer and from the dealer to the initial setup site, including setup. Condition II covers the secondary moves including takedown, transportation and setup.

*Purchased from first occupant/owners

1.0 INTRODUCTION

The objective of Task I was to develop and apply the analytical methodology which would accurately measure the effects of highway transportation and site installation activities upon the structural durability performance of typical mobile homes (both single-wide and double-wide types) during their useful life. Accordingly, in Task I a comprehensive dynamic and static analysis was performed by SwRI to identify and assess the *probable* dynamic and static loads (and stresses) imposed on the mobile homes during transit as well as typical setup-takedown procedures.

In an effort to make this Task I report comprehensible to those interested in the direct applicability of the Institute's findings as well as those more research oriented, this Dynamic Analysis Section (I) was divided into two volumes. Volume I (Applied Engineering Text) of Section I briefly describes the overall investigation. It also defines in detail the pertinent results as well as how the developed methodology can be readily applied to evaluating mobile home remaining useful life *(RUL)*. Volume II (Research and Development Text) describes in detail the systematic development and utilization of this mobile home dynamic analysis. Specifically, it includes the construction of the computer model through its utilization in the structural parametric study to the formulation of the *predictive equations* for defining *RUL*. Accordingly, with Volume I, the R & D text (Volume II) should be referred to for background information, development methodologies, etc.

2.0 PARAMETRIC INVESTIGATION FINDINGS

In the dynamic analyses, those parameters that were suspect at the beginning of this investigation were:

- Effective flexural stiffness (EI),
- Effective torsional stiffness (GJ),
- Road surface condition (rc),
- Mobile home transporting speed (V), and
- Mobile home damping properties (C_D).

The effective flexural stiffness of the mobile home, a term "coined" by Battelle Memorial Institute (BMI),[1] is the equivalent vertical bending stiffness of the unit, when considered as a simple beam rigidly supported at the hitch and wheel locations. It was BMI's belief that this structural property had a major influence on degradation, and could be used as a tool to estimate the quality and/or degradation of a mobile unit.

Similar to the effective bending stiffness, the effective torsional stiffness (GJ or J) can be considered in studying the mobile home's response to torsion (racking). Accordingly, in the Institute study, these stiffnesses, as well as speed, damping and road condition were investigated to determine which of these variable(s) has a significant effect on degradation. This was accomplished through a series of computer simulations of a 60-ft long, 14,000-lb unit, varying the parameters outlined above.

Results from the simulations emphasized the extreme sensitivity of induced "G" loadings in the mobile home to variations in effective torsional stiffness (GJ). It was further shown that variation in effective flexural stiffness (EI) did not affect the mobile home response accelerations to the same degree as the torsional stiffness.

Based on this parametric investigation via computer model simulations (detailed discussion in Volume II), the influence which the aforementioned structural and road-related properties have on mobile home degradation, is given below in *descending* order of importance.

(1) Effective torsional stiffness (GJ or J),

(2) Road surface condition (rc),

(3) Mobile home in-transit speed (V),

(4) Effective flexural stiffness (EI)*,

(5) Mobile home damping properties (C_D)*.

As noted from the computer simulations, the *effective torsional stiffness* seems to be the key parameter which should be considered and controlled if optimum *useful lives* for typical mobile homes are to be realized.

*For the rear section of the unit, changes in flexural stiffness were found to affect degradation to a greater extent than changes in damping properties. For the front section, however, the converse was found to be true.

3.0 PREDICTIVE EQUATION METHODOLOGY AND APPLICATION

Based on the findings outlined above, predictive equations were formulated* which incorporated the structural aspects of the mobile home as well as speed and road conditions and which addressed the problem of in-transit and setup-takedown degradation. These equations were based, in part, on results from the United Computer Systems (UCS) MULFIT computer program[2] which was used to develop regression equations based on SwRI findings. Specifically, from the data collected, utilizing the dynamic model simulations, the MULFIT program did a "best fit" analysis and derived the following expressions for evaluating mobile home degradation due to initial and secondary moves.

$$\sigma_R = 6.42 \times 10^4 \frac{V^{0.734} rc}{EI^{0.468} C_D^{0.363} \left[\text{Ln } 10^n - \dfrac{\text{Ln } 10^{n-1}}{n^2} \right]^{2.046}} \qquad (1)\dagger$$

$$\sigma_F = 7.13 \times 10^{-3} \frac{EI^{0.208} V^{0.530} rc}{C_D^{0.448} \left[\text{Ln } 10^n - \dfrac{\text{Ln } 10^{n-1}}{n^2} \right]^{1.610}} \qquad (2)\dagger$$

In the above,

σ_R – is the RMS‡ vertical acceleration (G units) of the mobile home rear corner,

σ_F – is the RMS vertical acceleration at an upper side wall location approximately midpoint between front axle and hitch,

V – is transport velocity (mph),

EI – is the effective vertical flexural stiffness (lb-in.^{2}),

J – is the effective torsional stiffness (in.^{4}),

C_D – is the structural damping of the unit ($0 < C_D < 1.0$).

TABLE 1

Road Condition	$\overline{rc}$
Paved (smooth)*	1.0
Paved (waves)**	1.2
Paved (rough)**	1.5
Unpaved (waves)	2.5
Gravel	3.0
Unpaved (rough)	10.0
Effective Torsional Stiffness (J in.^{4})	**n**
10	1
10^2	2
10^3	3
10^4	4
10^m	m

*Typical of primary roadways.
**Representative of secondary roadways.

and rc and n are found in Table 1. Equations (1) and (2) give an estimation of what the dynamic response of a particular mobile home will be during its move to a planned site. They also can be used to define the change in dynamic response due to setups and takedowns by substituting the appropriate reduced flexural and torsional stiffness (due to on-site procedures) into Expressions (1) and (2).

The remaining useful life (RUL) equation based on the above is:

$$RUL = 1 - \frac{(7.2 \times 10^3) fdP(\sigma_i > \sigma_B)}{VN_B} \qquad i = R \text{ or } F \qquad (3)^{**}$$

*Subject to modifications based on experimental findings from Task III study.
†Coefficient 6.42 X 10^4 and 7.13 X 10^{-3} defined to make expressions dimensionally homogeneous.
‡Root mean square value of acceleration also referred to as standard deviation. In terms of probabilities and random processes it correlates to a 68 percent confidence level that the actual acceleration levels will be equal to or less than this value.
**As with Expressions (1) and (2), Expression (3) coefficient 7.2 X 10^3 was defined to make equation dimensionally homogeneous.

where

R,F refer to the rear and front sections of the unit,

f – "apparent" response frequency of unit (Hz),

V– planned velocity of unit (mph),

d – distance between sites (miles),

$P(\sigma_i > \sigma_B)$* is the probability of the unit exceeding the "base" RMS acceleration and N_B is estimated number of times the "base" RMS value will be exceeded per 100 miles traveled by the unit. *The aforementioned "base ' values are input by the user and are assumed to be the RMS vertical acceleration response (σ_B) and number of occurrences (N_B) that a "zero remaining useful life" or unsafe mobile home would experience if it were transported 100 miles.* Physically, then, Expression (3) assumes the Remaining Useful Life (RUL) of a unit as zero when the total G levels experienced by the unit per 100 miles of travel exceeded the defined "base" values.

The overall procedure for estimating the *RUL* of a specific unit entails the following (see Appendix A for example):

(1) The user specifies the "base" structural parameters of a proposed "zero" life unit as well as planned velocity and probable road condition for this unit. He then utilizes Equations (1) and (2) to estimate the RMS acceleration (σ_B) at the rear corner and midpoint wall location between axle and hitch for this "zero" life unit.

(2) The user then estimates the number of occurrences (N_B) (per 100 miles traveled by the "zero" life unit) that σ_B will be exceeded. This is obtained from:

$$N_B = 7.2 \times 10^5 \frac{f_B}{V_B} [P'(\sigma_B)]\dagger$$

where f_B and V_B are estimated "base" frequency of response (Hz) and "base" velocity (mph).

(3) The user now estimates the RMS vertical acceleration (σ_i) for the present mobile home in question. This is obtained by inserting the appropriate structural parameters into Equations (1) and (2) along with the anticipated road condition and in-transit speed. (These values are either measured or estimated from available tables such as Table 1).

(4) Having determined the standard deviations (σ_i) for the mobile home, the probability of exceeding σ_B [i.e., $P(\sigma_i > \sigma_B)$], assuming a normal distribution, can be obtained from any standard statistical handbook.††

(5) The user then inputs $P(\sigma_i > \sigma_B)$ into (3) to obtain an estimation for the RUL of the unit when it reaches its setup site.

It is noted in Expression (2) that the RMS response for the location between axle and hitch is directly proportional to the unit's effective flexural stiffness (EI). Due to this, a newer mobile home would experience higher inertia loadings (G's) in this area than after this stiffness parameter has degraded. As a result, if the "base" values of a highly degraded unit were input into (2), the RMS response (σ_{FB}) would give an unrealistic level of degradation to the front section of the mobile home. This problem can be minimized if the user, when evaluating σ_{FB}, utilizes in (2) the actual flexural stiffness EI in place of EI_B.

Further details of how the above predictive methodology can be utilized may be found in Volume II.

*$P(\sigma_i > \sigma_B)$ is a function of the units speed, stiffness and damping as well as the type of road the unit is traveling.

†The probability $[P'(\sigma_B)]$ of the "base" unit exceeding σ_B is simply 0.317 or approximately 32 percent. (Definition of Standard Deviation)

††For example "Handbook of Probability and Statistics" by R. S. Burington and D.C. May.

4.0 DYNAMIC ANALYSIS OF SINGLE-WIDE (T-1)

As alluded to in the previous sections, transportation degradation is related to both the structural makeup of the unit as well as the transportation-related variables (i.e., road traveled and speed). Accordingly, an assessment of the performance of the T-1 under conditions I and II of Task I can vary substantially depending upon these variables. Because of this, the performance of the unit for each "condition" was investigated for various transportation modes (i.e., distance, speed, road type).

4.1 CONDITION I (T-1)

For this initial transportation condition (250-500 miles) from the manufacturer's plant to the owner's site the transportation modes shown in Table 2 were considered.

TABLE 2. TRANSPORTATION ARRAY (CONDITION I)

Condition	Distance, miles		Road Condition*			Typical Speed, mph		
	250	500	Well Paved	Paved, waves	Paved, rough	35	45	50
1A	X		X					X
1B		X	X					X
1C	X				X	X		
1D		X			X	X		
1E	X			X			X	
1F		X		X			X	

*Well paved: $\overline{rc}$ = 1.0 (primary roadways; above average secondary roads)
Paved (waves): $\overline{rc}$ = 1.2 (typical secondary roadways)
Paved (rough): $\overline{rc}$ = 1.5 (rough secondary roads)

Based on assumptions concerning a totally degraded T-1 unit (base unit), predictive Equations (1), (2) and (3) were utilized to define anticipated remaining useful life (*RUL*) or degradation for the various transportation modes given in Table 2. The results in terms of anticipated RMS vertical acceleration levels for the rear and front sections of the T-1 as well as degradation are given in Volume II. The degree of degradation was evaluated to be as low as *0.3 percent for the rear section* of the T-1 and as high as over *10 percent for the front section,* depending on the typical speed and the roughness of the (paved) road. It was also shown that the dynamic response and *the degree of degradation for the front section of the T-1 were anticipated to be greater than the rear portion of the unit.* This was attributed to the front section having torsionally weaker structural properties in comparison to the rear portion of the unit.

TABLE 3. TRANSPORTATION ARRAY FOR EACH MOVE (CONDITION II)

Condition	Distance, miles		Road Condition*			Typical Speed, mph		
	300	600	Well Paved	Paved, waves	Paved, rough	35	45	50
2A	X		X					X
2B		X	X					X
2C	X				X	X		
2D		X			X	X		
2E	X			X			X	
2F		X		X			X	

*Well paved; $\overline{rc}$ = 1.0
Paved (waves); $\overline{rc}$ = 1.2
Paved (rough); $\overline{rc}$ = 1.5

4.2 CONDITION II (T-1)

For this condition, the T-1 undergoes 15 years of use including three occupancy periods and two secondary moves ranging from 300 to 600 miles (including 4000 lb of added internal weight). As with Condition I, the unit's degradation depends, in part, on the transportation mode involved (i.e., road condition, speed, etc.). Accordingly, for these secondary moves, the transportation modes shown in Table 3 were considered.

From preliminary experimental data for the T-1, each setup and takedown was estimated to degrade the effective torsional and flexural stiffnesses for the front and rear sections of the unit in the following manner:

- 30-percent reduction in torsional stiffness for the front section (J_F).
- 40-percent reduction in torsional stiffness for the rear section (J_R).

- 20-percent reduction in flexural stiffness for the rear section (EI_R).

- 55-percent reduction in flexural stiffness for the front section (EI_F).

Based on the above, for each secondary move the structural parameters (EI, J) were reduced by these percentages when utilized with the predictive equations for defining transportation-related degradation.

As per the procedures used for Condition I along with the above-mentioned reduction in stiffnesses, the predictive Equations (1), (2) and (3) were used to estimate degradation of the T-1 for the modes shown in Table 3. *For the initial secondary move, the degradation to the unit varied from 0.2 percent to 42.2 percent depending on the transportation mode.* In comparison with the T-1's initial move, it was found that for this *initial* secondary move, the rear section degraded at a greater rate than the front section. This was the result of the dynamic response (RMS value) for the front section being directly proportional to the effective stiffness (EI_F). Accordingly, when a reduction in EI_F due to Condition I and setup and takedown occurred, the G levels experienced between axle(s) and hitch also diminished.

For the *second secondary move*, the structural properties were further reduced based on the previously defined percentages. With these reduced effective stiffnesses and the transportation modes defined in Table 3, the analytically evaluated degrees of degradation varied from *undefinable* for the front section to *100 percent* for the rear section.

4.3 CONDITION I AND II (T-1)

Based on the predictive analysis, the total degradation to this unit was assumed to be the sum of the degradation percentages for the various moves and setups and takedowns. As previously stated, the degradation depends, in part, upon the transportation modes experienced by the unit during the specified 15-year period. Based on the "best" and "worst" conditions from Tables 2 and 3, an assumed 15-year transportation mode array is given in Table 4. For these transportation modes, the probabilistic degradation to the T-1 was analytically evaluated. In terms of probable degradation levels for the entire unit (front and rear section), the lowest anticipated degradation to the unit was approximately *36 percent.* For seven of the defined twelve transportation modes the unit was anticipated to be *totally degraded* (i.e., zero *RUL*) after or during transit to its proposed *third* site (second secondary move).*

TABLE 4. TYPICAL SUMMATIONS IN TRANSPORTATION MODES FOR T-1 UNIT

Condition(s)*	Distance, miles		Road Condition			Typical Speed, mph		
	550	1700	Well Paved	Paved, waves	Paved, rough	35	45	50
1A plus 2A	X		X					X
1B plus 2B		X	X					X
1A plus 2C	X		X		X	X		X
1B plus 2D		X	X		X	X		X
1A plus 2E	X		X	X			X	X
1B plus 2F		X	X	X			X	X
1C plus 2C	X				X	X		
1D plus 2D		X			X	X		
1C plus 2E	X			X	X	X	X	
1D plus 2F		X		X	X	X	X	
1E plus 2E	X			X			X	
1F plus 2F		X		X			X	

*Conditions are summations taken from Tables 2 and 3. Includes degradation due to setup-takedown procedures.

Furthermore, it was noted that the rate of degradation was anticipated to be substantially greater for the rear section of the single-wide in comparison to the front section. Specifically, while a maximum 100 percent degradation was estimated for the rear section (for certain modes), the maximum level of degradation to the front section of the unit was estimated as *20 percent.*

*Note: The analysis did not consider the degradation incurred by the T-1 during its final setup at its third and last site. This would be included if the unit was taken down to be moved to a *fourth site.*

5.0 DYNAMIC ANALYSIS OF DOUBLE-WIDE (T-2A, T-2B)

For the evaluation of this unit, the *a priori* assumption was made that the T-2 could tolerate acceleration levels (*G* levels) *no greater* than the single-wide (T-1). Accordingly, in the following the "base" RMS values assumed for a *totally degraded* T-1 were used (details are given in Volume II).

5.1 CONDITION I (T-2B)

For this half of the double-wide (dry side, containing no plumbing fixtures), the transportation modes defined in Table 2 were also utilized. Based on these modes, the anticipated RMS acceleration levels and resulting degradation were evaluated. *For the initial move, the anticipated degradation varied from a low of 0.2 percent for the front section to a high of 28 percent for the rear section,* depending on the road traversed by the unit and the transport speed. It is further noted that the predictive analysis also defined *a higher degree of degradation for the rear section of the T-2B in comparison to its front section.* This is opposite the anticipated degradation effect for the T-1 and is believed due, in part, to the T-1 having a structurally very sound rear section compared to the T-2B rear section. It is also due to the flexural stiffness (EI_F) for the front section of the T-2B, which is less than the T-1's counterpart. Specifically, as noted previously, the dynamic response for the front section was found to be directly proportional to its flexural stiffness. Accordingly, the combination of a weaker rear section for the T-2B and a flexurally less stiff front section, when compared with the T-1, resulted in this anticipated *reverse sense* of degradation.

5.2 CONDITION II (T-2B)

For this condition, the T-2 unit (both wet and dry sides) is to experience 20 years of use including two occupancy periods and one secondary transportation move ranging from 300 to 600 miles. The transportation modes given in Table 3 are hence, still applicable. In addition, as per the T-1 unit, preliminary mobile home transportation test data performed at SwRI indicated the following reduction in structural properties for the T-2B as the result of a single setup and takedown:

- 40-percent reduction in effective flexural stiffness for the front section (EI_F),
- 50-percent reduction in effective flexural stiffness for the rear section (EI_R),
- 45-percent reduction in effective torsional stiffness for the front section (J_F), and
- 60-percent reduction in the effective torsional stiffness (J_R) for the rear section of the unit.

With this reduction in structural properties, the anticipated dynamic response and amount of degradation during the unit's *secondary move*, were evaluated. *The results show that prior to or upon arrival at the secondary setup site, the T-2B's rear section is predicted to have totally degraded. Conversely, only minimal degradation to the front section was anticipated.* The total anticipated degradation to the T-2B for *both the initial move to the owner's setup site and secondary move* (in terms of transportation modes given in Table 5), were found to vary from a minimum of *0.4 percent* to *19.4 percent* for the front section of the unit. For *all* the transportation modes, the rear section was anticipated to be *totally degraded* prior to or upon reaching its *final* setup site.

TABLE 5. TYPICAL SUMMATIONS IN TRANSPORTATION MODES FOR T-2 MOBILE HOME

Condition(s)*	Distance, miles		Road Condition			Typical Speed, mph		
	550	1100	Well Paved	Paved, waves	Paved, rough	35	45	50
1A plus 2A	X		X					X
1B plus 2B		X	X					X
1A plus 2C	X		X		X	X		X
1B plus 2D		X	X		X	X		X
1A plus 2E	X		X	X			X	X
1B plus 2F		X	X	X			X	X
1C plus 2C	X				X	X		
1D plus 2D		X			X	X		
1C plus 2E	X			X	X	X	X	
1D plus 2F		X		X	X	X	X	
1E plus 2E	X			X			X	
1F plus 2F		X		X			X	

*Conditions are summations taken from Tables 2 and 3.

5.3 CONDITION I (T-2A)

For this half section of the double-wide (wet side), using the same evaluation procedures (and transportation modes) utilized with the T-1 and T-2B, the *anticipated degradation for the T-2A was estimated to vary from 0.2 percent to 12.8 percent for the front section. The rear section was found to degrade from 4.6 percent to 35.4 percent depending on the transportation mode.**

5.4 CONDITION II (T-2A)

As with the T-2B, preliminary experimental data indicated the following reductions in flexural and torsional stiffness due to a single setup and takedown.

- 50-percent reduction in EI_F,
- 6-percent reduction in EI_R,
- 50-percent reduction in J_F, and
- 20-percent reduction in J_R.

Utilizing the above-defined reductions, the appropriate stiffnesses were substituted into the predictive equations for the transportation modes defined in Table 3. *Based on this analysis the rear section of this half of the double-wide was anticipated to degrade from 9.4 to 72.6 percent while the front was anticipated to degrade from 1.2 to 25.6 percent.*

The total anticipated degradation for the T-2A was based on the transportation modes defined in Table 5. *For these modes the unit was estimated to degrade from 1.4 to 38.4 percent for the front section. The rear section of the T-2A was anticipated to degrade less than the T-2B, i.e., from 14.0 to 100 percent.* Only *one* transportation mode resulted in *total* degradation of the rear portion of the unit compared with *all* the modes for the secondary move of the T-2B. In addition, as with the T-2B, the front section of the T-2A was anticipated to degrade at a slower rate than the rear section of the unit.

*Further details in Volume II.

6.0 COMPARISON OF IN-TRANSIT VERSUS SETUP-TAKEDOWN DEGRADATION

In the previous sections, degradation due to initial and secondary moves as well as on-site procedures was analytically evaluated for both the single-wide (T-1) and double-wide (T-2) units. The same methodology was applied to gain insight on the sensitivity to degradation that typical on-site procedures induce in a unit in comparison to degradation experienced by a unit while on the road. This was handled by making the *a priori* assumption that the unit makes the initial and secondary moves without any setups and takedowns. Accordingly, the evaluated degradation would then be wholly due to in-transit phenomena. A comparison of this section's findings with Sections 4 and 5 would then approximate the amount of degradation due solely to typical on-site procedures.

6.1 SINGLE-WIDE (T-1)

For the T-1, the degradation due to the initial move was as previously defined (for the transportation modes defined in Table 2). For the secondary moves, Table 3 as well as Table 4 are still valid with the exception that no setup-takedown degradation is assumed after each move. In terms of structural properties for the unit, the initial values assumed were held constant for all the moves. *While it was realized that this is not the case, at present there does exist enough information available which would permit one to conjecture on a definable relationship between the structural parameters (EI_F, EI_R, J_F, J_R) and in-transit conditions (e.g., speed, road-type).* Furthermore, in terms of reductions in torsional stiffness, a reduced parameter was input to the predictive equations to account for reductions in this variable due to a move. In terms of the flexural stiffness, it was noted that a change in this variable had only a small effect on the dynamic response of the unit. Accordingly, based on the above, the appropriate T-1 stiffness expressions were substituted into the predictive Equations (1), (2) and (3) for the conditions given in Table 3. The degradation results for each secondary move varied from a low of *0.4 percent* (rear section) to a high of *12.5 percent* for the front section. For the total transportation mode array (Table 4), the anticipated degradation varied from *1.1 percent* for the rear section to *35.4 percent* for the front section.

Comparing these results with the previous findings, it was noted that the *setup-takedown procedure attributed to well over 90-percent of the degradation in the rear section of the T-1 for most of the transportation modes.* Contrary to this phenomenon, the front section was evaluated to degrade *more* when no setups and takedowns were considered. It is noted, however, that the values in this instance cannot be wholly relied upon and are attributed to the predictive equations for front unit response (Equation 2) being directly proportional to flexural stiffness (EI_F).

Due to the above limiting assumptions, it is anticipated that the estimated degradation (percentages) are probabilistically *low* for the rear section of the T-1 and *high* for the front section. The findings are, however, of value in that they exemplify the following:

- Setup and takedown procedures for Conditions I and II for the T-1 may cause a larger degree of degradation to the unit's rear section in comparison to the corresponding degradation resulting from move between sites.

- A reduced flexural stiffness for the front section of the unit may result in significant "savings" in terms of a smaller degradation rate.

6.2 DOUBLE-WIDE (T-2)

As per the case with the single-wide, in an effort to define degradation due to setups and takedowns for this unit, the same *a priori* assumptions concerning structural stiffnesses were made. Accordingly, for the initial moves, degradation evaluations previously defined were still valid, as well as the transportation arrays illustrated in Tables 2 and 3. With the above conditions imposed, precluding degradation resulting from setups and takedowns, the degree(s) of degradation for the T-2A and T-2B were evaluated and found to vary from *0.2 percent (front section T-2A and T-2B) to 42.5 percent (rear section, T-2A).* A comparison of findings illustrated a substantial savings in "useful life" when degradation due to setup-takedown procedures are excluded. As with the T-1, however, the degradation levels are anticipated to be on the low side. With this in mind, however, the following pertinent findings can be made:

- The majority of the degradation to the rear section of the T-2B may be due to setup-takedown techniques.

- The degradation effects of setup and takedown for the T-2A is not as severe as for the T-2B.

- For both the T-2A and T-2B, typical setup and takedown procedures degrade the rear sections of the unit to a greater extent than what is incurred by the front sections.

7.0 POTENTIAL APPLICATIONS OF CRITERIA

As a result of the dynamic analysis and correlation of data with the necessary factors to develop the Remaining Useful Life Analysis, the following method of obtaining design loads for mobile home manufacturers is recommended.

A set of predictive equations have been presented to be used as a tool for estimating degradation due to the effects of transportation. These regression formulae can also be utilized to define dynamic load levels for both the rear and front sections of the unit. This latter aspect can be of use to the manufacturer during the construction of the individual homes. Specifically, if the probable dynamic load levels within a particular unit can be defined prior to the design of the unit, then the designer can determine if the present construction warrants modifications to enhance its structural integrity.

Based on the above premise, a set of graphs were constructed to estimate design load requirements for mobile homes. *Figures 1 through 4 are given to define dynamic load levels for the rear section, while Figures 5 through 8 are for the front section (between axle and hitch).* In either case, the resultant design loads are a function of the input structural stiffnesses (EI and J), damping property (C_D), speed and road conditions. Accordingly, depending upon the structural integrity of the unit as well as the anticipated speed and road to be safely traversed, the dynamic response (in *G's*) can be estimated for which the unit can be safely designed to withstand.

It is noted that resultant loads obtained from Figures 4 and 8 present a 99-percent confidence level. That is, 99 percent of the induced dynamic loads to the unit for a specific travel condition (speed, road) will probabilistically be equal to or less than these values. The graphs can hence be used by a manufacturer to define acceptable design requirements for structural components within a mobile home.

As noted, these enclosed graphs allow the builder, designer, etc., to set his own design loads by presenting a range of structural properties (EI, J and C_D). The values input can be based on actual field test data of existing units or be based on anticipated structural properties after a degree of degradation has occurred. This latter approach would be advantageous since, the dynamic response (and load levels) are anticipated to increase as the unit degrades. An example of how this criteria can be applied is given in the Appendix of Volume II. These potential criteria will be evaluated in a later task.

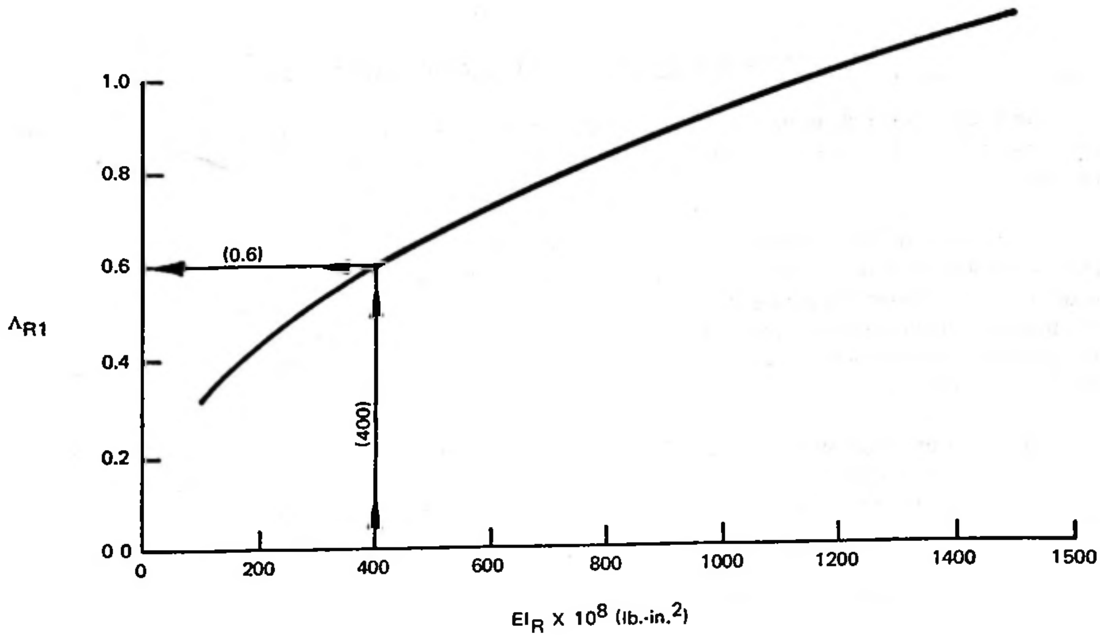

FIGURE 1. EFFECT OF FLEXURAL STIFFNESS ON DYNAMIC RESPONSE PARAMETER

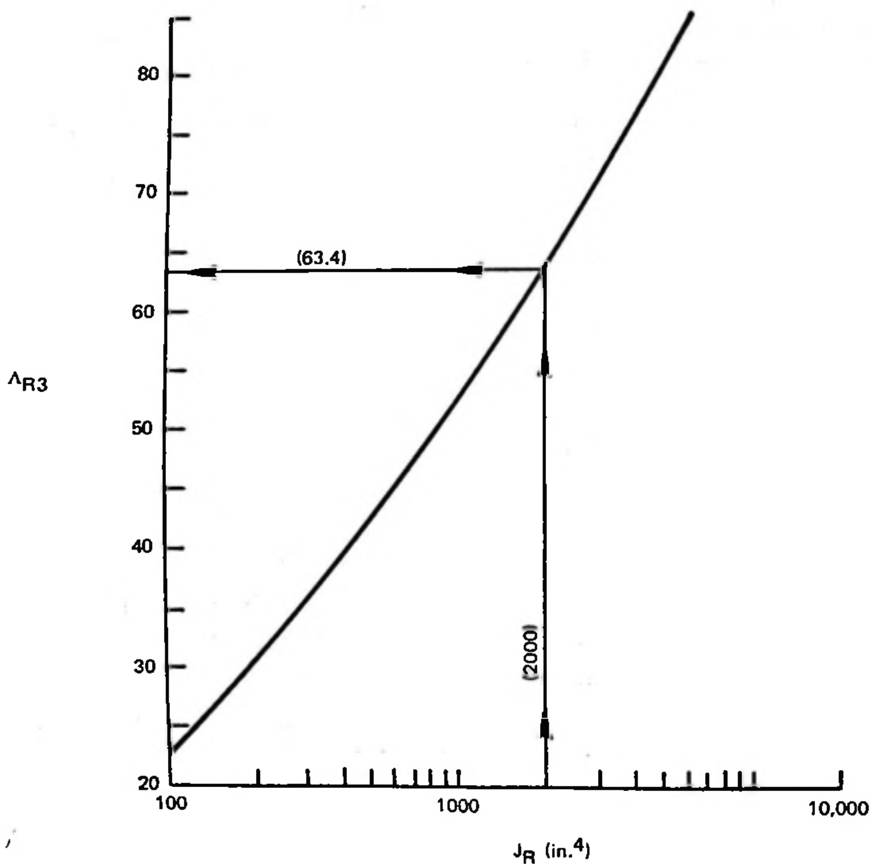

FIGURE 2. EFFECT OF TORSIONAL STIFFNESS ON DYNAMIC RESPONSE PARAMETER

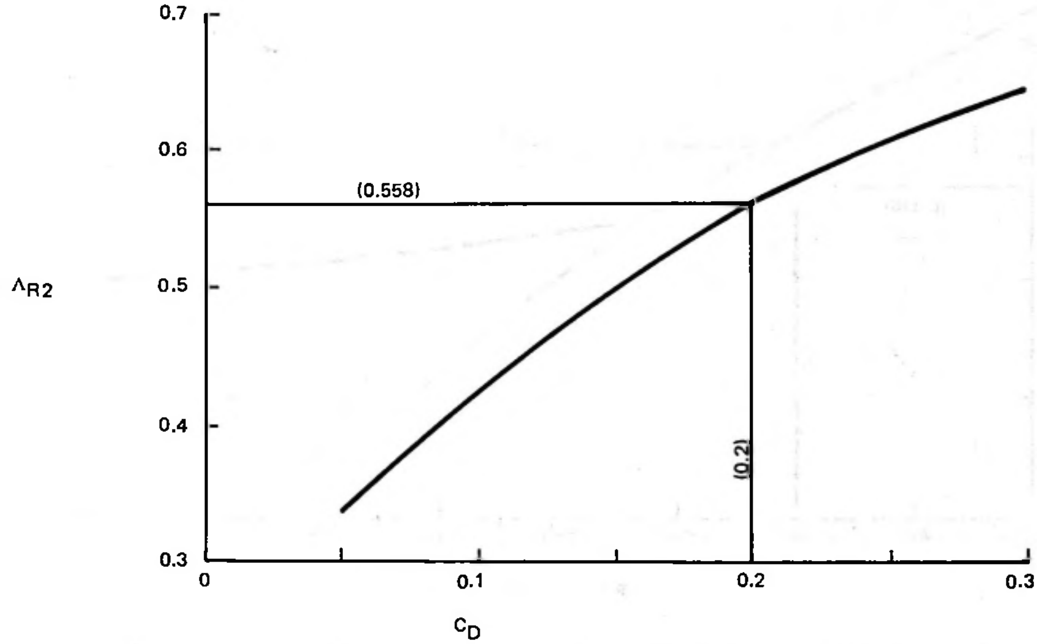

FIGURE 3. EFFECT OF DAMPING ON DYNAMIC RESPONSE PARAMETER

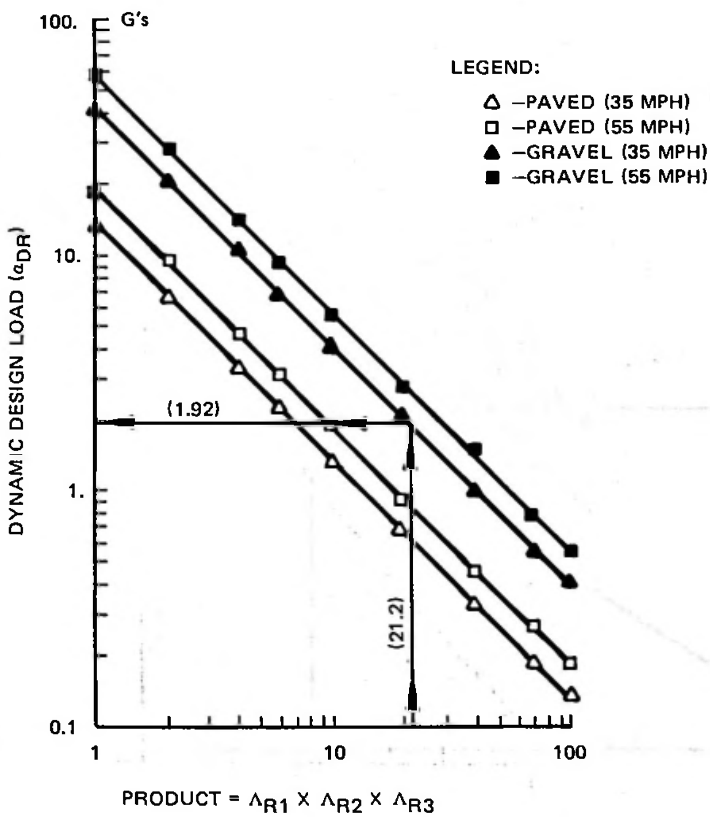

FIGURE 4. DEFINING ANTICIPATED DYNAMIC RESPONSE
FOR REAR SECTION OF HOME

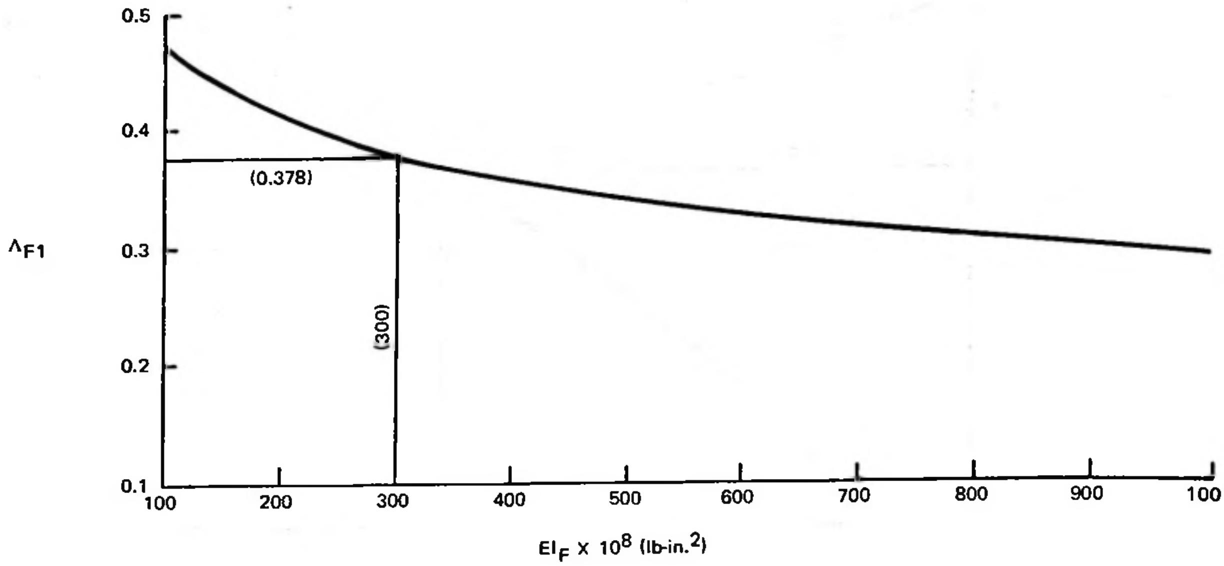

FIGURE 5. EFFECT OF FLEXURAL STIFFNESS ON DYNAMIC RESPONSE PARAMETER

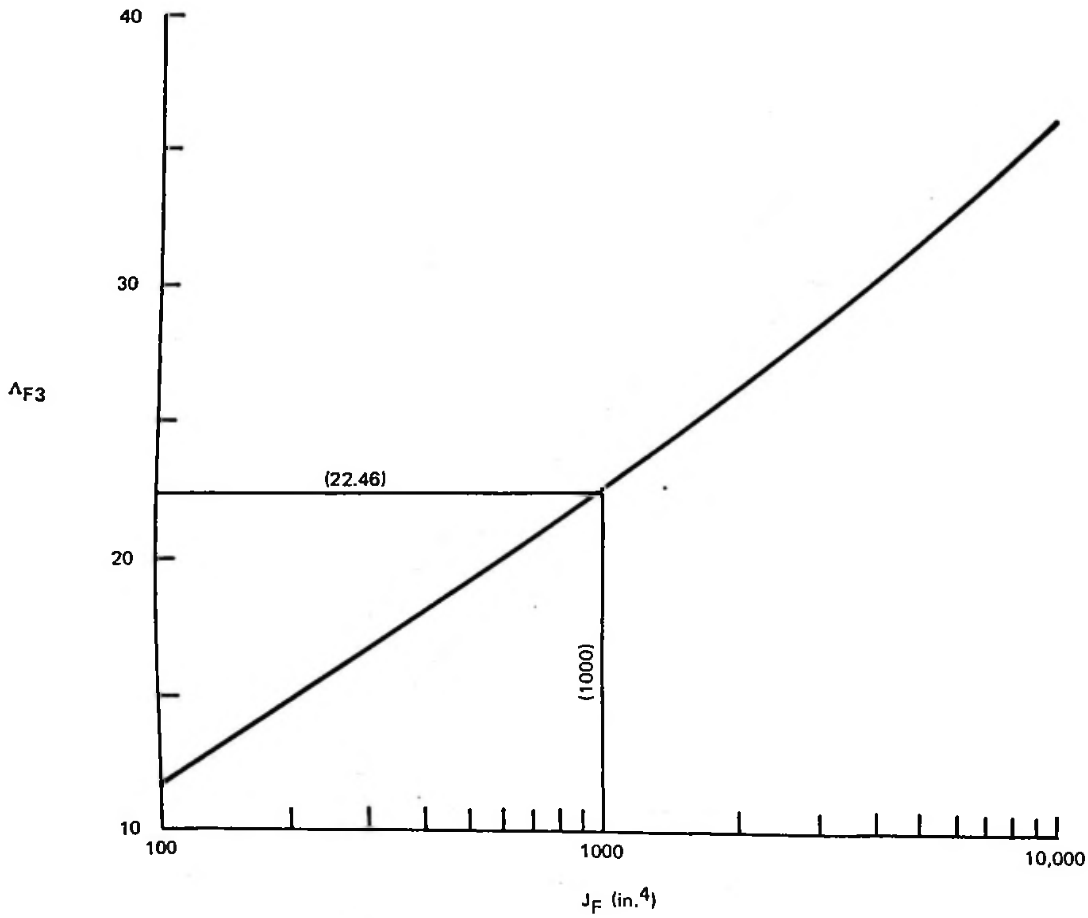

FIGURE 6. EFFECT OF TORSIONAL STIFFNESS ON DYNAMIC RESPONSE PARAMETER

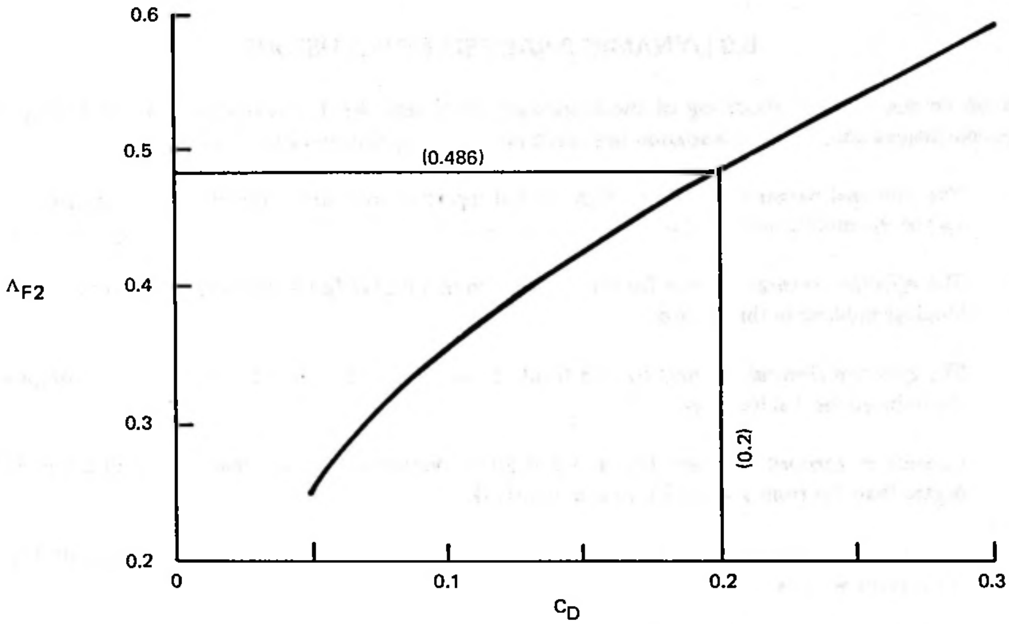

FIGURE 7. EFFECT OF DAMPING ON DYNAMIC RESPONSE PARAMETER

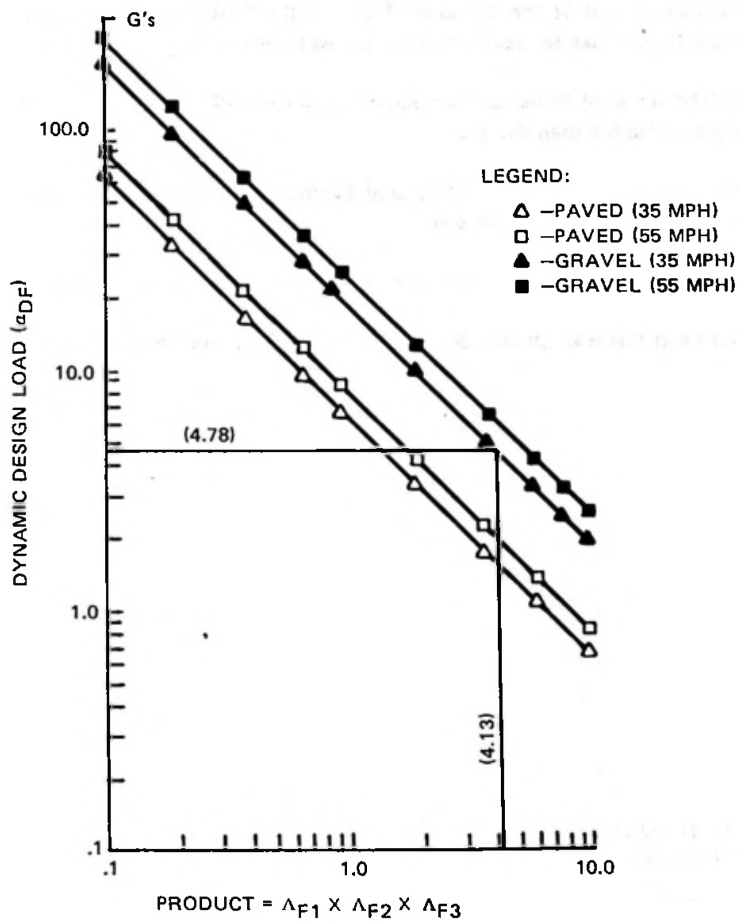

FIGURE 8. DEFINING ANTICIPATED DYNAMIC RESPONSE FOR FRONT SECTION OF HOME

8.0 DYNAMIC ANALYSIS CONCLUSIONS

Based on the dynamic modeling of the single-wide (T-1) and the double-wide (T-2A and B), the following *tentative* conclusions concerning degradation to mobile homes during transit have been drawn:

- The principal parameter affecting high inertial repetitive loads is the *effective torsional stiffness* (J_F and J_R) of the mobile home.
- The *effective flexural stiffness* for the rear section of a unit (EI_R) is inversely proportional to the inertial loadings induced in this section.
- The *effective flexural stiffness* for the front section (EI_F) of a mobile home is directly proportional to the induced inertial loadings.
- Changes in *torsional stiffness* (J_R and J_F) affect degradation of the rear section of a unit to a larger degree than the front section (from axle to hitch).
- Accumulative degradation of the rear section of a mobile home is more sensitive to transport speed than is the front section.
- For Conditions I and II the T-1 and T-2 units' rear sections are anticipated to degrade at a substantially faster rate than their front sections.*
- The rear section of the dry side (T-2B) of the double-wide is anticipated to degrade at a greater rate during transit than the rear section of the wet side (T-2A).†
- For the required initial and secondary moves (Conditions I and II), the T-1 was determined to have a longer useful life than the T-2.
- Degradation due to typical setup and takedown procedures may cause more degradation to a mobile home than in-transit phenomena.
- The degradation effect of setup-takedown procedures is greatest in the rear section of a mobile home.

As alluded to in this text, further details concerning the above findings may be found in Volume II (Section I) of this report.

*Based on Tables 14, 17 and 19 in Volume II.
†Based on Tables 17 and 19 in Volume II.

REFERENCES

1. Bearint, D.E. and Cress, H.A., "The Development of Performance Based Tests to Determine the Minimum Structural Integrity of Mobile Homes," Final Report, Battelle Memorial Institute, Columbus, Ohio, July 25, 1966.

2. United Computer Systems, *APEX/FORTRAN Reference Manual*, 1976.

APPENDIX A

SAMPLE PROBLEMS OF PREDICTIVE METHODOLOGY

In an effort to give a better understanding of the predictive equations, three illustrative "hypothetical" examples are given in the following:

A. A mortgage company has defined a high risk mobile home as one which has approximately a 32-percent probability (standard deviation) of experiencing at an upper rear corner location, inertia loadings (vertical direction) of 8.2 G's* or more when being transported over a paved highway at 55 mph. In terms of the pertinent structural properties, this "base" unit has:

$$EI_B = 164 \times 10^8 \text{ lb.-in.}^2$$

$$J_B = 10 \text{ in.}^4 \quad (n = 1)$$

$$C_{DB} = 0.10$$

The number of probable occurrences at which this acceleration level will be exceeded assuming a frequency response (f_B) of 5 Hz is:

$$N_B = \frac{(7.2 \times 10^5)(0.317)5}{55} = 2.07 \times 10^4 \text{ (per 100 miles)}$$

The mortgage company is interested in making a secondary loan on a particular mobile home. The owner plans to transport the unit from Childress to San Antonio, Texas (d = 400 miles) at the maximum allowable speed (55 mph) over essentially well paved and secondary roads. The unit's structural integrity is estimated in terms of its effective flexural stiffness, torsional stiffness, apparent frequency, and structural damping, i.e.,

$$EI = 120 \times 10^8 \text{ lb-in.}^2$$

$$J = 1000 \text{ in.}^4 \quad (n = 3)$$

$$C_D = 0.10$$

$$f = 5 \text{ Hz}^\dagger$$

*This value would be based on available data or from predictive equations with input of "poor structural properties" (i.e., EI_B, J_B etc.).
†It is noted that the apparent response frequency is dependent upon the type of road traveled as well as anticipated speed and structural makeup of the unit. Here it is assumed same as "base" value. The procedure for estimating f is given in Appendix A of this report.

Substituting this data into equation (1), the mortgage company obtains:

$$\sigma_R = 6.42 \times 10^4 \frac{(55)^{0.734}(1)}{(120 \times 10^8)^{0.468}(0.10)^{0.363}\left[\text{Ln } 10^3 - \dfrac{\text{Ln } 10^2}{9}\right]^{2.046}}$$

$$= \frac{1.22 \times 10^6}{1.01 \times 10^6} = 1.2 \text{ G's}$$

The standard deviation (RMS) of the mobile home is 1.2 G's..

The probability of exceeding 8.2 G's $[P(\sigma_i > \sigma_B)^*]$ is less than 0.002 (0.2 percent). Assuming 0.002 and substituting this data into equation (3) one obtains:

$$RUL = 1 - \frac{(7.2 \times 10^3)(5)(400)(0.002)}{55(2.07 \times 10^4)}$$

$$= 1 - 0.03 = 0.97$$

The unit's anticipated *RUL* when it reaches San Antonio is 97 percent or the unit lost 3 percent of its useful life during the move.

B. The second hypothetical example is same as the former except that the proposed road conditions are primarily unpaved (wavy). In this instance (from Table 1) $rc = 2.5$.

Substituting this change into equation (1), the RMS vertical acceleration is:

$$\sigma_R = 6.42 \times 10^4 \frac{(55)^{0.734}(2.5)}{(120 \times 10^8)^{0.468}(0.10)^{0.363}\left[\text{Ln } 10^3 - \dfrac{\text{Ln } 10^2}{9}\right]^{2.046}}$$

$$= \frac{3.04 \times 10^6}{1.01 \times 10^6} = 3.0 \text{ G's}$$

The probability $P(\sigma_R > \sigma_B)$ of exceeding 8.2 G's (2.73 σ) is approximately 0.007 (0.7 percent). Substituting the required data in (3):

$$RUL = 1 - \frac{(7.2 \times 10^3)(5)(400)(0.007)}{55(2.07) \times 10^4)}$$

$$= 1 - 0.09 = 0.91$$

The units anticipated *RUL* when it reaches San Antonio is 91 percent (the move would consume an estimated 9 percent of the mobile homes "useful life"). It is noted that in Example B the mobile home was assumed transported 400 miles over unpaved road to show an example where the *RUL* is substantially reduced.

For a variety of different road conditions and speed during transit of the unit, equations (1), (2) and (3) are modified as:

$^*\sigma_B = 8.2$ G; $\sigma = 1.2$ G; hence $\sigma_B = 6.83\sigma$ and P $(\sigma_i > 6.83\sigma)$ is less than .002

$$\sigma_{RK} = 6.42 \times 10^4 \frac{V_k^{0.734} rc_k}{EI^{0.468} C_D^{0.363} \left[\text{Ln } 10^n - \frac{\text{Ln } 10^{n-1}}{n^2} \right]^{2.046}} \tag{1'}$$

$$\sigma_{FK} = 7.13 \times 10^{-3} \frac{EI^{0.208} V_k^{0.530} rc_k}{C_D^{0.448} \left[\text{Ln } 10^n - \frac{\text{Ln } 10^{n-1}}{n^2} \right]^{1.610}} \tag{2'}$$

$$RUL = 1 - \frac{7.2 \times 10^3}{N_B} \frac{\Sigma d_k f_k P_k(\sigma_i > \sigma_B)}{V_k} \quad k = 1, 2, 3 \ldots . \tag{3'}$$

where the subscript "k" denotes the different anticipated road conditions (rc_k) during transit, the corresponding miles of each type of road (d_k) and proposed speed (V_k for each road).

As an example, consider the following:

C. The above unit is to be transported under the following conditions to San Antonio from Childress, Texas (a total of 400 miles).

- d_1 = 200 miles

  V_1 = 55 mph

  rc_1 = 1 (paved road)

  f_1 = 4 Hz

- d_2 = 100 miles

  V_2 = 45 mph

  rc_2 = 2.5 [unpaved (waves) road]

  f_2 = 5 Hz

- d_3 = 100 miles

  V_3 = 35 mph

  rc_3 = 3.0 (gravel road)

  f_3 = 6 Hz

It is decided that equation (1'), the response of the rear section, will be used to evaluate anticipated *RUL*. Accordingly, for each road condition we obtain:

$$\sigma_{RI} = 6.42 \times 10^4 \frac{(55)^{0.734}(1)}{(120 \times 10^8)^{0.468}(0.10)^{0.363} \left[\text{Ln } 10^3 - \frac{\text{Ln } 10^2}{9} \right]^{2.046}}$$

$$= \frac{1.22 \times 10^6}{1.01 \times 10^6} = 1.2 \text{ G's}$$

$$\sigma_{R2} = 6.42 \times 10^4 \frac{(45)^{0.734}(2.5)}{(120 \times 10^8)^{0.468}(0.10)^{0.363}\left[\text{Ln } 10^3 - \dfrac{\text{Ln } 10^2}{9}\right]^{2.046}}$$

$$= \frac{2.62 \times 10^6}{1.01 \times 10^6} = 2.60 \text{ G's}$$

$$\sigma_{R3} = 6.42 \times 10^4 \frac{(35)^{0.734}(3.0)}{(120 \times 10^8)^{0.468}(0.10)^{0.363}\left[\text{Ln } 10^3 - \dfrac{\text{Ln } 10^2}{9}\right]^{2.046}}$$

$$= \frac{2.62 \times 10^6}{1.01 \times 10^6} = 2.60 \text{ G's}$$

The above are the RMS vertical accelerations for the unit for the three different road speeds and road conditions. The corresponding probabilities of exceeding the "base" RMS value (8.2 G's) are:

$$P_1(\sigma_{R1} > \sigma_B) < 0.002 \text{ (0.2 percent)}$$

$$P_2(\sigma_{R2} > \sigma_B) = P_3(\sigma_{R3} > \sigma_B) \cong 0.003 \text{ (0.3 percent)}$$

These probabilities along with the corresponding velocities, frequencies and distances are substituted into expression (3') i.e.,

$$RUL = 1 - \frac{7.2 \times 10^3}{2.07 \times 10^4}\left[\frac{(200)(4)(0.002)}{55} + \frac{(100)(5)(0.002)}{45} + \frac{(100)(6)(0.003)}{35}\right] = 1 - 0.04 = 0.96$$

which approximates the remaining useful life of the mobile home upon reaching the installation site as 96 percent or in terms of degradation, the trip has "cost" 4 percent of the unit's *RUL.*

DYNAMIC ANALYSIS
RESEARCH AND DEVELOPMENT TEXT

DYNAMIC ANALYSIS
RESEARCH AND DEVELOPMENT TEXT

Prepared by

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ABSTRACT

This volume is the result of extensive computer modeling of intransit mobile homes. The study included a parametric investigation of the effect of changes in structural properties of mobile homes to probabilistic dynamic response and vice versa. In addition, the effect of road type and transport speed was also evaluated in terms of induced dynamic loadings. Results include regression equations that can be used by designers to define probable dynamic loadings of a mobile home during transit. Moreover, methodology is presented that can be used to gain insight into the anticipated remaining useful life of a particular unit.

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INTRODUCTION

The mobile home program conducted by the Institute is an eight task work effort entitled "Measurement and Evaluation of Structural Durability and Transportation Effects on Mobile Homes". These factors include over-the-road transportation, on-site setups and takedowns, and occupancy during the designated periods of time.

The objectives of the overall mobile home program are noted as:

(1) accurately measure, by analysis and/or test, the effects of highway transportation and site installation activities upon the structural durability performance of typical mobile homes (both single-wide and double-wide types) during their useful lives;

(2) to evaluate the current Federal Mobile Home Construction and Safety Standards to determine if clarification or revision is needed, particularly in "Subpart J", based upon the results of this research program;

(3) to develop a transportation-analysis methodology which could be used as a guide by enforcement agencies in uniformly evaluating the adequacy of manufacturer's plans and calculations for compliance with the Federal Construction and Safety Standards; and

(4) to develop an effective transportation field test method to judge the actual performance of a mobile home in meeting the Federal Standard.

The program is divided into eight (8) distinct Tasks or individual work efforts and a separate volume or report will be prepared for each task in order to submit the sequential work efforts in progressive steps for approval by the GTR.

The basic program involves the development of an analytical and predictive methodology for use on mobile home design and analysis in TASK I that is to be verified by experimental testing in TASK III. In order to better understand the program, the contractual requirements of TASK I, they are quoted as follows:

TASK I: ANALYTICAL DYNAMIC STRESS ANALYSIS: SwRI shall perform a comprehensive analytical dynamic stress and fatigue analysis and assessment for the new single-wide (T1) and the new double-wide (T2) mobile homes. The analyses shall identify and compute the probable dynamic loads and stresses which may be cumulatively imposed upon these new mobile homes as a result of normal transportation and site installation activities and assess the capability of the mobile homes to successfully resist these effects over their useful life spans.

SwRI shall calculate, analyze and assess the performance of the aforementioned mobile home assuming the following two separate and distinct loading conditions:

Condition I: Newly purchased units transported between 250 to 500 miles from the manufacturer's plant and installed upon the purchaser's site (initial transportation);

Condition II: The aforementioned units after the following activities have occurred:

T1: Fifteen (15) years of use, including three occupancy periods and two secondary transportation movements ranging between 300 to 600 miles. An added distributed weight of 4,000 pounds of occupants' personal effects shall be included in the transportation calculations.

T2: Twenty (20) years of use including two occupancy periods and one (1) secondary transportation movement ranging between 300 to 600 miles. An added distributed total weight of 8,000 pounds of occupants' personal effects shall be included in the transportation calculations.

For purposes of this task the SwRI shall assume a mix of seasonal highway travel factors (including wind forces) which will simulate various interstate, secondary and rural road conditions in terms of climate, grade, roadway surface, speed and traffic. Prior to conducting the dynamic stress and fatigue analyses, SwRI shall develop, justify and provide for approval by the GTR, the assumptions made as to the magnitude of raw shock and vibration forces that could realistically be encountered by each of the mobile home's chassis and frames under varying transportation and set-up conditions.

The SwRI's dynamic stress and fatigue analyses shall be clearly presented on exploded isometric type of drawings which shall display the transportation and site installation input forces and the resulting loads and stresses imposed upon the mobile homes, both as integrated structures and their separate systems. Supporting calculations shall be in full detail and presented in an organized manner to key with the specific drawings. The Institute shall identify and calculate the applicable input shock (measured in gravitational "G" forces) and vibration (frequency in Hertz). The stresses resulting from these induced forces (measured in terms of fatigue, bending, shear, etc.) and deflections upon the various structural members shall be identified and calculated. The performance of these structural members shall be assessed. SwRI shall separately compute, analyze and assess the probable structural degradation, or consumed life, for both Conditions I and II earlier defined, at the following points and locations as a minimum:

Structure: *Roof*—At the connection of the roof trusses to the sidewall framing, at the roof membrane/ sidewall interface, on the top and bottom chords of the roof trusses, on top of the furnace vent outlet. *Ceiling*—At the attachment to the roof trusses. *Exterior Walls*—At the sidewall and endwall interface with window and door frames, on window glazing, on exterior siding panels particularly on the foreward side of the mobile home. *Interior Walls*—On sidewall and endwall paneling, on partition walls particularly at the juncture with the sidewall and the ceiling. *Floor*—At selected points particularly over the axles and in the corridor, at joist splices and large notches; and at window and door locations. *Frame*—On the longitudinal "I" beams, crossmembers and outriggers particularly above the axles.

Plumbing: On the shower stall, bathroom sink and tub, toilet and flush tank, water heater, kitchen sink, selected locations on piping, joints and connections and supports.

Heating and Cooling: At the connection of the furnace vent with the furnace, at the supply duct connection with the furnace, on the longest supply duct and on the air-conditioning unit.

Electrical: On selected "snap-in" type receptacles.

Running Gear: On axles, wheels, tires, brakes, spring suspension, drawbar and coupling mechanism.

SwRI, upon completion of all of the above-defined research shall provide a comprehensive report embodying the results.

The analyses and assessments for both Conditions I and II above shall be presented in the following form:

1. Exploded isometric scale drawings identifying the probable input forces and the resulting loads and stresses imposed upon specific members or sections of each of the mobile homes.

2. Calculations fully supporting the drawings and graphs.

3. An evaluation assessing the performance of specific sections of each mobile home as well as the entire unit as an integral structure, and

4. Narrative explaining the concept, methodology and meaning of the analytical results.

The above requirements constitute a pioneering effort in predictive analyses for an integrated composite structure such as is used in the fabrication of a mobile home, containing steel, wood, aluminum, plastics assembled with glue, staples, nails, bolts and screws.

In addition to providing the above listed contract-deliverables, for the completion of TASK I, it is also necessary to provide the requisite analytical, predictive and detailed stress analysis as the basis for the conduct of the actual experimental instrumentation and test program of two (2) used and two (2) new mobile homes to confirm, if possible, the predictions of TASK I.

DEFINITIONS

The following pages contain definitions of physical words or terms used within the context of the TASK I effort.

CONSUMED LIFE: This is defined using the structural system of the mobile home as the basis for progressive degradation that eventually deteriorates the unit to the point that the useful life has been used up or consumed rendering the home unfit for:

- Transportation Modes
- Live-ability or occupancy
- Mortgage, Financial or Insurance Risk (See RUL, Remaining Useful Life and Structural Degradation)

STRUCTURAL DEGRADATION: Degradation measured in the form of structural stiffness and integrity with a factory new mobile home noted as "un-degraded". The reduction in structural stiffness is measured in two forms: (1) vertical stiffness designated as EI and (2) torsional stiffness designated as GJ. Other indicators of structural degradation are: increased deflections with decreased accelerations indicating a "softening" or loosening of the structure.

REMAINING USEFUL LIFE (RUL): TASK I utilizes this percent of useful life that is used up due to the transportation, setup and takedown cycle with a new/un-used mobile home designated as a unit of 1.0 or has 100 percent of its useful life left. Any operation will degrade the mobile home to some degree there-on. A zero percent RUL indicates the unit (or part of the unit) has been totally degraded.

DYNAMIC ANALYSIS MODEL: In order to totally analyze the mobile home, it was necessary to separate the TASK I predictive analysis into two modes: dynamic and static. The dynamic model evaluates the dynamic loads (or accelerations) generated by the mobile home during the transportation mode. The dynamic model is of the lump mass-beam element configuration with the key masses placed at the proper distance from the centerline of the system. During highway operations, this configuration generates the various accelerations,velocities and displacements as a result of induced excitations from the road surface. From their data, loads can be generated for use in the static finite element model in order to develop the various stress patterns in designated components of the mobile home.

FINITE ELEMENT STATIC ANALYSIS/MODEL: The finite element model consists of dividing the various components of the mobile home into a fine mesh system that is compatible with the actual structural system. All nodal points of the mesh on each component interconnect in order that the program can complete individual element analysis as well as the overall component and mobile home analyses. The finite element method analysis can be used with various basic computer programs such as STARDYNE, STRUDAL or ANSYS. The analysis output can provide stresses at selected points or junctions under various loadings that are usually obtained from the dynamic model. In this analysis, the mobile home structure was divided into major components such as chassis, floor, left wall, right wall, front end wall, rear end wall, roof and individual partitions within the mobile home.

VERTICAL STIFFNESS: The average mobile home can be considered a long box-like structure that has a certain structural stiffness with respect to bending in the vertical plane. Usually the longer the mobile home, the less the vertical stiffness and conversely the shorter the mobile home the greater the stiffness. Vertical stiffness is the ability of the mobile home structure to resist vertical loads/deflection and is synonymous with "flexural rigidity" and "EI". The mobile home can have two basic EI's, one forward of the running gear and one aft of the running gear.

TORSIONAL STIFFNESS: The average mobile home can be considered a long box-like structure that has a certain structural stiffness with respect to torsion about the fore and aft longitudinal axis. The torsional rigidity, like the flexural rigidity is higher in the shorter length mobile homes and lower in the longer mobile homes. Also, the torsional rigidity is a function of the "completeness" of the box structure with respect to the cross section of the mobile home. If there is no plywood structure on the roof under the metal to complete the structural torque box, the torsional rigidity or stiffness is lower than the mobile homes with the maximum section properties.

DYNAMIC LOADS AND DYNAMIC RESPONSE: During development of the RUL and dynamic model, it was anticipated that the TASK I program would be divided into the:

–Dynamic lump mass model

–Predictive, (RUL) remaining useful life formula

–Finite element static analysis model

–Exploded isometrics of detailed points on the mobile home for stress analysis

The finite element static analysis model requires inputs other than the static one "g" loadings. These inputs simulate the actual road condition excitations induced in the mobile home during transit. Accordingly, the acceleration levels from the dynamic model are input to the finite element as "equivalent" G (inertial) loads. The repetitive roadrun dynamic response, even if at a low G level, can be very damaging in terms of accumulative degradation.

STRUCTURAL INTEGRITY VERSUS DEGRADATION: The predictive analysis contained in Volumes I and II of TASK I, is based on the assumption that there exists a direct correlation between the structural integrity of the mobile home and the degree to which it has been or can be degraded. This degradation is attributable to–:

–Transportation modes

–Setup

–Take down

–Occupancy periods of high traffic and poor maintenance.

The structural integrity of a mobile home is measured as a function of the flexural rigidity and torsional stiffness; both of which may change significantly during transit as well as setup-takedown procedures. The mobile home can have a varying stiffness, both in flexural rigidity and torsional rigidity from the front of a mobile home to the rear. However, for the purpose of this report, the mobile home structural rigidity has been analyzed in two areas only: hitch to front axle and front axle to rear wall.

BEAM ELEMENTS: These elements are referred to in two areas:

–Dynamic model

–Finite element model

These elements predominently refer to elements used in the finite element analysis/model because the chassis acts as a beam; the floor acts as a beam and the side walls act as a beam. Also, the dynamic analysis utilizes a simplified lump/mass model with the various eccentric beam elements taken off the longitudinal beam (or axis) for the various dynamic responses generated by designated road conditions and velocities as inputs.

As an example, the sidewall or beams are divided into various elements or a grid mesh of approximately 32-inch centers (to match the 16-in. stud spacing). Each element of this side wall beam is specifically designated or located by the nodal points connecting each corner of the element to the adjacent element. Each beam element has the capacity of determining the stress at any point around the periphery of the element. Therefore, the finer the mesh, the finer the stress points. But, the finer the mesh, the more costly the program to run and analyze or interpret.

POWER SPECTRAL DENSITY (PSD): In terms of physical reality, the spectral density at any particular frequency may be regarded as the average power passing when a random signal is filtered by a narrow band pass filter centered at that frequency.

EFFECTIVE FLEXURAL RIGIDITY (EI): This is the equivalent bending (vertical) stiffness of a mobile home if the *a priori* assumption is made that the unit in flexure can be modeled as an Euler beam.

EFFECTIVE TORSIONAL RIGIDITY (GJ OR J): This is the mobile home's equivalent structural resistance to torsion if the *a priori* assumption is made that the unit in torsion responds as a closed channeled rectangular tube.

MOBILE HOME TEST UNITS: The mobile home test units are designated by the following prefixes:

T-1	1976 14 X 64–Single wide (new)
T-2A	1976 Double wide 24 X 56–Wet half (new)
T-2B	1976 Double wide 24 X 56–Dry half (new)
*T-3	1971 14 X 64–Single wide (used)
*T-4A	1974 Double Wide 24 X 56–Wet half (used)
*T-4B	1974 Double Wide 24 X 56–Dry half (used)

ATTACHMENTS OR FASTENERS: Refers to mechanical devices such as tacks, nails, bolts, screws or staples used to assemble the various joints or structural components. This does not include glue or welding.

JOINTS: Comprises the interface between two pieces of structure or components that are assembled using the attachments noted above. Examples of joints are stud to plate; header to stud; shear wall to side wall; side wall to end wall and roof to wall.

EXPLODED ISOMETRICS: The test mobile homes are shown in an overall exploded isometric configuration with a breakdown of the major components. The critical joints of each model are then detailed in an enlarged/exploded isometric drawing showing the load/stress input, transfer or flow. The exploded isometrics offer a pictorial presentation of the output from the finite element analysis.

RANDOM LOAD INPUT: Induced dynamic inertial loads incurred by the mobile home during transit due to the random excitations from the road surface.

TRANSPORTATION MODE: The mobile home transportation mode is divided into two sections as follows: Condition I covers the transportation from the manufacturer to the dealer and from the dealer to the initial setup site, including setup. Condition II covers the secondary moves including take down, transportation and setup.

*Purchased from first occupant/owners

PRELIMINARY METHODOLOGY

At the outset of this program, the initial problem was to determine the methodology for the pioneering development effort of the predictive analyses, a simplified dynamic analysis, as well as the possible applications of the finite element theory to a composite material assembly or structure, such as a mobile home. Also, one of the outstanding questions that need be answered at some point in the program pertains to the definition of "consumed life" or "when is a mobile home unfit for transportation, live-ability and a bad financial risk?" A recommendation will be made after completion of TASK III as to a more positive definition of these factors. However, a preliminary definition is contained in the preceding section.

Inspection and discussion of/with mobile home dealers, mobile home transporters, mobile home financial institutions and mobile home owners as well as repair shops resulted in a wealth of information pertaining to the various degradation factors associated with mobile home transportation and setup/takedown operations. From these data, the initial methodology or approach to the problem was developed in the form of anticipated or projected factors or projections of the probable direction or course the degradation cycle will follow.

It is anticipated at this time that a mobile home will degrade in proportion to the structural integrity or structural stiffness of the overall assembly. A steady rate of degradation, anticipated in the form of a downward curve as presented in Figure *ii* is generated by factors associated with transportation and setup/takedown cycles starting with a new mobile home that is considered as new with 100 percent integrity. Each trip over any type of road will degrade the structure to some degree. Also, the usual setup and takedown as accomplished by many transporters or dealers, adds to the degradation along with the time and environmental or weathering factors such as wind, rain, snow and temperature variations plus occupancy loads.

Various factors need be developed for these variables that will be used to develop the theoretical curves for the degradation cycle wherein mode 1 could include wind, snow, occupancy and material aging. Mode 2 could be designated as transportation, while mode 3 could be designated for setup and takedown factors. Torsion is to be included in these early predictions since it has been found to be a significant and critical factor in the structural response of the mobile home type structure.

The predictive analysis, dynamic analysis, and finite element analysis required in TASK I and discussed within this program requires an in-depth pioneering effort involving the many parameters associated with the transportation mode of mobile homes being moved from one site or location to another plus the setup and takedown mode as well as the occupancy mode. Due to the broad spectrum of operating conditions and parameters involved in the mobile home structure and running gear on various types of roads and under varying environmental conditions combined with the setup/takedown and occupancy forces, the three above-noted basic types of analysis will be necessary to comply with the requirements of TASK I.

The first program constitutes a SwRI-developed theoretical predictive analysis of "Remaining Useful Life" (RUL). The formulation was developed for the utilization of basic parameters that are available or can be generated via tests on the mobile home in question utilizing simplified tests with basic equipment. The predictive analysis will utilize factors such as velocity, effective vertical stiffness, effective torsional stiffness, road surface type or class and structural damping plus other factors that can be programmed into the development of the predictive formulas.

During the development of the various parameters required for the assembly of the predictive analysis, it was first necessary to also develop the simplified dynamic model because the degradation generated during the transportation mode occurs as a result of various dynamic applications with a certain degree of dampening between the wheel/axle and the mobile home box structure.

The simplified dynamic model is flexible in that the varying types of parameters can be added or subtracted, increased or decreased to fit the mobile home in question. Also, the model can be applied to both single- and double-wide units with emphasis on the placement of off-center masses such as refrigerator, bath units, washer, dryer, ovens, stoves and water heaters. The weight eccentricity due to location has a greater dynamic effect on the double-wide units than on the single wide units because of the absence of the rigidity in the mating wall. Wind effects are also a part of the dynamic factors and are considered significant due to the under-carriage system that is more narrow than the box structure and the soft spring systems that contribute to basic lateral and torsional instability. From the dynamic analysis, predictive accelerations at various locations and directions can be assessed as a result of the accelerations generated during the transportation mode.

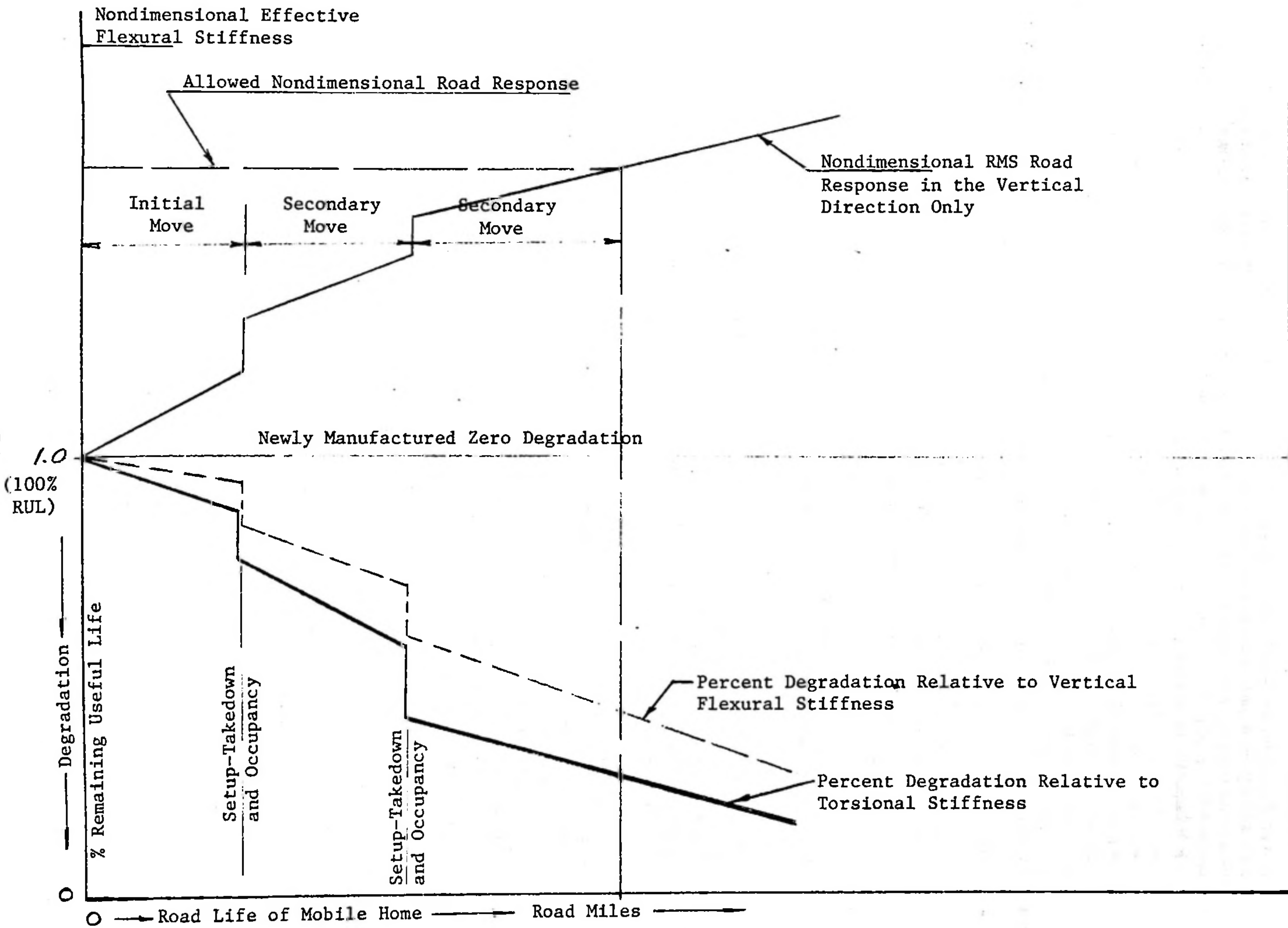


FIGURE 11 PROJECTED DEGRADATION CYCLES OF A MOBILE HOME

These accelerations, in turn, can be applied to the finite element programs in the form of equivalent static loading for the analysis of components or joints. Once again, the effects of wind loads during the transportation mode can be applied or added to the dynamic loads generated due to vehicle velocity and road conditions for the overall input load spectrum for use in the finite element model. All of these data/analyses (with exception of the finite element analyses) are presented in Volume II. The finite element model is presented in Volume III while the exploded isometrics are presented in Volume IV.

DYNAMIC ANALYSIS

I. BACKGROUND DISCUSSION

During the past decade in the United States, there has been a significant increase in the utilization of mobile homes as a normal family dwelling. It has also been realized by the mobile home industry and the Federal Government that mobile homes are subjected to unique conditions (e.g., manufacturing, transportation and siting) which differ significantly from conventional housing. Because of these conditions, typical mobile homes during their lifetime may experience unusual dynamic as well as static loading conditions. The static loadings may be the result of placement, leveling and settling of the mobile home in its foundation and also due to environmental conditions. The dynamic loadings may include environmental as well as transportational-related loads (e.g., road roughness, railroad crossings, potholes). This is exemplified by the number of intransit unit losses during high wind periods and rain storms.

As a result of these rather complex loading phenomena, mobile homes have exhibited significant problems over relatively short periods of time. This performance problem is closely related to the reduction or degradation in the structural integrity of the mobile unit. Therefore, the structural integrity of the newly manufactured mobile homes, especially those in excess of 50-ft long, is important since any transportation except a very smooth highway and slow towing speeds will induce dynamic forces in the unit which may seriously diminish the unit's "remaining useful life."

The major damage to the mobile home's structure by external forces as well as occupant forces (e.g., furniture locations, excessive concentration of furniture, etc.) is fatigue-like in nature. Repeated dynamic and/or static loads which may be minor for each application, can, on a cumulative basis, result in progressive degradation and eventual structural failure.

The main objective of Task I is to develop the analytical methodology which will identify these variables as well as compute the probable dynamic and static loads and resulting stresses due to normal transportation and site installation activities. Since the dynamic loading conditions are highly random in nature, any methodology must be probabilistic in nature and should be based upon analytical and experimental studies. Additionally, an in-depth analytical investigation of mobile home response to both dynamic and static loads has been performed by SwRI. This phase, utilizing sophisticated finite element computer programs has identified those pertinent variables associated with the mobile home's structural integrity which affect the rate of degradation. This analytical phase has also estimated the probable G loadings which would be experienced by a mobile home in transit, under various transportation conditions, such as different towing speeds and road conditions (paved, rough, gravel, wavy). Based on these findings, regression equations have been formulated which can be utilized to estimate a mobile home's remaining useful life. This formulation will be modified, if necessary, after the experimental phase of this study is complete. A detailed discussion of the approach SwRI has taken to date as well as the resulting methodology and regression formulae are given in the following sections. In the dynamic analysis volume SwRI addresses the problem of mobile home degradation resulting from in-transit and setup and takedown effects. In the static analysis volume a more detailed look at degradation due to setups and takedowns is considered, in addition to the effect on specific components within the unit.

II. DEVELOPMENT

II.1. Model Selection

The beneficial aspects of simulating the dynamic response of a mobile home due to transportation-related excitations includes the ability to investigate the effect of changes in inherent structural properties and variations in external loadings on the unit. Accordingly, for this analysis, the Institute required a math model which would effectively model the mobile home's structural properties and the random excitations from a road surface that is imposed on the unit. After considering various available computer programs to handle these aspects, Control Data Corporation's MRI/STARDYNE analysis system(1) was selected to consider the dynamic analysis phase of Task I.

The MRI/STARDYNE analysis system consists of a series of compatible, digital computer programs designed to analyze linear, elastic structural models. These programs provide the analyst with a sophisticated, cost effective, structural-dynamical analysis system. Specifically, the STARDYNE system can be used to evaluate a wide variety of static and dynamic problems, e.g.

- The static capability includes the computation of structural deformation and member loads and stresses caused by an arbitrary set of thermal, nodal applied loads and/or prescribed displacements.

- Utilizing either the direct integration or the normal mode technique, dynamic response analysis can be performed for a wide range of loading conditions, including transient, steady state, harmonic, random and shock spectra excitation types.

Dynamic response results can be presented as structural deformations (displacements, velocities, or accelerations) and/or internal member loads/stresses.

II.2. Model Construction

The programs (of the STARDYNE system) chosen by the Institute as most applicable to the present study are STAR and DYNRE 3. The STAR program has two distinct functions; they are static load analysis and eigenvalue (natural frequency) eigenfunction (mode shape) extraction. This program was used to construct the dynamic model which consists of 17 beam elements, 18 nodal points and three material properties (steel, wood, rubber). In the construction of this model, the nodal points located at the mobile home's weight distribution concentration points were displaced from the beam elements to simulate the eccentricities in the internal loading environment due to concentrated masses such as furniture, kitchen appliances, bathroom fixtures, etc. The suspension systems at the hitch and wheel locations were modeled by beam elements with similar compressive resistive properties of typical suspension systems. For our model, this program performs a modal analysis of the mobile home, extracting the various eigenvalues and eigenfunctions based on the computer-calculated stiffness and associated mass matrix. In the present study, the STAR program was utilized with varying structural characteristics of the mobile home to simulate various degrees of structural degradation.

The DYNRE 3 program was utilized to evaluate mobile home response to random road excitations. It was used in conjunction with the structural models formulated by the STAR program. In DYNRE 3, the random dynamic road excitations are input in terms of power spectral density (PSD) functions. In terms of physical reality, the power spectral density at any particular frequency, may be regarded as the average power passing when a random signal is filtered by a narrow power pass filter. In this analysis, it is the limiting mean square value (e.g., of acceleration, velocity and displacement) per unit bandwidth i.e., the limit of the mean square value in a given rectangular bandwidth divided by the bandwidth as the bandwidth approaches zero. The output from this program includes:

- Root mean square (*RMS*) response of the mobile home (i.e., displacement, velocity and accelerations) at the designated nodal points.

- Power spectral density (*PSD*) curves for selected locations (nodal points) in the unit.

II.3. Computer Model Input and Methodology

For the dynamic model described above, certain structural input data for the mobile home as well as road surface condition were required. In terms of the structural program STAR, the most essential input requirements were the effective flexural stiffness (*EI*) of the mobile home and the effective torsional stiffness (*GJ*). In a previous study[2], investigators evaluating mobile home degradation concluded that the effective flexural stiffness of a mobile unit was a significant factor relating to the structural integrity of a mobile unit as well as a key in determining its potential to degrade as a result of transit. In Ref. 2 it was noted that when a unit was subjected to careful *EI* measurements both before and after extensive roadway loadings, the value of *EI* changed significantly (i.e., decreased).

Due to these findings, the STAR program was run with various values of *EI* to simulate the degradation phenomenon due to transit as well as setups and takedowns. In addition to this structural aspect, the computer program was run varying the effective torsional stiffness (*GJ*) of the unit. SwRI early in this study, believed that the effective *GJ* could be a significant factor in terms of defining the structural adequacy of a unit to withstand numerous moves from take down site to installation site. Accordingly, utilizing the STAR program, a total of twenty (20) structural models (each with different *EI* and *GJ* combinations) were computed to simulate the various degrees of structural integrity (or degradation) of a mobile home (see Table 1).

The road condition excitation data input to the DYNRE 3 program were based on previous research efforts. Specifically, descriptions of highway roughness measurements in terms of power spectra (PSD) have been studied by Pevzner[3], Parkhilovskiy[4] and Van Deusen[5]. These studies followed an investigation in 1958 by Thompson[6] on airport runway roughness measurements. More recently, roughness in terms of power spectra has been studied by Jaeger and Schuring[7] who investigated surface roughness for the moon's Mare Cognitum. A detailed description of this approach is given in Bekker's "Introduction to Terrain Vehicle Systems"[8].

In the present study, the *PSD* values for various road conditions quoted in Ref. 5 were utilized, as shown in Table 2. These coefficients are input into the empirically derived equation[5]

$$PSD(\Omega) = K_\nu \Omega^{-n_\nu} \qquad (1)$$

to estimate the road excitation *PSD* for a given frequency Ω where K_ν and n_ν are constants related to the type of road traveled and Ω is spatial frequency in cycles per foot. It is noted that equation (1) was obtained by approximating *PSD* data collected experimentally and gives a good approximation of the *PSD* for the ground profile in the low frequency range (i.e., 0 to 6.0 Hz). For the DYNRE 3 program Equation (1) was modified from a spatial to temporal domain to be compatible with the program input requirements (i.e., *PSD* in G^2/Hz). It is further noted that while Table 2 includes both paved and unpaved roads, only paved roads were considered as being typical for initial and secondary moves of mobile homes. Accordingly, while paved, unpaved and gravel roads were considered in the overall methodology of Task I, the conclusions derived from the dynamic analysis are based on paved highways and secondary roads.

TABLE 1

STAR STRUCTURAL MODELS OF MOBILE HOMES

	Effective Torsional Stiffness ($\bar{J}$)** $in.^4$				
$\overline{EI}$ ($lb\text{-}in.^2$)*	10	23	10^2	10^3	10^4
88×10^8	X †	X	X	X	X
158×10^8	X	X	X	X	X
194×10^8	X	X	X	X	X
264×10^8	X	X	X	X	X

*Effective flexural stiffness
**Effective torsional stiffness divided by torsional rigidity constant (G)
† Each X signifies a model with specified effective flexural and torsional stiffnesses.

TABLE 2

VALUES OF PSD EQUATION COEFFICIENTS FOR VARIOUS ROAD SURFACES

Surface	K_v *	n_v *
Paved road	1.2×10^{-6}	2.1
Unpaved with gravel	1.1×10^{-5}	2.1
Unpaved, waved	3.7×10^{-6}	2.4
Unpaved, rough	2.0×10^{-6}	3.8
Virgin, cross-country	1.6×10^{-3}	2.0

*Empirically evaluated constants defined by B.D. Van Deusen.[5]

III. MODEL APPLICATION

III.1. Parametric Investigation

If the rate of degradation of a mobile home due to transportation effects as well as setups and takedowns is to be defined and hopefully, substantially reduced, it is essential that the pertinent parameters having the greatest effect on these phenomena be identified. In the dynamic model described above, those parameters that were suspect at the beginning of this investigation were:

- Effective flexural stiffness (EI),
- Effective torsional stiffness (GJ),
- Road surface condition,
- Mobile home transporting speed,
- Mobile home damping properties.

The effective flexural stiffness of the mobile home is the equivalent vertical bending stiffness of the unit, if it is considered as a simple beam, firmly supported at the hitch and wheel location. In the reference study(2), Battelle Memorial Institute (BMI) evaluated this effective stiffness by jacking up the unit at the wheel and hitch locations and then by applying known loads in the vertical direction, first at the midpoint of the unit between the hitch and the wheels, and then at the rear of the home. Deflections were measured and then by using Euler's beam equation, the effective stiffness (EI) was estimated. It was BMI's belief that this structural property had a major influence on degradation, and could be used as a tool to estimate the quality and/or degradation of a mobile unit.

Similar to the effective bending stiffness, the effective torsional stiffness (GJ or J) can be considered in studying the mobile home's response to torsion (racking). Accordingly, in this parametric study, these stiffnesses, as well as speed, damping and road condition were investigated to determine which variable(s) has a significant effect on degradation. A series of simulations were performed for a 60-ft long, 14,000-lb unit, varying the parameters outlined above.

III.1.a Flexural and Torsional Stiffness Effects

In the first series of simulations, variations in the mobile home's flexural and torsional stiffness were made (Table 1). In these computer runs a paved road was modeled, the speed of the unit was maintained at 45 mph and the damping of the unit was specified at 0.04 and 0.10. The response parameters monitored were the vehicle's root mean square (RMS), accelerations, velocities and displacements. (It is noted that by definition a random response will be probabilistically equal to or less than the RMS value 68.3 percent of the time.)

Results emphasized the sensitivity of induced "G" loadings in the mobile home to variations in effective torsional stiffness (GJ). This is clearly shown in Figures 1 through 4 where the "monitored" RMS accelerations at a rear upper corner of the mobile home dramatically increase as the effective torsional stiffness is reduced. Figures 1 through 4 also show that variation in effective flexural stiffness (EI) does not effect the mobile home response accelerations to the same degree as the torsional stiffness. It is further noted that an increase in damping (from 0.04 to 0.10) can substantially diminish the G loadings the unit may experience during a move.

In terms of probability of occurrence, the significance that the torsional stiffness of a mobile home has on probable G loadings experienced during transporting of the unit from site to site is illustrated in Appendix C.

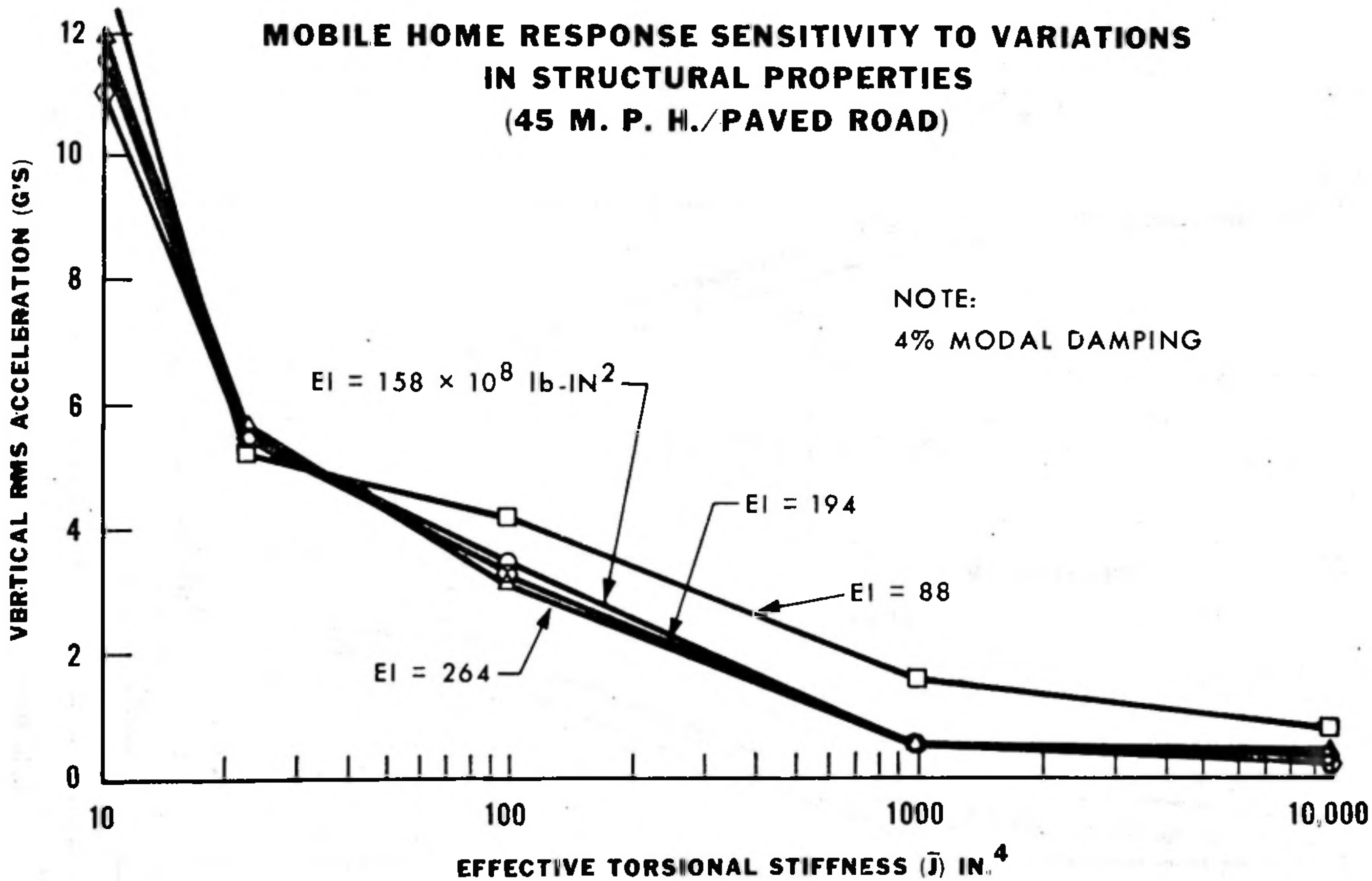

MOBILE HOME RESPONSE SENSITIVITY TO VARIATIONS
IN STRUCTURAL PROPERTIES
(45 M. P. H./PAVED ROAD)
NOTE:
4% MODAL DAMPING
EI = 158 × 10^8 lb-IN^2
EI = 194
EI = 88
EI = 264
VERTICAL RMS ACCELERATION (G'S)
EFFECTIVE TORSIONAL STIFFNESS (J̄) IN.^4
12
10
8
6
4
2
0
10
100
1000
10,000

FIGURE 1

MOBILE HOME RESPONSE SENSITIVITY TO VARIATIONS IN STRUCTURAL PROPERTIES (45 M. P. H./PAVED ROAD)

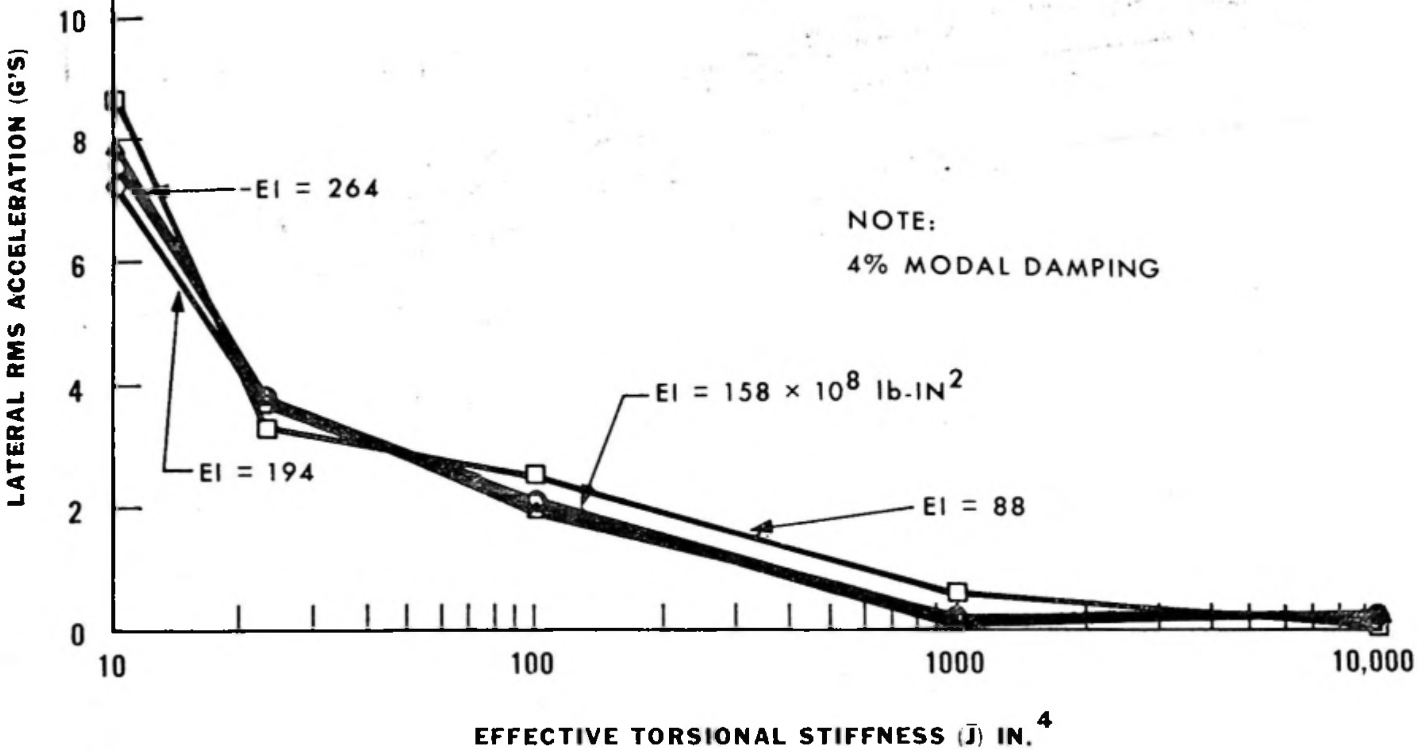


FIGURE 2

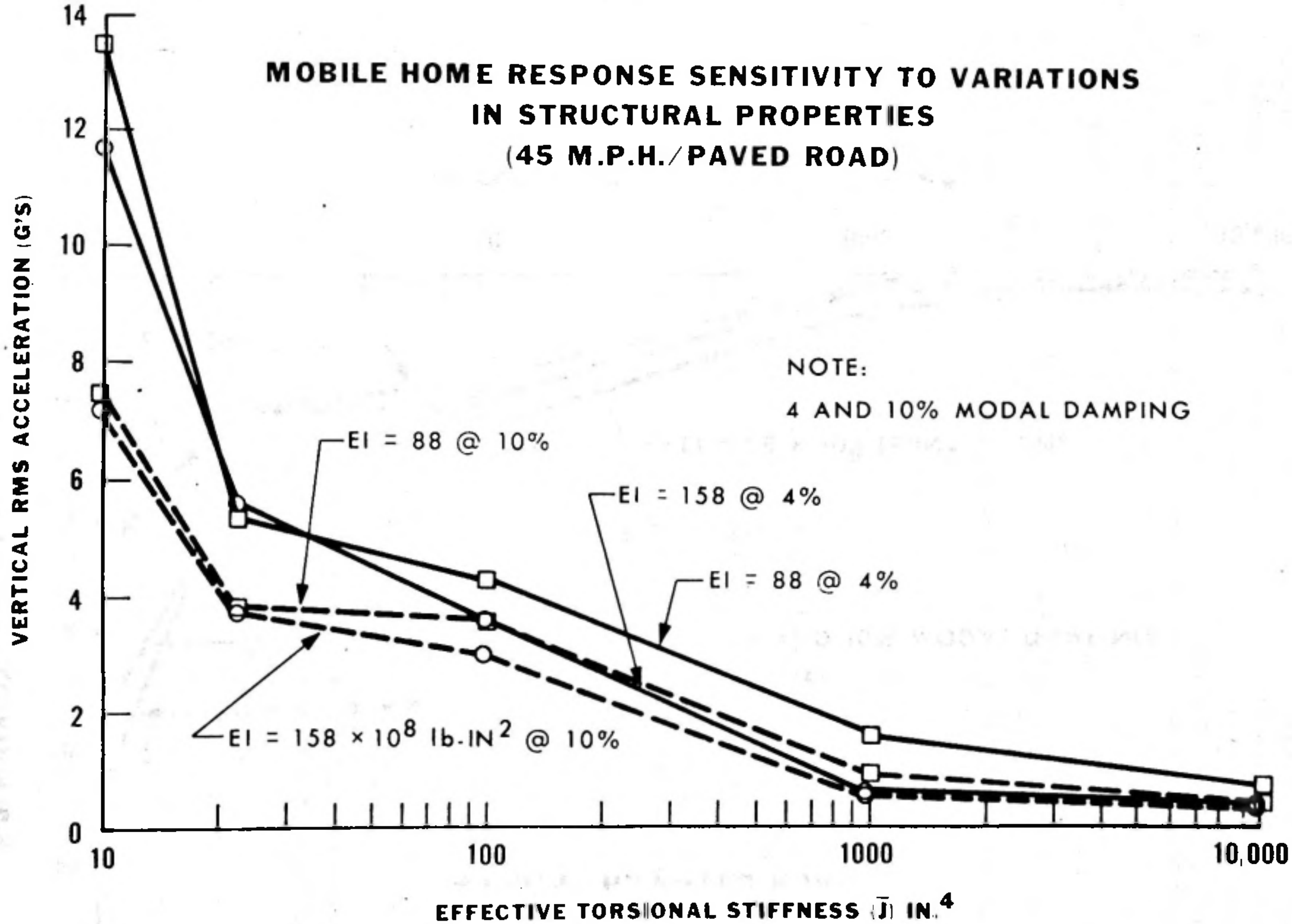
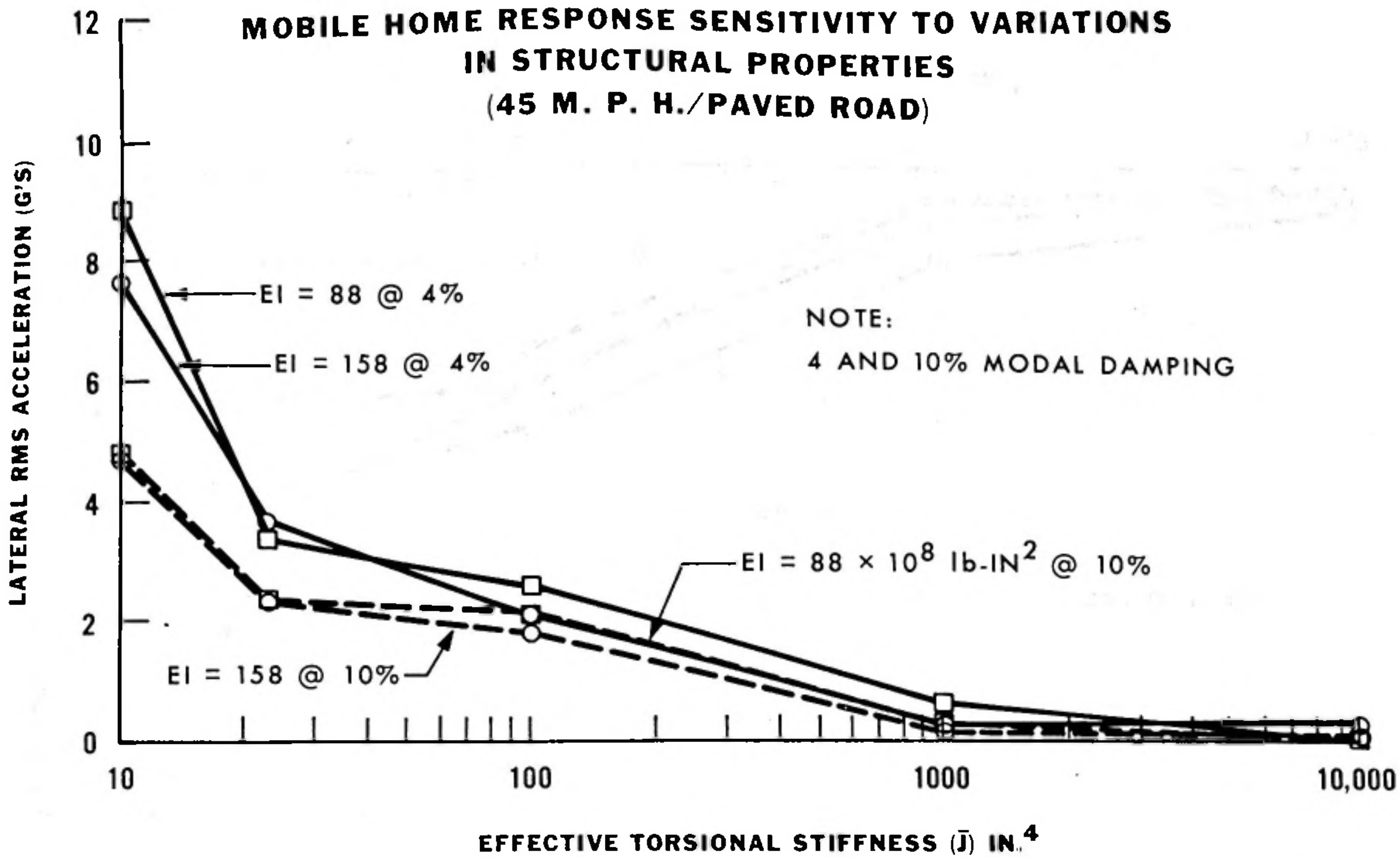

MOBILE HOME RESPONSE SENSITIVITY TO VARIATIONS
IN STRUCTURAL PROPERTIES
(45 M.P.H./PAVED ROAD)
NOTE:
4 AND 10% MODAL DAMPING
EI = 88 @ 10%
EI = 158 @ 4%
EI = 88 @ 4%
EI = 158 × 10^8 lb.IN^2 @ 10%
VERTICAL RMS ACCELERATION (G'S)
0
2
4
6
8
10
12
14
10
100
1000
10,000
EFFECTIVE TORSIONAL STIFFNESS (J) IN.^4

FIGURE 3



MOBILE HOME RESPONSE SENSITIVITY TO VARIATIONS
IN STRUCTURAL PROPERTIES
(45 M. P. H./PAVED ROAD)
12
10
8
6
4
2
0
LATERAL RMS ACCELERATION (G'S)
EI = 88 @ 4%
EI = 158 @ 4%
NOTE:
4 AND 10% MODAL DAMPING
EI = 88 × 10^8 lb-IN^2 @ 10%
EI = 158 @ 10%
10
100
1000
10,000
EFFECTIVE TORSIONAL STIFFNESS (J̄) IN.^4

FIGURE 4

III.1.b. Effect of Road Condition and In-Transit Speed

The second series of simulations investigated the influence of speed and road condition on the rate of degradation of a mobile home. As shown in Figures 5 and 6, for a paved road the mobile home response does not vary significantly as the speed increases from 45 to 65 mph. However, it was anticipated that the velocity effect on degradation for a unit traveling along a paved road would be small in comparison to other types of road surfaces (e.g., gravel, rough, etc.). Accordingly, simulations were made of a mobile home traveling at 45 mph along both paved and unpaved roads. As illustrated in Figures 7 and 8, the acceleration levels within the unit can be substantially increased going from a paved to unpaved road, while maintaining the same speed.

III.2. (T-1) Model-1976 14 X 65-ft

As alluded to in the aforementioned parametric study, a total of twenty (20) structural models of mobile homes were constructed to simulate the dynamic response of a unit during transporting between site locations. Of these models, the one which structurally comes closest to the mobile home test unit T-1, has a flexural and torsional stiffness of:

$$EI = 264 \times 10^8 \text{ lb-in.}^2$$

$$J = 10^4 \text{ in.}^4$$

This model was utilized to simulate the T-1 traveling along a well paved road at 45 mph. As anticipated, due to the unit's stiff construction, the RMS (root mean square) vertical acceleration response (in G's) throughout the unit, as shown in Figure 9 and Table 3 was rather small. The lateral acceleration levels (not shown in figure) were approximately 75 percent the vertical G loads.

While small in amplitude, these dynamic loadings are cyclic in nature. The "apparent" frequency of random load input (based on analysis in Appendix A) for this particular model is:

$$f = 11.74 \frac{EI^{0.036} C_D{}^{0.427}}{V^{0.102} J^{0.028}}$$

$$= \frac{11.74(264 \times 10^8)^{0.036}(0.2)^{0.427}}{(45)^{0.102}(10^4)^{0.028}}$$

$$= 7.34 \text{ Hz}$$

where a damping coefficient (C_D) of 20 percent was utilized for the single wide model. Based on the above, dynamic loadings equal to or greater than those RMS values illustrated in Figure 9, (31.7 percent probability of being exceeded) can be assumed having an occurrence rate of:

$$f_{rms} = 7.34(0.317)$$

$$= 2.32 \text{ Hz}$$

over 2 cycles per second or 8,000 cycles per hour (16,000 load applications per hour). Here then, exists an environment where dynamically induced inertial loads, though small in magnitude can conceivably result in substantial degradation because of a cumulative damage effect.

The degradation for the T-1 was simulated with the dynamic model by reducing the torsional stiffness of the unit from 10^4 to 10^3 in.^{4} while keeping constant the other structural properties of the model. The effect which this reduction in torsional stiffness had on the induced vertical RMS G loads, is shown in Table 4 and Figure 10. Here again, since the T-1 initially was considered structurally very stiff the vertical RMS loadings were approximately 0.3 G's or less. When compared to Figure 9, however, an approximate 50-percent increase in G loadings is realized (left side, rear).

EFFECT OF MOBILE HOME SPEED ON STRUCTURAL RESPONSE

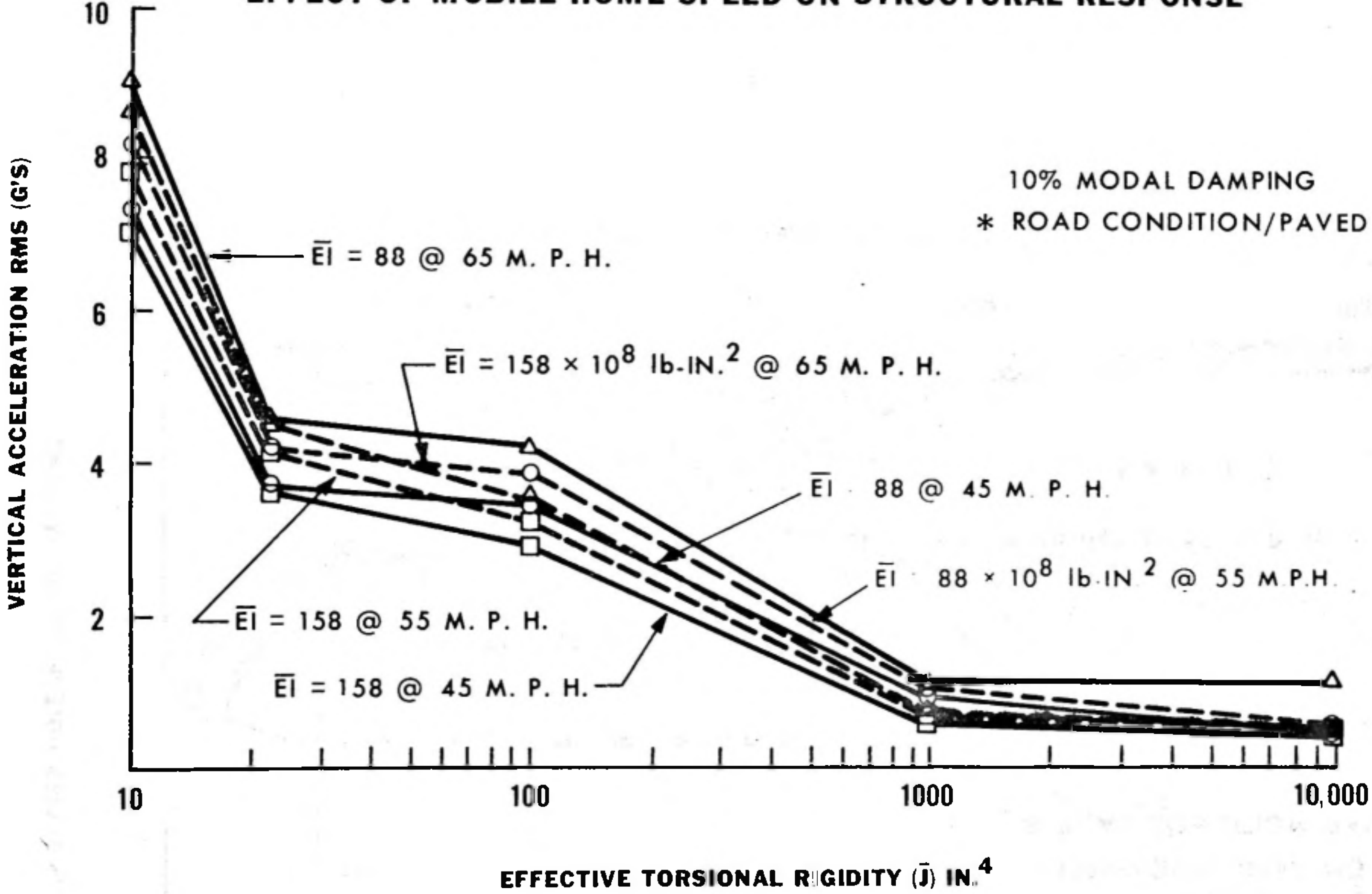


FIGURE 5

EFFECT OF MOBILE HOME SPEED ON STRUCTURAL RESPONSE

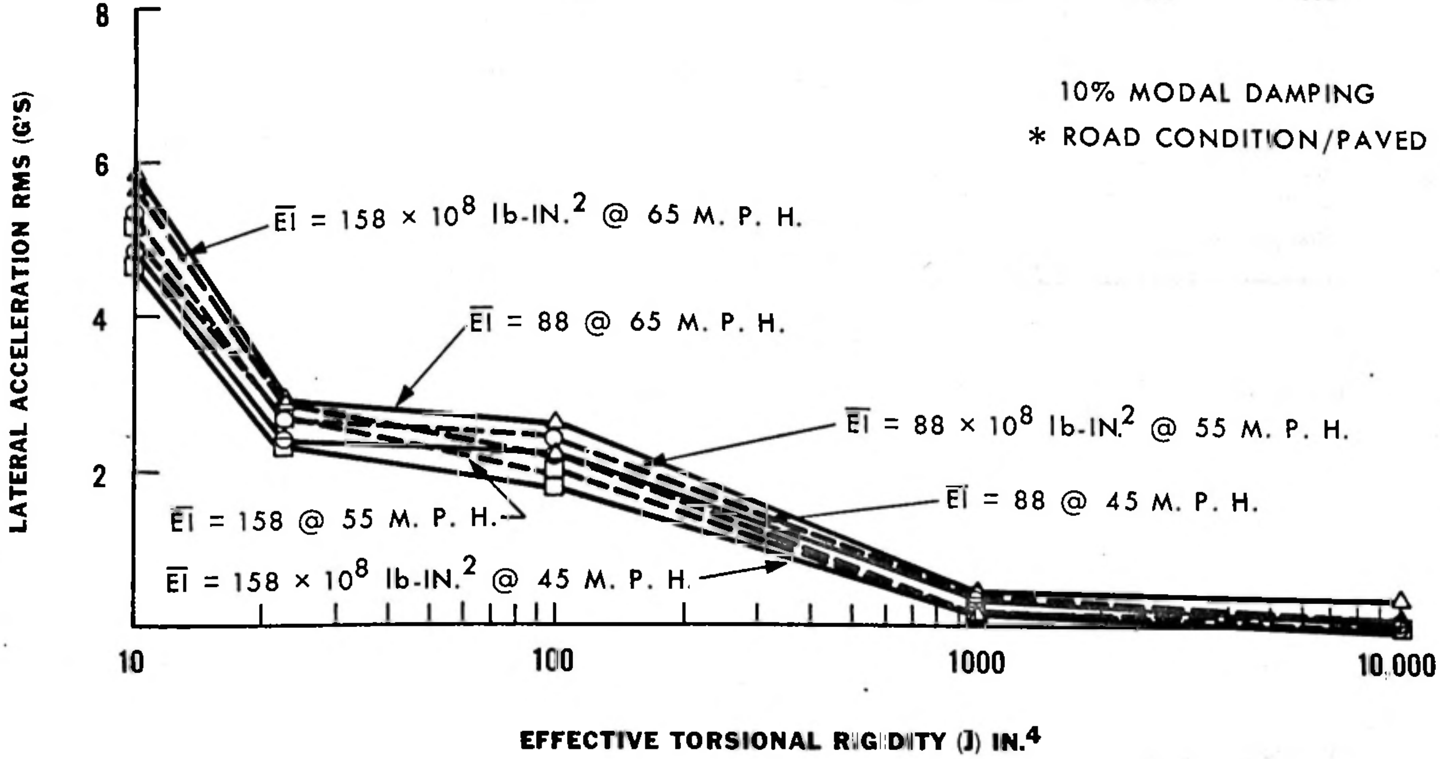


FIGURE 6

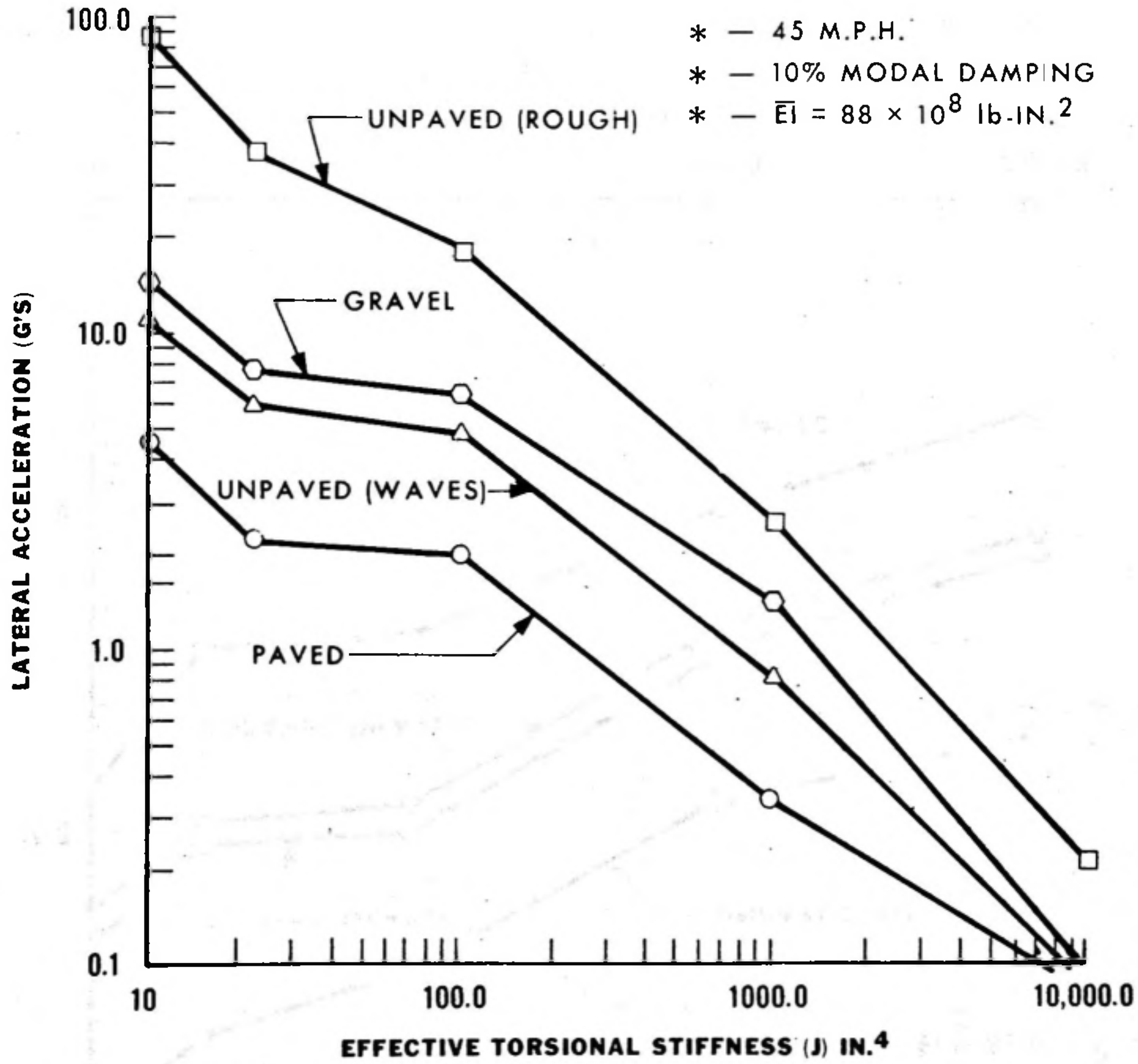


FIGURE 7. EFFECT OF ROAD ROUGHNESS ON MOBILE HOME RESPONSE

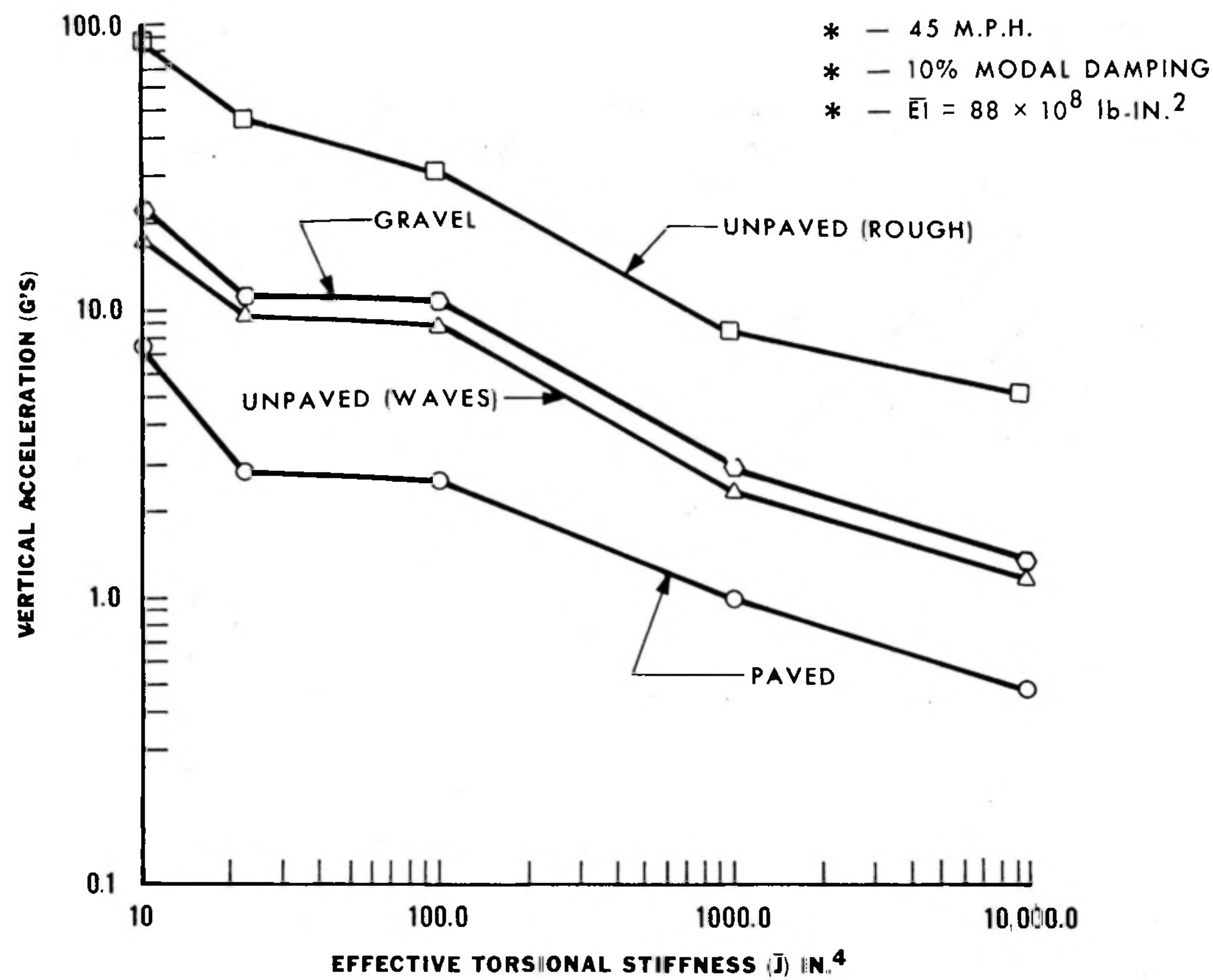


FIGURE 8. EFFECT OF ROAD ROUGHNESS ON MOBILE HOME RESPONSE

TABLE 3

SINGLE WIDE (T-1) MODEL DYNAMIC RESPONSE LOADS (G's)*

Location (in.)	Left Side	Centerline	Right Side
-235**	.226	.214	.202
-180	.192	.179	.167
-120	.159	.148	.138
-60	.137	.131	.125
Rear most axle	.129	.128	.128
Center axle	.129	.128	.128
Front axle	.129	.128	.128
60***	.163	.154	.145
120	.201	.188	.176
180	.227	.216	.205
240	.243	.233	.223
300	.243	.233	.223
360	.226	.216	.206
420	.200	.191	.181

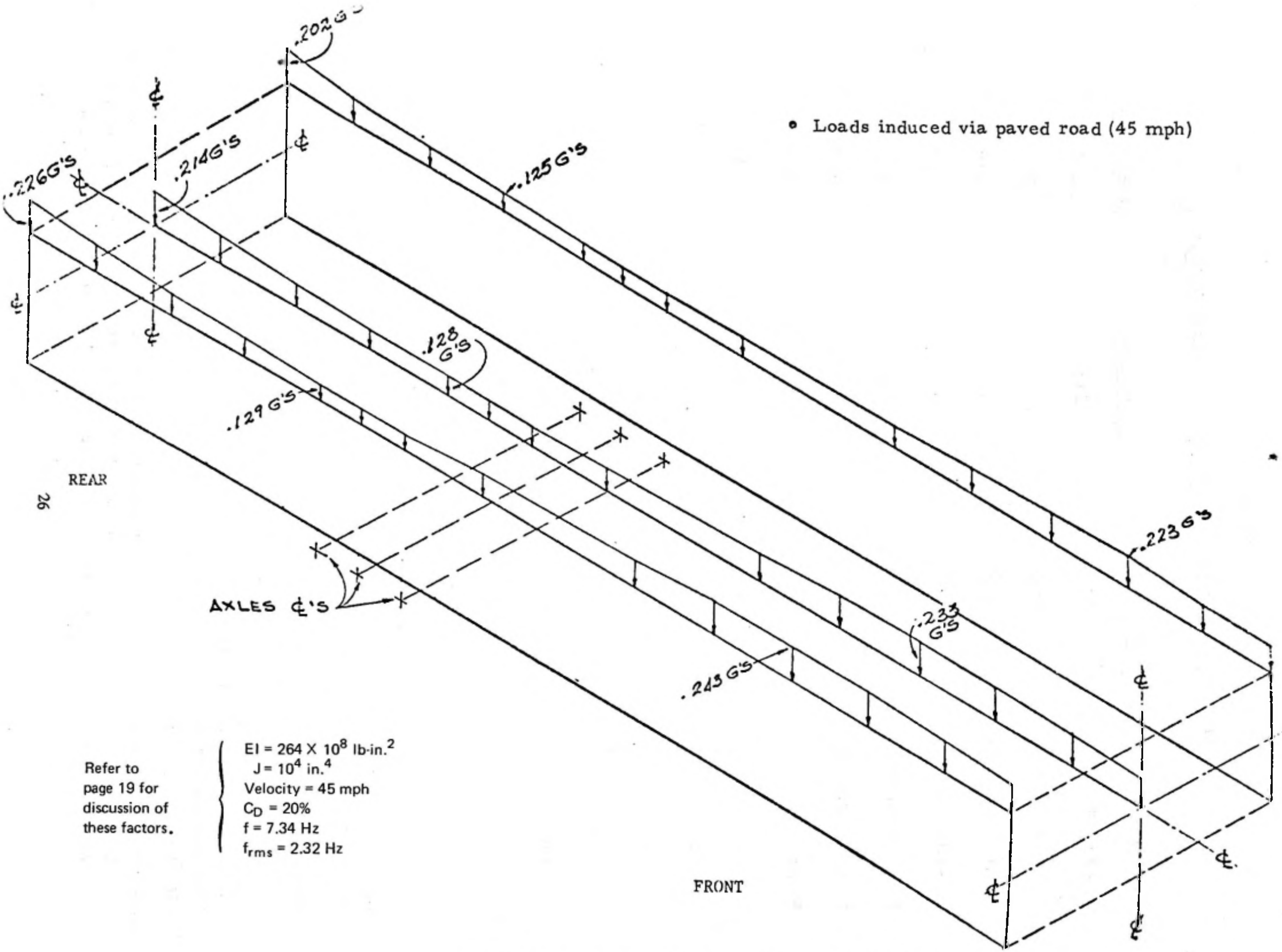
Refer to page 19 for discussion of these factors.

$EI = 264 \times 10^8$ lb-in.^{2}
$J = 10^4$ in.^{4}
Velocity = 45 mph
C_D = 20%
f = 7.34 Hz
f_{rms} = 2.32 Hz

*Vertical RMS accelerations
**Behind rear most axle
***In front of foremost axle

Note: Values are small due to strong construction as well as paved (smooth) road. In addition, as previously noted, the RMS value represents a level which would be exceeded approximately 32 percent of the time during transit.

• Loads induced via paved road (45 mph)



Refer to page 19 for discussion of these factors.

- $EI = 264 \times 10^8$ lb-in.^{2}
- $J = 10^4$ in.^{4}
- Velocity = 45 mph
- C_D = 20%
- f = 7.34 Hz
- f_{rms} = 2.32 Hz

FIGURE 9. DYNAMIC LOADINGS TO SINGLE WIDE (T-1)

TABLE 4

SINGLE WIDE (T-1) MODEL DYNAMIC RESPONSE LOADS (G's)*

Location (in.)	Left Side	Centerline	Right Side
-235**	.348	.222	.096
-180	.323	.196	.069
-120	.264	.159	.054
-60	.193	.134	.075
Rear most axle	.130	.129	.128
Center axle	.130	.129	.128
Front axle	.130	.129	.128
60**	.257	.168	.079
120	.330	.209	.088
180	.316	.222	.128
240	.308	.239	.170
300	.293	.240	.187
360	.268	.226	.184
420	.234	.200	.166

Refer to page 19 for discussion of these factors.

$EI = 264 \times 10^8$ lb-in.^{2}
$J = 10^3$ in.^{3}
Velocity = 45 mph
$C_D = 20\%$
f = 7.34 Hz
$f_{rms} = 2.32$ Hz

*Vertical RMS acceleration
**Behind rear most axle
***In front of foremost axle

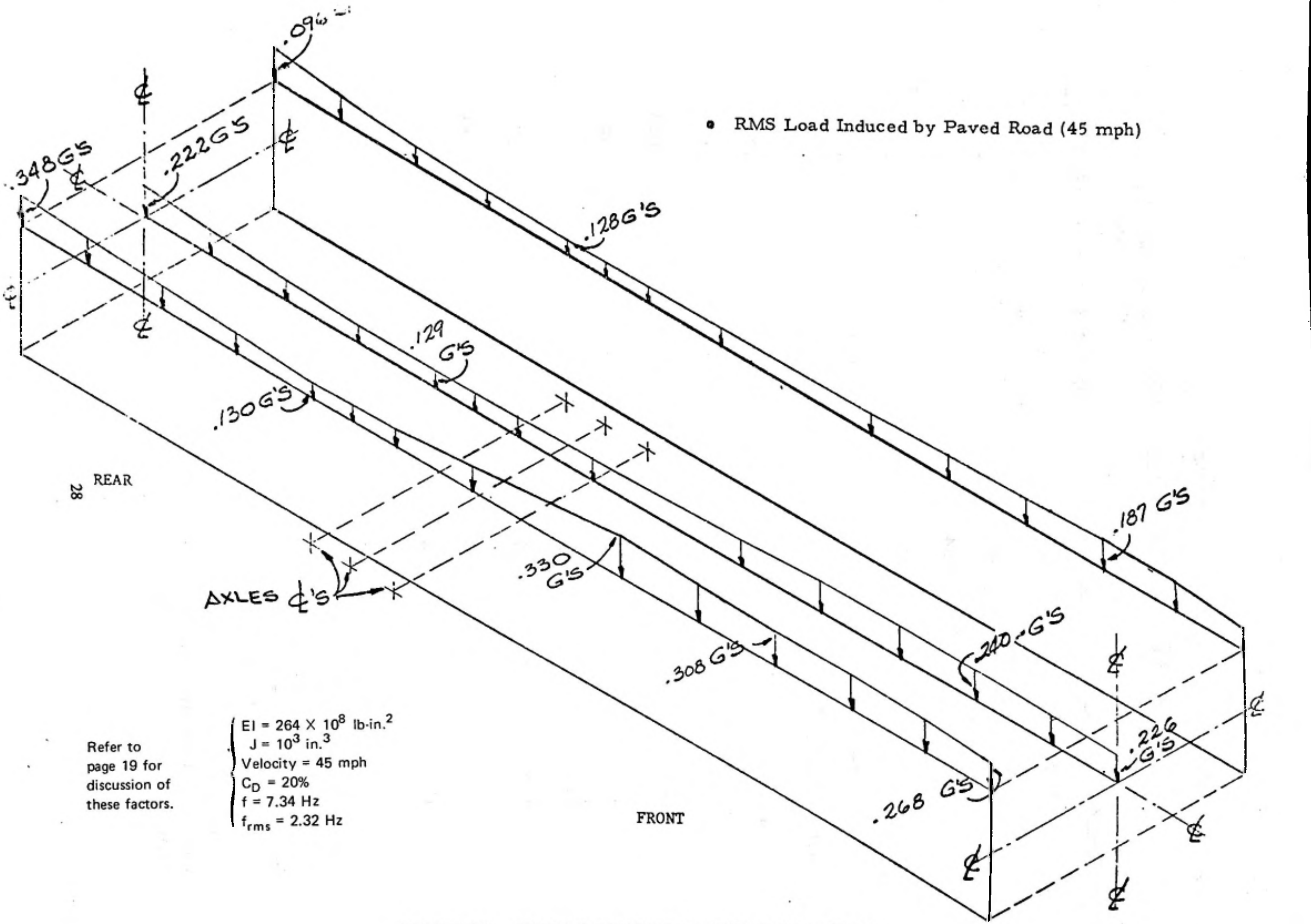


FIGURE 10. DYNAMIC LOADINGS TO SINGLE WIDE (T-1)

IV. MODEL LIMITATIONS

The Institute realizes the analysis of degradation in mobile homes resulting from transportation-related effects is difficult because of the complexity of a typical unit and the random nature of the induced dynamic loads. For example, due to interior walls, fixtures, etc., the flexural and torsional stiffness for a mobile home will vary substantially between the front and rear sections of a unit. The dynamic model, however, was constructed with these structural properties considered independent of the location within the unit. Accordingly, the dynamic model simulations described above can realistically only be considered a simplification of a unique phenomenon which is stochastic. With this in mind, the findings in terms of exact values should only be used in terms of defining structural parameter sensitivity to overall mobile home degradation. This sensitivity approach was investigated by SwRI in developing predictive equations for estimating the remaining useful life (*RUL*) of a mobile home.

V. PREDICTIVE ANALYSIS

V.1. Methodology and Formulation*

Based on the findings outlined in the previous section, predictive equations have been formulated which incorporate the structural aspects of the mobile home as well as speed and road conditions and which address the problem of in-transit and setup-takedown degradation. These equations are based in part, on results from the United Computer Systems (UCS) MULFIT computer program[9] which were used to develop regression equations based on SwRI findings. Specifically, from the dynamic model simulations utilizing the data collected, the MULFIT program performed a "best fit" analysis of the data and derived the following expressions for evaluating mobile home degradation due to initial and secondary moves.

$$\sigma_R = 6.42 \times 10^4 \frac{V^{0.734}}{EI^{0.468} C_D{}^{0.363} (\mathrm{Ln}\ J)^{2.046}} \qquad (2)\dagger$$

$$\sigma_F = 7.13 \times 10^{-3} \frac{EI^{0.208} V^{0.530}}{C_D{}^{0.448} (\mathrm{Ln}\ J)^{1.610}} \qquad (3)\dagger$$

In the above,

σ_R—is the RMS ‡ vertical acceleration (G units) of the mobile home at rear corner,

σ_F—is the RMS vertical acceleration at an upper side wall location approximately midpoint between front axle and hitch,

V—is transport velocity (mph),

EI—is the effective vertical flexural stiffness (lb-in.^{2}),

J—is the effective torsional stiffness (in.^{4}) and

C_D—is the structural damping of the unit ($0 < C_D < 1.0$).

Since the MULFIT program could not input *PSD* functions, equations (2) and (3) were modified to handle the various road condition effects on the unit as well as a reduction in the torsional stiffness (J) during the move. These modified equations were taken as:

$$\sigma_R = 6.42 \times 10^4 \frac{V^{0.734} rc}{EI^{0.468} C_D{}^{0.363} \left[\mathrm{Ln}\ 10^n - \frac{\mathrm{Ln}\ 10^{n-1}}{n^2}\right]^{2.046}} \qquad (4)$$

$$\sigma_F = 7.13 \times 10^{-3} \frac{EI^{0.208} V^{0.530} rc}{C_D{}^{0.448} \left[\mathrm{Ln}\ 10^n - \frac{\mathrm{Ln}\ 10^{n-1}}{n^2}\right]^{1.610}} \qquad (5)$$

where *rc* and *n* are found in Table 5. Equations (4) and (5) give an estimation of what the dynamic response of a particular mobile home will be during its move to a planned site. They also define the change in dynamic response to a unit due to setups and takedowns. This latter aspect is achieved by substituting the appropriate reduced flexural and torsional stiffnesses (due to on-site procedures) into expressions (4) and (5).

---

*Subject to modifications based on experimental findings from Task III study.

†Coefficient 6.42×10^4 and 7.13×10^{-3} defined to make expressions dimensionally homogeneous.

‡Root mean square values also referred to as standard deviations.

TABLE 5

Road Condition	$\overline{rc}$
Paved (smooth) *	1.0
Paved (waves) **	1.2
Paved (rough) **	1.5
Unpaved (waves)	2.5
Gravel	3.0
Unpaved (rough)	10.0

Effective Torsional Stiffness ($\tilde{J}$ in.^{4})	n
10	1
10^2	2
10^3	3
10^4	4
10^m	m

*Typical of primary roadways
**Representative of secondary roadways

The remaining useful life (RUL) equation based on the above is:

$$RUL = 1 - \frac{(7.2 \times 10^3) f d P(\sigma_i > \sigma_B)}{V N_B} \qquad i = R \text{ or } F \quad \text{(Rear or Front)} \qquad (6)^*$$

where

f = "apparent" frequency of response of unit (Hz)

V = planned velocity of unit (mph),

d = distance between sites (miles),

$P(\sigma_i > \sigma_B)$† is the probability of the unit exceeding the "base" RMS acceleration and N_B is estimated number of times the "base" RMS value will be exceeded per 100 miles traveled by the unit. *The aforementioned "base" values are input by the user and are assumed to be the RMS vertical acceleration response (σ_B) and number of occurrences (N_B) that a "zero remaining useful life" or unsafe mobile home would experience if it were transported 100 miles.* As an example, from these simulations the following "base" values were taken for the upper rear wall location:

f_B = 5 Hz (frequency of response),

V_B = 55 mph (on paved road),

σ_B = 7.4 G's‡ (RMS vertical acceleration).

From these values the probability $[P'(\sigma_B)]$ of the base unit exceeding σ_B is simply 0.317 or approximately 32 percent. Accordingly, based on the expression (6) for an RUL = 0, the estimated number of occurrences that σ_B will be exceeded per 100 miles traveled is:

$$N_B = 7.2 \times 10^5 \frac{f_B}{V_B} [P'(\sigma_B)] = 2.07 \times 10^4$$

The overall procedure for estimating the RUL of a specific unit entails the following:

(1) The user specifies the "base" structural parameters of a proposed "zero" life unit as well as planned velocity and probable road condition for this unit. He then utilizes equations (4) and (5) to estimate the RMS acceleration (σ_B) for this "zero" life unit at the rear corner and midpoint wall location between axle and hitch.

(2) The user estimates the number of occurrences (N_B) (per 100 miles traveled by the "zero" life unit) that σ_B will be exceeded. This is obtained from:

$$N_B = 7.2 \times 10^5 \frac{f_B}{V_B} [P'(\sigma_B)]$$

where f_B and V_B are estimated "base" frequency of response (Hz) and "base" velocity (mph).**

(3) The user now estimates the RMS vertical accelerations (σ_i) for the present mobile home in question. This is obtained by inserting the appropriate structural parameters into equations (4) and (5) along with the anticipated road condition and in-transit speed. (These values are either measured or estimated from available tables such as Table 5.)

---

*7.3 X 10^3 coefficient defined to make expressions dimensionally homogeneous.

†$P(\sigma_i > \sigma_B)$ is a function of mobile home speed, stiffness, damping as well as the type of road the unit is traveling.

‡Measured at upper rear corner of unit.

**These values would be based on best available data.

(4) Having determined the standard deviations (σ_i) for the mobile home, the probability of exceeding σ_B [i.e., $P(\sigma_i > \sigma_B)$] can be obtained from any standard statistical handbook.

(5) The user then inputs $P(\sigma_i > \sigma_B)$ into (6) to obtain an estimation on the *RUL* of the unit when it reaches its setup site.

It is noted in expression (5) that the RMS response for the location between axle and hitch is directly proportional to the unit's effective flexural stiffness (*EI*). Due to this, a newer mobile home would experience higher inertia loadings (*G*'s) in this area than after this stiffness parameter has degraded. As a result, if the "base" values of a highly degraded unit were input into (5), the RMS response (σ_{FB}) would give an unrealistic level of degradation to the front section of the mobile home. This problem can be minimized if the user, when evaluating σ_{FB}, utilizes in (5) the actual flexural stiffness EI in place of EI_B. This can be justified since, as shown in Figures 3 and 4, the dynamic response of the "modeled" mobile homes were found to vary only slightly to changes in flexural stiffness.

V.2. Examples

In an effort to give a better understanding of the predictive equations, three illustrative "hypothetical" examples are given in the following:

A. A mortgage company has defined a high risk mobile home as one which has approximately a 32-percent probability (standard deviation) of experiencing at an upper rear corner location, inertia loadings (vertical direction) of 8.2 G's* or more when being transported over a paved highway at 55 mph. In terms of the pertinent structural properties, this "base" unit has:

$$EI_B = 164 \times 10^8 \text{ lb.-in.}^2$$

$$J_B = 10 \text{ in.}^4 \ (n = 1)$$

$$C_{DB} = 0.10$$

The number of probable occurrences at which this acceleration level will be exceeded assuming a frequency response (f_B) of 5 Hz is:

$$N_B = \frac{(7.2 \times 10^5)(0.317)5}{55} = 2.07 \times 10^4 \text{ (per 100 miles)}$$

The mortgage company is interested in making a secondary loan on a particular mobile home. The owner plans to transport the unit from Childress to San Antonio, Texas (d = 400 miles) at the maximum allowable speed (55 mph) over essentially well paved and secondary roads. The unit's structural integrity is estimated in terms of its effective flexural stiffness, torsional stiffness, apparent frequency, and structural damping, i.e.,

$$EI = 120 \times 10^8 \text{ lb-in.}^2$$

$$J = 1000 \text{ in.}^4 \ (n = 3)$$

$$C_D = 0.10$$

$$f = 5 \text{ Hz}^\dagger$$

*This value would be based on available data or from predictive equations with input of "poor structural properties" (i.e., EI_B, J_B etc.).
†It is noted that the apparent response frequency is dependent upon the type of road traveled as well as anticipated speed and structural makeup of the unit. Here it is assumed same as "base" value. The procedure for estimating f is given in Appendix A of this report.

Substituting this data into (4) the mortgage company obtains:

$$\sigma_R = 6.42 \times 10^4 \frac{(55)^{0.734}(1)}{(120 \times 10^8)^{0.468}(0.10)^{0.363}\left[\text{Ln } 10^3 - \frac{\text{Ln } 10^2}{9}\right]^{2.046}}$$

$$= \frac{1.22 \times 10^6}{1.01 \times 10^6} = 1.2 \text{ G's}$$

The standard deviation (RMS) of the mobile home is 1.2 G's..

The probability of exceeding 8.2 G's $[P(\sigma_i > \sigma_B)^*]$ is less than 0.002 (0.2 percent). Assuming 0.002 and substituting this data into equation (6) one obtains:

$$RUL = 1 - \frac{(7.2 \times 10^3)(5)(400)(0.002)}{55(2.07 \times 10^4)}$$

$$= 1 - 0.03 = 0.97$$

The unit's anticipated *RUL* when it reaches San Antonio is 97 percent or the unit lost 3 percent of its useful life during the move.

B. The second hypothetical example is same as the former except that the proposed road conditions are primarily unpaved (wavy). In this instance (from Table 5) $rc = 2.5$.

Substituting this change into equation (4), the RMS vertical acceleration is:

$$\sigma_R = 6.42 \times 10^4 \frac{(55)^{0.734}(2.5)}{(120 \times 10^8)^{0.468}(0.10)^{0.363}\left[\text{Ln } 10^3 - \frac{\text{Ln } 10^2}{9}\right]^{2.046}}$$

$$= \frac{3.04 \times 10^6}{1.01 \times 10^6} = 3.0 \text{ G's}$$

The probability $P(\sigma_R > \sigma_B)$ of exceeding 8.2 G's (2.73 σ) is approximately 0.007 (0.7 percent). Substituting the required data in (6):

$$RUL = 1 - \frac{(7.2 \times 10^3)(5)(400)(0.007)}{55(2.07) \times 10^4)}$$

$$= 1 - 0.09 = 0.91$$

The units anticipated *RUL* when it reaches San Antonio is 91 percent (the move would consume an estimated 9 percent of the mobile homes "useful life"). It is noted that in Example B the mobile home was assumed transported 400 miles over unpaved road to show an example where the *RUL* is substantially reduced.

For a variety of different road conditions and speed during transit of the unit, equations (4), (5) and (6) are modified as:

$^*\sigma_B = 8.2$ G; $\sigma = 1.2$ G; hence $\sigma_B = 6.83\sigma$ and P $(\sigma_i > 6.83\sigma)$ is less than .002

$$\sigma_{RK} = 6.42 \times 10^4 \frac{V_k^{0.734} rc_k}{EI^{0.468} C_D^{0.363} \left[\text{Ln } 10^n - \frac{\text{Ln } 10^{n-1}}{n^2} \right]^{2.046}} \tag{4'}$$

$$\sigma_{FK} = 7.13 \times 10^{-3} \frac{EI^{0.208} V_k^{0.530} rc_k}{C_D^{0.448} \left[\text{Ln } 10^n - \frac{\text{Ln } 10^{n-1}}{n^2} \right]^{1.610}} \tag{5'}$$

$$RUL = 1 - \frac{7.2 \times 10^3}{N_B} \frac{\Sigma d_k f_k P_k(\sigma_i > \sigma_B)}{V_k} \quad k = 1, 2, 3 \ldots. \tag{6'}$$

where the subscript "k" denotes the different anticipated road conditions (rc_k) during transit, the corresponding miles of each type of road (d_k) and proposed speed (V_k for each road).

As an example considering the following:

C. The above unit is to be transported under the following conditions to San Antonio from Childress, Texas (a total of 400 miles).

- d_1 = 200 miles

  V_1 = 55 mph

  rc_1 = 1 (paved road)

  f_1 = 4 Hz

- d_2 = 100 miles

  V_2 = 45 mph

  rc_2 = 2.5 [unpaved (waves) road]

  f_2 = 5 Hz

- d_3 = 100 miles

  V_3 = 35 mph

  rc_3 = 3.0 (gravel road)

  f_3 = 6 Hz

It is decided that equation (4′), the response of the rear section, will be used to evaluate anticipated RUL. Accordingly, for each road condition we obtain:

$$\sigma_{RI} = 6.42 \times 10^4 \frac{(55)^{0.734}(1)}{(120 \times 10^8)^{0.468}(0.10)^{0.363} \left[\text{Ln } 10^3 - \frac{\text{Ln } 10^2}{9} \right]^{2.046}}$$

$$= \frac{1.22 \times 10^6}{1.01 \times 10^6} = 1.2 \text{ G's}$$

$$\sigma_{R2} = 6.42 \times 10^4 \frac{(45)^{0.734}(2.5)}{(120 \times 10^8)^{0.468}(0.10)^{0.363}\left[\text{Ln } 10^3 - \dfrac{\text{Ln } 10^2}{9}\right]^{2.046}}$$

$$= \frac{2.62 \times 10^6}{1.01 \times 10^6} = 2.60 \text{ G's}$$

$$\sigma_{R3} = 6.42 \times 10^4 \frac{(35)^{0.734}(3.0)}{(120 \times 10^8)^{0.468}(0.10)^{0.363}\left[\text{Ln } 10^3 - \dfrac{\text{Ln } 10^2}{9}\right]^{2.046}}$$

$$= \frac{2.62 \times 10^6}{1.01 \times 10^6} = 2.60 \text{ G's}$$

The above are the RMS vertical accelerations for the unit for the three different road speeds and road conditions. The corresponding probabilities of exceeding the "base" RMS value (8.2 G's) are:

$$P_1(\sigma_{R1} > \sigma_B) < 0.002 \text{ (0.2 percent)}$$

$$P_2(\sigma_{R2} > \sigma_B) = P_3(\sigma_{R3} > \sigma_B) \cong 0.003 \text{ (0.3 percent)}$$

These probabilities along with the corresponding velocities, frequencies and distances are substituted into expression (6′) i.e.,

$$RUL = 1 - \frac{7.2 \times 10^3}{2.07 \times 10^4}\left[\frac{(200)(4)(0.002)}{55} + \frac{(100)(5)(0.002)}{45} + \frac{(100)(6)(0.003)}{35}\right] = 1 - 0.04 = 0.96$$

which approximates the remaining useful life of the mobile home upon reaching the installation site as 96 percent or in terms of degradation, the trip has "cost" 4 percent of the unit's RUL.

V.3. Application to Single-Wide (T-1) and Double-Wide (T-2)

As alluded to in the previous sections, transportation degradation is related to both the structural makeup of the unit as well as the transportation related variables (i.e., road travelled and speed). Accordingly, an assessment of the performance of the T-1 and T-2 (A and B) under conditions I and II of Task I can vary substantially depending upon these variables. Because of this, the performance of the units for each "condition" will be investigated for various transportation modes (distance, speed, road type).

V.3.1. Condition I (T-1)

For this initial transportation condition (250-500 miles) from the manufacturer's plant to the owner's site the transportation modes shown in Table 6 were considered. Based on preliminary experimental data for the T-1, the structural properties for a "new" single-wide were taken as:

$$EI_R = 1000 \times 10^8 \text{ lb-in.}^2$$

$$J_R = 3500 \text{ in.}^4$$

$$EI_F = 250 \times 10^8 \text{ lb-in.}^2$$

$$J_F = 875 \text{ in.}^4$$

$$C_{DF} = C_{DR} = C_D = 0.20$$

TABLE 6

TRANSPORTATION ARRAY (CONDITION I)

CONDITION	DISTANCE (miles)		ROAD CONDITION*			TYPICAL SPEED (mph)		
	250	500	Well Paved	Paved (waves)	Paved (rough)	35	45	50
1A	X		X					X
1B		X	X					X
1C	X				X	X		
1D		X			X	X		
1E	X			X			X	
1F		X		X			X	

*Well paved; $\overline{rc} = 1.0$ (primary roadways; above average secondary roads)
Paved (Waves); $\overline{rc} = 1.2$ (typical secondary roadways)
Paved (Rough); $\overline{rc} = 1.5$ (rough secondary roads)

where the subscripts "R" and "F" signify structural properties pertaining to the rear and front sections of the unit. For a "zero life" or "base" unit, the structural properties were assumed as:

$$EI_{RB} = EI_R = 1000 \times 10^8 \text{ lb-in.}^2$$

$$EI_{FB} = EI_F = 250 \times 10^8 \text{ lb-in.}^2$$

$$J_{RB} = (0.05) J_R = 175 \text{ in.}^4$$

$$J_{FB} = (0.05) J_F = 43.8 \text{ in.}^4$$

where it was conjectured that a reduction in flexural stiffness (EI) during a unit's "life span" would not change (reduce) substantially in comparison to the torsional stiffness and hence, can be assumed constant. *A reduction by 95 percent of the unit's "original" torsional stiffness would be considered structurally unsafe.* It was further assumed that this "base" unit could withstand a maximum 100-mile move between sites over a paved (rough) road at an average speed of 55 mph (i.e., before RUL = 0). Under these conditions the RMS vertical acceleration response and the "apparent" frequency at the rear and front locations of the base unit are:

$$\sigma_{FB} = 3.15 \text{ G's} \qquad f_{FB} \simeq f_{RB} \simeq 8 \text{ Hz}$$
$$\sigma_{RB} = 0.81 \text{ G's}$$

Based on the above assumptions, predictive equations (4), (5) and (6) were utilized to define anticipated remaining useful life (RUL) or degradation for the various transportation modes given in Table 6. The results in terms of anticipated RMS vertical acceleration levels for the rear and front sections* of the T-1, as well as degradation are given in Table 7. As noted in this table the degree of degradation was evaluated to be as low as *0.3 percent* for the rear section of the single-wide and as high as over *10 percent* for the front section, depending on the typical speed and the roughness of the (paved) road. Furthermore, from Table 7 it is shown that the dynamic response and the degree of degradation for the front or fore-section of the T-1 is anticipated to be greater than the rear portion of the unit. This is attributed to the front section having torsionally weaker structural properties in comparison to the rear portion of the unit.

V.3.2 Condition I (T-2B)

For this half section of the double-wide, which does not contain the plumbing fixtures (dry side), the pertinent structural properties (based on limited experimental data) were taken as:

$$EI_R = 730 \times 10^8 \text{ lb-in.}^2$$

$$J_R = 2600 \text{ in.}^4$$

$$EI_F = 170 \times 10^8 \text{ lb-in.}^2$$

$$J_F = 600 \text{ in.}^4$$

$$C_{DF} = C_{DR} = C_D = 0.20$$

Making the *a priori* assumption that the T-2 can tolerate acceleration levels no greater than the T-1, the previously defined "base" RMS values were used, i.e.,

*Upper rear corner and midpoint location between axle and hitch.

TABLE 7

ANALYTICALLY EVALUATED T-1 DEGRADATION DUE TO INITIAL MOVE (CONDITION I)

CONDITION	RMS Vertical Acceleration (G's)		Degradation (percent)	
	Rear Location	Front Location	Rear Section	Front Section
1A	.22	.89	0.3	0.5
1B	.22	.89	0.6	1.0
1C	.26	1.10	2.4	5.2
1D	.26	1.10	4.8	10.4
1E	.25	1.00	1.5	2.0
1F	.25	1.00	3.0	4.0

*Rear monitoring location at rear most upper corner.
Front monitoring location at upper wall-roof interface, midway between axle and hitch.

$$\sigma_{FB} = 3.15 \text{ G's} \qquad f_{FB} \cong f_{RB} \cong 8 \text{ Hz}$$

$$\sigma_{RB} = 0.81 \text{ G's}$$

As with the T-1, based on the above for the various transportation modes defined in Table 6, anticipated RMS acceleration levels and degradation for the T-2B are given in Table 8.

As noted, anticipated degradation for the initial move varied from a low of *0.2 percent* for the front section to a high of *28 percent* for the rear section, depending on the road traversed by the unit and the transport speed. It is further noted that the predictive analysis anticipated a higher degree of degradation for the rear section of the T-2B in comparison to its front section. This is opposite the anticipated degradation effect for the T-1 and is due, in part, to the T-1 having a structurally very sound rear section compared to the T-2B rear section. It is also due to the fact that the flexural stiffness (EI_F) for the front section of the T-2B is less than the T-1's counterpart. As noted previously, the dynamic response for the front section was found to be directly proportional to its flexural stiffness. Accordingly, the combination of a weaker rear section for the T-2B and a flexurally less stiff front section, when compared with the T-1, resulted in this anticipated *reverse sense* of degradation.

V.3.3. Condition I (T-2A)

For this half section of the double-wide (wet side), based on preliminary experimental data, the required structural properties for the predictive equations were taken as:

$$EI_R = 720 \times 10^8 \text{ lb-in.}^2$$

$$J_R = 2500 \text{ in.}^4$$

$$EI_F = 170 \times 10^8 \text{ lb-in.}^2$$

$$J_F = 600 \text{ in.}^4$$

$$C_{DF} = C_{DR} = C_D = 0.2$$

As with T-1 and T-2B, utilizing the previously defined assumptions, the anticipated RMS acceleration levels and degradation for the T-2A are given in Table 9. As noted, degradation to the rear section of this half of the double-wide is somewhat greater than the T-2B.

V.3.4. Condition II (T-1)

For this condition, the T-1 undergoes fifteen (15) years of use including three (3) occupancy periods and two secondary moves ranging from 300 to 600 miles (including 4000 lb of added internal weight). As with Condition I, the unit's degradation will depend, in part, on the transportation modes involved (i.e., road condition, speed, etc.). Accordingly, for these secondary moves, the transportation modes shown in Table 10 were considered.

From preliminary experimental data for the T-1, each setup and takedown degrades the effective torsional and flexural stiffnesses for the front and rear sections of the unit in the following manner:

- Thirty (30) percent reduction in torsional stiffness for the front section (J_F).
- Forty (40) percent reduction in torsional stiffness for the rear section (J_R).
- Twenty (20) percent reduction in flexural stiffness for the rear section (EI_R).
- Fifty-five (55) percent reduction in flexural stiffness for the front section (EI_F).

Based on the above, for each secondary move the structural parameters (EI, J) were reduced by these percentages when utilized with the predictive equations for defining transportation-related degradation.

TABLE 8

ANALYTICALLY EVALUATED T-2B DEGRADATION DUE TO INITIAL MOVE (CONDITION I)

CONDITION	RMS Vertical Acceleration (G's)*		Degradation (percent)	
	Rear Location	Front Location	Rear Section	Front Section
1A	.28	.91	3.4	.2
1B	.28	.91	6.8	.4
1C	.32	1.13	14.1	6.4
1D	.32	1.13	28.2	12.8
1E	.31	1.03	8.8	2.1
1F	.31	1.03	17.5	4.2

*Rear monitoring location at rear most upper corner.
Front monitoring location at upper wall-roof interface, midway between axle and hitch.

TABLE 9

ANALYTICALLY EVALUATED T-2A DEGRADATION DUE TO INITIAL MOVE (CONDITION I)

CONDITION	RMS Vertical Acceleration (G's)*		Degradation (percent)	
	Rear Location	Front Location	Rear Section	Front Section
1A	.29	.91	4.6	.2
1B	.29	.91	9.2	.4
1C	.33	1.13	17.7	6.4
1D	.33	1.13	35.4	12.8
1E	.32	1.03	11.0	2.1
1F	.32	1.03	22.0	4.2

*Rear monitoring location at rear most upper corner.
Front monitoring location at upper wall-roof interface, midway between axle and hitch.

TABLE 10

TRANSPORTATION ARRAY FOR EACH MOVE (CONDITION II)

CONDITION	Distance (miles)		Road Condition*			Typical Speed (mph)		
	300	600	Well Paved	Paved (Waves)	Paved (Rough)	35	45	50
2A	X		X					X
2B		X	X					X
2C	X				X	X		
2D		X			X	X		
2E	X			X			X	
2F		X		X			X	

*Well Paved; $\overline{rc} = 1.0$
Paved (Waves); $\overline{rc} = 1.2$
Paved (Rough); $\overline{rc} = 1.5$

A. *First Secondary Move*—As alluded to above, the pertinent structural parameters utilized for the Condition I analysis were estimated to degrade to the following values after the units first setup and takedown:

$$EI_R = 800 \times 10^8 \text{ lb-in.}^2$$

$$J_R = 2100 \text{ in.}^4$$

$$EI_F = 113 \times 10^8 \text{ lb-in.}^2$$

$$J_F = 613 \text{ in.}^4$$

Utilizing the same "base" conditions defined in the previous section, the predictive equations (4), (5) and (6) were used to estimate degradation of the T-1 for the modes shown in Table 10. The degrees of degradation for this *initial* secondary move are given in Table 11. As noted in this table, the degradation to the unit varied from *0.2 percent* to *42.2 percent* depending on the transportation mode. In comparison with Table 7, it is also noted that for this *initial* secondary move, the rear section is shown degrading at a greater rate than the front section. This is the result of the dynamic responses (*RMS* value) for the front section being directly proportional to the effective stiffness (EI_F). Accordingly, when a reduction in EI_F due to Condition I and setup and takedown occurs, the G levels experienced between axle(s) and hitch also diminish.

B. *Second Secondary Move*—As per case A, the reduced structural stiffness for the T-1 based on the aforementioned percentages were taken as:

$$EI_R = 640 \times 10^8 \text{ lb-in.}^2$$

$$J_R = 1260 \text{ in.}^4$$

$$EI_F = 51 \times 10^8 \text{ lb-in.}^2$$

$$J_R = 429 \text{ in.}^4$$

With these effective stiffnesses and the transportation modes defined in Table 10, the degrees of degradation for the T-1 are shown in Table 12. As noted, the analytically evaluated degrees of degradation varied from *undefinable* for the front section to *100 percent* for the rear section.*

V.3.5. Condition I and II (T-1)

Based on the predictive analysis, the total degradation to this unit is assumed to be the sum of the degradation percentages for the various moves and setups and takedowns. As previously stated, the degradation depends in part, upon the transportation modes experienced by the unit during the specified 15-year period. Based on the "best" and "worst" conditions from Tables 6 and 10, an assumed 15-year transportation mode array is given in Table 13. For these transportation modes, the probabilistic degradation to the T-1 was analytically evaluated and is shown in Table 14. In terms of the entire unit (front and rear sections), the lowest anticipated degradation to the unit is approximately *36 percent*. For seven(7) of the defined twelve (12) transportation modes the unit is anticipated to be *totally degraded* (i.e., zero *RUL*) after or during transit to its proposed *third* site (second secondary move).

Furthermore, as noted in Table 14, the rate of degradation is anticipated to be substantially greater for the rear section of the single-wide in comparison to the front section. The maximum level of degradation to the front section of the unit is limited to *20 percent.*

V.3.6. Condition II (T-2B)

For this condition, the T-2 unit (both wet and dry sides) experience twenty (20) years of use including two (2) occupancy periods and one (1) secondary transportation move ranging from 300 to 600 miles†. Accordingly,

* Note: The analysis does not consider the degradation incurred by the unit during its final setup at its third and last site. This would be included if the unit was taken down to be moved to a *fourth* site.

† Includes added distributed weight of 8000 lb (occupant's personal effects).

TABLE 11

ANALYTICALLY EVALUATED T-1 DEGRADATION DUE TO INITIAL SETUP AND TAKEDOWN AND INITIAL SECONDARY MOVE (CONDITION II)

CONDITION	RMS Vertical Acceleration (G's)		Degradation (percent)	
	Rear Location	Front Location	Rear Section	Front Section
2A	.29	.83	5.4	0.2
2B	.29	.83	10.8	0.4
2C	.33	1.03	21.1	3.3
2D	.33	1.03	42.2	6.6
2E	.32	.94	13.2	0.9
2F	.32	.94	26.4	1.9

TABLE 12

ANALYTICALLY EVALUATED T-1 DEGRADATION DUE TO SECONDARY SETUP AND TAKEDOWN AND SECOND SECONDARY MOVE (CONDITION II)

CONDITION	RMS Vertical Acceleration (G's)		Degradation (percent)	
	Rear Location	Front Location	Rear Section	Front Section
2A	.37	.78	30.0	negligible*
2B	.37	.78	60.0	negligible*
2C	.42	.97	80.0	1.9
2D	.42	.97	100.0	3.6
2E	.41	.88	55.3	0.5
2F	.41	.88	100.0	0.9

*Probabilities of exceeding "base" RMS values where extremely small

TABLE 13

TYPICAL SUMMATIONS IN TRANSPORTATION MODES FOR T-1 UNIT

CONDITION(S)*	DISTANCE (miles)		ROAD CONDITION			TYPICAL SPEED (mph)		
	550	1700	Well Paved	Paved (Waves)	Paved (Rough)	35	45	50
1A plus 2A	X		X					X
1B plus 2B		X	X					X
1A plus 2C	X		X		X	X		X
1B plus 2D		X	X		X	X		X
1A plus 2E	X		X	X			X	X
1B plus 2F		X	X	X			X	X
1C plus 2C	X				X	X		
1D plus 2D		X			X	X		
1C plus 2E	X			X	X	X	X	
1D plus 2F		X		X	X	X	X	
1E plus 2E	X			X			X	
1F plus 2F		X		X			X	

*Conditions are summations taken from Tables 6 and 10. Includes degradation due to setup-takedown procedures.

TABLE 14

ESTIMATED FIFTEEN YEAR DEGRADATION (CONDITIONS I AND II) FOR TYPICAL SINGLE WIDE (T-1) MOBILE HOME

TRANSPORTATION MODE(S)*	DEGRADATION (percent)	
	Rear Section	Front Section
1A plus 2A	35.7	0.7
1B plus 2B	71.4	1.4
1A plus 2C	100.0	5.7
1B plus 2D	100.0	11.2
1A plus 2E	68.8	1.9
1B plus 2F	100.0	3.8
1C plus 2C	100.0	10.4
1D plus 2D	100.0	20.6
1C plus 2E	70.9	6.6
1D plus 2F	100.0	13.2
1E plus 2E	70.0	4.8
1F plus 2F	100.0	6.8

*Includes degradation due to setup and takedown procedures.

the transportation modes considered shown in Table 10 still are applicable. In addition, as per the T-1 unit, preliminary experimental data indicated the following reduction in structural properties for the T-2B to be the result of a single setup and takedown:

- Forty (40) percent reduction in effective flexural stiffness for the front section (EI_F).
- Fifty (50) percent reduction in effective flexural stiffness for the rear section (EI_R).
- Forty-five (45) percent reduction in effective torsional stiffness for the front section (J_F).
- Sixty (60) percent reduction in the effective torsional stiffness (J_R) for the rear section of the unit.

Based on this data and the assumed initial structural properties for the T-2B (defined in Section V.3.2.), the reduced stiffnesses after setup and takedown of the unit were assumed as:

$$EI_R = 365 \times 10^8 \text{ lb-in.}^2$$

$$J_R = 1040 \text{ in.}^4$$

$$EI_F = 102 \times 10^8 \text{ lb-in.}^2$$

$$J_F = 330 \text{ in.}^4$$

With these structural properties, the anticipated dynamic response and amount of degradation during the unit's secondary move, are given in Table 15. As shown in this table, prior to, or upon arrival at the secondary setup site, the T-2B's rear section is predicted to have *totally degraded.* Conversely, only minimal degradation to the front section is anticipated. The total anticipated degradation to the T-2B for both the initial move to the owner's setup site and secondary move (in terms of transportation modes given in Table 16), are shown in Table 17.

V.3.7. Condition II (T-2A)

As with the T-2B, preliminary experimental data indicated the following reductions in flexural and torsional stiffness due to a single setup and takedown.

- Fifty (50) percent reduction in EI_F,
- Six (6) percent reduction in EI_R,
- Fifty (50) percent reduction in J_F, and
- Twenty (20) percent reduction in J_R.

Utilizing the initial data defined in Section V.3.3. for the T-2A, the pertinent structural properties after takedown were defined as:

$$EI_R = 677 \times 10^8 \text{ lb-in.}^2$$

$$J_R = 2000 \text{ in.}^4$$

$$EI_F = 85 \times 10^8 \text{ lb-in.}^2$$

$$J_F = 300 \text{ in.}^4$$

$$C_{DF} = C_{DR} = C_D = 0.2$$

TABLE 15

ANALYTICALLY EVALUATED T-2B DEGRADATION DUE TO INITIAL SETUP AND TAKEDOWN AND SECONDARY MOVE (CONDITION II)

CONDITION	RMS Vertical Acceleration (G's)		Degradation (percent)	
	Rear Location	Front Location	Rear Section	Front Section
2A	.51	.83	100.0	0.2
2B	.51	.83	100.0	0.4
2C	.59	1.03	100.0	3.3
2D	.59	1.03	100.0	6.6
2E	.57	.94	100.0	.9
2F	.57	.94	100.0	1.9

TABLE 16

TYPICAL SUMMATIONS IN TRANSPORTATION MODES FOR T-2 MOBILE HOME

CONDITION(S)*	DISTANCE (miles)		ROAD CONDITION			TYPICAL SPEED (mph)		
	550	1100	Well Paved	Paved (Waves)	Paved (Rough)	35	45	50
1A plus 2A	X		X					X
1B plus 2B		X	X					X
1A plus 2C	X		X		X	X		X
1B plus 2D		X	X		X	X		X
1A plus 2E	X		X	X			X	X
1B plus 2F		X	X	X			X	X
1C plus 2C	X				X	X		
1D plus 2D		X			X	X		
1C plus 2E	X			X	X	X	X	
1D plus 2F		X		X	X	X	X	
1E plus 2E	X			X			X	
1F plus 2F		X		X			X	

*Conditions are summations taken from Tables 6 and 10.

TABLE 17

ESTIMATED TWENTY YEAR DEGRADATION (CONDITIONS I AND II) FOR TYPICAL (HALF) DOUBLE WIDE (T-2B) MOBILE HOME

TRANSPORTATION MODE(S)	DEGRADATION (percent)	
	Rear Section	Front Section
1A plus 2A	100.0	0.4
1B plus 2B	100.0	0.8
1A plus 2C	100.0	3.5
1B plus 2D	100.0	7.0
1A plus 2E	100.0	1.1
1B plus 2F	100.0	2.3
1C plus 2C	100.0	9.7
1D plus 2D	100.0	19.4
1C plus 2E	100.0	7.3
1D plus 2F	100.0	14.7
1E plus 2E	100.0	3.0
1F plus 2F	100.0	6.1

Substituting the above properties into the predictive equations (4), (5) and (6) for the transportation modes defined on Table 10, one obtains the anticipated degradation to this half of the double-wide because of *setup, take-down* and *secondary move.* These results are given in Table 18. As noted, the rear section of the half of the double-wide is anticipated to degrade at a substantially faster rate than the front portion of the unit. In addition, when compared with Table 15 it is seen that the rear section of this unit will probabilistically degrade at a slower rate than the corresponding section of the T-2B.

The total degradation for the T-2A for the transportation modes given in Table 16 (i.e., Conditions I and II) are given in Table 19. As illustrated by this table, the T-2A is predicted overall to degrade less than the T-2B during its move to the secondary setup site. Specifically, only *one* transportation mode would result in *total* degradation of the rear portion of the unit compared with *all* the modes for the secondary move of the T-2B. In addition, as with the T-2B, the front section of the T-2A is anticipated to degrade at a slower rate than the rear section of the unit.

V.4. Comparison of In-Transit Versus Setup-Takedown Degradation

In the previous section (V.3.), degradation due to initial and secondary moves as well as on-site procedures were analytically evaluated for both the single-wide (T-1) and double-wide (T-2) units. The same methodology can be applied to gain insight on the sensitivity to degradation that typical on-site procedures possess in comparison to degradation experienced by a unit while on the road. This will be handled by making the *a priori* assumption that the unit makes the initial and secondary moves without any setups and takedowns. Accordingly, the evaluated degradation would then be wholly due to in-transit phenomena. A comparison of this section findings with Section V.3 would then define the amount of degradation due solely to typical on-site procedures.

V.4.1. Single Wide (T-1)

For the single-wide (T-1), the degradation due to the initial moves is as shown in Table 7 (for the transportation modes defined in Table 6). For the secondary moves, Table 10 as well as Table 13 are still valid with the exception that *no* setup-takedown degradation is assumed after each move. In terms of structural properties for the unit, the initial values assumed will be held constant for *all* the moves. While it is realized that this is not the case, at present there does exist enough information available which would permit one to conjecture on a definable relationship between the structural parameters (EI_F, EI_R, J_F, J_R) and in-transit conditions (e.g., speed, road-type). Furthermore, in terms of reductions in torsional stiffness, a reduced parameter was input to the predictive equations to account for reductions in this variable due to a move. Furthermore, in terms of the flexural stiffness, it was noted that a change in this variable has only a small effect on the dynamic response of the unit. Accordingly, based on the above, the following expressions for the T-1 are assumed valid for *all* the moves:

$$EI_R = 1000 \times 10^8 \text{ lb-in.}^2$$

$$J_R = 3500 \text{ in.}^4$$

$$EI_F = 250 \times 10^8 \text{ lb-in.}^2$$

$$C_{DF} = C_{DR} = C_D = 0.2$$

Substituting the above expressions into the predictive equations (4), (5) and (6) for the conditions given in Table 10, one obtains the degradation results shown in Table 20 for each secondary move. For the total transportation mode array (Table 13), the anticipated degradation is given in Table 21.

Comparing Table 21 with Table 14, it is noted that the setup-takedown procedure attributed to well over 90 percent of the degradation in the rear section of the T-1 for most of the transportation modes.* Contrary to this phenomenon, the front section was evaluated to degrade *more* when no setups and takedowns were considered. The values in this instance, however, cannot be wholly relied upon and are attributed to the predictive equation for front unit response (equation 5) being directly proportional to flexural stiffness (EI_F).

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*Divide typical values from Table 21 by the corresponding values from Table 14 to estimate degradation attributed to in-transit move *only*.

TABLE 18

ANALYTICALLY EVALUATED T-2A DEGRADATION DUE TO INITIAL SETUP AND TAKEDOWN AND SECONDARY MOVE (CONDITION II)

CONDITION	RMS Vertical Acceleration (G's)		Degradation (percent)	
	Rear Location	Front Location	Rear Section	Front Section
2A	.31	.97	9.4	1.2
2B	.31	.97	18.8	2.4
2C	.36	1.20	36.3	12.8
2D	.36	1.20	72.6	25.6
2E	.35	1.10	24.1	4.9
2F	.35	1.10	48.1	9.7

TABLE 19

ESTIMATED TWENTY YEAR DEGRADATION (CONDITIONS I AND II) FOR TYPICAL (HALF) DOUBLE WIDE (T-2A) MOBILE HOME

TRANSPORTATION MODE(S)	DEGRADATION (percent)	
	Rear Section	Front Section
1A plus 2A	14.0	1.4
1B plus 2B	28.0	2.8
1A plus 2C	40.9	13.0
1B plus 2D	81.8	26.0
1A plus 2E	28.7	5.1
1B plus 2F	57.3	10.1
1C plus 2C	54.0	19.2
1D plus 2D	100.0	38.4
1C plus 2E	41.8	11.3
1D plus 2F	83.5	22.5
1E plus 2E	35.1	7.0
1F plus 2F	70.1	13.9

TABLE 20

ANALYTICALLY EVALUATED T-1 DEGRADATION DUE TO EACH SECONDARY MOVE*

CONDITION	RMS Vertical Acceleration (G's)		Degradation (percent)	
	Rear Location	Front Location	Rear Section	Front Section
2A	.22	.89	0.4	0.6
2B	.22	.89	0.7	1.2
2C	.26	1.10	2.9	6.2
2D	.26	1.10	5.8	12.5
2E	.25	1.00	1.8	2.9
2F	.25	1.00	3.6	4.8

*Excluding setup-takedown degradation

TABLE 21

ESTIMATED DEGRADATION FOR TYPICAL SINGLE WIDE (T-1) MOBILE HOME EXCLUDING SETUP-TAKEDOWN EFFECTS

TRANSPORTATION MODE(S)	DEGRADATION (percent)	
	Rear Section	Front Section
1A plus 2A	1.1	1.7
1B plus 2B	2.0	3.4
1A plus 2C	6.1	12.9
1B plus 2D	12.2	26.0
1A plus 2E	3.9	6.3
1B plus 2F	7.8	10.6
1C plus 2C	8.2	17.6
1D plus 2D	16.4	35.4
1C plus 2E	6.0	11.0
1D plus 2F	12.0	20.0
1E plus 2E	5.1	7.8
1F plus 2F	10.2	13.6

Due to the above limiting assumptions, it is anticipated that the degradation (percentages) shown in Table 21 are probabilistically *low* for the rear section of the T-1 and *high* for the front section. The table is of value, however, in that it exemplifies the following:

- Setup and takedown procedures for Conditions I and II for the T-1 may cause a larger degree of degradation to the unit's rear section in comparison to the corresponding degradation resulting from move between sites.

- A reduced flexural stiffness for the front section of the unit may result in significant "savings" in terms of a smaller degradation rate.

V.4.2. Double-Wide (T-2)

As per the case with the single-wide, in an effort to define degradation due to setups and takedowns for this unit, the same *a priori* assumptions concerning structural stiffnesses are made. Accordingly, for the initial moves, degradation evaluations defined in Tables 8 and 9 are still valid, as well as the transportation arrays illustrated in Tables 10 and 16. With the above conditions imposed, precluding degradation resulting from setups and takedowns, the degree(s) of degradation for the T-2A and T-2B were evaluated as shown in Tables 22 and 23 (for secondary move only). A comparison of Tables 15, 18, 22 and 23 illustrates a substantial savings in "useful life" when degradation due to setup-takedown procedures are excluded. As with the T-1, however, the values in Tables 22 and 23 are anticipated to be on the low side. With this in mind, the following pertinent findings can be made from these tables:

- The majority of the degradation to the rear section of the T-2B may be due to setup-takedown techniques.

- The degradation effects of setup and takedown for the T-2A is not as severe as for the T-2B.

- For both the T-2A and T-2B, typical setup and takedown procedures degrade the rear sections of the unit to a greater extent than what is incurred by the front sections.

TABLE 22

ANALYTICALLY EVALUATED T-2B DEGRADATION DUE TO SECONDARY MOVE EXCLUDING SETUP-TAKEDOWN EFFECTS

CONDITION	RMS Vertical Acceleration (G's)		Degradation (percent)	
	Rear Location	Front Location	Rear Section	Front Section
2A	.28	.91	4.8	.2
2B	.28	.91	8.2	.5
2C	.32	1.13	16.9	7.7
2D	.32	1.13	33.8	15.4
2E	.31	1.03	10.6	2.5
2F	.31	1.03	21.0	5.0

TABLE 23

ANALYTICALLY EVALUATED T-2A DEGRADATION DUE TO SECONDARY MOVE EXCLUDING SETUP-TAKEDOWN EFFECTS

CONDITION	RMS Vertical Acceleration (G's)		Degradation (percent)	
	Rear Location	Front Location	Rear Section	Front Section
2A	.29	.91	5.5	.2
2B	.29	.91	11.0	.5
2C	.33	1.13	21.2	7.7
2D	.33	1.13	42.5	15.4
2E	.32	1.03	13.2	2.5
2F	.32	1.03	26.4	5.0

VI. DYNAMIC ANALYSIS CONCLUSIONS

Based on the dynamic modeling of the single-wide (T-1) and the double-wide (T-2A and B) the following *tentative* conclusions concerning degradation to mobile homes during transit have been drawn:

- The principal parameter affecting high inertial repetitive loads is the *effective torsional stiffness* (J_F and J_R) of the mobile home.
- The *effective flexural stiffness* for the rear section of a unit (EI_R) is inversely proportional to the inertial loadings induced in this section.
- The *effective flexural stiffness* for the front section (EI_F) of a mobile home is directly proportional to the induced inertial loadings.
- Changes in *torsional stiffness* (J_R and J_F) affect degradation of the rear section of a unit to a larger degree than the front section (from axle to hitch).
- Accumulative degradation of the rear section of a mobile home is more sensitive to transport speed than is the front section.
- For Conditions I and II (see Tables 14, 17 and 19) the T-1 and T-2 units' rear sections are anticipated to degrade at a substantially faster rate than their front sections.
- The rear section of the dry side (T-2B) of the double-wide is anticipated to degrade at a greater rate during transit than the rear section of the wet side (T-2A) (see Tables 17 and 19).
- For the required initial and secondary moves (Conditions I and II), the T-1 was determined to have a longer useful life than the T-2.
- Degradation due to typical setup and takedown procedures may cause more degradation to a mobile home than in-transit phenomena.
- The degradation effect of setup-takedown procedures is greatest in the rear section of a mobile home.

VII. PREDICTIVE EQUATION LIMITATIONS

The predictive equations as well as conclusions are based on a regression analysis of the dynamic model simulations. Due to this dependency wholly on an analytical model, their utilization as an effective tool to measure mobile home degradation should be restrained until the experimental phase (Task III) of the present contract is complete. This cautionary measure is warranted, due to the complexity of a mobile home structure. Accordingly, care must be used at present in utilizing the predictive *RUL* formulae.

It is also noted that, in the above analysis, a "zero" life mobile home was based on certain percent reductions in the unit's original structural integrity. Whether or not such figures are *apropos* cannot be confirmed until the data collected from actual testing (Task III) are evaluated. Furthermore, it may be that significant structural stiffness reductions in a unit which is initially very stiff can be realized and still be "useful" in terms of a family dwelling. Conversely, a unit which is initially rather weak structurally may not be able to sustain near this level of degradation and be either safe to transport or suitable to live in.

It is realized, however, that a substantial reduction in the mobile home's structural integrity will have a pronounced effect on its level of risk in terms of safety during transporting of the unit, resalability, repairability potential, etc. Accordingly in the above analyses, the estimated degradation was based on conjectured structural properties of a zero life unit. Based on the experimental phase of this study, these structural property values may warrant change as well as the overall methodology used to define transportation-related degradation for typical mobile homes.

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APPENDIX A
APPROXIMATING "APPARENT" FREQUENCY OF MOBILE HOME REAR SECTION

As stated in the Task I report, from the STARDYNE computer results, it was noted that the response frequency of the unit is dependent on the structure, speed and road surface during transit. In an effort to better define the apparent frequency, the UCS MULFIT computer program has been utilized to calculate a regression equation based on the early STARDYNE runs.

In this evaluation of the response frequency (in vertical direction), it was assumed that the frequency can be approximated by:

$$f = \frac{1}{2\pi} \frac{\sigma_{\dot{z}}}{\sigma_z} \qquad \text{(A-1)}$$

where $\sigma_{\dot{z}}$ and σ_z are the RMS vertical velocity and displacement of the mobile home's rear section (node 1 in STARDYNE runs). Assuming (A-1), $\sigma_{\dot{z}}$ and σ_z regression equations were calculated (by MULFIT) as:

$$\sigma_{\dot{z}} = 168.5 \frac{V^{0.504}}{EI^{0.211} J^{0.005} C_D{}^{0.115}} \qquad \text{(A-2)}$$

$$\sigma_z = 2.28 \frac{V^{0.606} J^{0.023}}{EI^{0.247}\, C_D{}^{0.542}} \qquad \text{(A-3)}$$

where

V = home velocity (mph),

EI = effective flexural stiffness (lb-in.^{2}),

J = effective torsional stiffness (in.^{4}),

C_D = damping constant.

and where $\sigma_{\dot{z}}$ and σ_z are in in./sec and inches respectively.

Substituting (A-2) and (A-3) into equation (A-1), the apparent response frequency (in Hz) for the rear section of the unit (on paved roadway) is:

$$f = 11.74 \frac{EI^{0.036} C_D{}^{0.427}}{V^{0.102} J^{0.028}} \qquad \text{(A-4)}$$

This regression equation was then modified to consider the various road surface effects on the frequency, i.e.,

$$f = 11.74R \frac{EI^{0.036} C_D{}^{0.427}}{V^{0.102} J^{0.028}} \qquad \text{(A-5)}$$

where R is a constant dependent upon the road traveled by the mobile home (Table A-1). Equation (A-5) should be used to estimate f in equations (6) and (6′) of the Task I report.

TABLE A-1

EFFECT OF ROAD SURFACE ON FREQUENCY OF MOBILE HOME

Road Type	R
Paved	1.00
Unpaved (gravel)	1.00
Unpaved (waves)	.86
Unpaved (rough)	.05

APPENDIX B
THEORETICAL-PREDICTIVE ANALYSIS
EXAMPLES OF POTENTIAL APPLICATION OF DESIGN LOADS

As a result of the Dynamic Analysis and correlation of data with the necessary factors to develop the Remaining Useful Life Analysis, the following method of obtaining design loads for mobile home manufacturers is recommended. In the TASK I report, a set of predictive equations are presented to be used as a tool for estimating degradation due to the effects of transportation. These regression formulae can also be utilized to define dynamic load levels for both the rear and front sections of the unit. This latter aspect can be of use to the manufacturer during the construction of the individual homes. Specifically, if the probable dynamic load levels within a particular unit can be defined prior to the design of the unit, then the designer can determine if the present construction warrants modifications to enhance its structural integrity.

Based on the above premise, a set of graphs were constructed to estimate design load requirements for mobile homes. Figures B-1 through B-4 are given to define dynamic load levels for the rear section, while Figures B-5 through B-8 are for the front section (between axle and hitch). In either case, the resultant design loads are a function of the input structural stiffnesses (EI and J), damping property (C_D), and speed and road conditions. Accordingly, depending upon the structural integrity of the unit as well as the anticipated speed and road to be safely traversed, the dynamic response (in G's) can be estimated for which the unit can be designed to withstand.

It is noted that resultant loads obtained from Figures B-4 and B-8 present a *99-percent confidence level*. That is, 99 percent of the induced dynamic loads to the unit for a specific travel condition (speed, road) will probabilistically be equal to or less than these values. The graphs can hence be used by a manufacturer to define acceptable design requirements for structural components within a mobile home.

As noted, these enclosed graphs allow the builder, designer, etc., to set his own design loads by presenting a range of structural properties (EI, J and C_D). The values input can be based on actual field test data of existing units or be based on anticipated structural properties after a degree of degradation has occurred. This latter approach would be advantageous since, the dynamic response (and load levels) are anticipated to increase as the unit degrades. In the following, an example is given of how the enclosed figures may be used.

EXAMPLE:

A mobile home manufacturer is interested in structurally enhancing its units by strengthening components in the rear section of the unit where a high degree of degradation has been reported during moves. From available data on test procedures, the following structural properties for the rear section of this particular unit are:

$$EI_{R'} = 600 \times 10^8 \text{ lb-in.}^2$$

$$J_{R'} = 3000 \text{ in.}^4$$

$$C_{D'} = 0.2$$

To minimize actual degradation and, since the dynamic loads for the rear section will increase as degradation occurs, the manufacturer *assumes* a reduction in the above structural properties, i.e.,

$$EI_R = 400 \times 10^8 \text{ lb-in.}^2$$

$$J_R = 2000 \text{ in.}^4$$

$$C_D = 0.2$$

For the above properties, he obtains from Figures B-1 through B-3 the following:

$$\lambda_{R1} = 0.6$$

$$\lambda_{R2} = 0.558$$

$$\lambda_{R3} = 63.4$$

The product of these values ($\lambda_{R1} \times \lambda_{R2} \times \lambda_{R3}$) is then input into Figure B-4. The manufacturer is interested in defining loads (to be designed against) induced by the unit traveling along a gravel road at 35 mph. Accordingly, as shown in Figure B-4, a vertical line is drawn to intersect the appropriate curve from which a horizontal line is formed. For this case, the recommended design load is 1.92 G's. Hence, components within the rear section of the unit, designed to withstand *both vertical and lateral loads* of this magnitude, would significantly enhance the useful life of the homes by minimizing transportation-related degradation.

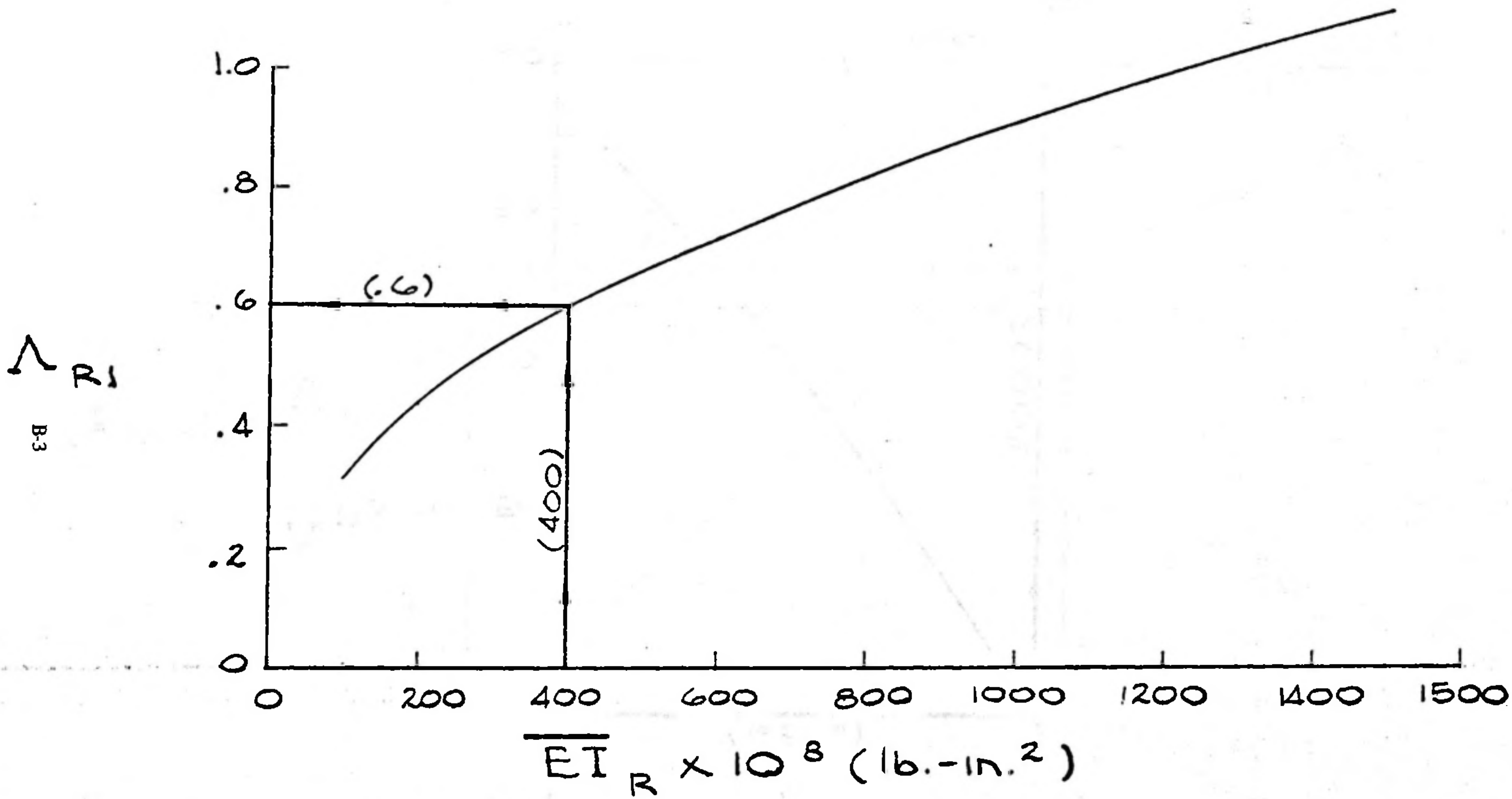

FIGURE B-1. EFFECT OF FLEXURAL STIFFNESS ON DYNAMIC RESPONSE PARAMETER

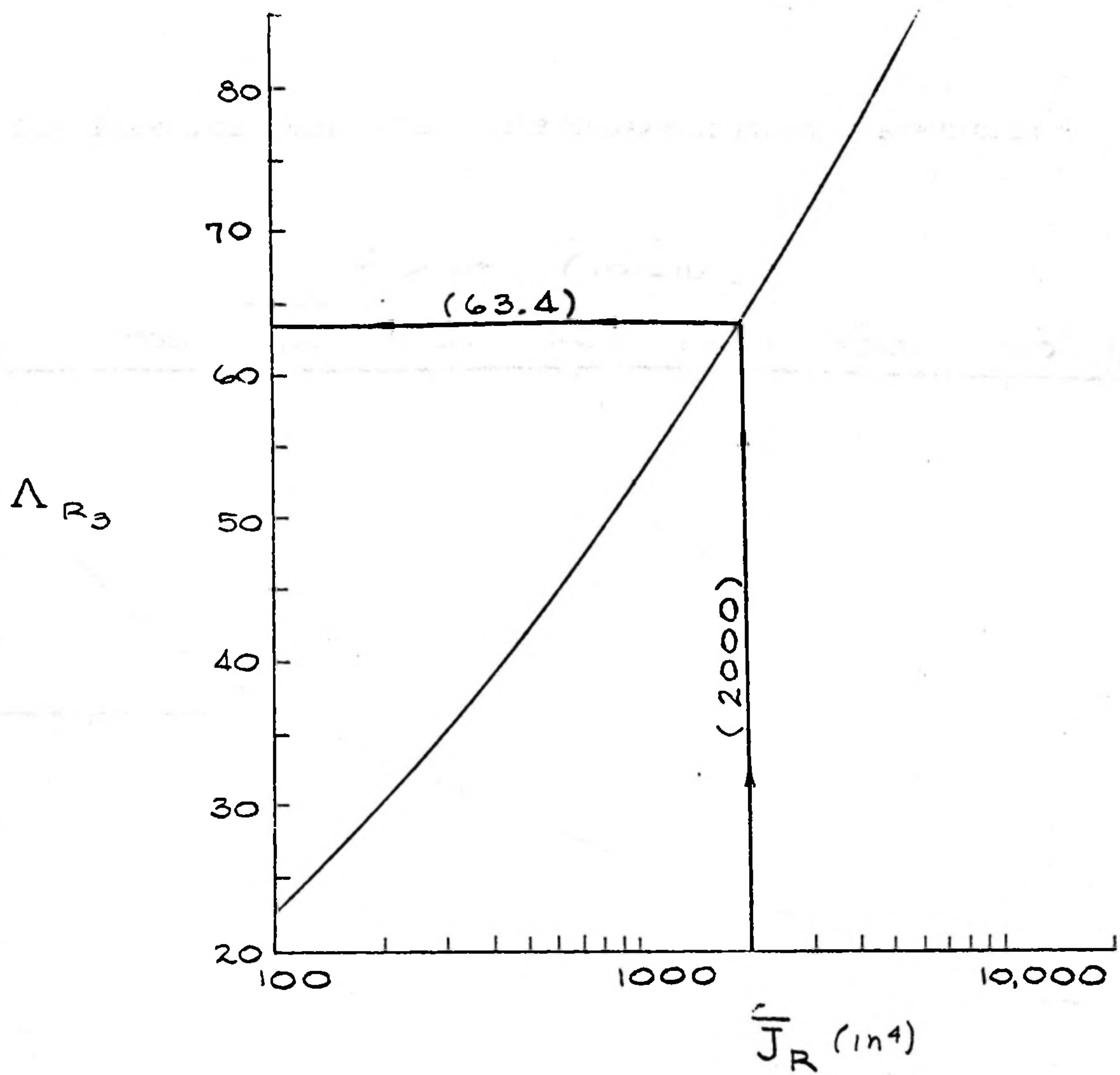

FIGURE B-2. EFFECT OF TORSIONAL STIFFNESS ON DYNAMIC RESPONSE PARAMETER

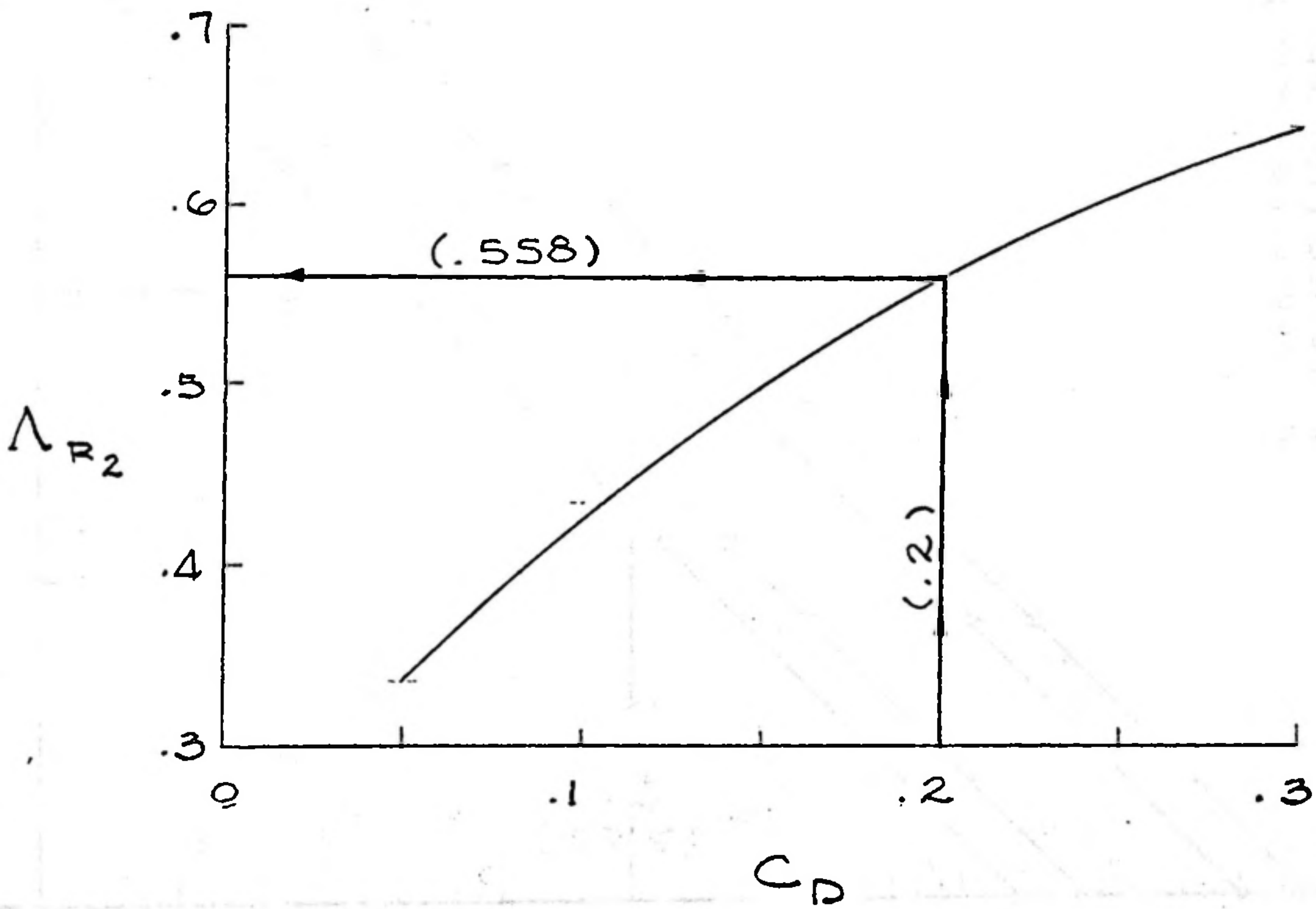

FIGURE B-3. EFFECT OF DAMPING ON DYNAMIC RESPONSE PARAMETER

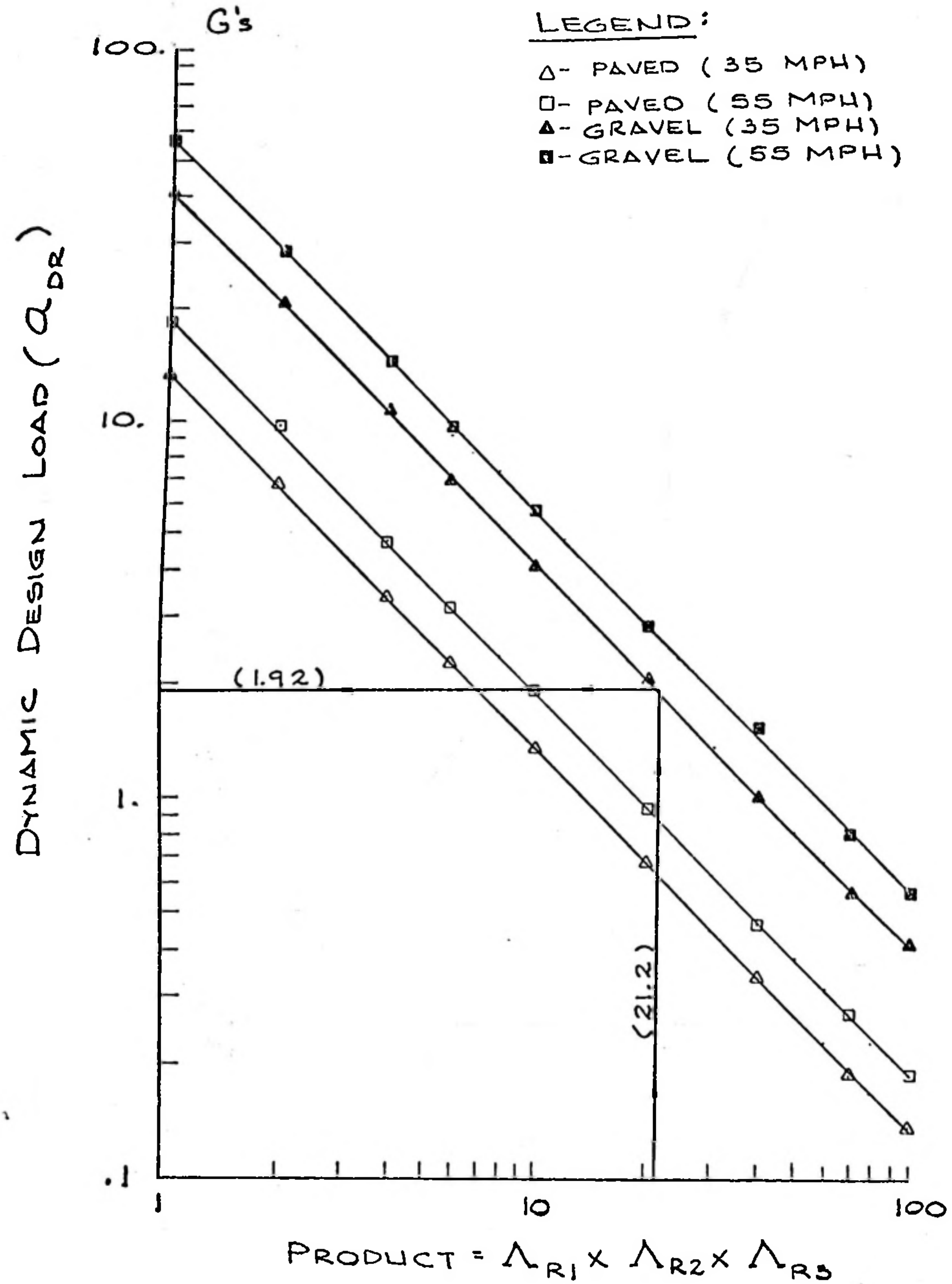

FIGURE B-4. DEFINING ANTICIPATED DYNAMIC RESPONSE FOR REAR SECTION OF HOME

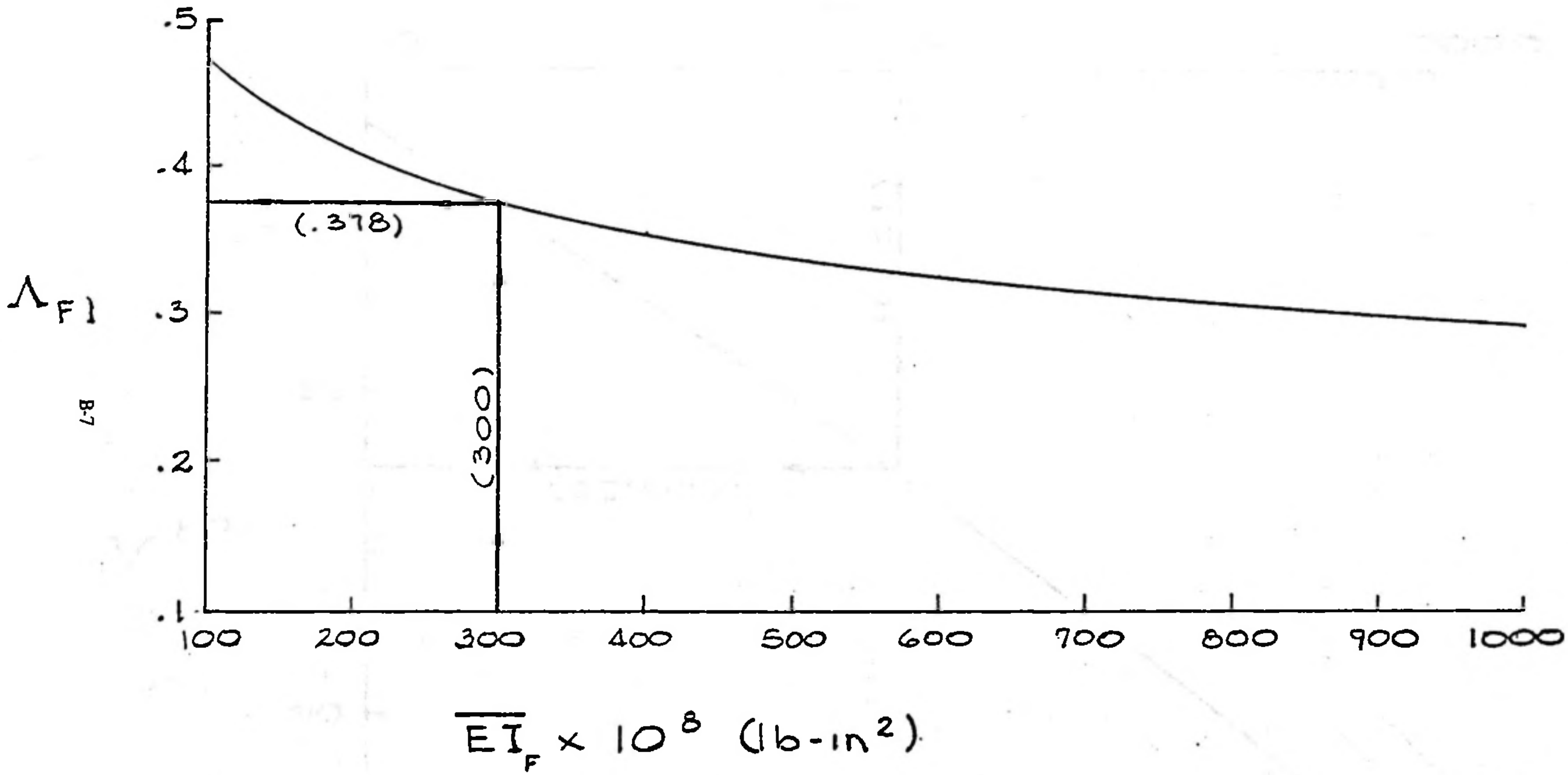

FIGURE B-5. EFFECT OF FLEXURAL STIFFNESS ON DYNAMIC RESPONSE PARAMETER

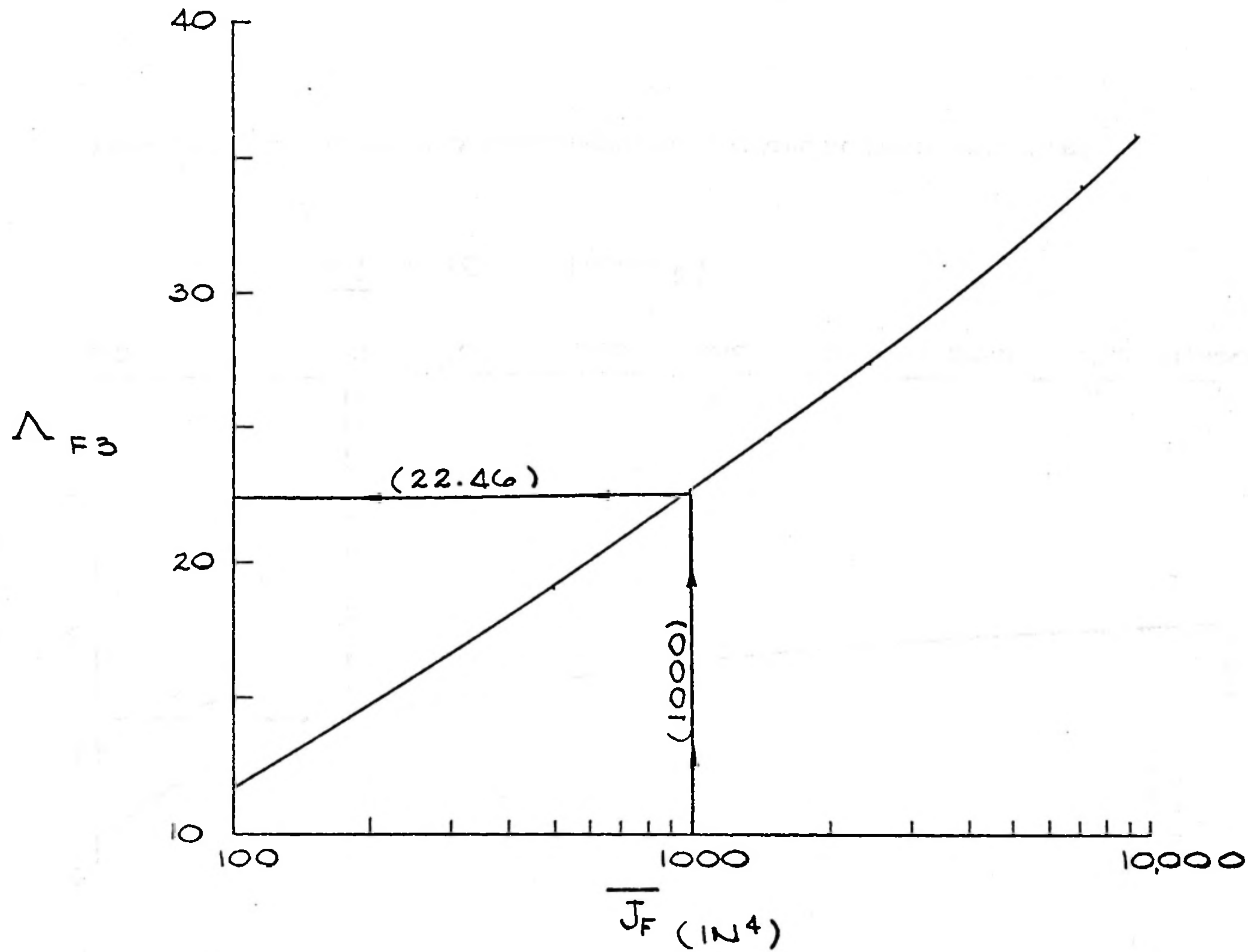

FIGURE B-6. EFFECT OF TORSIONAL STIFFNESS ON DYNAMIC RESPONSE PARAMETER

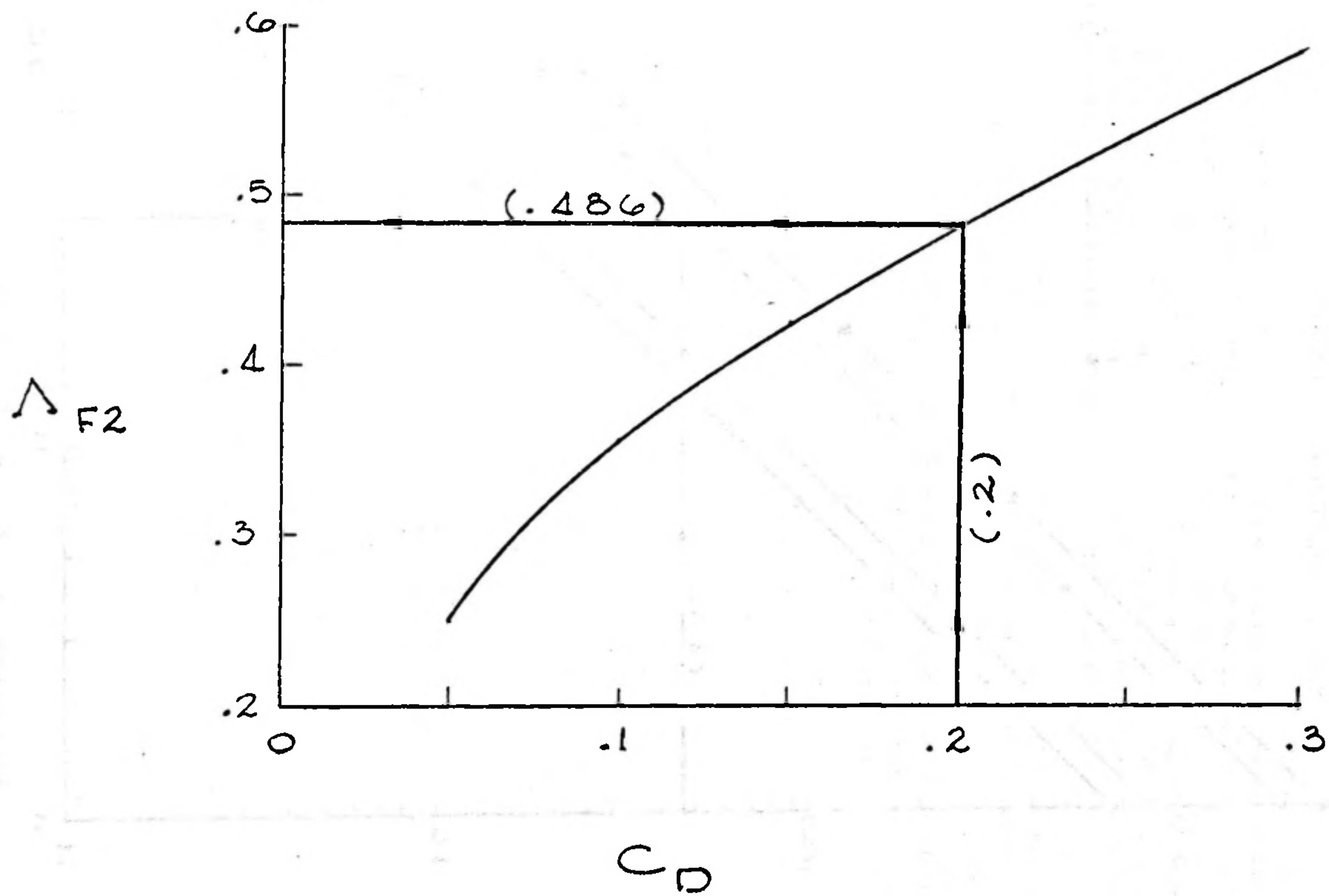

FIGURE B-7. EFFECT OF DAMPING ON DYNAMIC RESPONSE PARAMETER

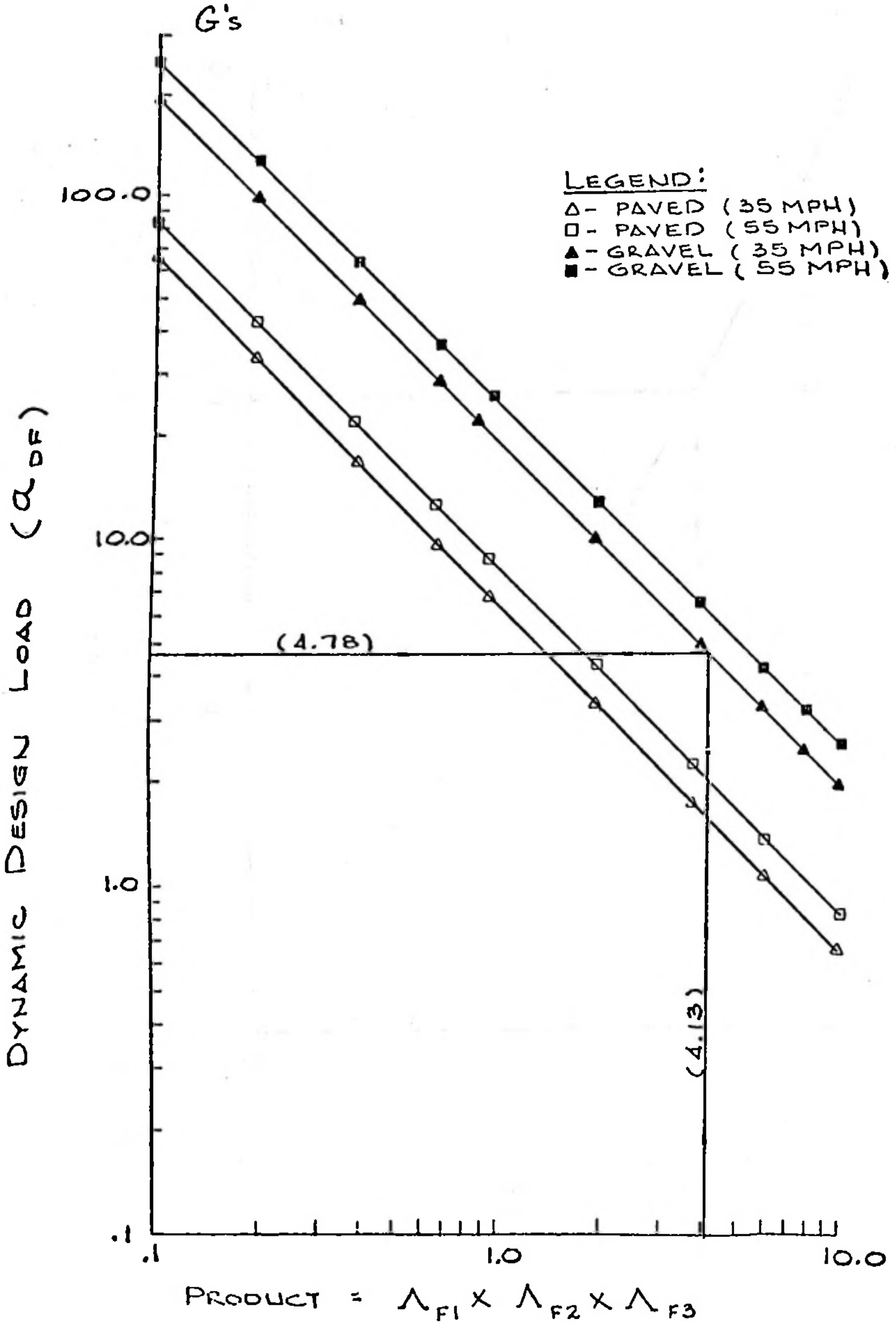

FIGURE B-8. DEFINING ANTICIPATED DYNAMIC RESPONSE FOR FRONT SECTION OF HOME

APPENDIX C

EFFECT OF STRUCTURAL PROPERTIES ON IN-TRANSIT EXCITATIONS

The effect of torsional stiffness on probable G loadings induced in an in-transit mobile home is shown in Figures C-1 and C-2. As shown in these figures, a torsionally weak mobile home (i.e., $J = 10$ in.^{4}) would have over a 90-percent probability of experiencing a one G or more loading compared to less than a 10-percent probability for the torsionally stiffer unit (i.e., $\bar{J} = 10^4$ in.^{4}). These findings can also be shown in terms of probable loadings and number of occurrences during the transporting of the Unit (Figures C-3 and C-4). For example, a comparison of probable lateral G loadings in Figure C-4, show that for the same occurrence rate of 100 times per mile, the weakest unit experiences over 5 G's while the stiffest unit experiences less than 0.1 G.

The type of road traveled as well as in-transit speed also has a significant effect on transportation-related degradation to a mobile home. It is of interest to note that for the unpaved road, the acceleration levels were found to be substantially smaller for a torsionally very stiff unit when compared with a torsionally weak unit traveling an unpaved road at the same speed. This is shown in Figures C-5 and C-6,emphasizing the substantial influence a torsionally very rigid mobile home has on diminishing the rate of degradation. The combined effect of speed and road condition is illustrated in Figure C-7. Note that the probable acceleration responses (for all types of roads) for the stiffer unit ($J = 10^4$ in.^{4}) are less than 2 G's while for the torsionally weak unit ($J = 10$ in.^{4}), the probable acceleration levels go as high as 20+ G's.

PROBABILITY OF EXCEEDING G LEVELS IN MOBILE HOME FOR VARIOUS STRUCTURAL CONDITIONS

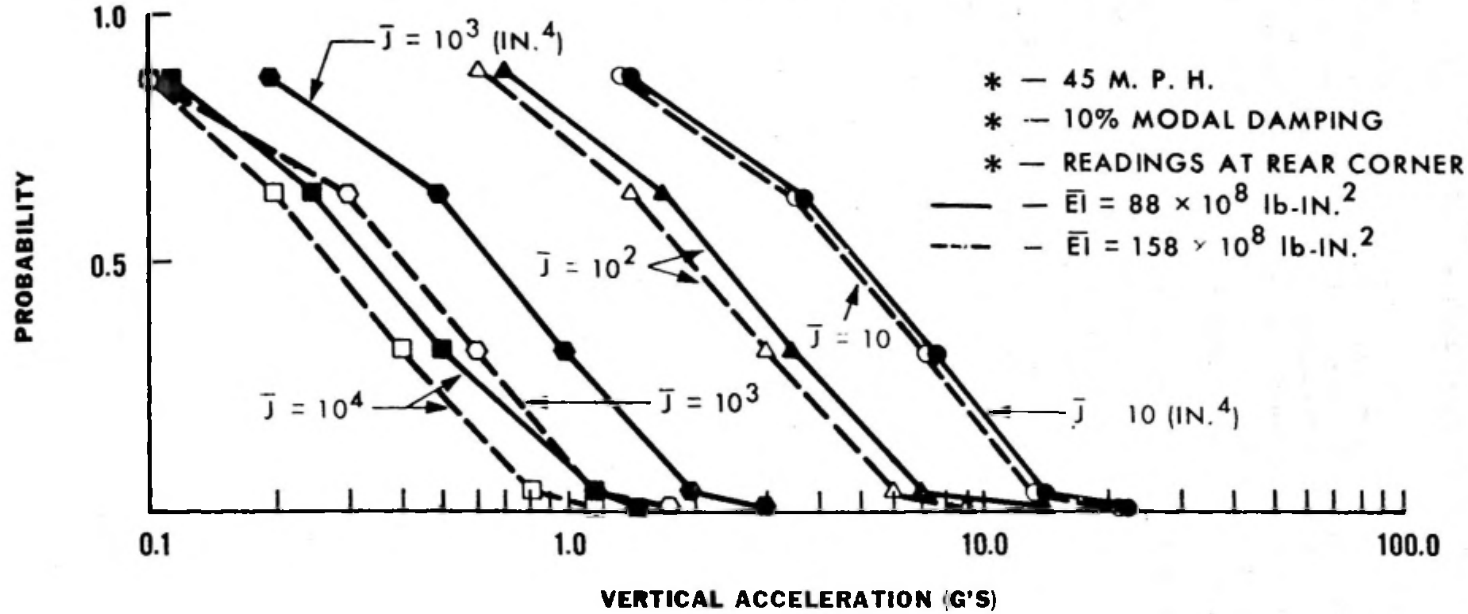

FIGURE C-1

PROBABILITY OF EXCEEDING G LEVELS IN MOBILE HOME FOR VARIOUS STRUCTURAL CONDITIONS

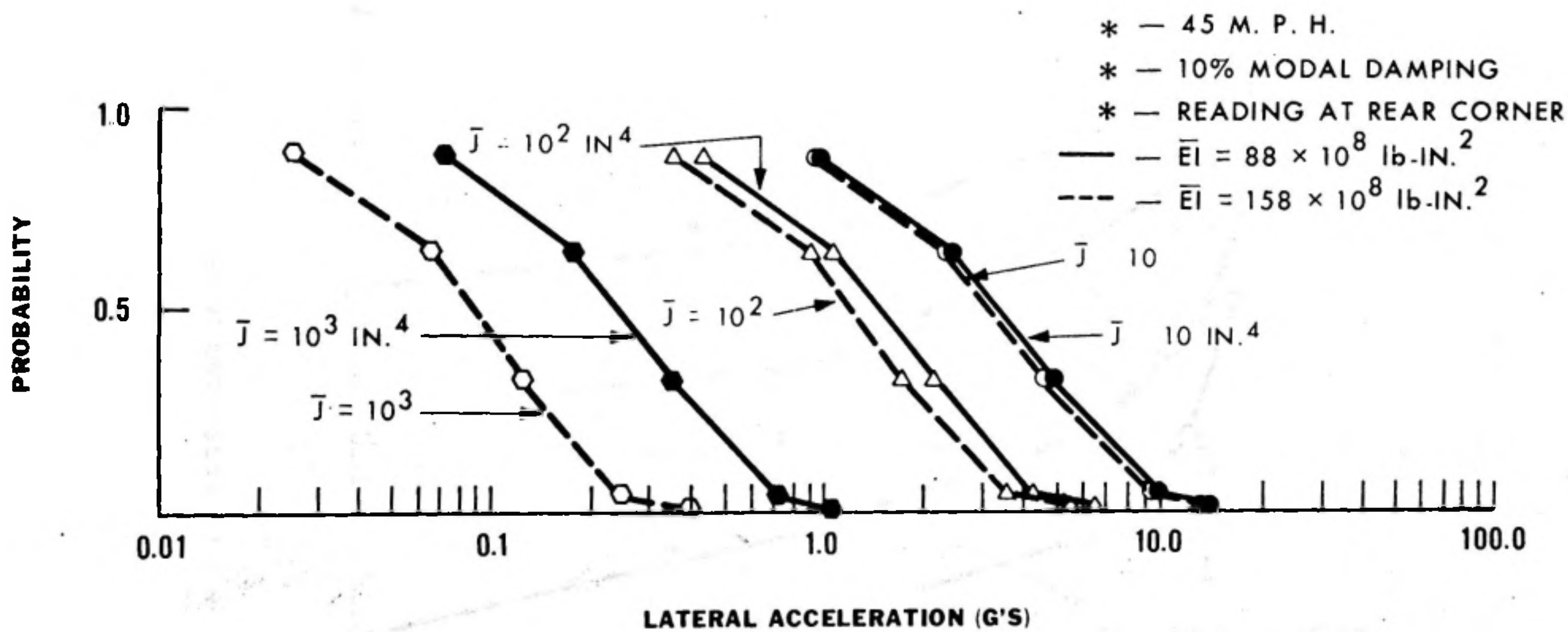

FIGURE C-2

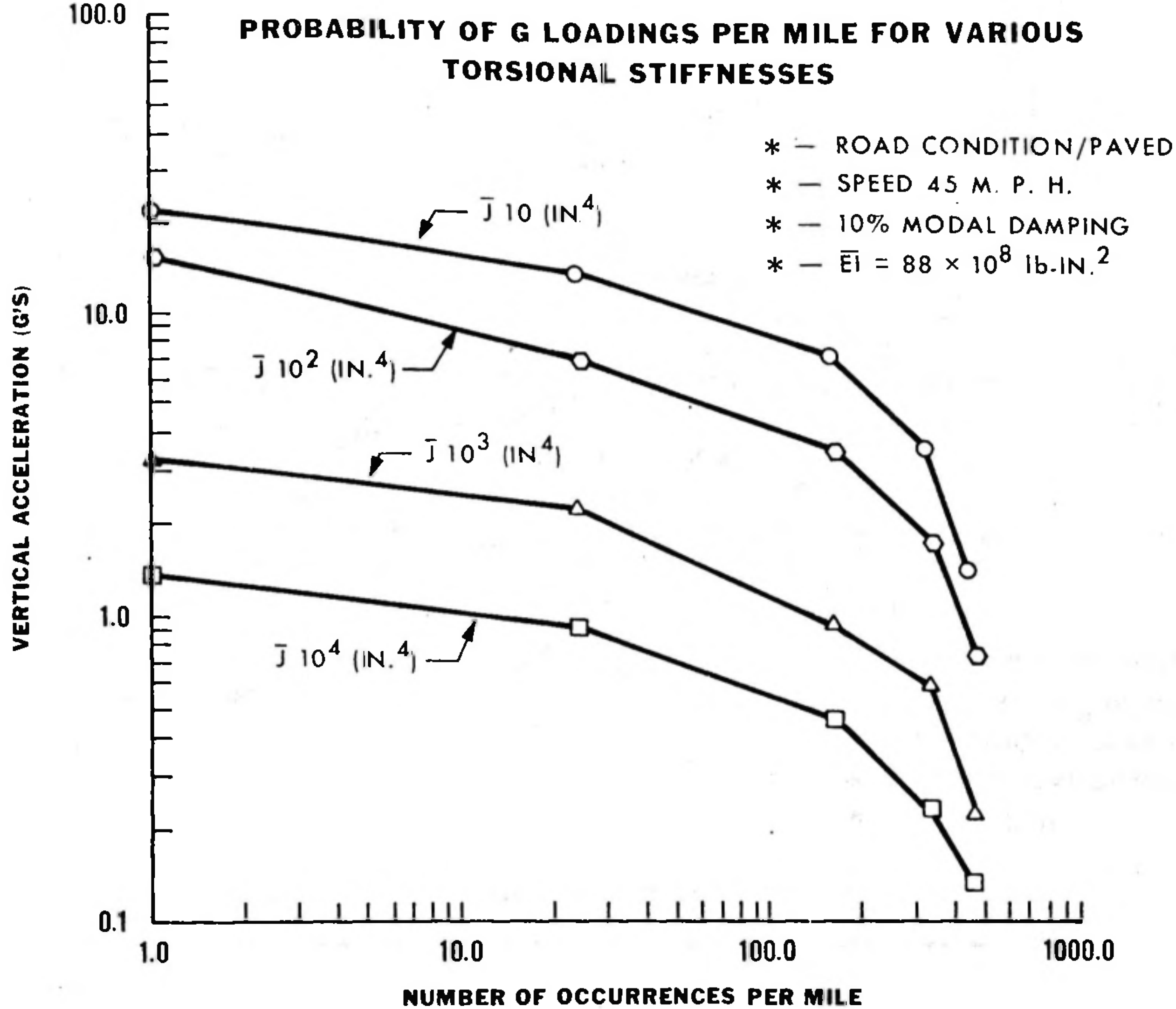
PROBABILITY OF G LOADINGS PER MILE FOR VARIOUS
TORSIONAL STIFFNESSES
* — ROAD CONDITION/PAVED
* — SPEED 45 M. P. H.
* — 10% MODAL DAMPING
* — $\overline{EI} = 88 \times 10^8$ lb.-IN.^{2}
$\bar{J}$ 10 (IN.^{4})
$\bar{J}$ 10^2 (IN.^{4})
$\bar{J}$ 10^3 (IN.^{4})
$\bar{J}$ 10^4 (IN.^{4})
VERTICAL ACCELERATION (G'S)
100.0
10.0
1.0
0.1
1.0
10.0
100.0
1000.0
NUMBER OF OCCURRENCES PER MILE

FIGURE C-3

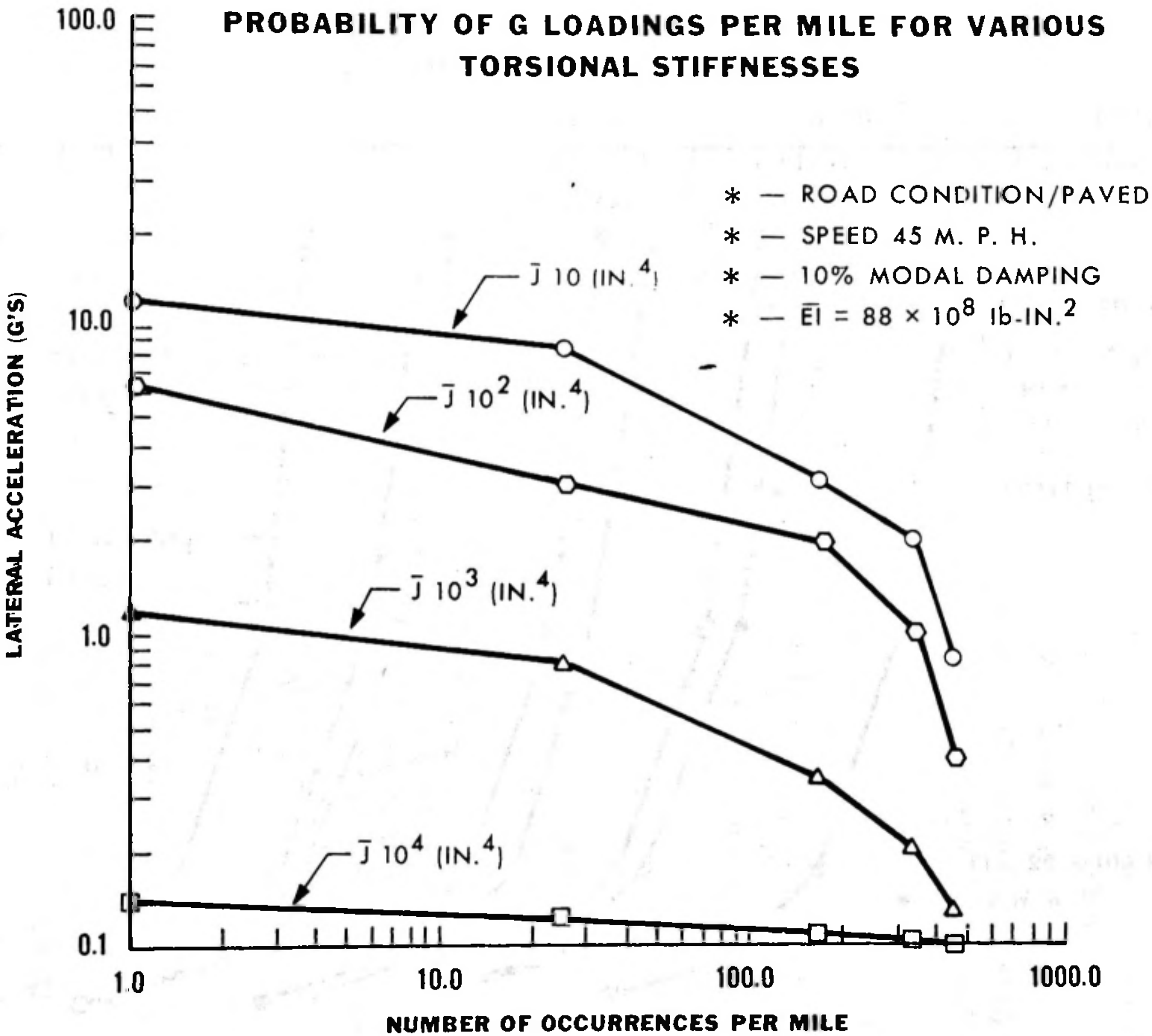
PROBABILITY OF G LOADINGS PER MILE FOR VARIOUS TORSIONAL STIFFNESSES
* — ROAD CONDITION/PAVED
* — SPEED 45 M. P. H.
* — 10% MODAL DAMPING
* — $\bar{EI}$ = 88 × 10^8 lb-IN.^{2}
$\bar{J}$ 10 (IN.^{4})
$\bar{J}$ 10^2 (IN.^{4})
$\bar{J}$ 10^3 (IN.^{4})
$\bar{J}$ 10^4 (IN.^{4})
LATERAL ACCELERATION (G'S)
100.0
10.0
1.0
0.1
1.0
10.0
100.0
1000.0
NUMBER OF OCCURRENCES PER MILE

FIGURE C-4

EFFECT OF ROAD CONDITION ON PROBABLE ACCELERATION LEVELS IN MOBILE HOME

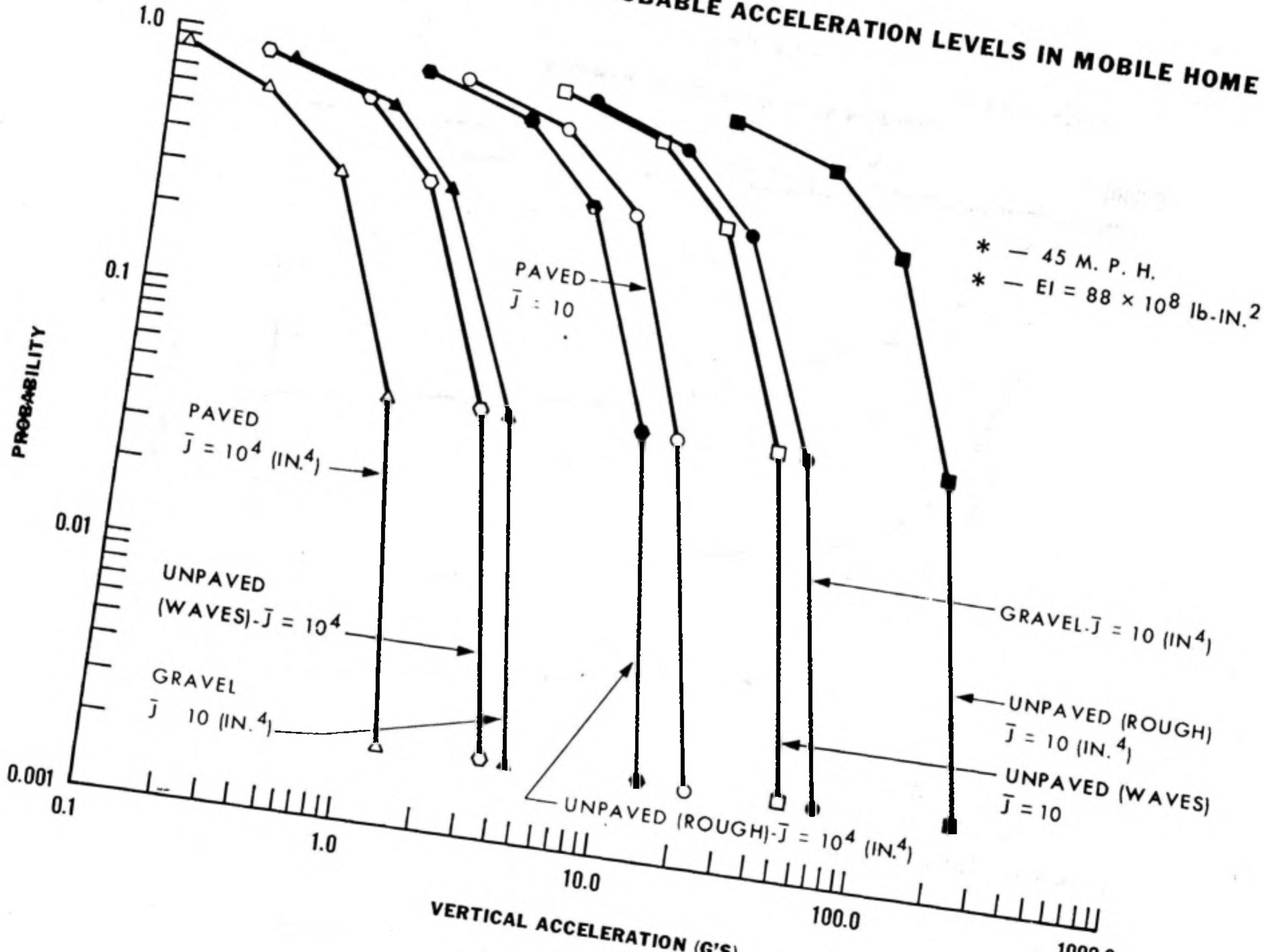

FIGURE C-5

EFFECT OF ROAD CONDITION AND TORSIONAL STIFFNESS ON PROBABLE ACCELERATION LEVELS

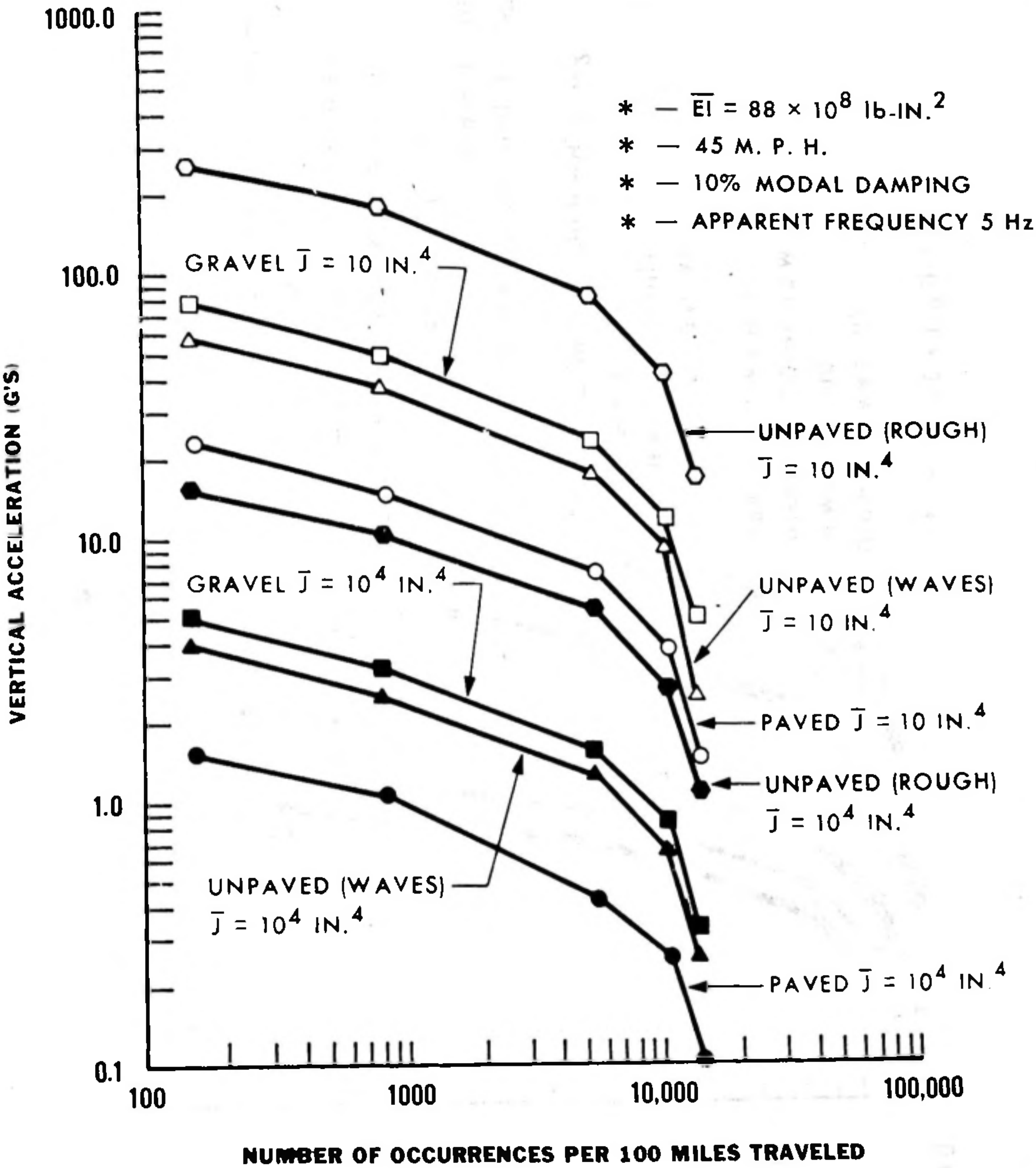

FIGURE C-6

EFFECT OF SPEED AND ROAD CONDITION ON MOBILE HOME ACCELERATION LEVELS

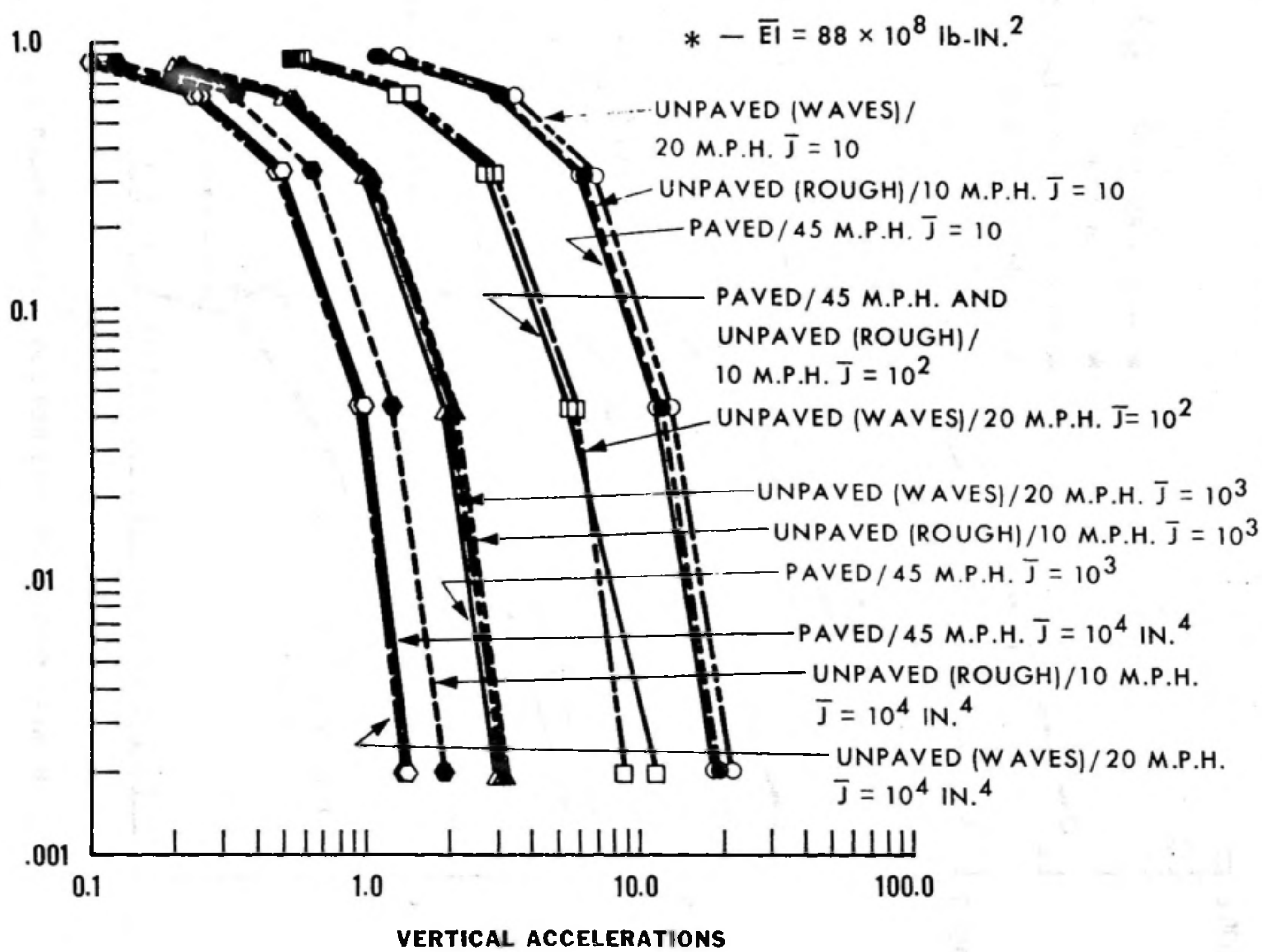

FIGURE C-7

FINITE ELEMENT MODEL AND ANALYSIS

FINITE ELEMENT MODEL AND ANALYSIS

Prepared by

C. R. Ursell, II
E. O. Wiles
L. R. Calcote, Ph.D.

ABSTRACT

Finite element modeling and analysis of mobile homes are used to predict the stresses and loads imposed upon test units in dynamic and static loading conditions. A finite element model is a mathematical representation of a complex structure by a simpler collection of discrete members. For this effort, the computer program ANSYS develops the models and uses them to generate stress and displacement plots of mobile home members. Analysis of these data details the effects of the various loadings on the mobile homes.

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LIST OF TABLES

DEFINITIONS

The following pages contain definitions of words or terms used in this document.

ANSYS - A large-scale general purpose computer program developed by Swanson Analysis Systems, Incorporated, Elizabeth, Pennsylvania. Analysis capabilities of the program include: (1) static and dynamic, (2) plastic, creep and swelling, (3) small and large deflection, (4) steady state and transient heat transfer, and (5) steady state fluid flow types of problems. The matrix displacement method of analysis based on finite element idealization of the structure is employed in the program. The library of finite element types in the program numbers more than 40 for static and dynamic analyses and 10 for heat transfer analyses. This variety of elements gives the program user the capability of analyzing frame structures, piping systems, two-dimensional plane and axisymmetric solids, flat plates, three-dimensional solids, axisymmetric and three-dimensional shells, and nonlinear problems. In this study, the program is used for static analysis of the mobile home structure, idealized as an assemblage of bar, beam, and membrane elements.

ELEMENT - A component part of a structure for which the relationships between forces and displacements at a finite number of points (or nodes) on the element are known. In this study, elements used are bars, prismatic beams, tapered beams, and membranes.

NODAL POINT - A point in space where two or more elements are connected in the idealization of the structure.

DEGREE OF FREEDOM - The direction of force or displacement at a node. For example, the three-dimensional elastic beam element used in the study has two nodes, one at each end. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes.

BOUNDARY CONDITIONS - Specified external loads and/or displacements applied at the nodes of the idealized structure.

RESTRAINT - A displacement boundary condition specified as zero in ANSYS. For example, if the node at the hitch is assumed stationary, displacements in the x, y, and z directions are all specified as zero.

MODULUS OF ELASTICITY - The slope of the stress-strain diagram of a material in the elastic range.

MASS DENSITY - The mass of a body per unit volume. When multiplied by the acceleration of gravity, the mass density becomes the specific weight in pounds per unit volume.

GRAVITY LOAD - Load applied to the structure by the weight of a component part.

EQUIVALENT STATIC LOAD - The load obtained by multiplying the weight of a structural component by its root-mean-square acceleration, as determined from the dynamic analysis (32 percent probability of not being exceeded or multiply by a factor of 3 to obtain 99.9 percent probability).

MAXIMUM/MINIMUM IN-PLANE STRESSES - The maximum and minimum principal stresses acting in the plane of a membrane element. (Note that a membrane element is not capable of resisting a force component applied perpendicular to the plane of the element.)

STRESS CONTOUR PLOT - A plot of a membrane element showing contours (or lines) of constant maximum or minimum stress levels.

EXPONENTIAL - Standard form of presentation of a number in E format, showing the number of places the indicated decimal must be moved to the right (plus exponent) or left (negative exponent). For example , 1.4 E + 03 = 1400., and 1.4 E - 02 = 0.014.

CARD SET - A group of input cards used in ANSYS for common input data (e.g., card set D defines the element types and card set E defines the nodes to which the elements are connected). The total conglomorate of all the various card sets forms the specified input data required to conduct a run of the program.

ISOTROPIC - Characteristic of a material that has identical properties in all directions.

I. INTRODUCTION

The objective of Task I, Volume III was to develop and apply a finite analysis theory or methodology that would accurately measure the stresses and/or loads in a mobile home resulting from various forces imposed by the transportation mode or the setup/takedown mode. This analysis would be applicable to both the single- and double-wide models. Accordingly, in Task I, a comprehensive dynamic and static analysis was performed by SwRI to identify and assess the probable dynamic and static loads occurring in mobile homes during transit and typical setup and takedowns.

For the static finite element model, realistic inputs were necessary to develop and validate the formulation. Actual dimensions of the mobile home units were used as well as the predicted accelerations and loads developed in the dynamic analysis. These were used as input into the finite element model as equivalent static loads, noting that the analysis was limited to static loads. The model was used in conjunction with the "predictive analysis" to analyze the structure at any two given points in the degradation cycle.* The accelerations and loads, which vary with degradation,** were inserted into the computer program to measure the loads and stresses at the two points in the degradation cycle.

The data employed herein will be used for correlation with actual test analysis in Task III.

---

* Refer to Task III, Volume III.
** Condition I parameters were used: Avg. 500 miles.

II. BACKGROUND DISCUSSION

The overall objectives of the finite element method of analysis were to:

- Identify critical structural areas in a mobile home (i.e., stress concentrations around door or window openings and at load application points);
- Assess the mobile home structure and the effects that static and dynamic loads have on it;
- Consider the effects of setup and takedown procedures;
- Evaluate resulting data for use in economic analysis;
- Support (if possible) the Development of an Analytical Methodology required by Task V;
- Evaluate resulting data for use in recommendations for Subpart J.

Through the application of the finite element analysis, the influence of transportation effects was established by comparing stress-trajectory plots before and after application of (dynamically induced) equivalent static loads to the structure. Restart capabilities were available in the computer program to apply new loads without regenerating the master stiffness matrix. When the structural model was changed, such as by relocating wall panels, doors or windows, the associated input data were appropriately modified and complete computer runs conducted. The capability of the computer program to be modified easily enabled the modeling of the mobile home units at various stages in their life. Comparison of results of different conditions of the same unit can be used as a predictive tool in the analysis of the consumed life and remaining useful life of the mobile home.

The proposed computer programs for use in the static investigation included ANSYS, STARDYNE, and STRUDL. An evaluation of these programs revealed that each have advantages and disadvantages for studying the mobile home degradation problem. As an example, the member release features in STARDYNE and STRUDL are much superior to the necessity for degree of freedom coupling in ANSYS; however, neither STARDYNE nor STRUDL have the important stress plot capability for the membrane elements. Furthermore, STARDYNE does not have the tapered beam element warranted for members such as outriggers and roof trusses. Consequently, despite the programming effort required to effect member releases, ANSYS was selected as the most appropriate program for the study.

ANSYS is a large-scale general purpose computer program designed for the solution of several classes of engineering analysis problems. For the analysis of mobile homes in this program, the static analysis capabilities of the ANSYS computer program were utilized.

The method of analysis in ANSYS is based on finite element idealization. Therefore, each structure analyzed in this program was broken down into an approximate assembly of discrete structural elements connected at a finite number of points (nodal points). After a unit was properly modeled, loading conditions were defined to represent the transportation or setup/takedown mode. From this input, a solution was generated that obtained the nodal point displacements at each node in the structure which in turn, enabled the calculation of the forces and stresses within each structural element.

Figure 1 is a brief summary of this computer modeling procedure with ANSYS. A detailed description of the ANSYS computer program and its application to the mobile home is contained in the appendix.

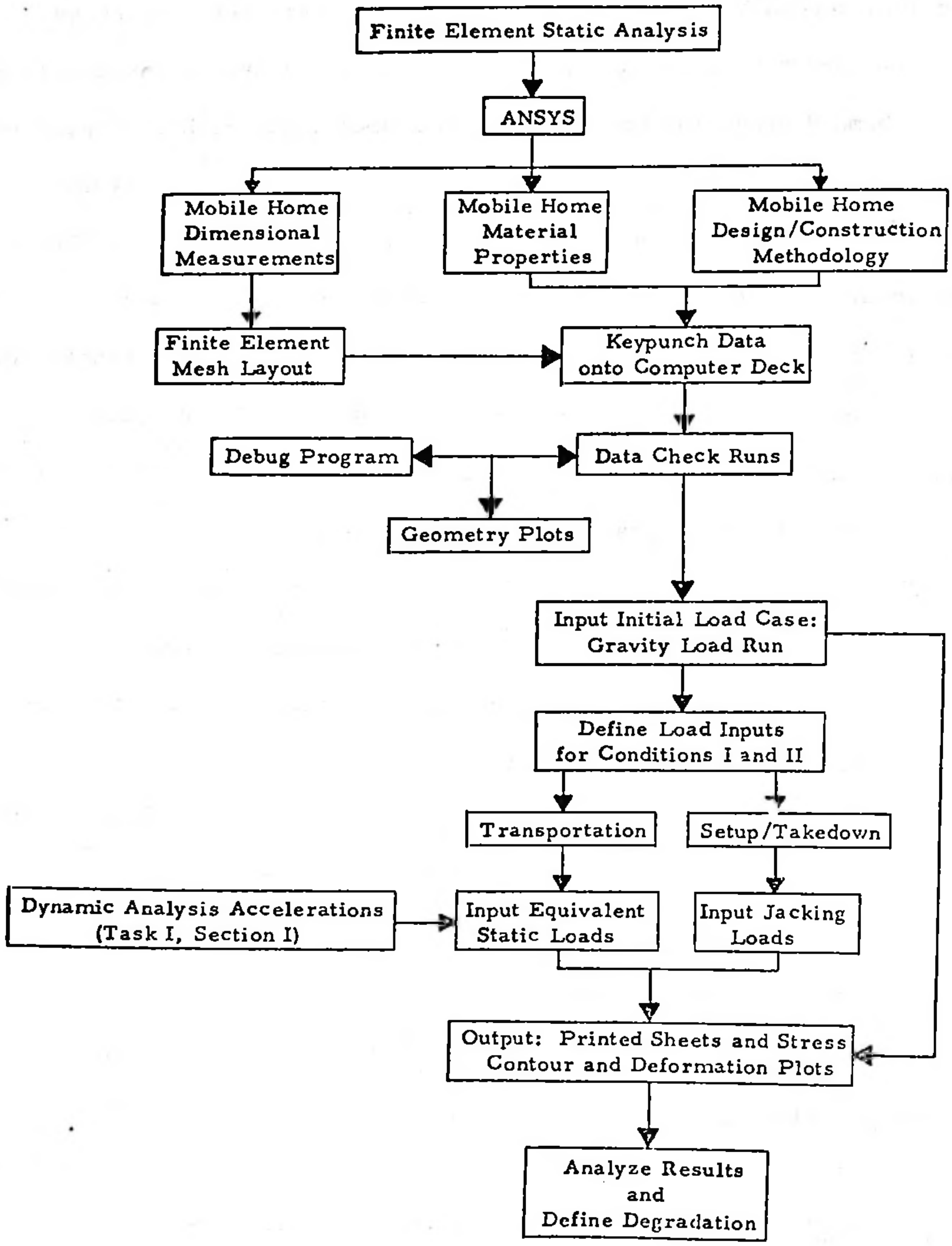


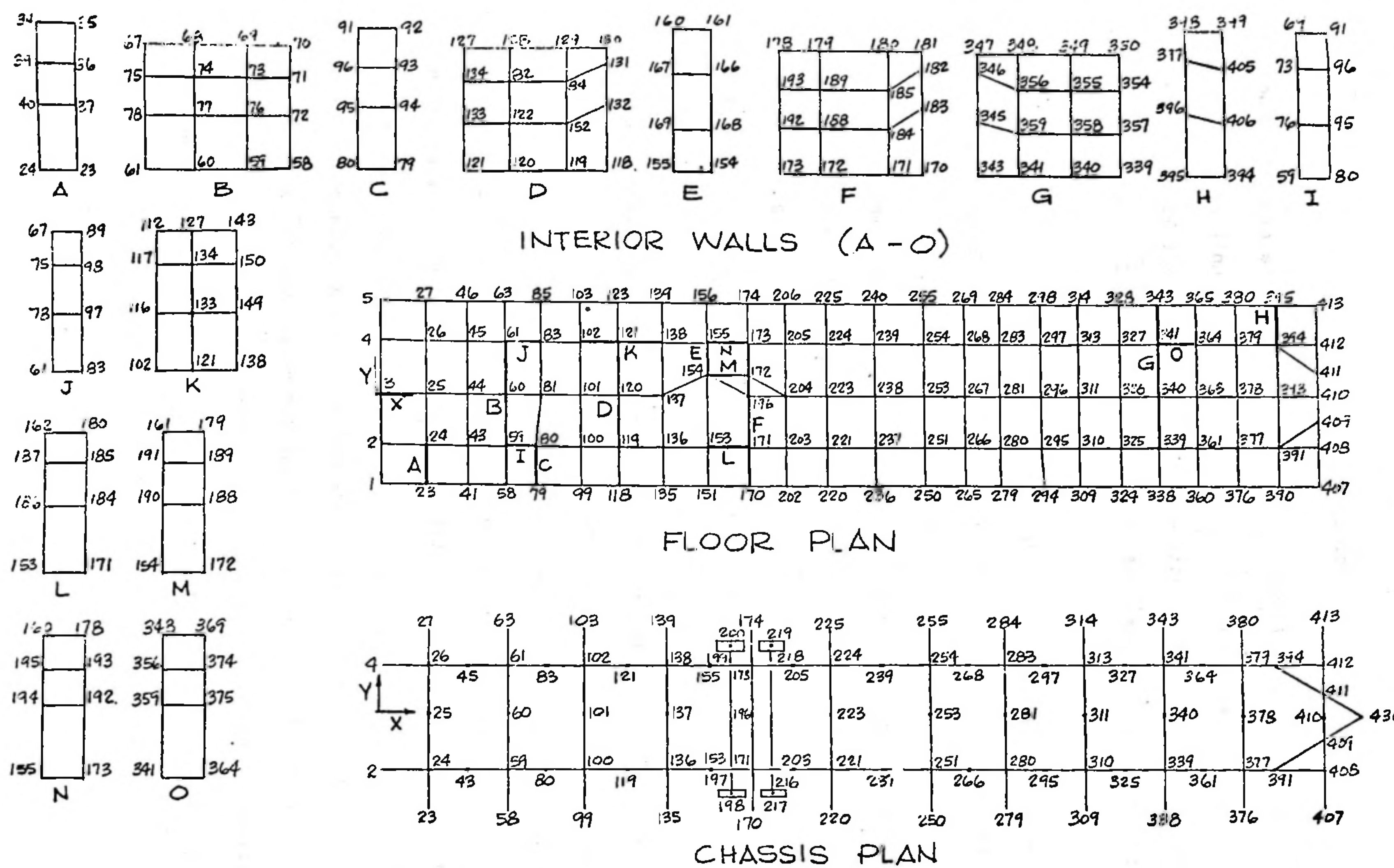
FIGURE 1. FINITE ELEMENT COMPUTER MODEL DEVELOPMENT AND ANALYSIS

III. DEVELOPMENT

The first step in the development of the finite element method analysis was to model the T-5 mobile home (the first unit transported to Southwest Research). This unit was 12-ft wide and 65-ft long with two axles. The model consisted of the series of idealized finite or discrete elements shown in Figures 2 and 3. Measurements of the structure were made and properties of the various materials were estimated for the required input to the program. (A description of the input data necessary for a typical computer run can be found in the appendix.)

At the start of the developmental effort, only membrane elements were used for the floor, ceiling, and walls. This approach was taken to minimize computer time. The model was then loaded with the distributed weights of the various elements and the concentrated weights of typical appliances and furniture.

At this stage the thicknesses to be used for the wall, floor and ceiling elements had to be determined. Two methodologies were utilized for this determination. The first assumed a material thickness based upon the estimated weight of the panels and their respective areas. The results of this analysis indicated unrealistically low stresses in the home but areas of high stress concentration in the vicinity of the axles and at the edges of some doors and windows. At this point, it was decided to run the same model with what was considered the smallest wall thickness in the home (one layer of 5/32-in. lauan plywood). The difference in the original and the final thickness varied from about 0.45 to



NOTE: Numbers shown indicate nodal point locations

FIGURE 2. FINITE ELEMENT MODEL OF T-5

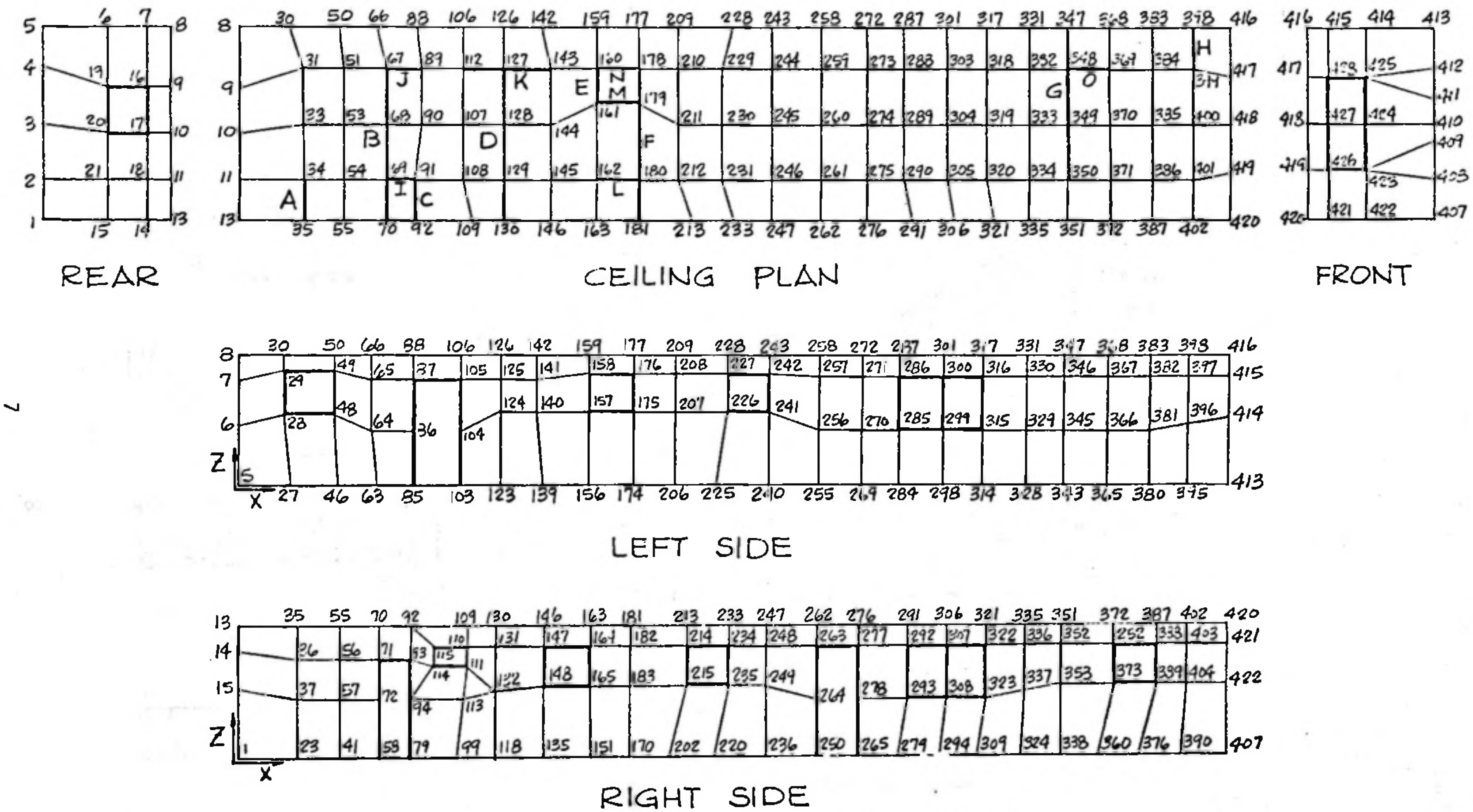
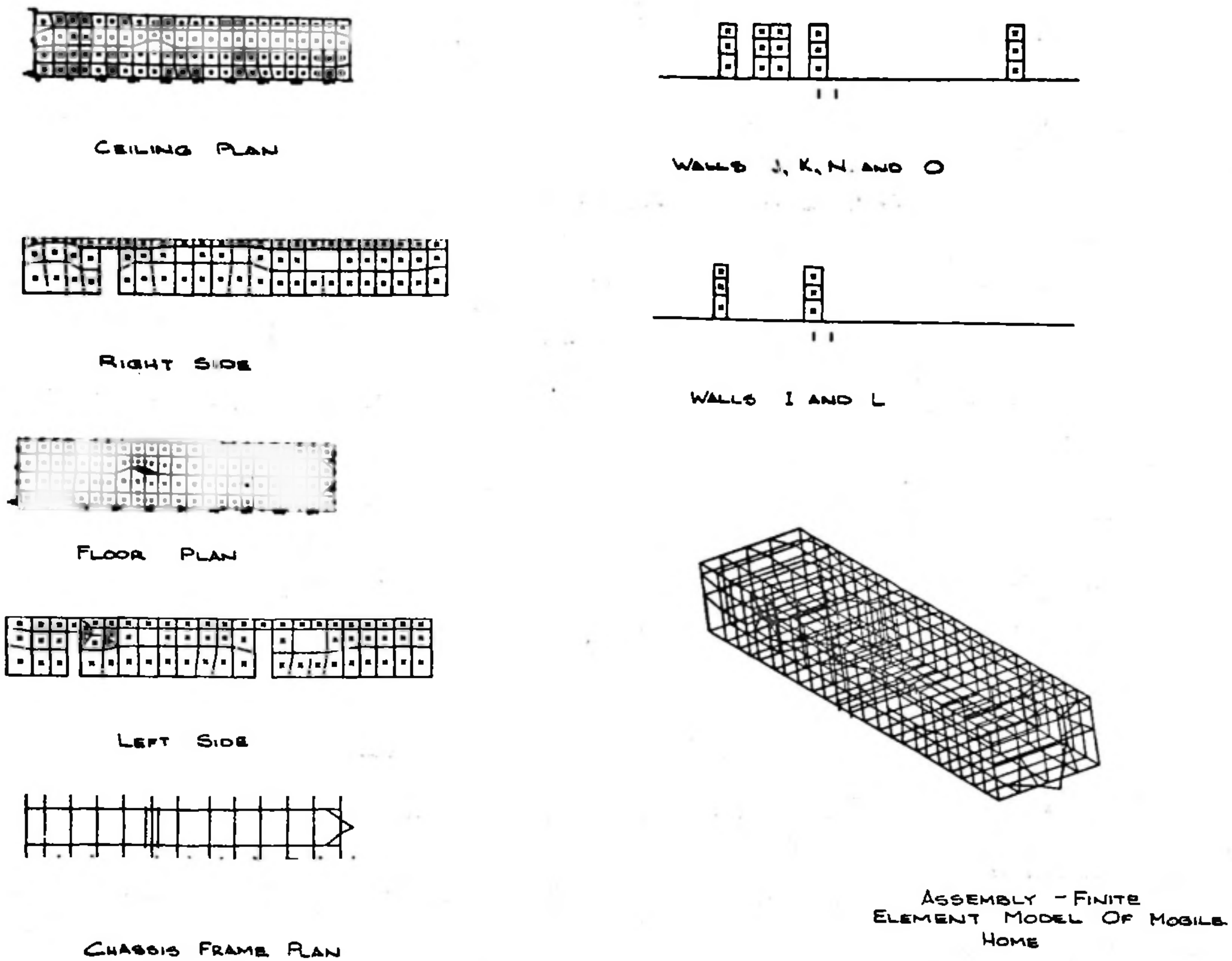


FIGURE 2 (Cont'd)



NOTE: This figure contains the geometry plots from an ANSYS computer run to document the correct location of all elements in the T-5 model defined in Figure 2.

FIGURE 3. COMPUTER GRAPHIC MODEL OF T-5

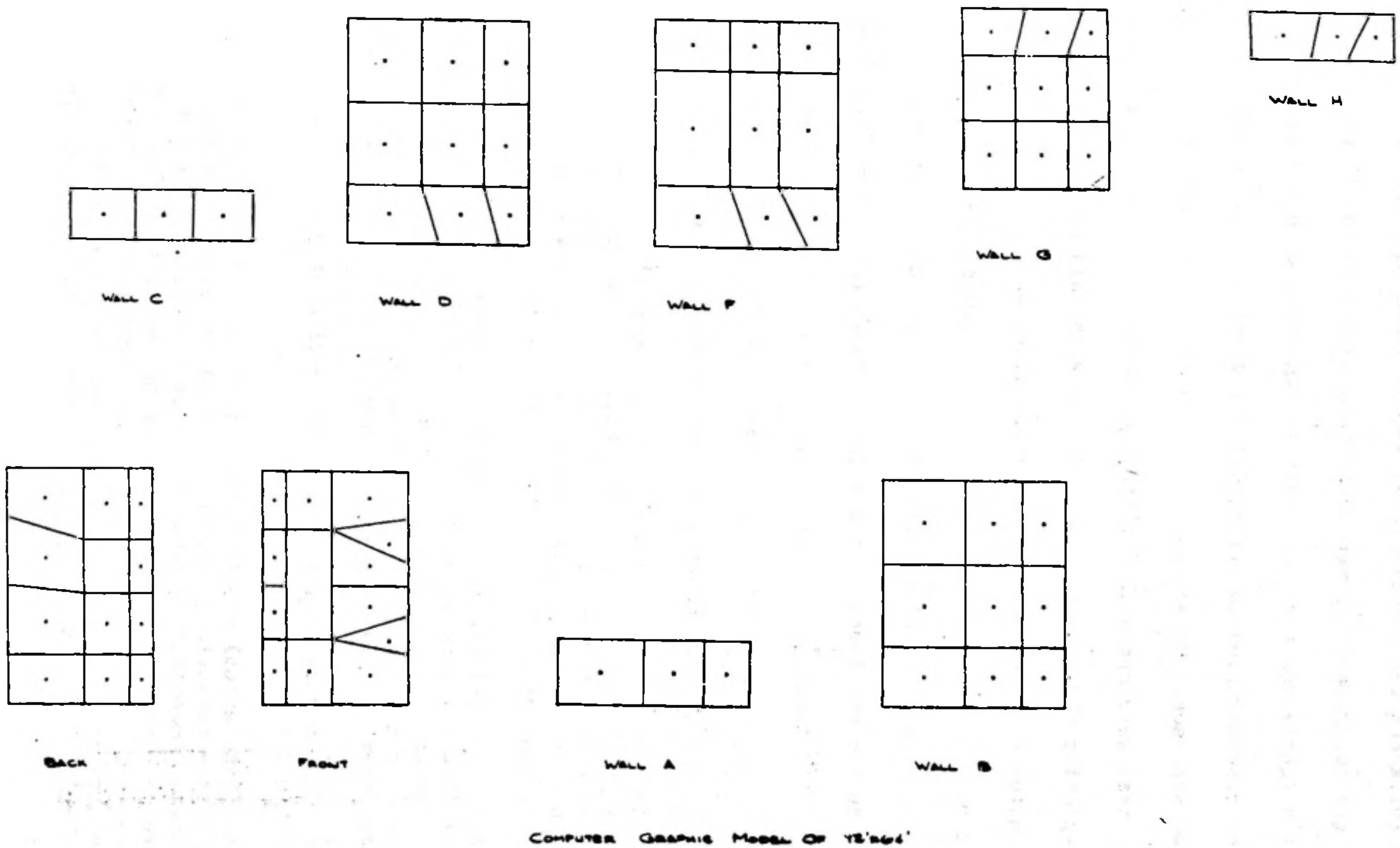


FIGURE 3 (Cont'd)

0.15-in. wood thickness for the first and second approach, respectively. Comparison of the two results showed that the stresses in the thinner wall were only slightly greater. The interesting feature, however, was that the stress concentration locations did not significantly change between the two analyses. These results demonstrated that the high stress concentration areas were not significantly sensitive to the wall thickness.

On inspecting the deflections predicted with this finite element model, it was noted that the membrane elements alone were not adequate and stiffening was required to prevent unrealistic deflections of the structure about the chassis beams. To alleviate this problem, stud stiffeners for the walls, joists for the floor, and the roof trusses for the ceiling were added to the model. Computer simulations were then made to correlate the model predictions with the field measurements shown in Table 1. The 400-lb load was selected, and the following runs were made:

- The 400-lb rear loading was added to the dead loads of the fully stiffened structure. Subtracting the dead load deflection from the combined load deflection yielded 0.277 - 0.206 = 0.071 inch for the 400-lb load. With a field measurement of 0.412 inch, the model was too stiff.

- Since the model prediction should be linear, it was decided to remove all dead loads and apply only the 400-lb load. This would eliminate the double runs of combined load and then dead load only. For this run, the wall studs were reduced from two 2 x 3's at each panel interface to only one 2 x 3, and the rotational inertias were reduced to zero. The results, however, yielded a deflection of 0.034 inch which was too small.

- Due to the actual construction, it was considered that the wall stud connections at the floor and ceiling could not transmit moments. In order to release these moments and develop pinned connections, it was necessary with the ANSYS program to double number all of the common nodes and couple the translational degrees of freedom. With this condition of "pinned" stud points, the computer yielded a deflection of

TABLE 1

STIFFNESS CALCULATIONS
(T-5 USED 12 ft x 65 ft)

From Battelle Memorial Institute Final Report:*

$$(\overline{EI})_f = 36\ell_f^{\,3}\left(\frac{P}{y}\right)_f \quad \& \quad (\overline{EI})_r = 575\ell_r^{\,3}\left(\frac{P}{y}\right)_r\left[1+\frac{\ell_f}{\ell_r}\right]$$

For Forward Loading:

ℓ_f (ft)	P (lb)	y (in)	$(\frac{P}{y})_f$ (lb/in)	$(\overline{EI})_f$ (lb-in^2)
37.33	100	0.043	2326	4.356×10^9
37.33	200	0.062	3226	6.041×10^9
37.33	300	0.090	3333	6.242×10^9
37.33	400	0.115	3478	6.513×10^9
37.33	500	0.163	3067	5.744×10^9
			Avg =	5.779×10^9 lb-in^2

For Rear Loading:

ℓ_r (ft)	P (lb)	y (in)	$(\frac{P}{y})_r$ (lb/in)	$(\overline{EI})_r$ (lb-in^2)
20.67	100	0.114	877	1.250×10^{10}
20.67	200	0.187	1070	1.525×10^{10}
20.67	300	0.331	906	1.291×10^{10}
20.67	400	0.412	971	1.384×10^{10}
20.67	500	0.504	992	1.413×10^{10}
20.67	730	0.638	1144	1.630×10^{10}
			Avg =	1.416×10^{10} lb-in^2

* D. E. Bearint and H. A. Cress, "The Development of Performance - Based Tests to Determine the Minimum Structural Integrity of Mobile Homes," Batelle Memorial Institute, July 25, 1966, p. 29.

0.034 inch. Additional runs, reducing the wall panel thickness from 5/34-inch to 1/32-inch, and another removing the the ceiling and interior walls to check the effect of an open structure (with 1/32-inch wall panel thickness), predicted deflections of 0.093 inch and 0.118 inch, respectively. Each of these deflections indicated the unit modeled was still too stiff.

- It was calculated that, with a 400-lb rear load, the chassis beams by themselves would deflect 0.9 inch. Thus, it was conjectured that the wall panels were carrying a disproportionate share of the load and effecting a deep beam type of response. Consequently, it was decided to reduce the wall panel modulus of elasticity to simulate the "looseness" that was apparent in many of the joint connections. Hand calculations were made to determine the approximate modulus of elasticity needed to effect the EI value determined from field measurements. The wall panels were returned to the 5/32-inch thickness, and the modulus of elasticity was reduced from 1.45×10^6 psi to 50,000 psi. Interior walls were not put back in the model. The deflection was 0.313 inch, fairly close to the 0.412 measured value.

- The forward loading of 400-lb was checked with the reduced modulus. A deflection of 0.051 inch was predicted as opposed to a measured value of 0.115 inch.

- The program was again modified to uncouple the wall panels, as well as the wall studs, at the wall/ceiling and wall/floor connect points. The deflection for the 400-lb forward loading was 0.051 inch which represented no change from the previous run.

To determine the degree of accuracy obtained with the final model, linear extrapolations were calculated from the 400-lb load run. The results are shown in Table 2, where it can be seen that the comparisons of the simulation results and in-field measured results are fairly consistent. Specifically, the model predicted averages of 39 percent of the measured deflections for forward loading and 78 percent for rear loading. These results were considered to be about as close as could reasonably be expected, and further reductions in the modulus of elasticity for tuning purposes were considered unwarranted.

TABLE 2

COMPARISON OF FIELD TEST RESULTS AND FINITE ELEMENT PREDICTIONS

Forward Loading:

Load (lb)	Deflections (in.) Test	F. E.*	Error F. E. /Test
100	0.043	0.013	0.30
200	0.062	0.026	0.42
300	0.090	0.038	0.42
400	0.115	0.051 (run)	0.44
500	0.163	0.064	0.39
		Av.	0.39

Rear Loading:

Load (lb)	Deflections (in.) Test	F. E.	Error F. E. /Test
100	0.114	0.078	0.68
200	0.187	0.157	0.84
300	0.331	0.235	0.71
400	0.412	0.313 (run)	0.76
500	0.504	0.391	0.78
730	0.638	0.571	0.89
		Av.	0.78

* F. E. = Finite Element

The attempt to minimize the complexity of the model by using only membrane panel elements was not successful; stiffeners had to be added to obtain reasonable results. It was decided that all future models should be prepared on 32-in. modules (every other wall stud) and that the structure should be idealized to fit this pattern in order to reduce the size as much as possible and eliminate the necessity for the odd-shaped panels as shown in Figure 2. This approach requires that certain members - windows, doors, etc. - be moved slightly to fit the pattern. The size of the model, however, can be reduced significantly without affecting the results. Furthermore, the model should be developed in the same way the unit is constructed; i.e., model separately the floor, the walls, and the ceiling. The separate models can then be combined by coupling the translational degrees of freedom at the wall stud/floor joist and wall stud/ceiling truss connect points.

IV. PROBLEM AREAS

The finite element approach assumes a compatibility between contiguous elements that, in actuality, does not exist in a typical mobile home (particularly in the advanced stages of degradation). In order to simulate the condition that wall panel connections to the studs have loosened and movement has taken place before the full loads are transmitted into the panels, the elasticity modulus of the wall panels was reduced. The predicted stresses, however, are directly proportionate to the modulus used. Thus, for an upper boundary on the stress levels, the actual modulus of the panel material should be used.

The shear panels were modelled with a linear elastic and isotropic membrane element that yeilds stress results from loadings, regardless of load magnitudes. Local buckling of individual panels can be investigated by comparing the compressive loads of each element to a hand-calculated buckling strength (dependent upon the material properties and dimensions of the panel in question). Because of the large quantity of shear panel elements in the mobile home models, a buckling analysis was not feasible. Furthermore, to compare the cyclic stresses imposed on the material with fatigue data of the material itself is not realistic. As mentioned before, the problem exists in the connections of the shear panels and studs, and fatigue tests of typical panel configurations would be required to generate the needed data. The process of determining flexural and torsional stiffnesses of the unit by simple field measurements, and then relating these values to degradation appears to be a much simpler technique. The design loads for appliances, fixtures, etc., can also be determined by dynamic analysis. The effect of (dynamic) equivalent static loads on stress concentration areas can then be determined from the finite element analysis. This methodology has been applied in the analysis of the T-1 and T-2 units.

V. T-1 ANALYSIS METHODOLOGY

The model for the T-1 mobile home is detailed in Figures 4, 5 and 6. On comparing this model with the T-5 model in Figures 2 and 3, it is noted that a coarser, modular mesh idealization is used. However, the use of separate parts for the chassis, floor, walls, and ceiling is considered more representative of the actual structure. These separate modules are integrated into the program input by coupling the translational degrees of freedom at the common nodes. The following computer runs were then conducted:

- Data check run to generate geometry plots (see Figure 6) and check boundary conditions, elements, material property definitions, and other input data for completeness and inconsistencies.

Condition I*

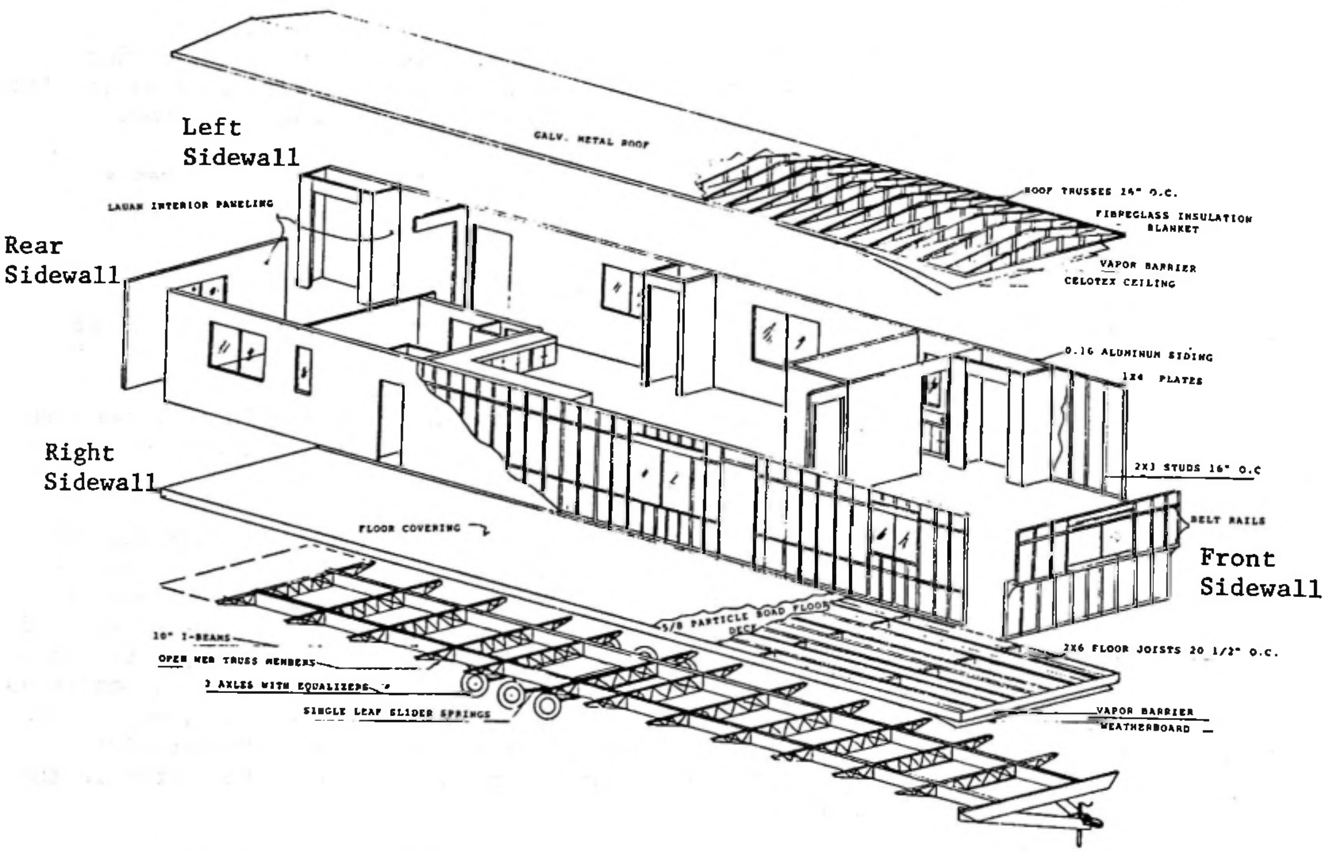
- Load 1 - Gravity load run to generate the base-line stresses and deformations for the unit under gravity loads of the structure and its furnishings.
- Load 2 - Gravity loads of the structure and its furnishings plus equivalent static loads from the dynamic analysis (well-paved road, 45 mph, Test Run No. 1).
- Load 3 - Gravity loads of the structure and its furnishings plus equivalent static loads from the dynamic analysis (well-paved road, 45 mph, Test Run No. 5).

Condition II*

- Load 4 - Gravity loads of the structure and its furnishings plus a concentrated load of 4000 lb acting on the right longitudinal I-beam at the rear of the chassis (nodal point 2 on Figure 3). This loading case, unlike the preceding two cases, was developed to simulate site installation activities where the unit is jacked up at each corner and set on blocks. (For this loading condition, the unit was restrained at the hitch, the three axles, and at the front end at the longitudinal I-beams. This last restraint assumes that the front end was blocked prior to this step in the installation procedure.)
- Load 5 - Gravity loads of the structure and its furnishings plus equivalent static loads from the dynamic analysis. This load case represents probabilistic "worst case" conditions.

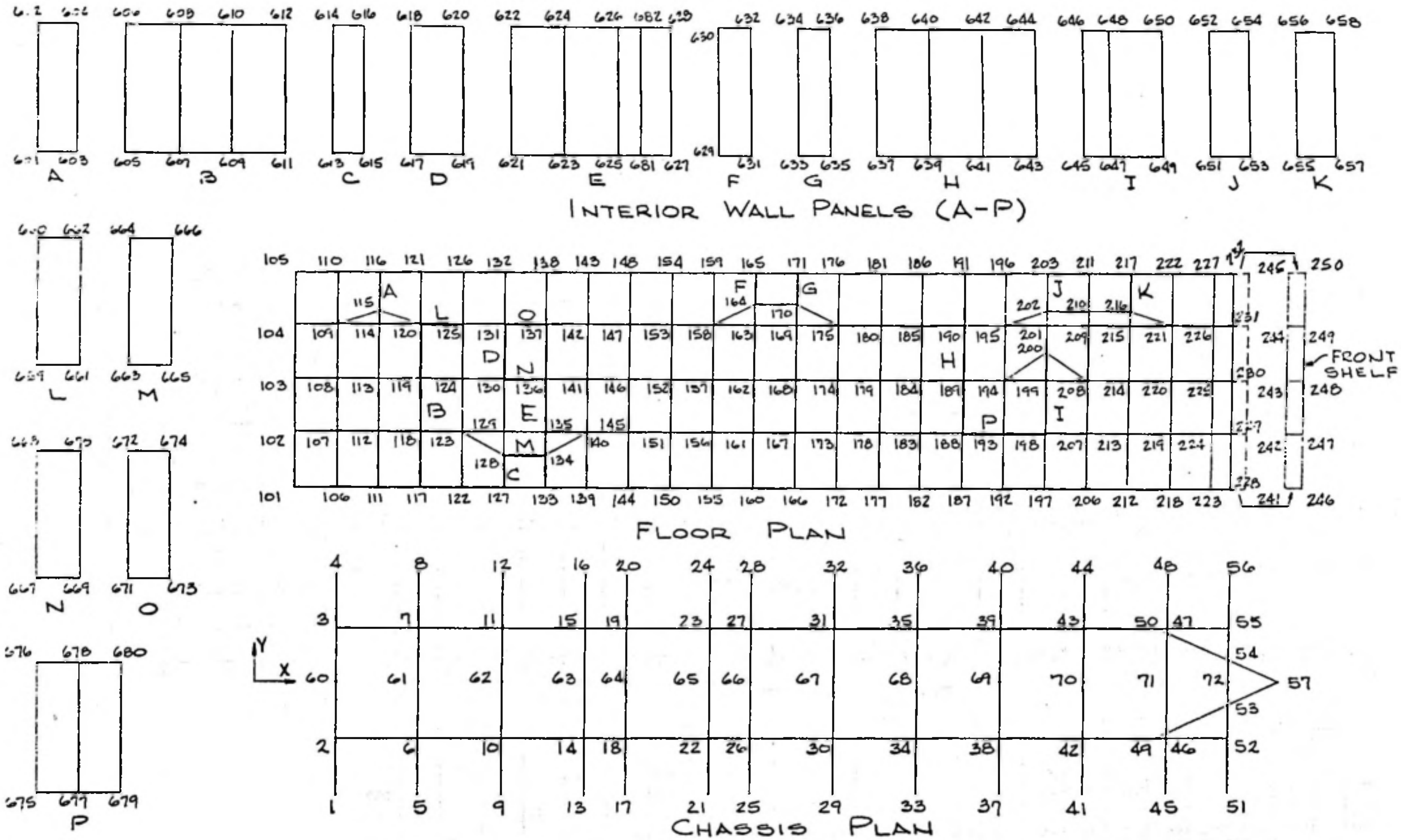
Load Cases I through 5 are summarized in Table 3.
*See Table 3 for description of Conditions I and II.

a) Floor Plan



b) Exploded Isometric

FIGURE 4. T-1 MOBILE HOME LAYOUT



NOTE: Numbers shown indicate nodal point locations.

FIGURE 5. FINITE ELEMENT MODEL OF T-1

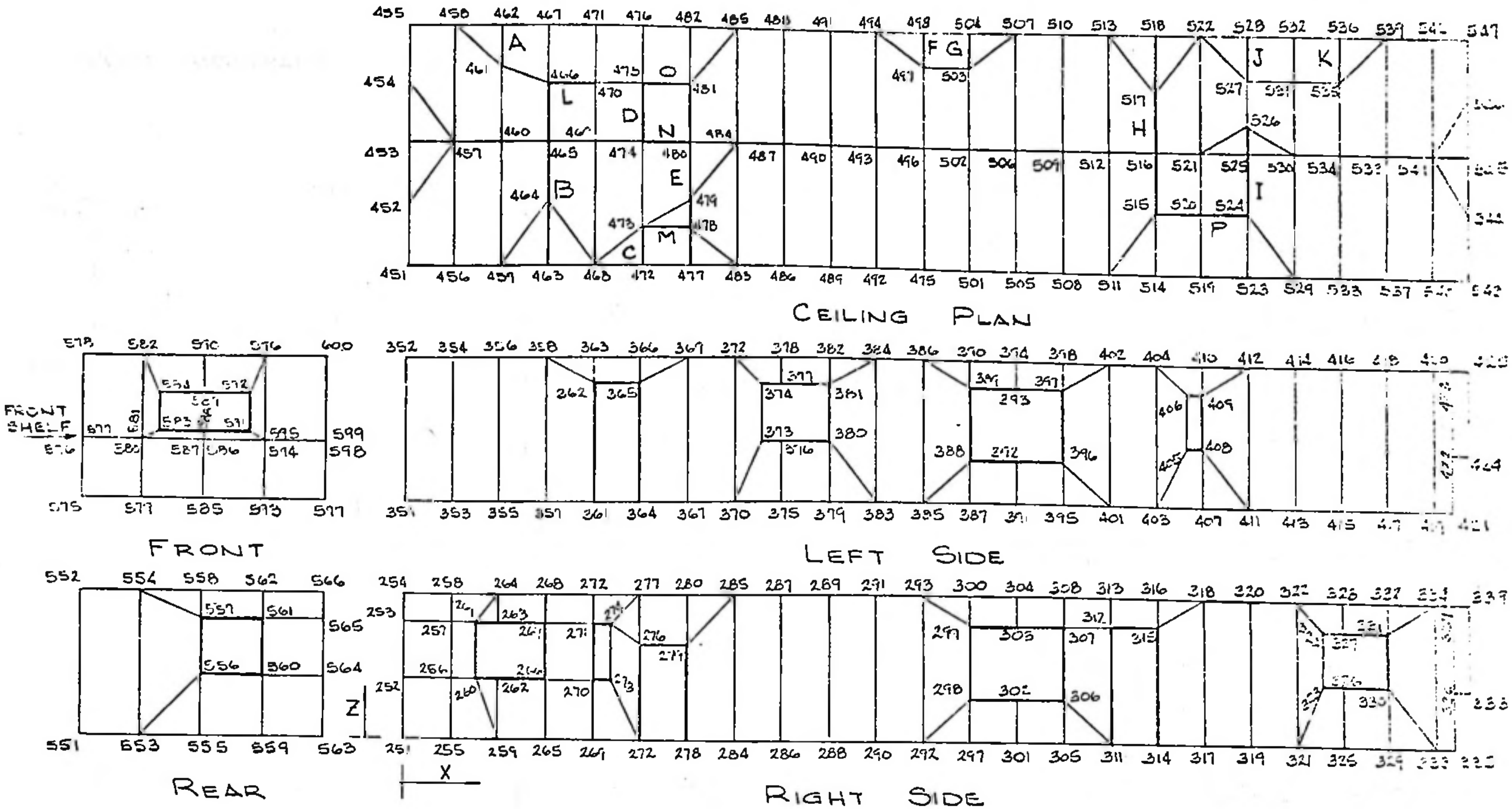
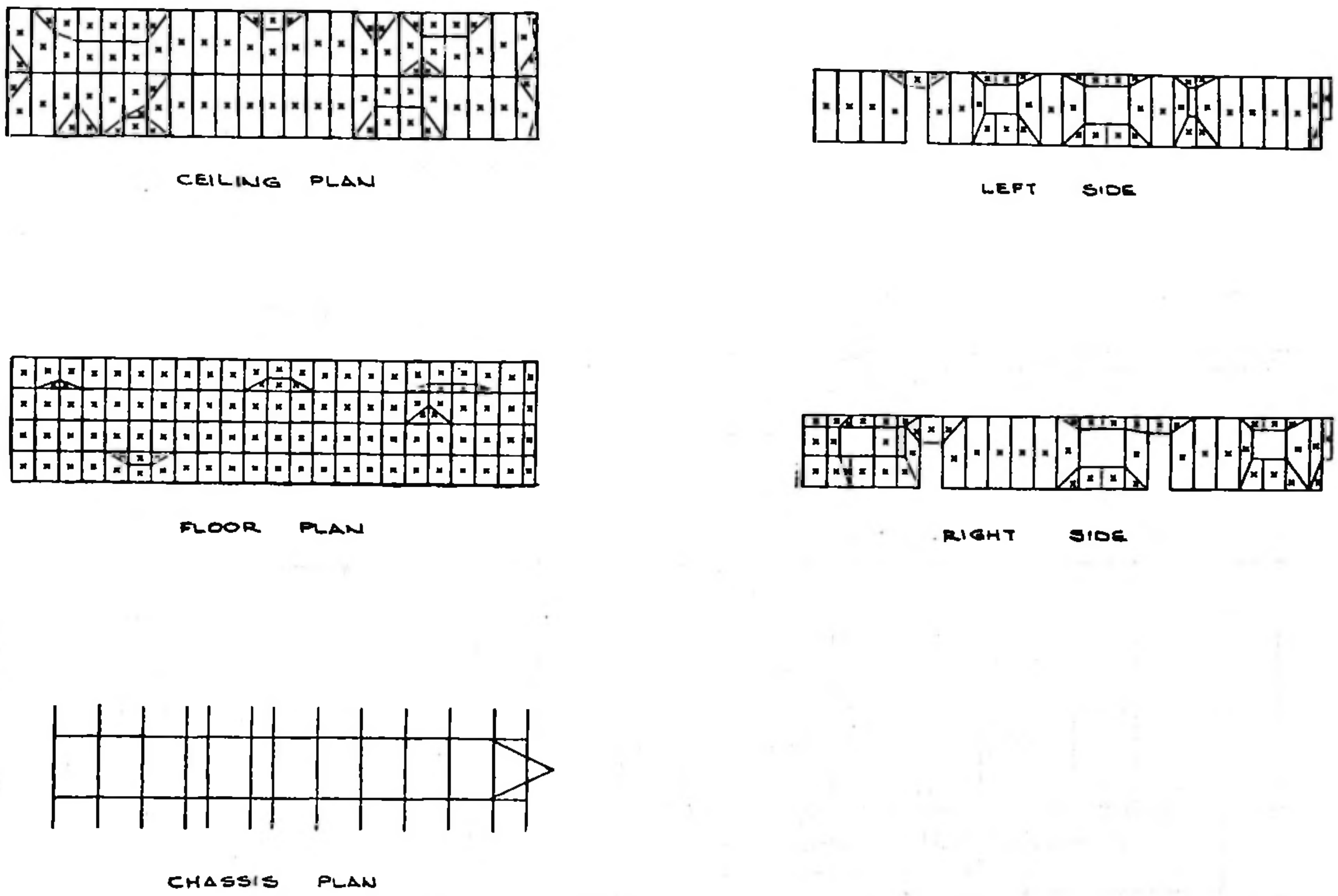


FIGURE 5 (Cont'd)



NOTE: This figure contains the geometry plots from an ANSYS computer run to document the correct location of all elements in the model defined in Figure 5.

FIGURE 6. COMPUTER GRAPHIC MODEL OF T-1

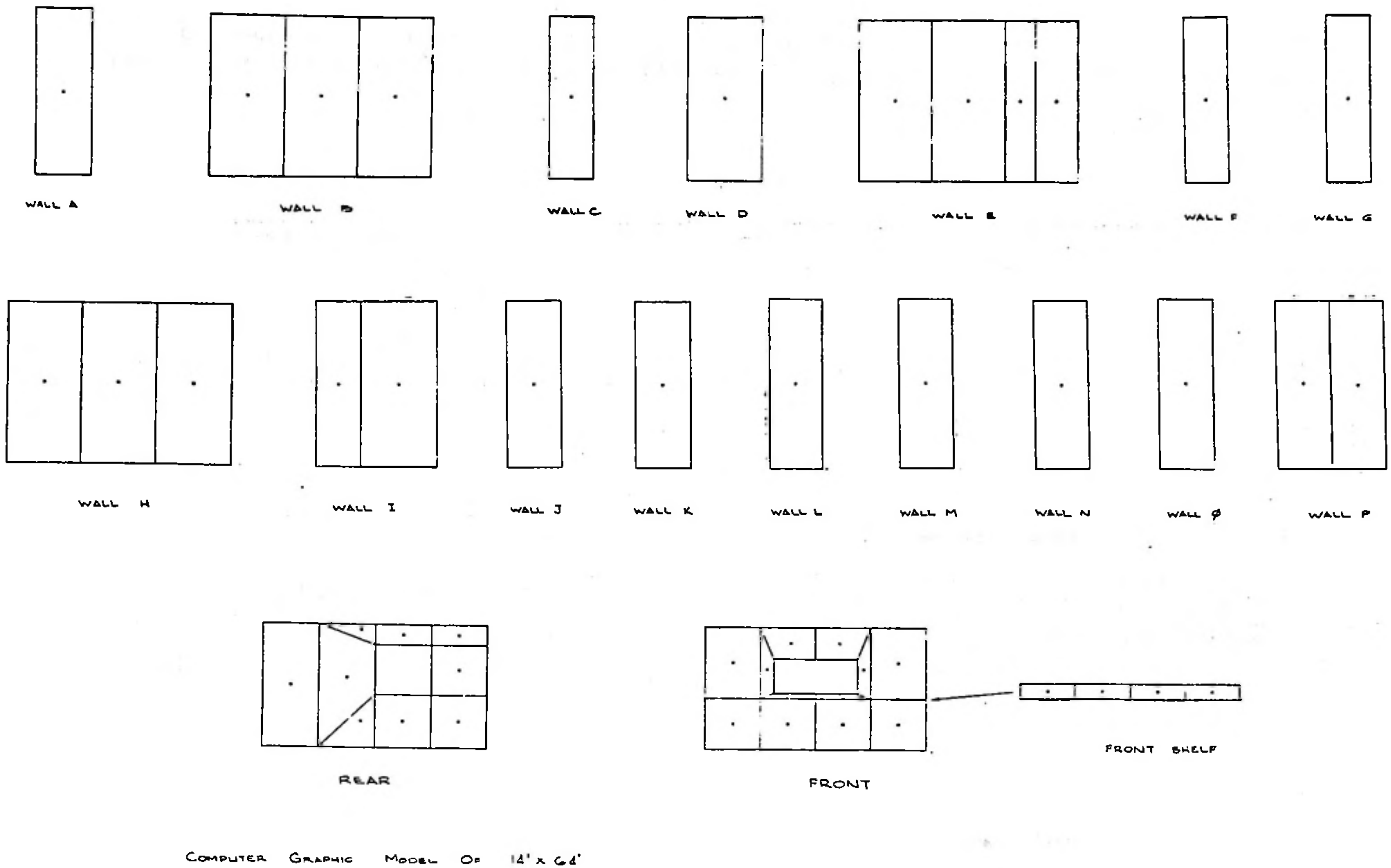


FIGURE 6 (Cont'd)

TABLE 3

DESCRIPTION OF LOAD CASES AND LOAD CONDITIONS

CONDITION I	LOAD CASE 1	Gravity Load - Weight of Mobile Home Unit With Furnishings Included
	LOAD CASE 2	Furnishings Added With Dynamic Loading Induced by Well-Paved Road at 45 mph (Test Run No. 1)
	LOAD CASE 3	Furnishings Added With Dynamic Loading Induced by Well-Paved Road at 45 mph (Test Run No. 5)
CONDITION II	LOAD CASE 4	Setup/Takedown (Jackup) Loading with Furnishings Included
	LOAD CASE 5	Worst Case Condition - Furnishings Plus Dynamic Loading Induced by Paved, Secondary Road

The equivalent static loads used from the dynamic analysis for Load Cases 2, 3 and 5 were based upon three times the RMS*, or sigma (σ), values calculated in Task I, Volume I of this report. These values probabilistically assure a 99.9 percentile level that the dynamic loads induced via the road condition are equal to or less than the associated G levels.

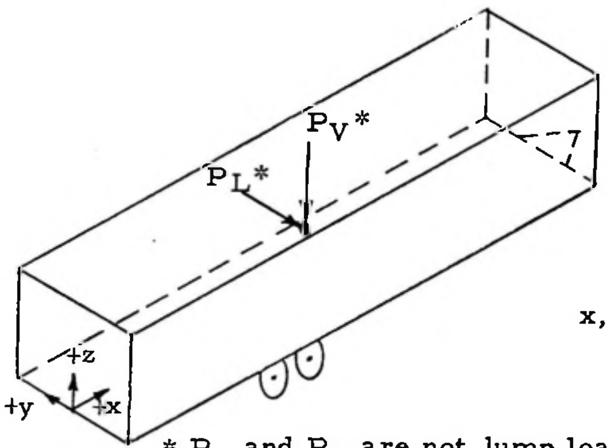
From the dynamic analysis, the computer-evaluated RMS (G loads) were obtained throughout the mobile home unit. With these values, the forces were calculated for the components that most influence the dynamic loadings. Knowing the acceleration of these components, SwRI factored their weights to produce the equivalent static loads to be input into the finite element program - thus, symbolizing the dynamic condition. For example, if a vertical G_{RMS} value of 3.0 G's is obtained from the dynamic analysis for a position where a particular component of weight W is located, its contributing load in the finite element program would be 3 times the G_{RMS} value times W, or 9W. The equivalent static load of 3σ times weight would correlate to 9 times W or 9W. When this is done for all components considered (with their respective G_{RMS} and weight values), the mobile home model is subjected to a static load equivalent to the forces induced by the dynamic response characteristics obtained from the dynamic analysis.

It is noted that in applying the equivalent static loads from the dynamic analysis to the unit, the assumed directional sense for all vertical loads was downward (-z direction) and all lateral loads were applied from left to right looking from the rear to the front of the unit (-y direction).

* Root mean square values of acceleration response.

In actuality, the loading directions would be random in nature. The assumed directions represent a possible service loading condition. (Figure 7)

Complete details of a typical computer run are contained in the appendix.



P_V - vertical load
P_L - lateral load
x, y, z - origin of unit's coordinate system

* P_V and P_L are <u>not</u> lump loads. They provide directional sense only.

FIGURE 7. T-1 EQUIVALENT STATIC LOAD DIRECTIONAL SENSE

VI. DISCUSSION OF T-1 RESULTS

Output plots*for the ANSYS program were specified for stress trajectories and displacements of the membrane elements in the floor, walls, and ceiling. Output results for all elements of the structure are available in the computer output sheets (available upon request at Southwest Research). The before and after results of the analysis (i.e., results for dead load only and results for dead load plus equivalent static loads from the dynamic analysis) are shown in Figures 8 through 13.

Note that the two stress plots for each load case associated with each component (floor, ceiling, etc.) of the unit refer to the maximum and minimum in-plane principal stresses.

These plots can be useful in several ways:

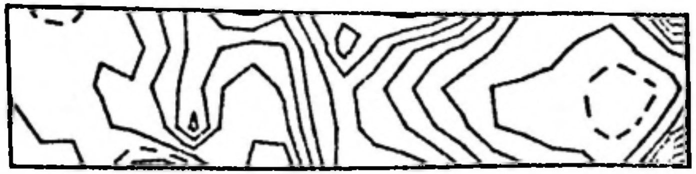
- For each load case, the plots locate areas where stress gradients are high (the lines of equal stress come closer together indicating stress concentrations).

- When comparing load cases, the plots locate areas of changing stress due to the different load applications.

The stress plots of the various load cases for the T-1 mobile home show definite patterns of high stress concentrations at locations of maximum bending along the unit, around doors and windows, and particularly at the corners of these openings.

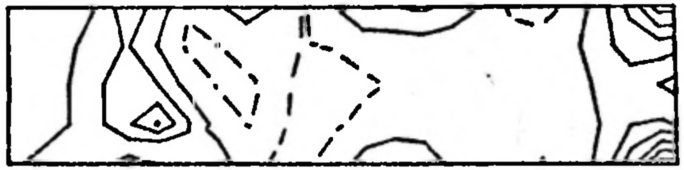
Comparison of the stress plots for Condition I, Load Cases 1, 2 and 3 reveals that the increases in stress levels were small. The conditions for analyses, although not severe (well-paved road, 45 mph), were based on equivalent static loads induced by a range of acceleration levels from 0.1 to 1.0 G's, vertically and laterally. The result of these loads is more recognizable only in cases such as Figure 8, where stress contours do vary in a more obvious pattern between the first load case and the next two load cases.

*See Appendix C for method of interpretation.

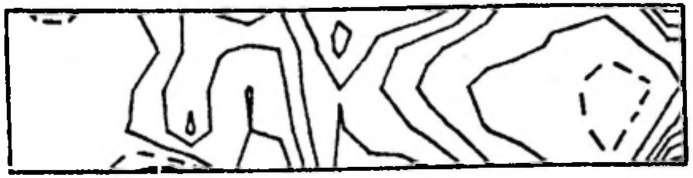


(rear) (front)

Load 1* (max.) **

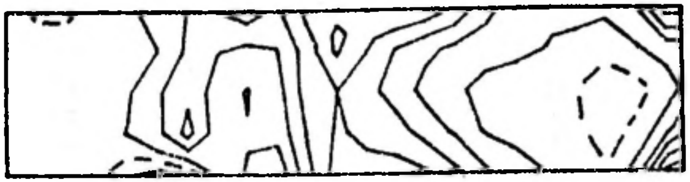


Load 1 (min.)**



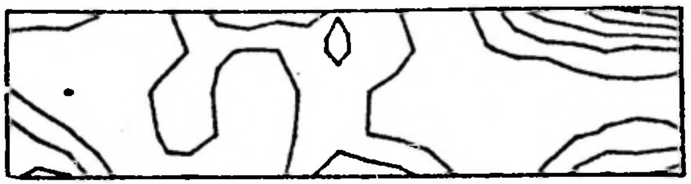
Load 2 (max.)

Load 2 (min.)



Load 3 (max.)

Load 3 (min.)



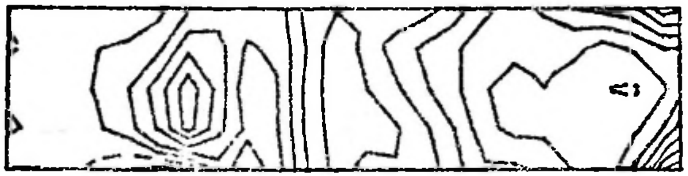
Load 4 (max.)

Load 4 (min.)

*Load 1 - Gravity load of structure and furnishings
Load 2 - Gravity load (Load 1) plus equivalent static load from dynamic analysis (well-paved road, 45 mph, Test Run No. 1)
Load 3 - Gravity load (Load 1) plus equivalent static load from dynamic analysis (well-paved road, 45 mph, Test Run No. 5)
Load 4 - Gravity load (Load 1) plus 5000-lb jacking load on chassis rear, right side

**Maximum and minimum in-plane principal stresses.

FIGURE 8. COMPARISON OF T-1 STRESS PLOTS - FLOOR

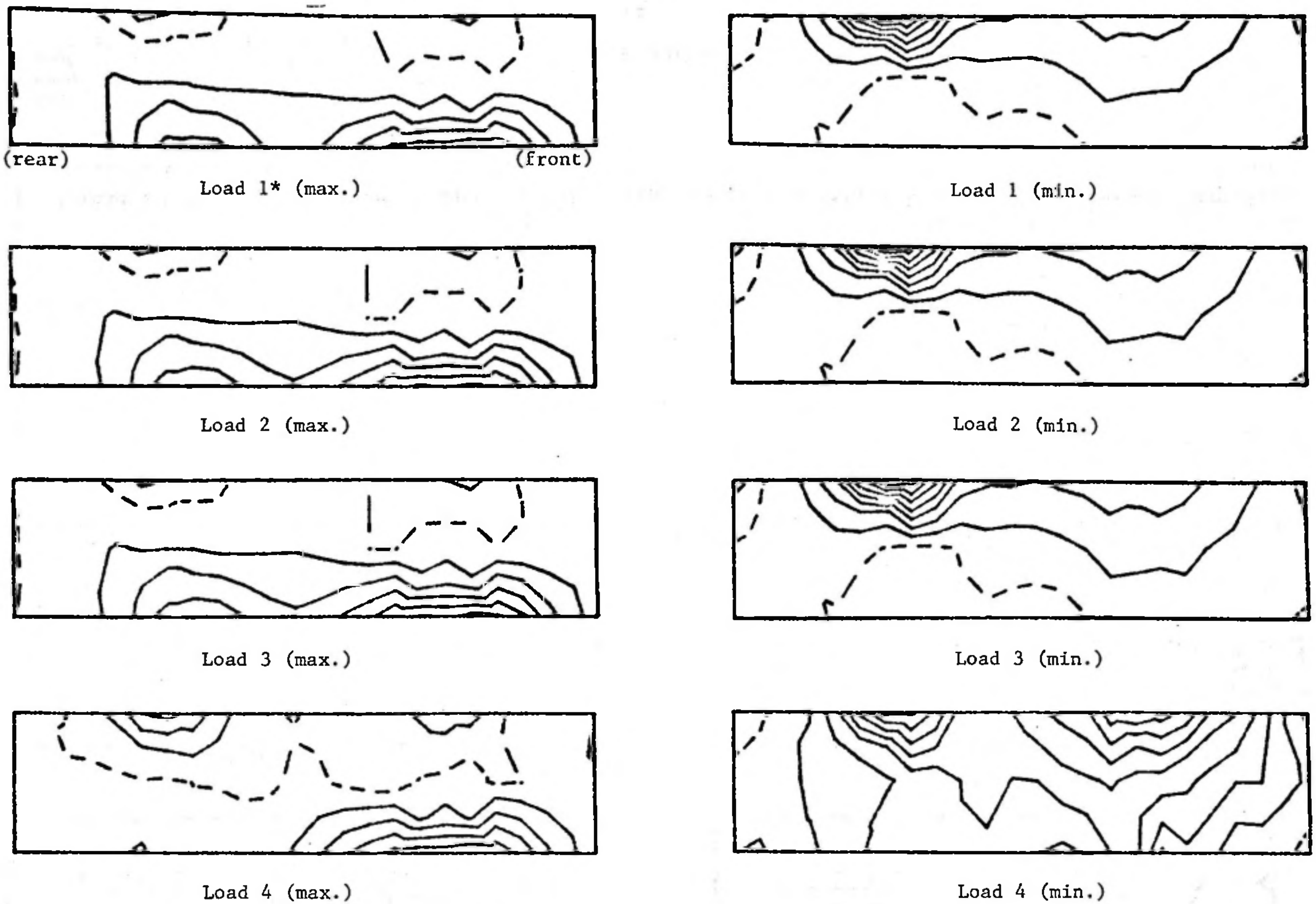


Load 5* (max.)

Load 5 (min.)

* Load 5 - Gravity Load (Load 1) plus equivalent static load from dynamic analysis ("worst-case" condition)

FIGURE 8 (Cont'd)



*For load descriptions, see Figure 8 or Table 3.

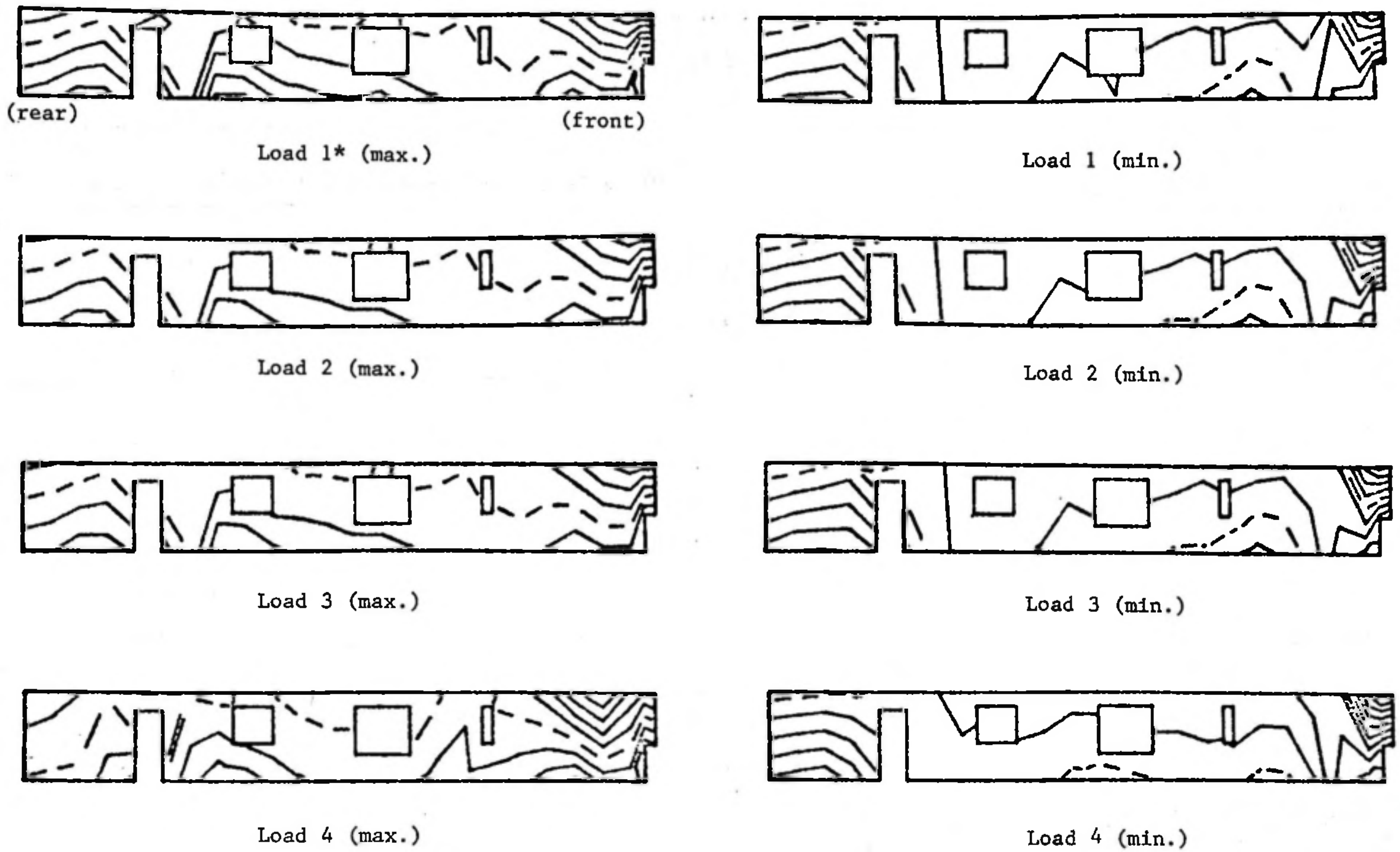
FIGURE 9. COMPARISON OF T-1 STRESS PLOTS - CEILING

Load 5 *   (max.)

Load 5 (min.)

* For load description, see Figure 8 or Table 3.

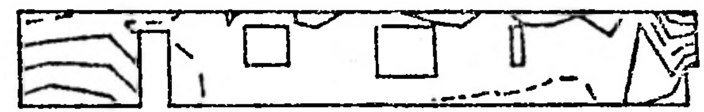
FIGURE 9 (Cont'd)



*For load descriptions, see Figure 8 or Table 3.

FIGURE 10. COMPARISON OF T-1 STRESS PLOTS - LEFT SIDE

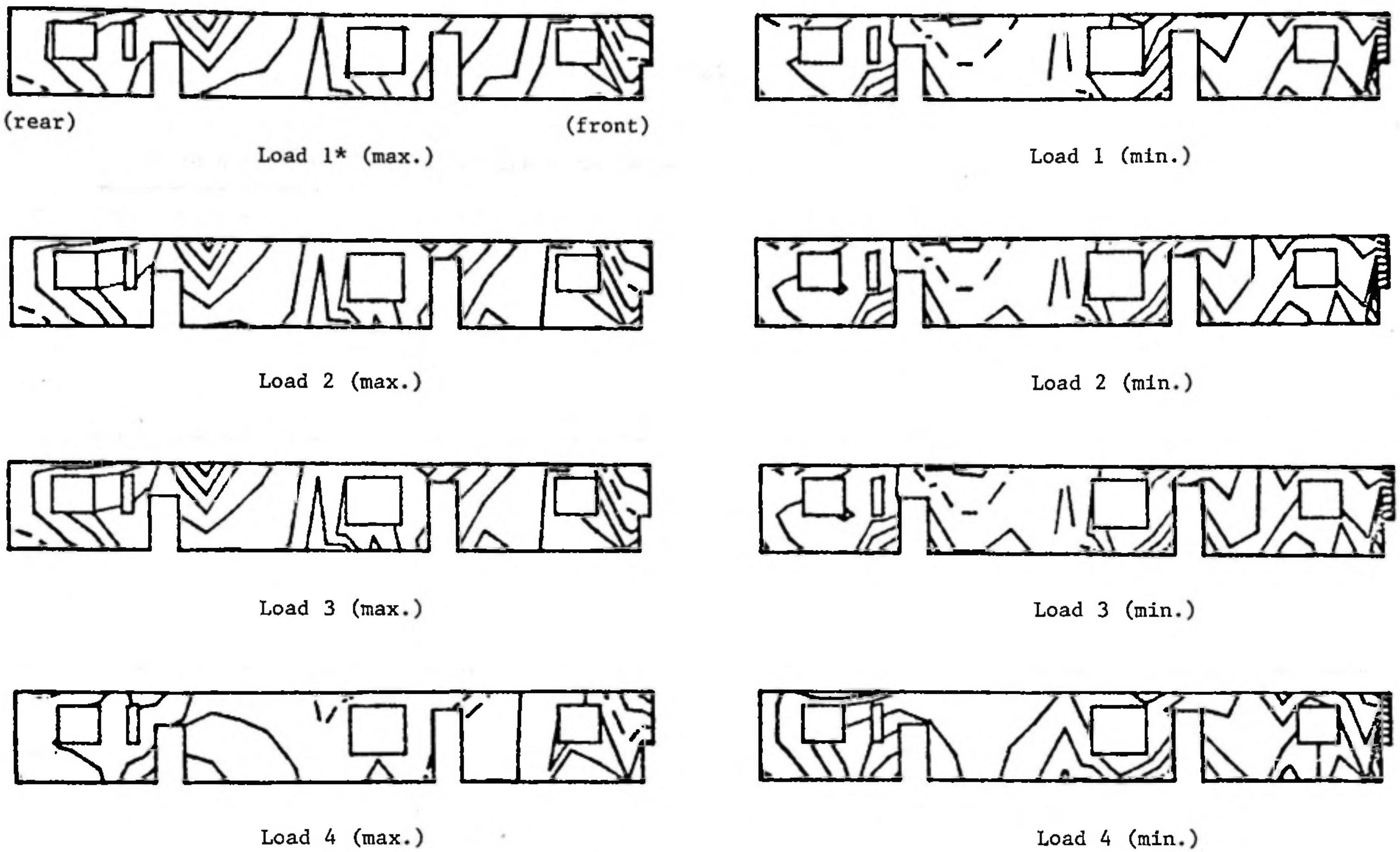
Load 5 * (max.)



Load 5 (min.)

* For load description, see Figure 8 or Table 3.

FIGURE 10 (Cont'd)



*For load descriptions, see Figure 8 or Table 3.

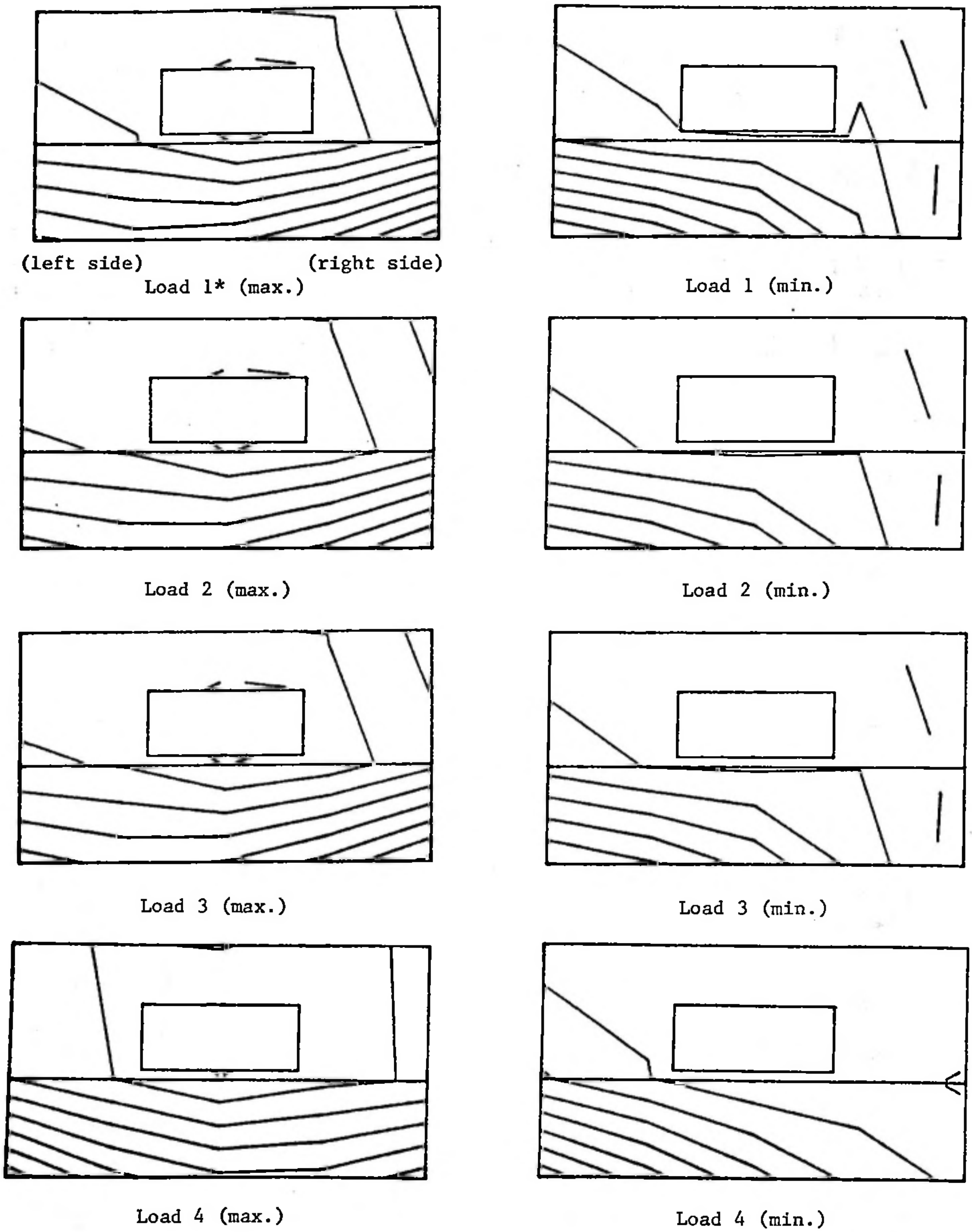
FIGURE 11 . COMPARISON OF T-1 STRESS PLOTS - RIGHT SIDE

Load 5 * (max.)

Load 5 (min.)

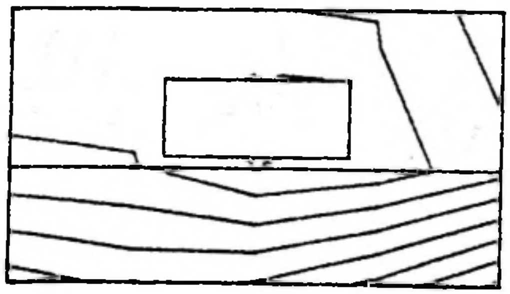
* For load description, see Figure 8 or Table 3.

FIGURE 11 (Cont'd`

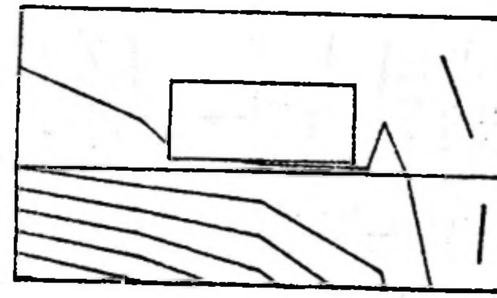


*For load descriptions, see Figure 8 or Table 3.

FIGURE 12. COMPARISON OF T-1 STRESS PLOTS - FRONT



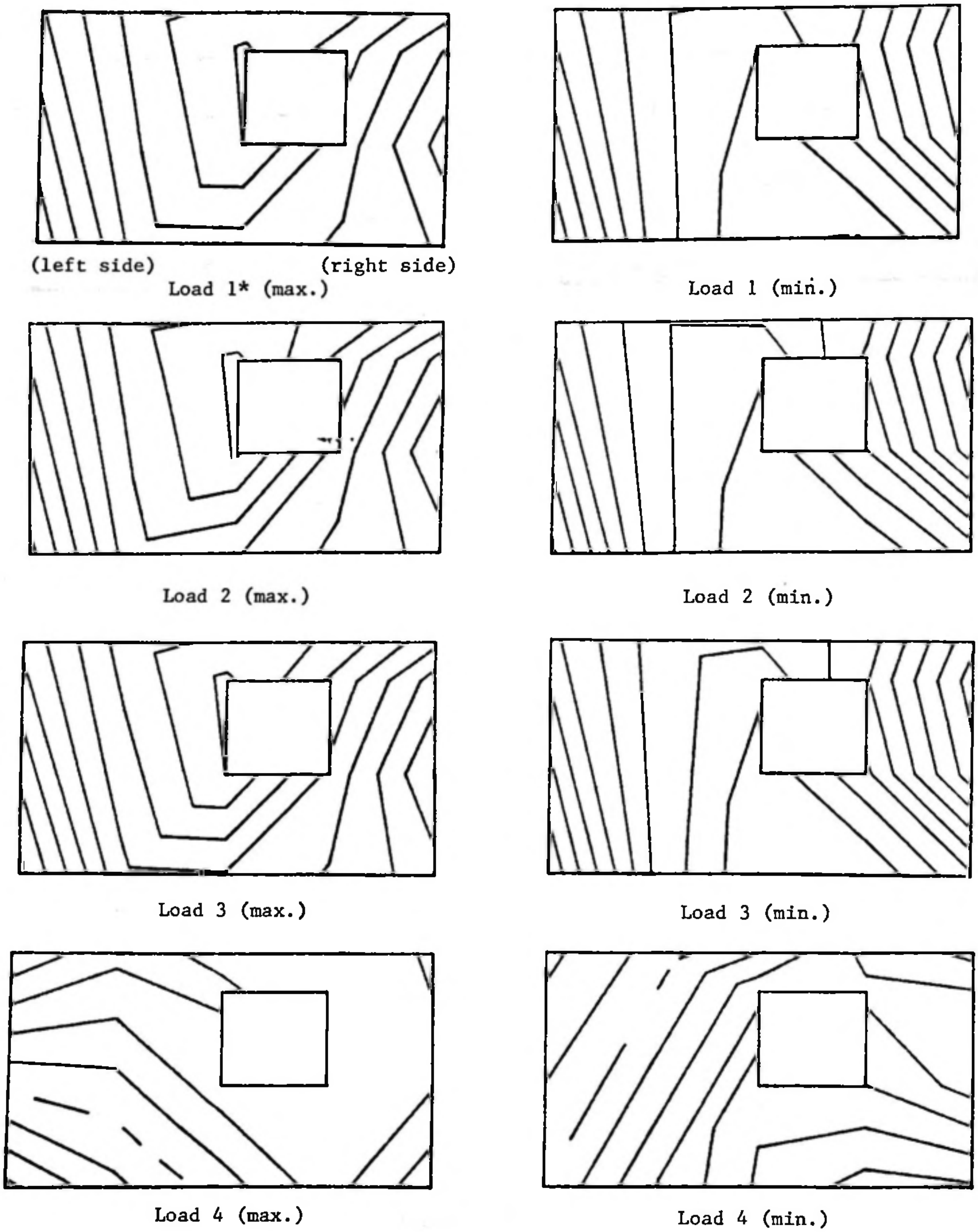
Load 5 * (max.)



Load 5 (min.)

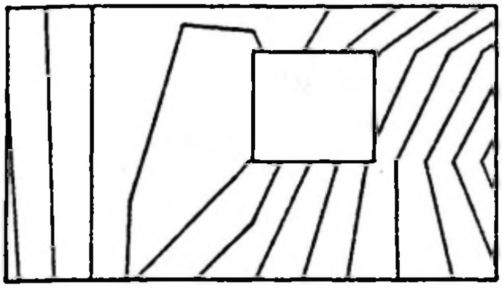
* For load description, see Figure 8 or Table 3.

FIGURE 12 (Cont'd)

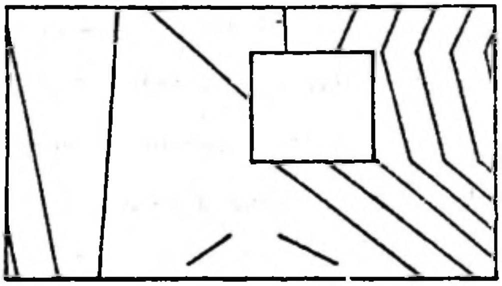


*For load description, see Figure 8 or Table 3.

FIGURE 13. COMPARISON OF T-1 STRESS PLOTS - REAR



Load 5 * (max.)



Load 5 (min.)

* For load description, see Figure 8 or Table 3.

FIGURE 13 (Cont'd)

Refining these results one step further, however, a comparison of the ANSYS output plot summary data between Load Cases 1 and 2 shows increases in maximum stress levels in the order of +10 percent tensile, +10 percent compressive in the floor; and +9 percent tensile, +7 percent compressive in the ceiling; +13 percent compressive on the front sides.

Little change is noted in the levels of maximum stress between Load Cases 2 and 3 because of their similar loading conditions. Yet, these results do support the type of changes in stresses expected in the behavior of the unit caused by the loading conditions defined for this study. These are static (or equivalent static) loads. One of the most degrading phenomena* is the repetitive 0.1 to 1.0 g cyclic loading at a 10-Hz frequency for the entire duration of the transportation cycle.

Comparison of the stress plots between Load Cases 1 and 4 (Condition I and II, respectively) shows results quite different from the previous comparison of Load Cases 1, 2 and 3.** It is evident from the stress plot information that the stresses have developed a substantially different pattern. Changes in maximum stress levels occur in the order of +14 percent tensile, -30 percent compressive in the floor; -28 percent tensile, -52 percent compressive in the ceiling; -63 percent tensile, -37 percent compressive in the right side; +13 percent tensile, +44 percent compressive in the left side; -10 percent tensile, +22 percent compressive in the back side; and -42 percent tensile, -6 percent compressive for the front side. Unlike the comparison between Load Cases 1 and 2 above, these results substantiate the expectation that certain sections

*See Task III, Volume I for supporting data.
**See definitions for Load Cases in Table 3.

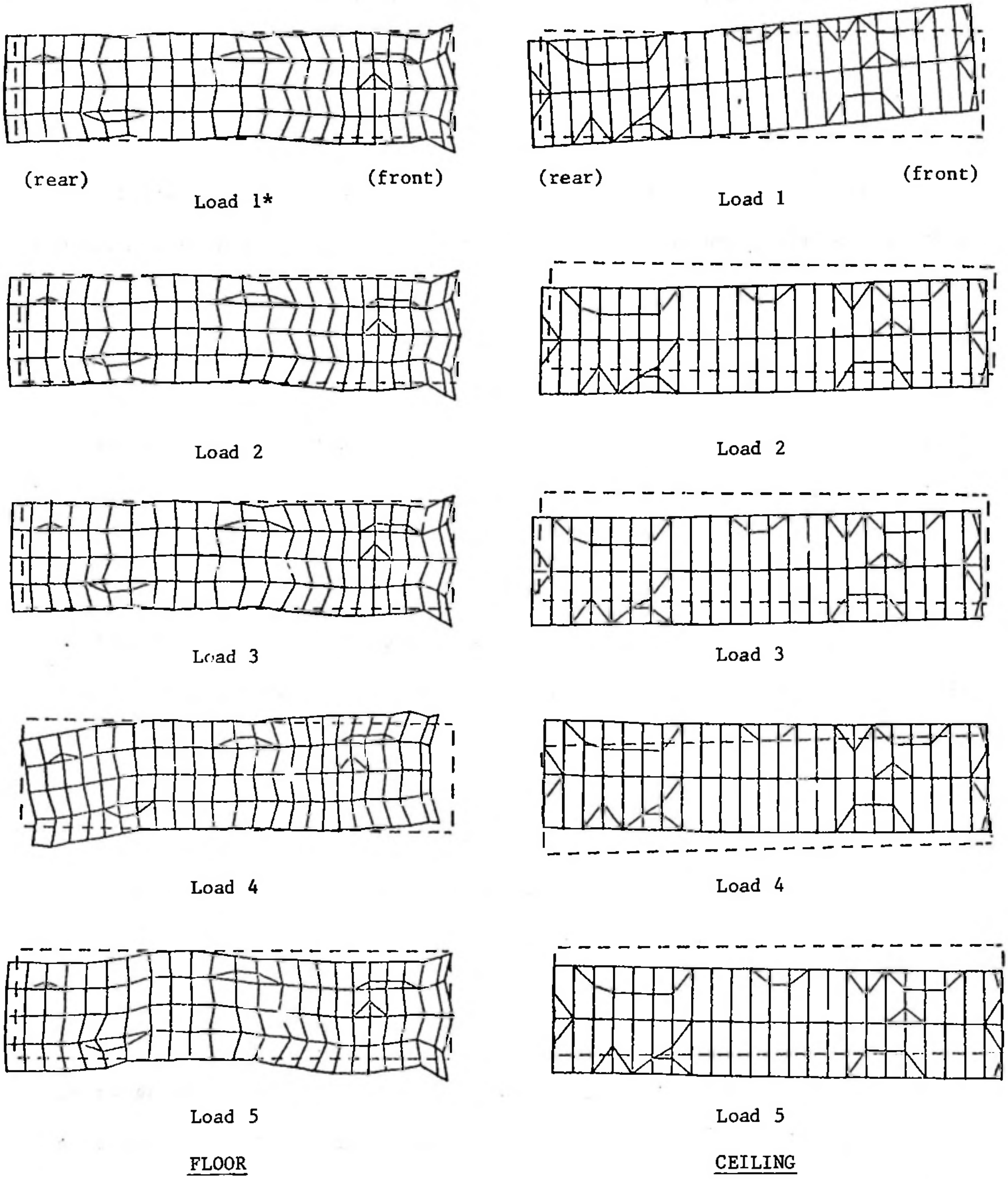
of the unit will experience a stress relief rather than an increase because of the nature of the jacking load imposed in this particular loading scheme.

Unlike the previous load cases, a comparison of results between the baseline and "worst-case" conditions, Load Cases 1 and 5, respectively, indicates severe changes in maximum stress levels. Results show increases in maximum stress of +117 percent tensile, +113 percent compressive in the floor; +96 percent tensile, +63 percent compressive in the ceiling; +110 percent tensile, +141 percent compressive in the right side; +178 percent tensile, +170 percent compressive in the left side; +154 percent tensile, +138 percent compressive in the back side; and +130 percent tensile, +132 percent compressive in the front side of the unit. EI and J stiffness factors used were from the mobile home in test and analysis.

Examining the stress plots for Load Case 5 in Figures 8 through 13 the critical areas, or areas of high stress levels and/or concentrations, remain along the perimeter and around the window and door openings of each section of the unit as in previous loading cases; but, the magnitude of the stress levels is much more critical. It should be recalled that the previous load cases using equivalent static loads from the dynamic analysis were based upon acceleration levels ranging from 0.1 to 1.0 G's, vertically.* Load Case 5 was based on infrequent acceleration levels from 5.0 to 9.4 G's.

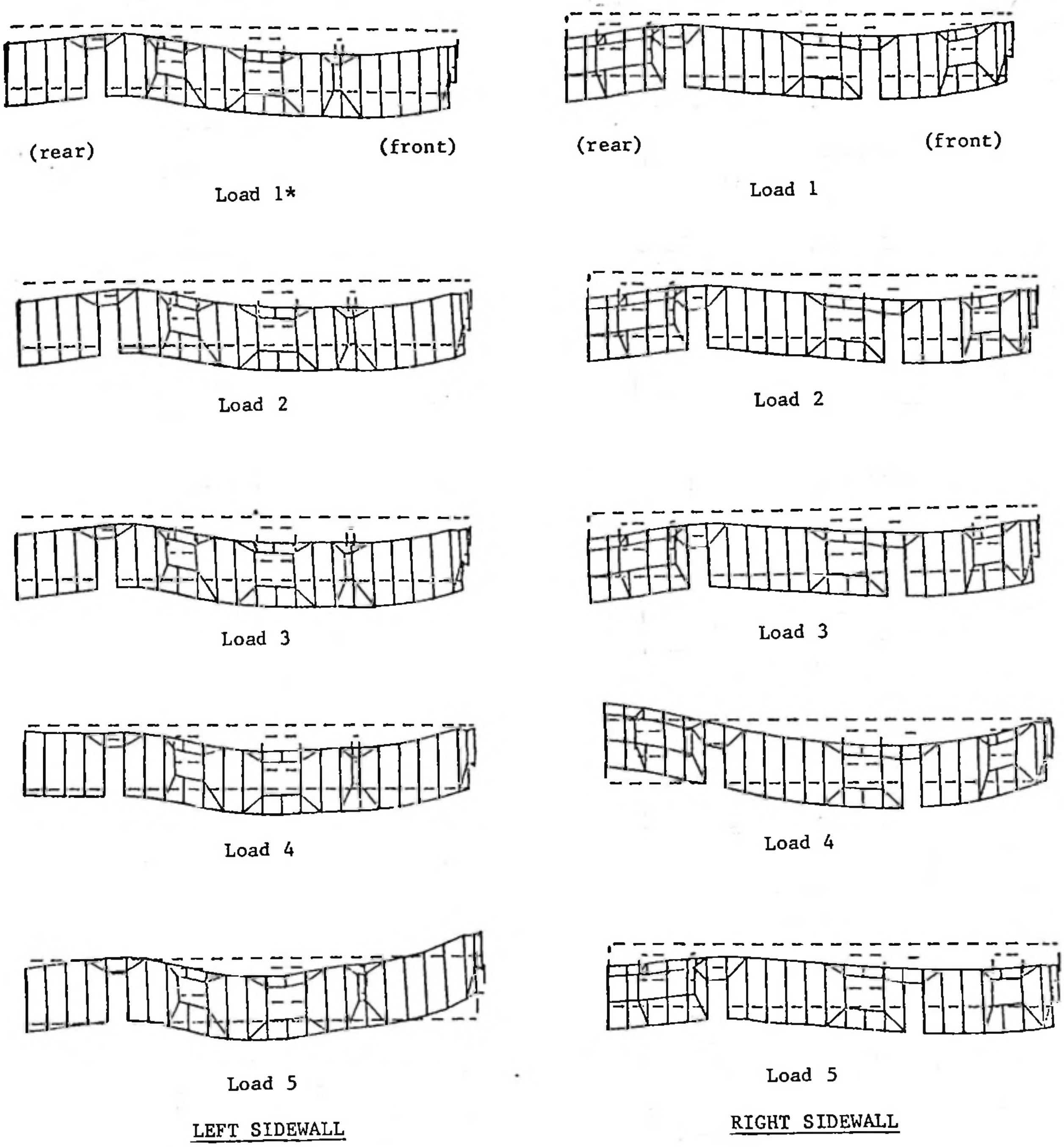
The deformations of the structure for each load case are shown in Figures 14 through 16. Unlike the stress data, the deformation data were calculated from the reduced elasticity modulus for the wall panels, developed during the correlation of the T-5 mobile home computer model. Note that because of the scale factor involved, the results shown in

*+1-G static loads on new mobile homes.



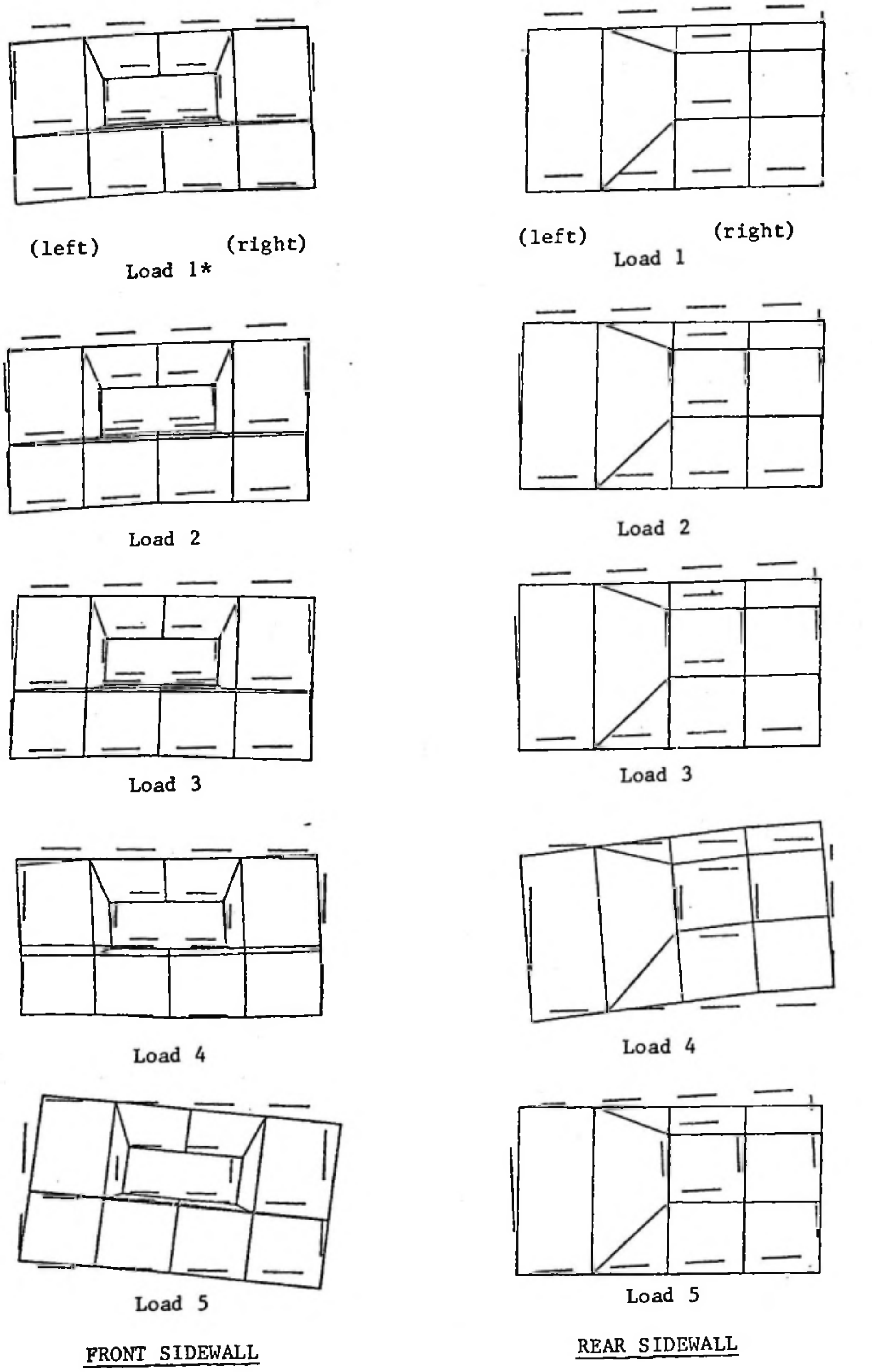
*For load descriptions, see Figure 8 or Table 3.
The deformations are not to scale. See Table 4 for actual deflections.

FIGURE 14. COMPARISON OF T-1 DISPLACEMENT PLOTS - FLOOR AND CEILING



*For load descriptions, see Figure 8 or Table 3.
The deformations are not to scale. See Table 4 for actual deflections.

FIGURE 15. COMPARISON OF T-1 DISPLACEMENT PLOTS - LEFT AND RIGHT SIDEWALLS



*For load descriptions, see Figure 8 or Table 3.
The deformations are not to scale. See Table 4 for actual deflections.

FIGURE 16. COMPARISON OF T-1 DISPLACEMENT PLOTS - FRONT AND REAR SIDEWALLS

these figures are magnified considerably to readily identify the movement in the unit. It is necessary, therefore, to collaborate this information with the results compiled in Table 4 to define the magnitude of these movements.

In studying the results of each load case individually, it was revealed that several displacement characteristics appear common to each unit. The lateral displacement of the floor of the unit is considerably less than the rest of the unit. The vertical displacement of the front sidewall is less than the other components of the unit because of its proximity to the hitch.

Comparison of the results of Load Case 1 to Load Cases 2, 3 and 5 shows the torquing effect on the unit. Not only does the vertical deflection of the unit increase with the severity of loading, but also the twisting of the unit becomes more severe, particularly in Load Case 5. In this case, the lateral deflections sharply increased and the torquing effect lifted the left sidewall over 0.7 in. and dropped the right sidewall approximately 1.2 in. from their original positions (Load Case 1).

Comparison of the results of Load Case 4 with the other load cases shows results similar to that of the stress plots. The jacking load has decreased the deflections in both directions. This indicates areas of stress relief in many sections of the unit. However, areas such as over the main door on the right sidewall of the unit should be noted (see Figure 15). The lack of cross-sectional area at this point along the unit appears to be critical to its vertical bending strength.

TABLE 4

SUMMARY OF T-1 MAXIMUM DISPLACEMENTS

	Maximum Deflection (In.)/Node Location†									
Mobile Home Component	Load Case 1*		Load Case 2		Load Case 3		Load Case 4		Load Case 5	
	Lateral*	Vertical**	Lateral	Vertical	Lateral	Vertical	Lateral	Vertical	Lateral	Vertical
Floor	-0.010/228	-1.210/203	-0.570/241	-1.286/101	-0.886/250	-1.341/101	0.027/250	-0.803/171	-1.180/250	-4.159/197
Ceiling	0.230/543	-1.210/528	-0.329/451	-1.286/451	-0.374/451	-1.342/451	0.181/451	-0.803/504	-2.856/547	-4.160/320
Left Sidewall	0.228/425	-1.210/412	-0.324/352	-1.061/398	-0.369/352	-1.013/398	0.176/352	-0.803/390	-2.856/425	1.191/421
Right Sidewall	0.230/339	-0.969/254	-0.329/254	-1.286/254	-0.374/254	-1.342/254	0.181/254	-0.496/308	-2.852/339	-4.160/320
Rear Sidewall	-0.105/566	-0.969/566	-0.329/566	-1.286/566	-0.374/566	-1.342/566	0.181/566	0.308/566	-1.959/566	-3.650/566
Front Sidewall	0.230/578	-0.712/599	-0.158/600	-0.672/577	-0.171/592	-0.233/600	0.078/600	-0.103/599	-2.856/600	-3.373/577

†For node point locations, see Figure 5.
*For load descriptions, see Figure 8 or Table 3.
**For displacement directional sense, see Figure 7.

VII. T-2 ANALYSIS METHODOLOGY

The models for the T-2A (wet side) and T-2B (dry side) mobile home unit are detailed in Figures 17 through 19 and Figures 20 through 22, respectively. Again these models are a coarser, modular mesh idealization compared to that of the T-1. Separate parts for the chassis, floor, walls, and ceiling were utilized, integrating these parts into the computer program input by coupling the translational degrees of freedom at the common nodes. The following computer runs were then conducted for each model, T-2A and T-2B:

- Data check run to generate geometry plots (see Figures 24 and 27) and check boundary conditions, elements, material properties, definitions and other input data for completeness and inconsistencies.

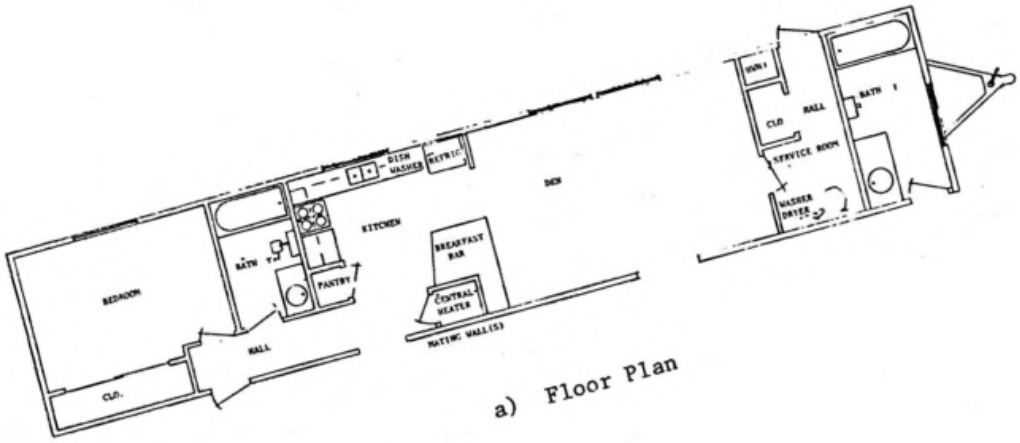
Condition I

- Load 1 - Gravity load run to generate the base line stresses and deformations for each unit under gravity loads of the structure and its furnishings.
- Load 2 - Gravity loads of each structure and its furnishings plus equivalent loads from the dynamic analysis (well-paved road, 45 mph).

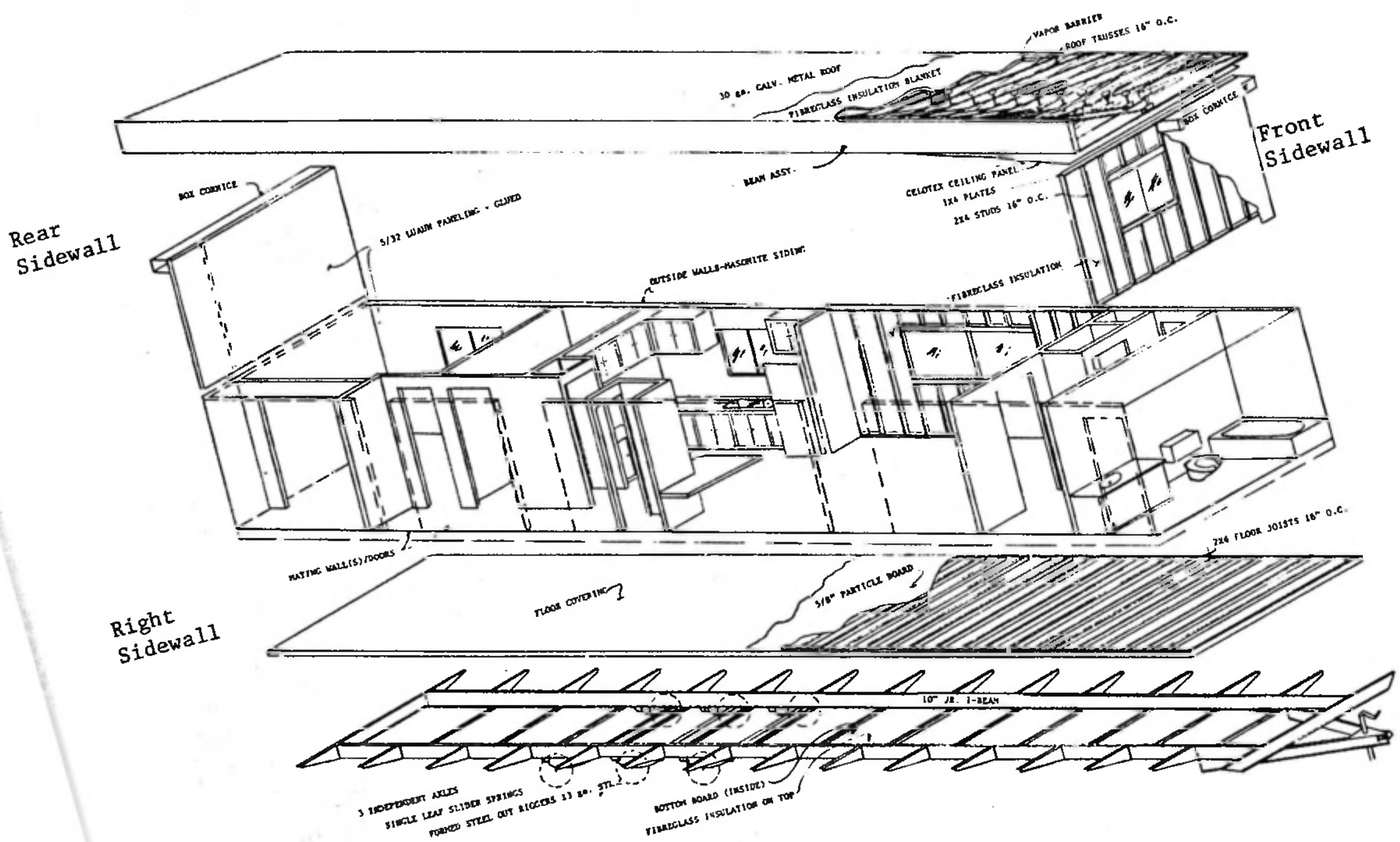
Condition II

- Load 4 - Gravity loads of the structure and its furnishings plus a concentrated load of 4000 lb acting on the right longitudinal I-beam at the rear of the chassis (nodal point 2 on Figure 3). This loading case, unlike the preceding two cases, was developed to simulate site installation activities where the unit is jacked up at each corner and set on blocks. (For this loading condition, the unit was restrained at the hitch, the three axles, and at the front end at the longitudinal I-beams. This last restraint assumes that the front end was blocked prior to this step in the installation procedure.)
- Load 5- Gravity loads of the structure and its furnishings plus equivalent static loads from the dynamic analysis. This load case represents probabilistic "worst case" conditions.

Load Cases 1 through 5 are summarized in Table 3.
*See Table 3 for description of Conditions I and II.

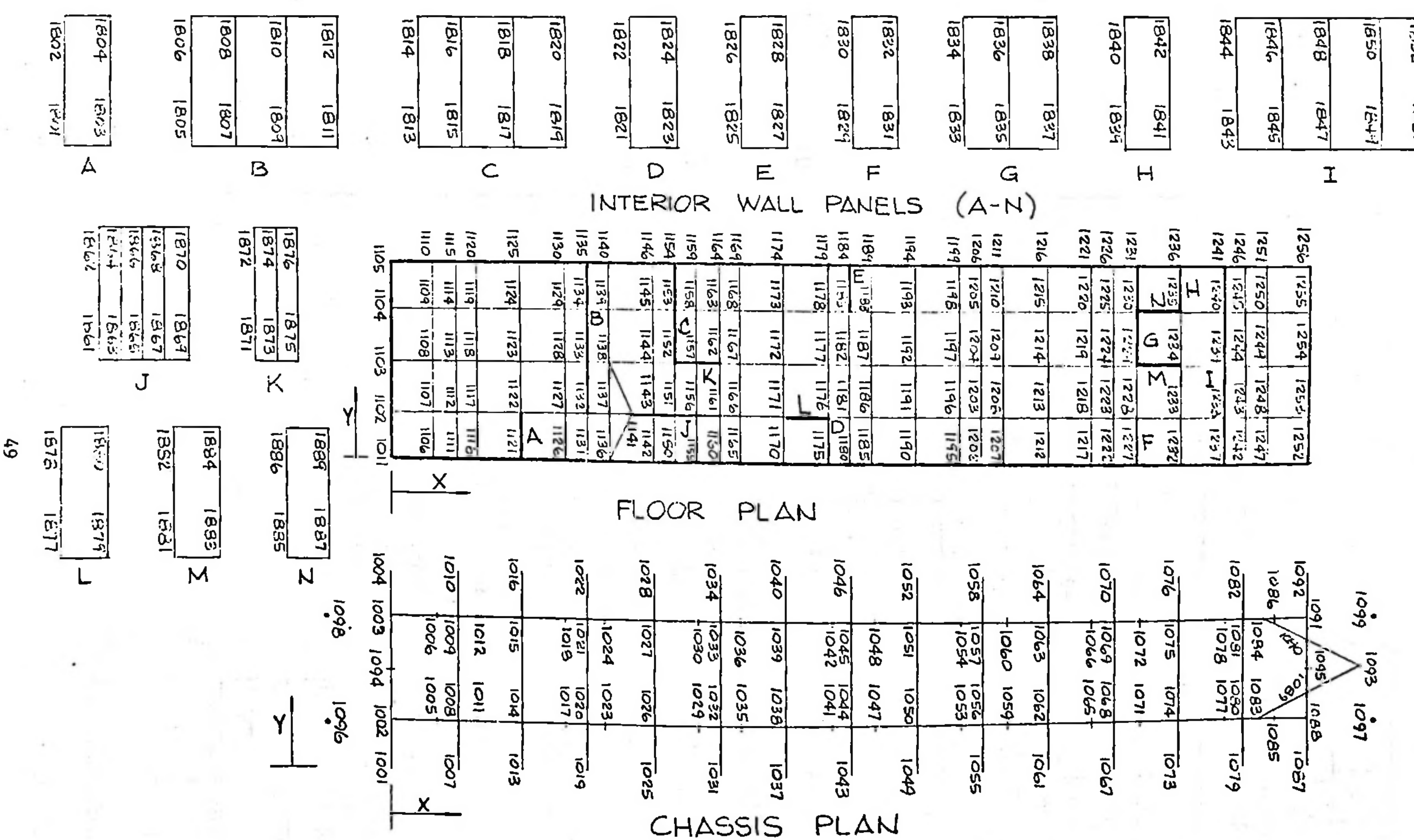


a) Floor Plan



b) Exploded Isometric

FIGURE 17. T-2A MOBILE HOME LAYOUT



Note: Numbers shown indicate nodal point locations.

FIGURE 18. FINITE ELEMENT MODEL OF T-2A

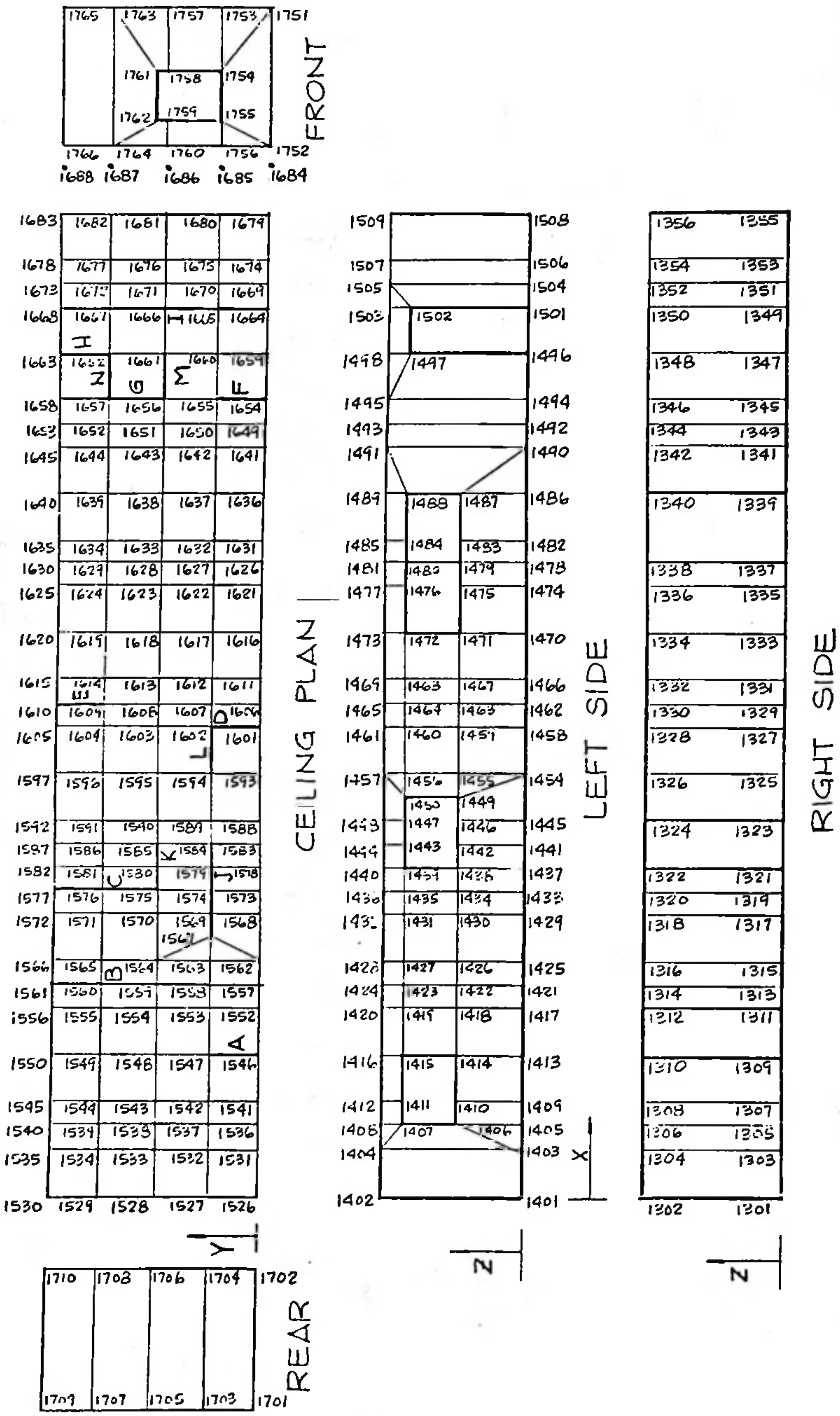
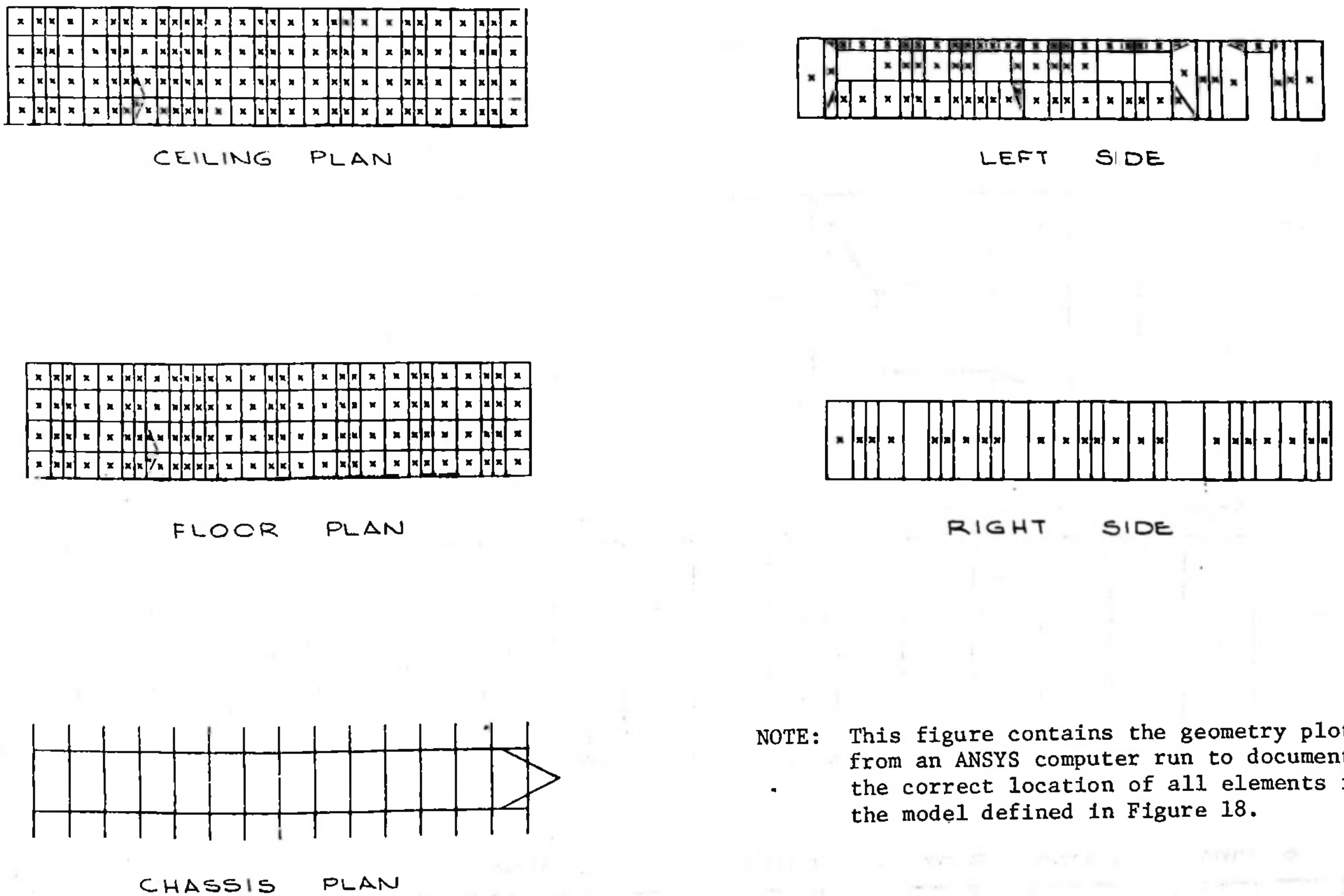


FIGURE 18. (Cont'd)



NOTE: This figure contains the geometry plots from an ANSYS computer run to document the correct location of all elements in the model defined in Figure 18.

FIGURE-19. COMPUTER GRAPHIC MODEL OF T-2A

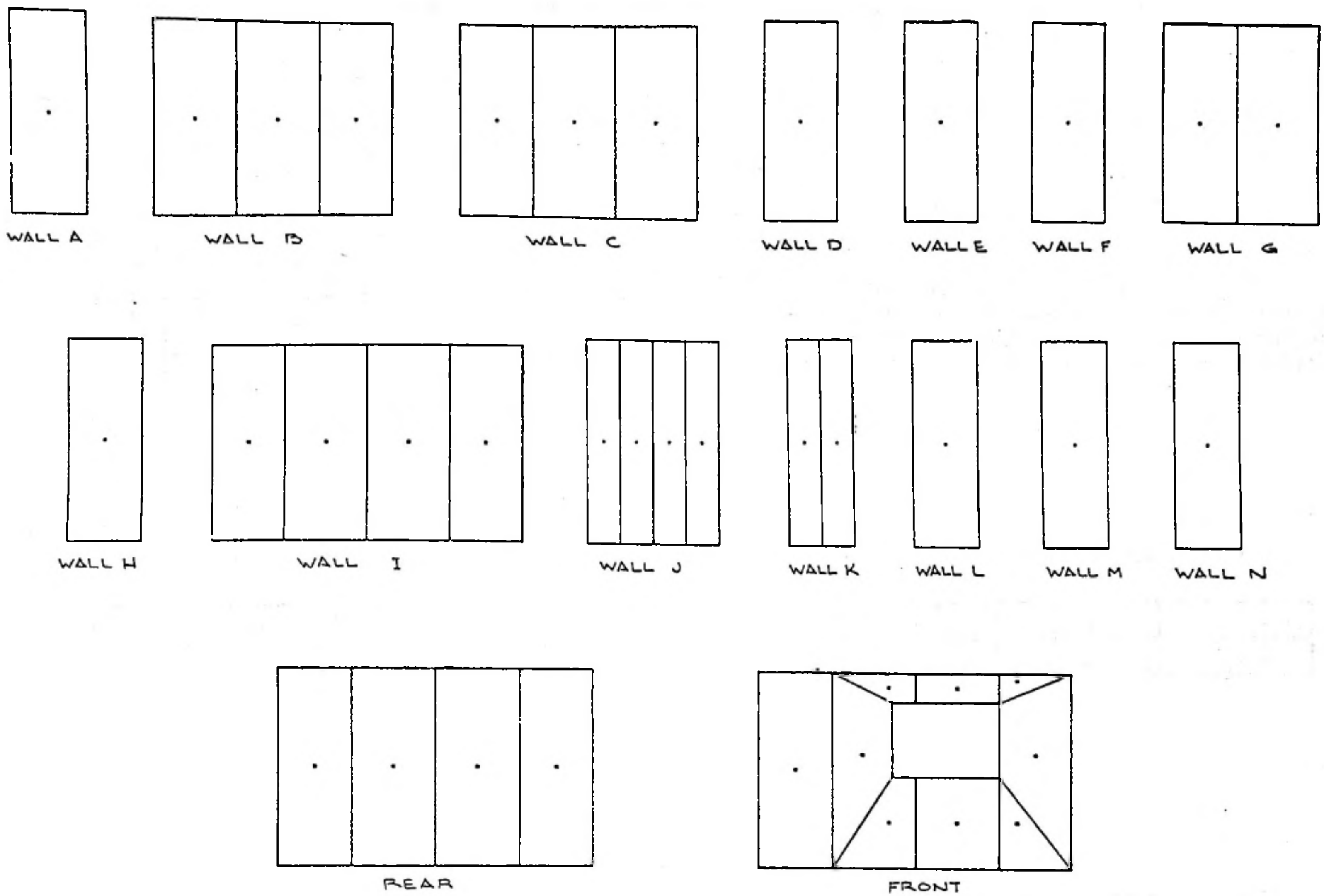
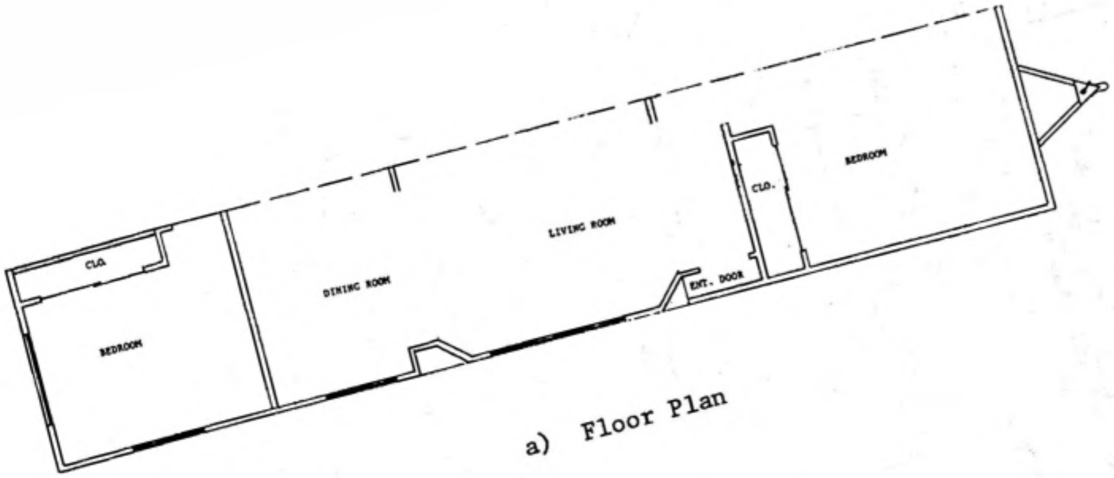
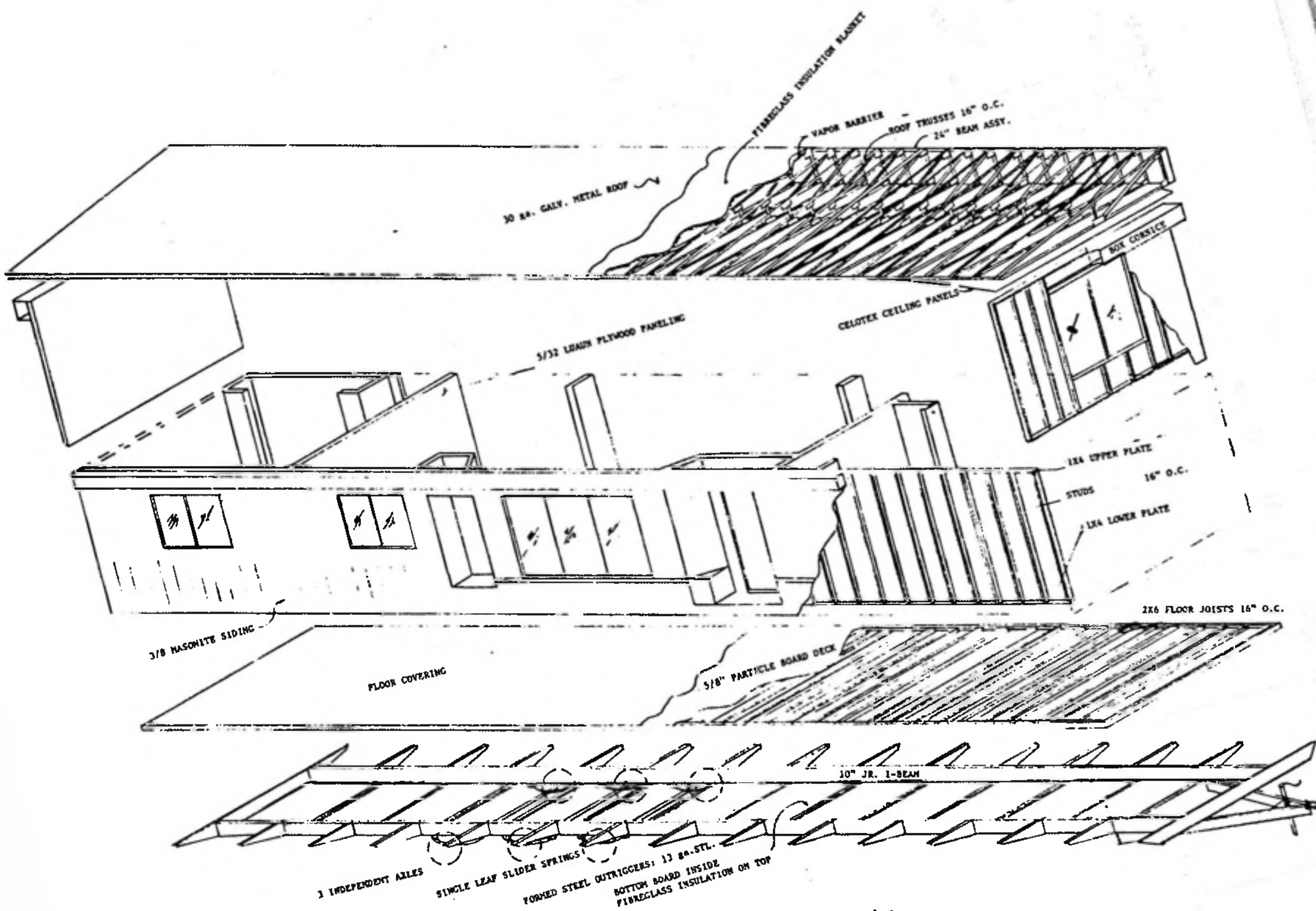


FIGURE 19. (Cont'd)

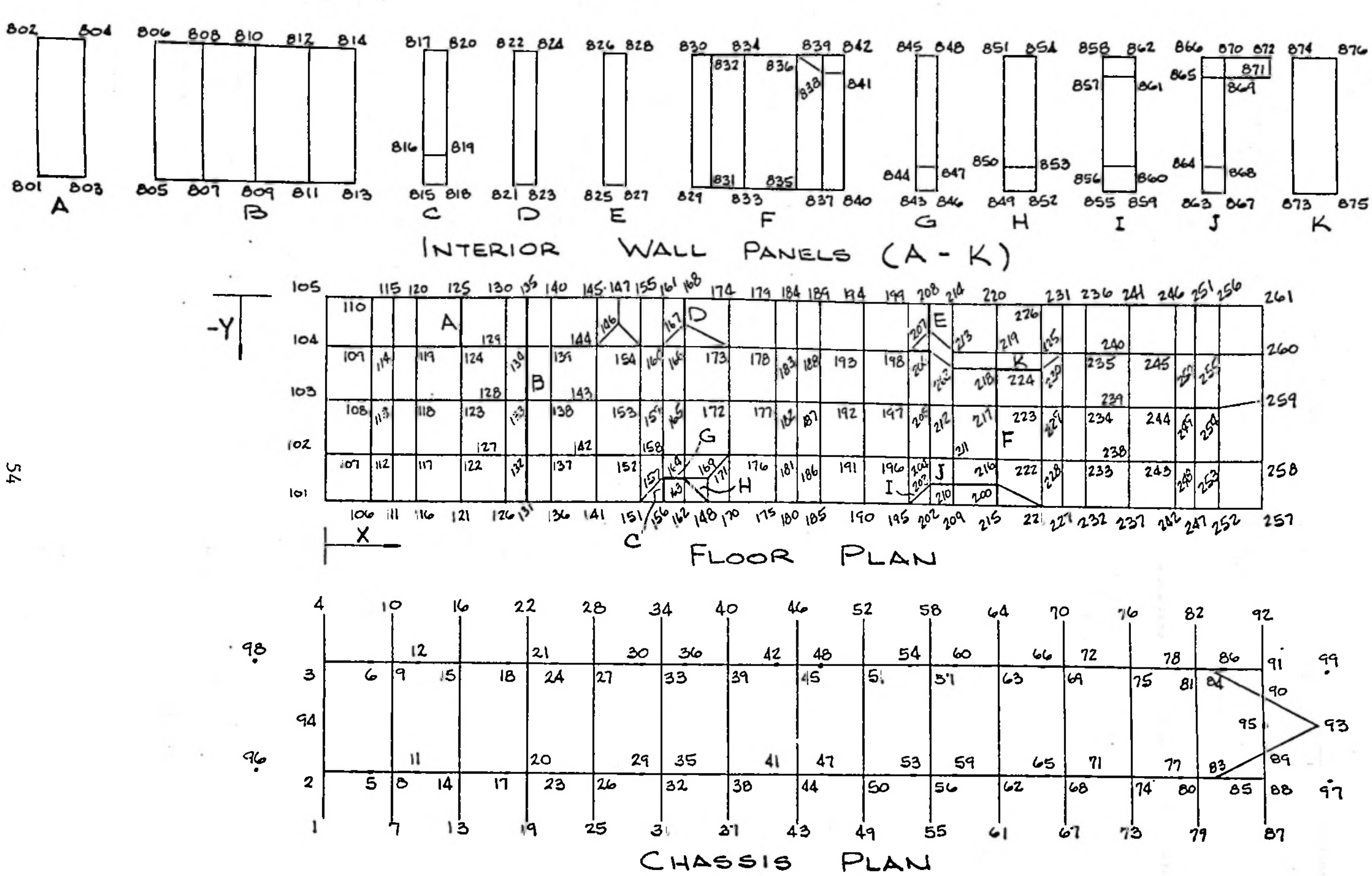


a) Floor Plan



b) Exploded Isometric

FIGURE 20. T-2B MOBILE HOME LAYOUT



NOTE: Numbers shown indicate nodal point locations

FIGURE 21 - FINITE ELEMENT MODEL OF T-2B

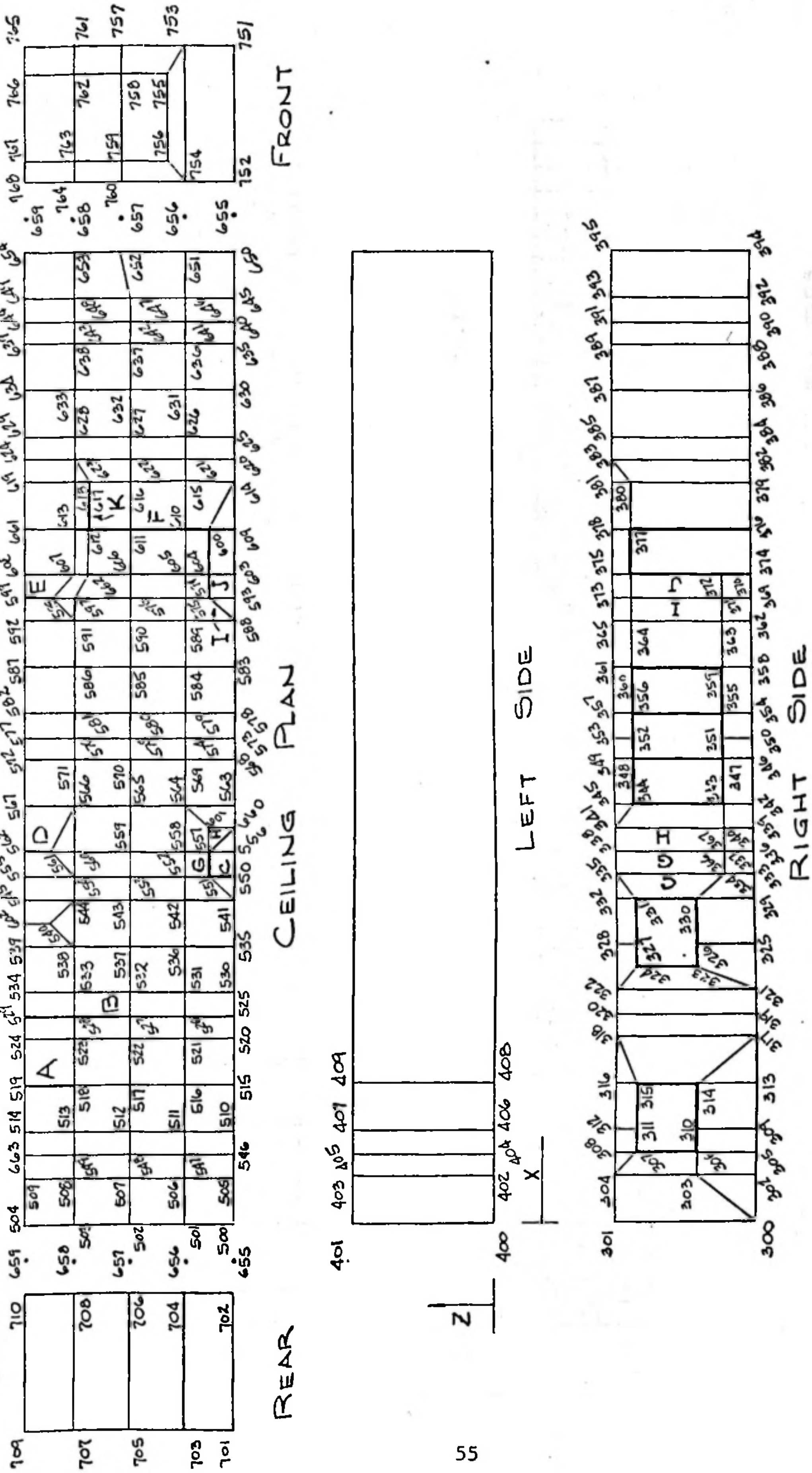
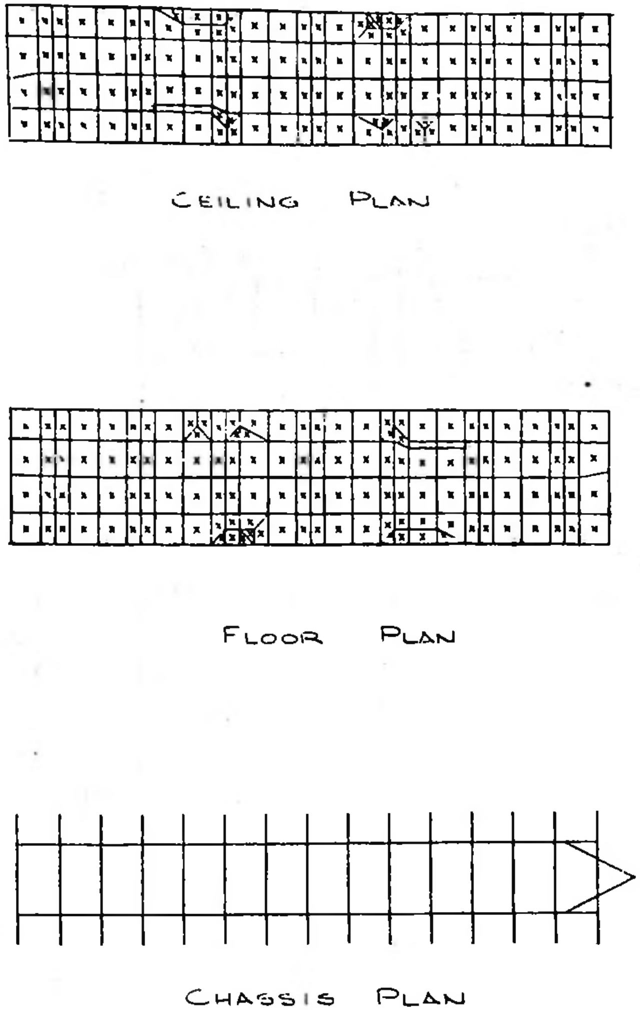
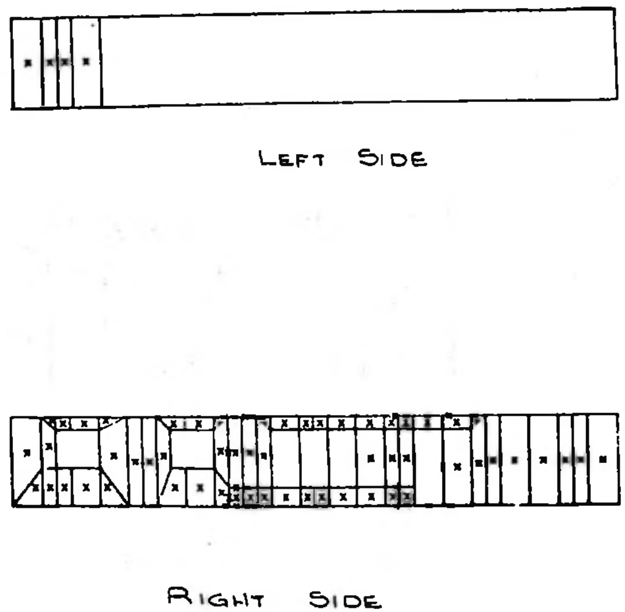


FIGURE 21. (Cont'd)





NOTE: This figure contains the geometry plots from an ANSYS computer run to document the correct location of all elements in the model defined in Figure 21.

FIGURE 22. COMPUTER GRAPHIC MODEL OF T-2B

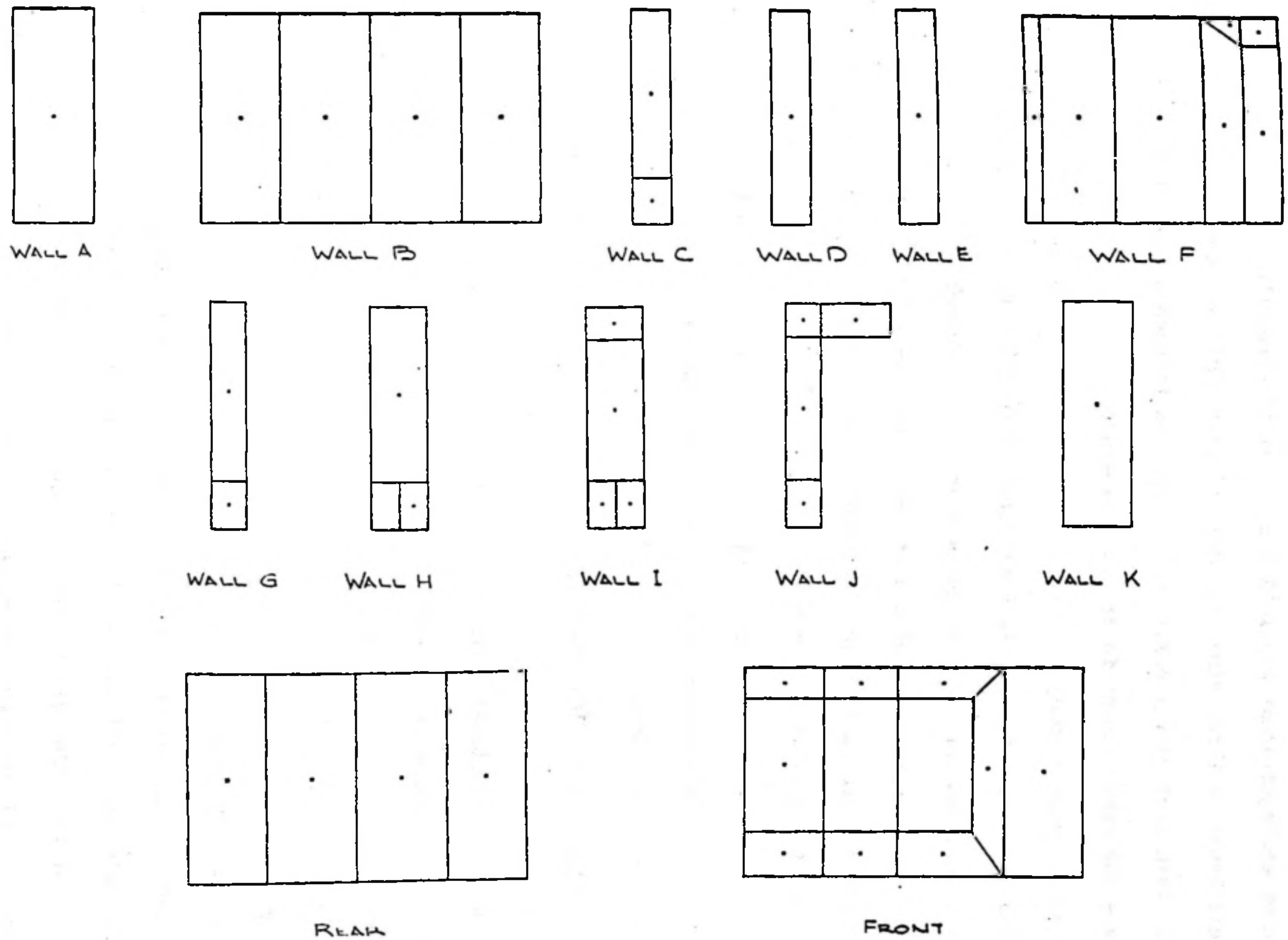


FIGURE 22. (Cont'd)

Again, the equivalent static loads calculated from the dynamic analysis were based on three times the RMS, or sigma (σ), values defined in Volume I, Task I of this report. Values applied to each side of the T-2 unit were the same, except in directional sense.

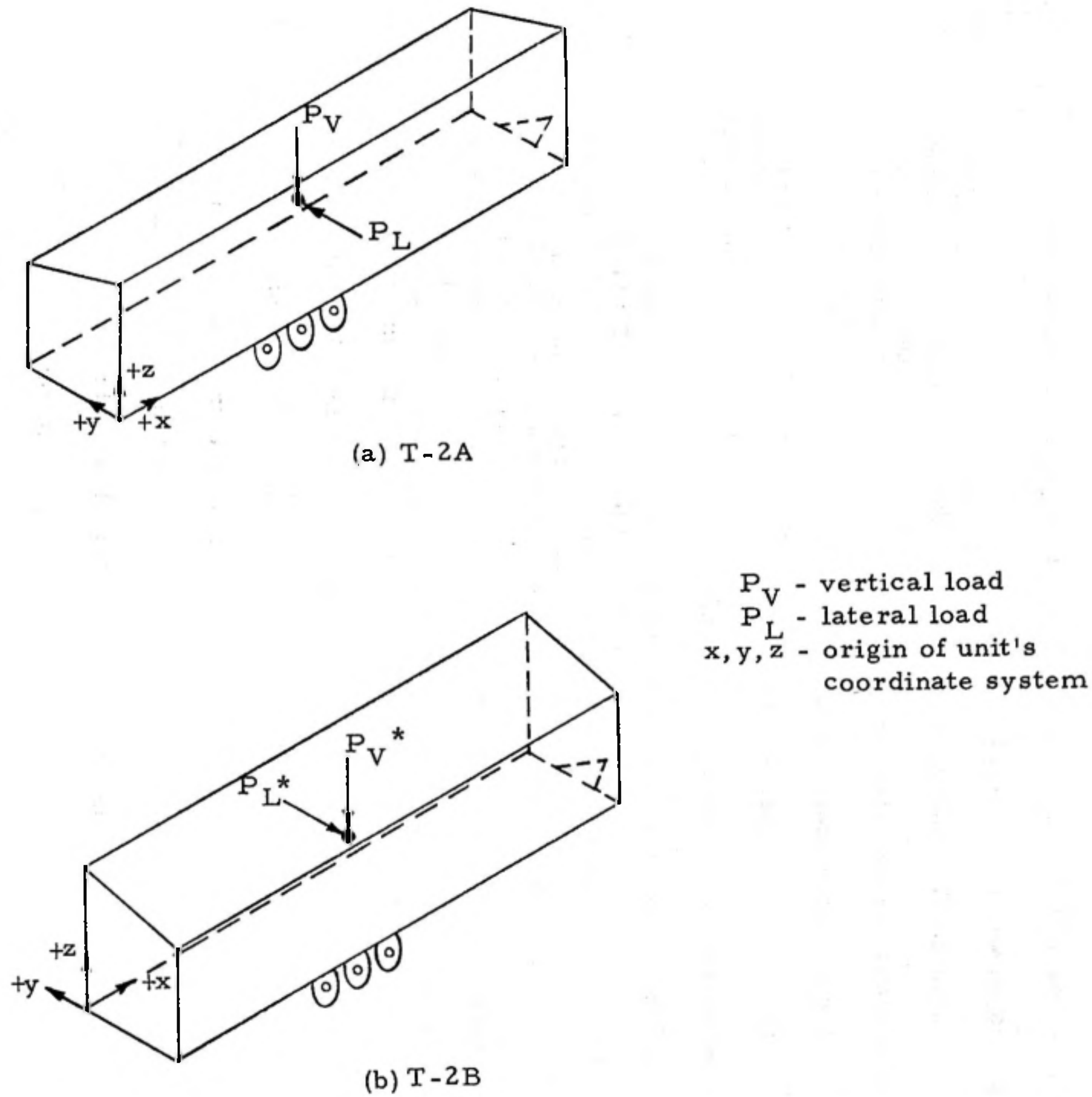
From the dynamic analysis, the computer-evaluated RMS (G loads) were obtained throughout the mobile home unit. With these values, the forces were calculated for the components that most influence the dynamic loading. With the acceleration of the latter components known, these accelerations were factored to produce the equivalent static loads to be input into the finite element program, symbolizing the dynamic condition. For example: if a vertical G_{RMS} value of 3.0 G's is obtained from the dynamic analysis for a position where a particular component of weight W is located, its contributing load in the finite element program would be 3 times the G_{RMS} value times W, or 9W. The equivalent static load of 3σ times weight would correlate to 9 times W or 9W. When this is done for all components considered (with the respective G_{RMS} and weight values) the mobile home model is subjected to a static load equivalent to the forces induced by the dynamic response characteristics obtained from the dynamic analysis.

For the equivalent static loading of the T-2A, all vertical loads input from the dynamic analysis were assumed to be acting downward (-z direction), and all lateral loads were applied from right to left looking down the unit from rear to front (+y direction). For the equivalent static loading of the T-2B, all vertical loads input from the dynamic analysis were assumed to be acting downward (-z direction), and all lateral loads were applied from left to right looking down the unit from rear to front (- y direction). The directional sense of these loading schemes is shown in Figure 23.

As in the T-1 analysis, the loading directions in each of these two conditions are actually random in nature. The directions assumed represent a possible loading condition.

Details of a typical computer run similar to that used to analyze these units are contained in the appendix.

Page 47 contains the Condition I load cases for analysis. The Condition II load cases are the same with the only variable relating to the EI and J stiffness factors resulting from the degradation of the mobile home structure. As the mobile home structure degrades and loosens, the accelerations are reduced but the deflections increase resulting in higher stresses.



*P_V and P_L are <u>not</u> lump loads. They provide directional sense only.

FIGURE 23. T-2A AND T-2B EQUIVALENT STATIC LOAD DIRECTIONAL SENSE

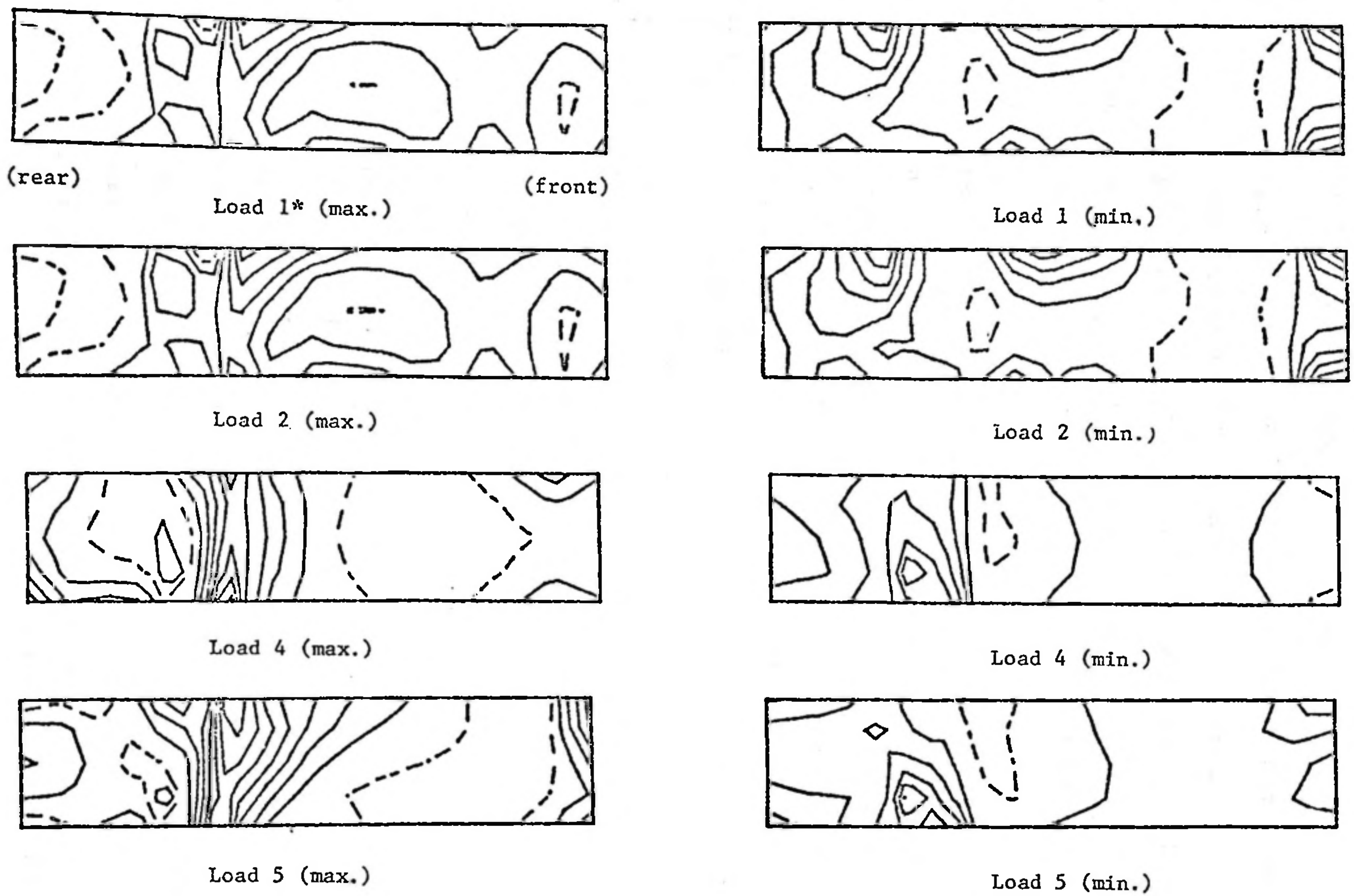
VIII. DISCUSSION OF T-2A RESULTS

Output plots* for the ANSYS program were specified for stress trajectories and displacements of the membrane elements in the floor, walls and ceiling. Plots could not be developed for walls containing too few membrane elements such as the marriage wall side of this double-wide. Output results for all elements of the structure are available in the computer output sheets (available upon request at Southwest Research).

The before and after stress results of the analysis (Condition I, Loads 1 and 2) are shown in Figures 24 through 27. Comparing the plots of Load Cases 1 and 2 shows increased stress levels in areas of maximum bending moments, particularly near axle locations on the floor, and window and door locations on the sidewalls. Because of the existence of an interior wall along most of the right side of the T-2A unit, the stresses were well distributed throughout the unit. The increased load in Load Case 2 had a limited effect on the stress pattern. Results from the plot data from the ANSYS output show that the increases in maximum stresses for various sections of the unit were: floor, +6 percent tensile and +4 percent compressive; ceiling, -1 percent tensile and +5 percent compressive; left side, -6 percent tensile and +3 percent compressive; right side, +27 percent tensile and +6 percent compressive; and front side, +3 percent tensile and +5 percent compressive.

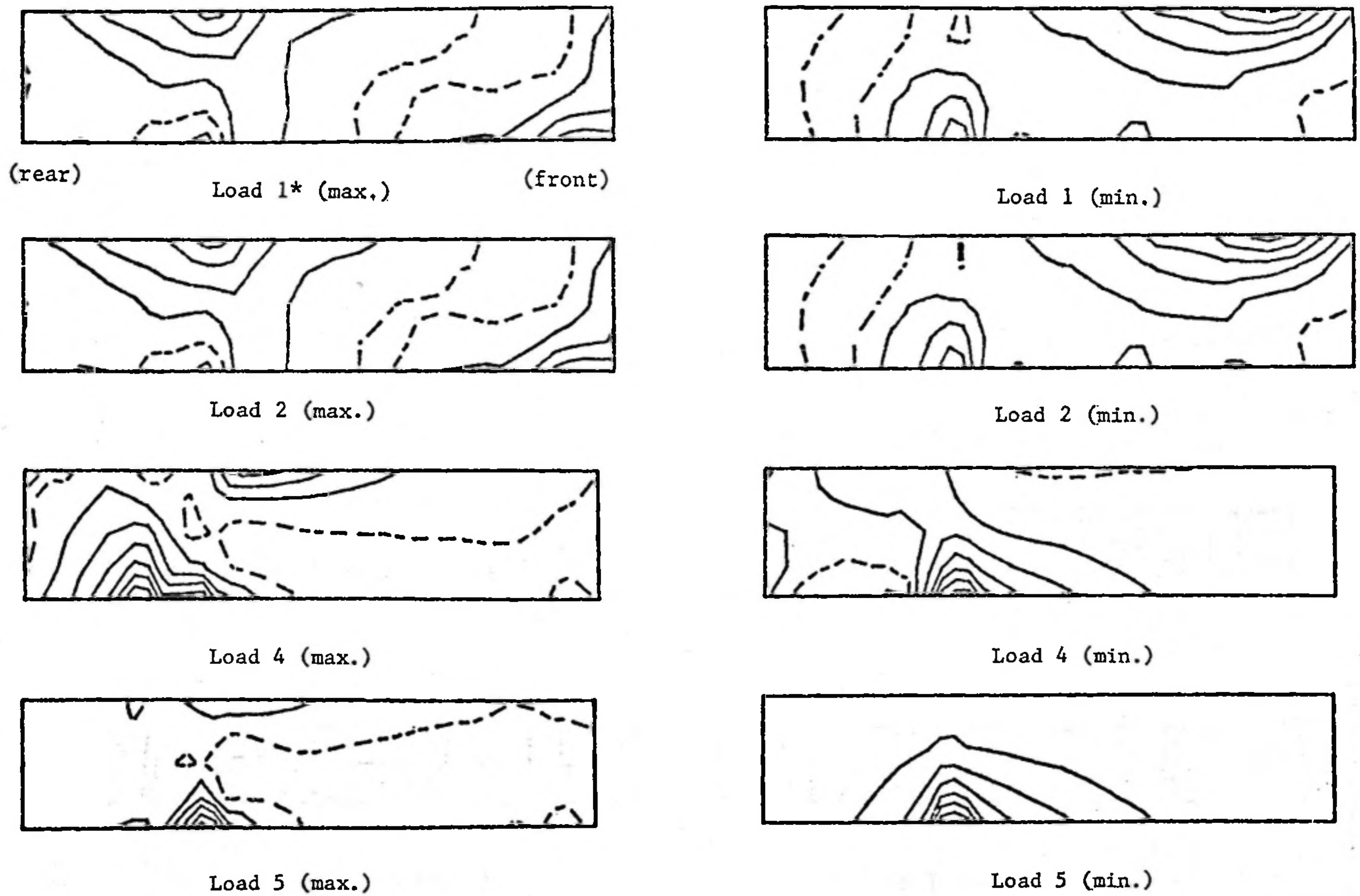
The deformations of the structure for each load case are shown in Figures 28 and 29. A summary of the maximum deflections is compiled in Table 5. These deformation data were derived from the same load cases used to calculate the stress data, but the elasticity modulus of the wall panels was reduced, as detailed previously in the T-5 mobile home computer model.

*See Appendix C for method of interpretation.



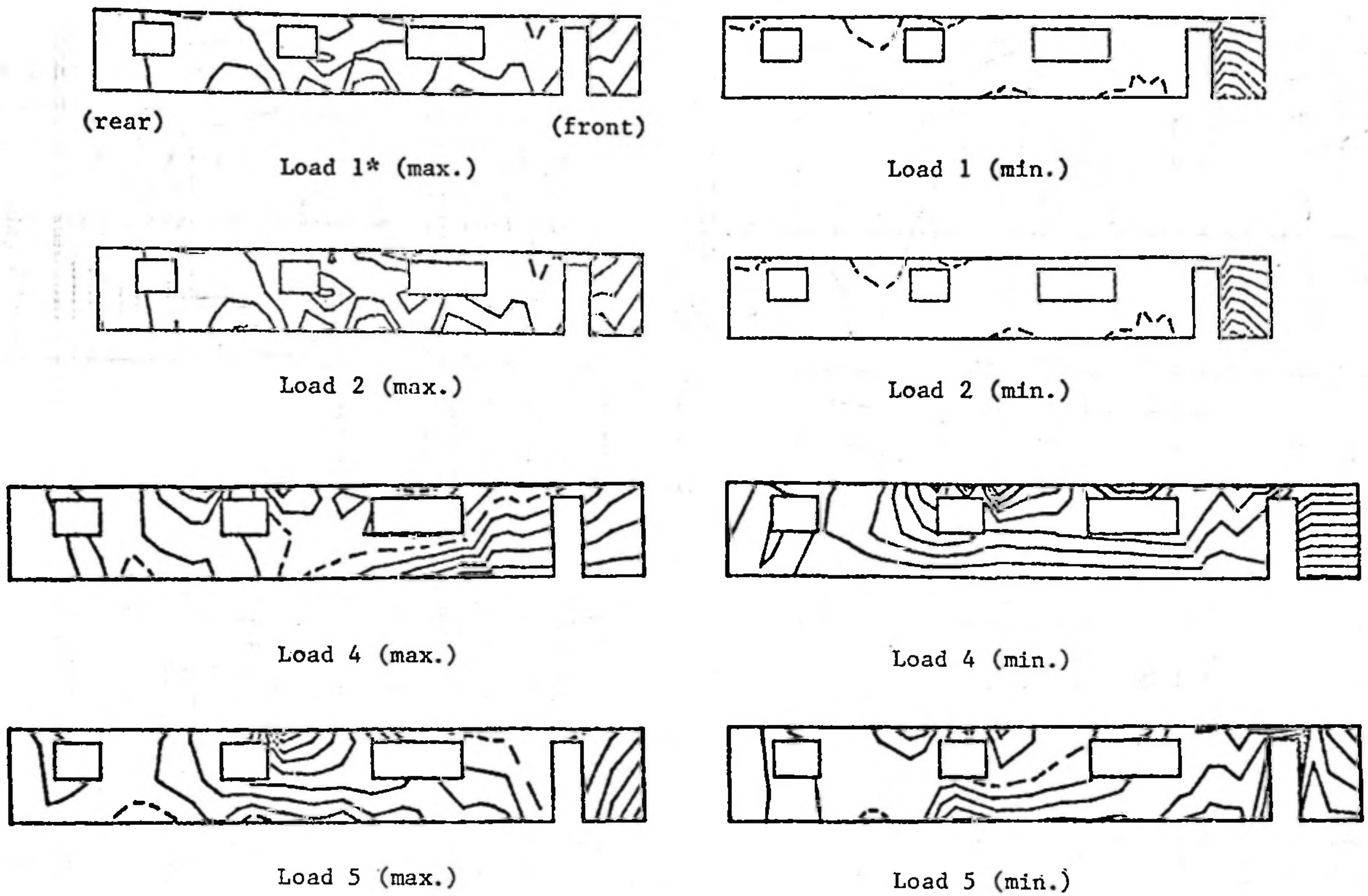
*See Table 3 for load descriptions.

FIGURE 24. COMPARISON OF T-2A STRESS PLOTS - FLOOR



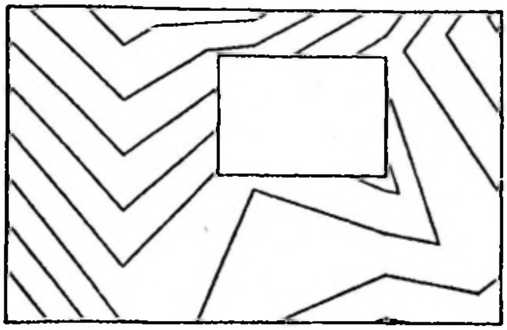
*See Table 3 for load descriptions.

FIGURE 25. COMPARISON OF T-2A STRESS PLOT - CEILING



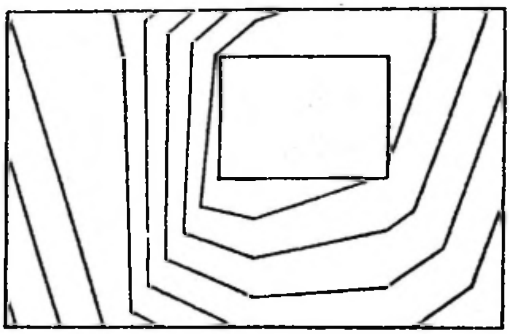
*See Table 3 for load descriptions.

FIGURE 26. COMPARISON OF T-2A STRESS PLOTS - LEFT SIDE

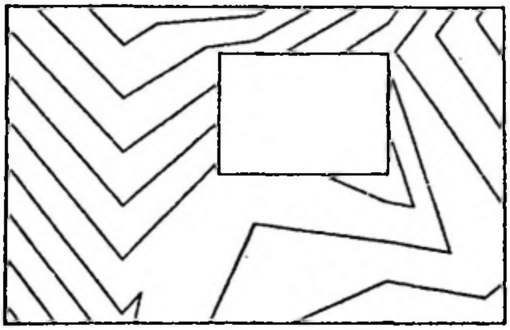


(left side) (right side)

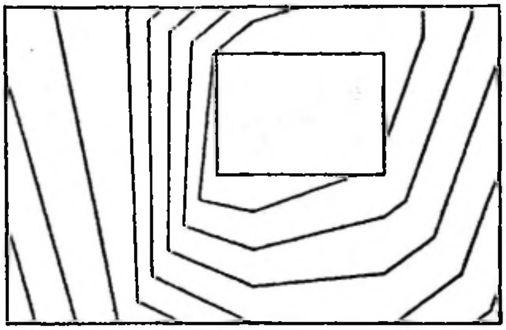
Load 1* (max.)



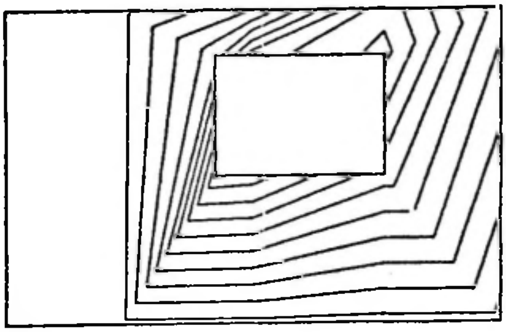
Load 1 (min.)



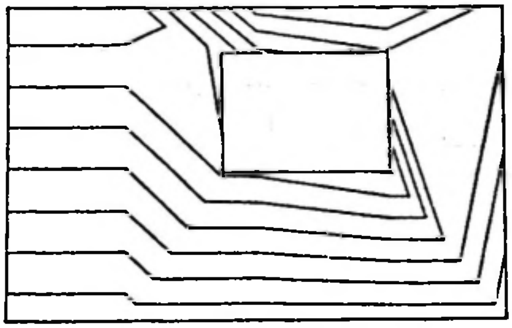
Load 2 (max.)



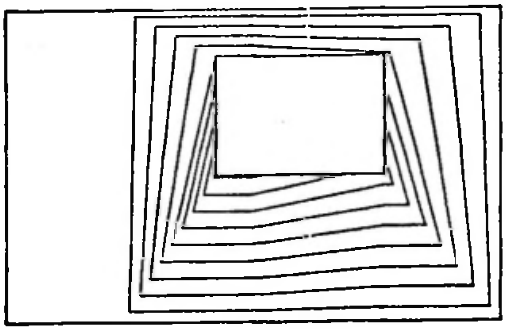
Load 2 (min.)



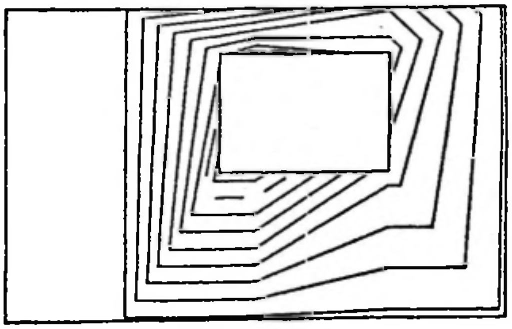
Load 4 (max.)



Load 4 (min.)



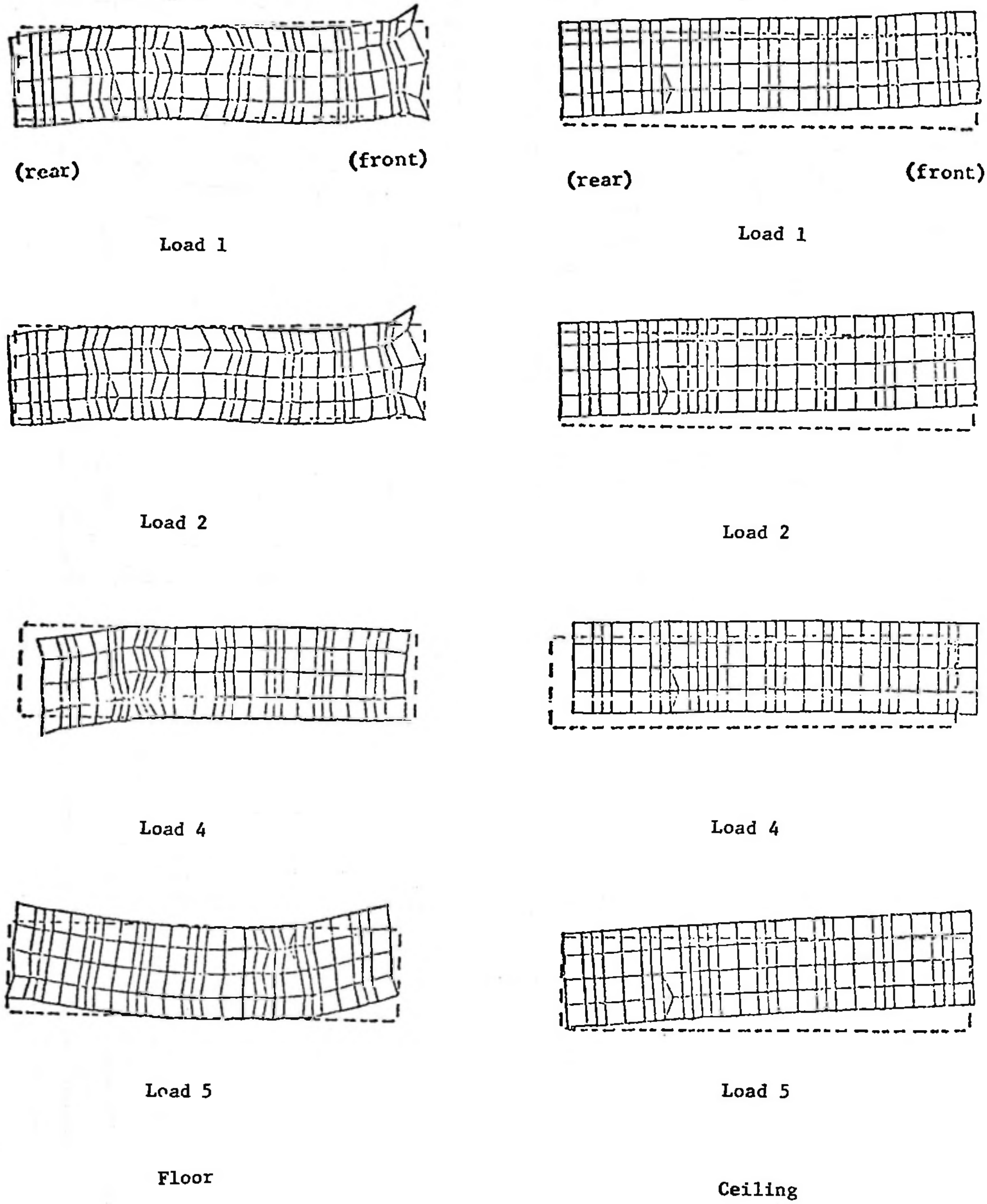
Load 5 (max.)



Load 5 (min.)

*See Table 3 for load descriptions.

FIGURE 27. COMPARISON OF T-2A STRESS PLOTS - FRONT END

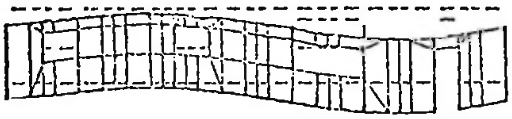


*See Table 3 for load descriptions.

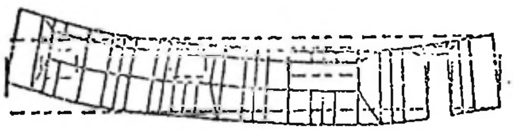
FIGURE 28. COMPARISON OF T-2A DISPLACEMENT PLOTS - FLOOR AND CEILING

(rear) (front)

Load 1



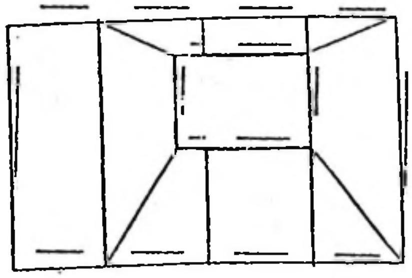
Load 2



Load 4

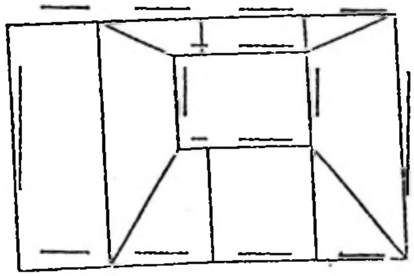
Load 5

LEFT SIDE

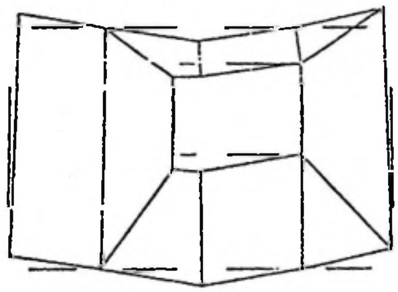


(left) (right)

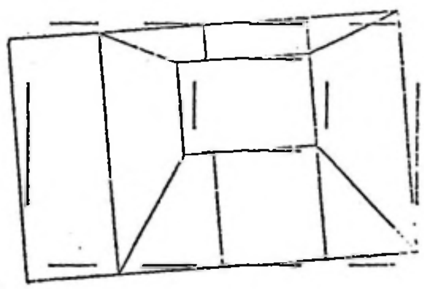
Load 1



Load 2



Load 4



Load 5

FRONT END

*See Table 3 for load descriptions.

FIGURE 29. COMPARISON OF T-2A DISPLACEMENTS PLOTS - LEFT SIDE AND FRONT END

TABLE 5

SUMMARY OF T-2A MAXIMUM DISPLACEMENTS

Mobile Home Component	Maximum Deflection (In.)/Node Location†							
	Load Case 1*		Load Case 2		Load Case 4		Load Case 5	
	Lateral **	Vertical**	Lateral	Vertical	Lateral	Vertical	Lateral	Vertical
Floor	0.005/1256	-0.587/1226	-0.006/1256	-0.661/1226	-0.0162/1101	1.472/1101	-0.0710/1105	-5.10/1256
Ceiling	0.198/1679	-0.585/1658	0.281/1679	-0.661/1658	0.264/1578	-551/1683	4.93/1679	-8760/1683
Left Sidewall	0.188/1509	-0.587/1492	0.270/1509	-0.661/1492	0.248/1440	0.834/1402	2.37/1440	-5.10/1509
Right Sidewall	0.198/1356	-0.241/1343	0.281/1356	-0.218/1341	0.264/1322	1.472/1301	2.51/1322	3.94/1355
Rear Sidewall	0.057/1710	-0.304/1709	0.089/1710	-0.351/1709	0.247/1702	1.472/1701	0.505/1710	2.33/1702
Front Sidewall	0.198/1752	-0.343/1766	0.281/1752	-0.412/1766	-0.00862/176	0.0195/1751	6.02/1766	-5.10/1765

*For load descriptions, see Figure 24 or Table 3.
†For node point locations, see Figure 18.
**For displacement directional sense, see Figure 23(a).

Analysis of the results of each load case revealed that the maximum vertical deflections occur at the left front end of the unit. It is on this area of the unit along the sidewall that the main exterior door and several large windows are located.

The effect of the lateral load was obtained through comparison of the two load cases revealing an increase in lateral displacements throughout the unit. Vertical deformations also increased. Since the lateral loads were input acting from right to left, these increased downward vertical deformations on the left sidewall of the unit were predictable.

The stresses and displacements of Load Case 4, presented in the same figures as Load Cases 1 and 2, twisted the rear of the mobile home counter-clockwise about the forward axis. Coupled with this was a slight twist about the left lateral axis. Stress concentrations occurred in the floor and ceiling over the axles, at the right rear floor, right front side wall, and about the front wall window. The vertical displacements of the right wall, upward rear of the axles and downward forward of the axles, explain the floor over axle concentrations.

Load Case 5 also generated stress concentrations in the floor over the axles and around the front end wall window. This dynamic case forced the front end down to the left, the closed and heavier side. The left side experienced stress concentrations at the lower forward corner joining those of the floor at its left front corner.

IX. DISCUSSION OF T-2B RESULTS

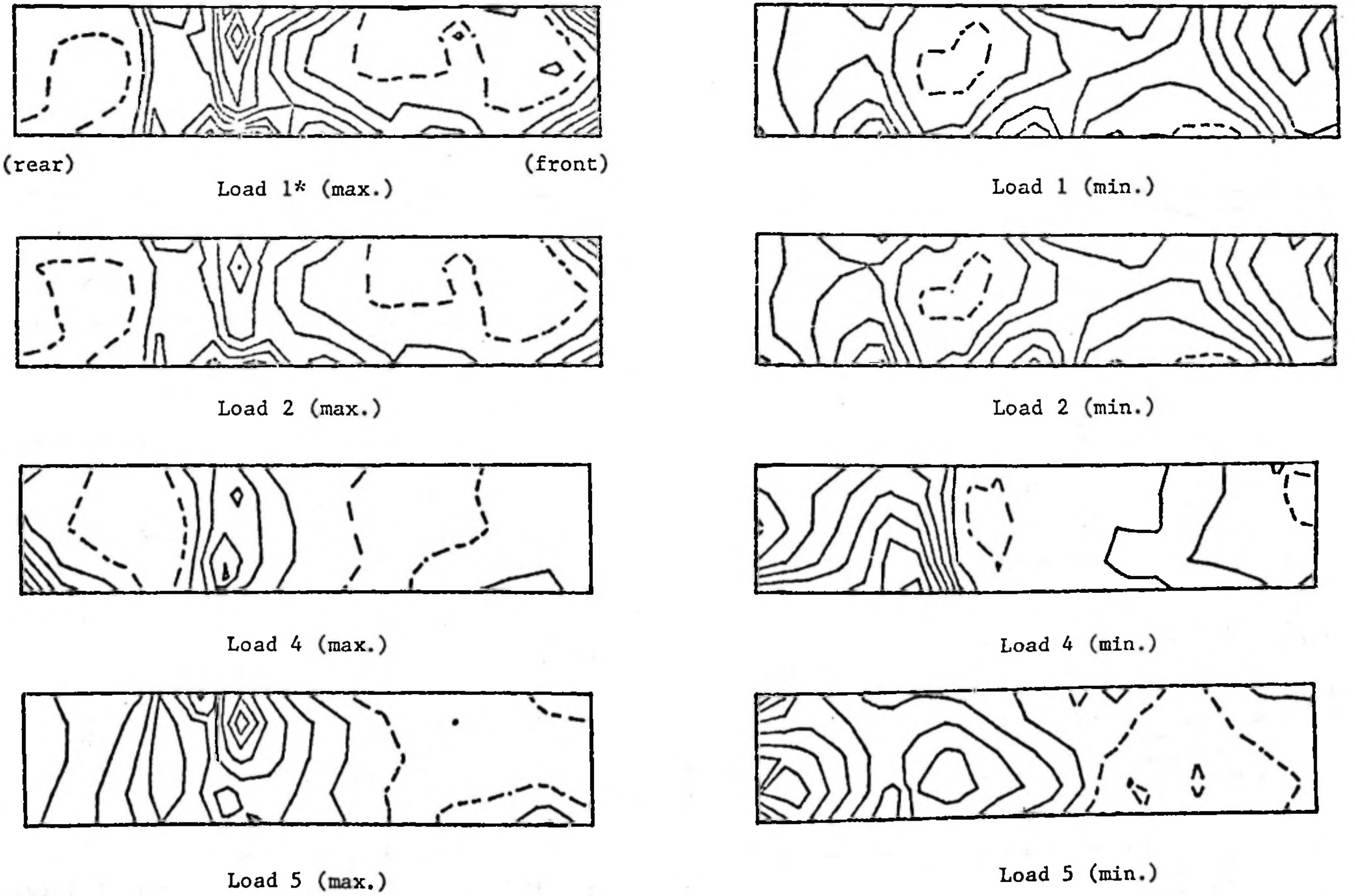
Again, output plots*for the ANSYS program were specified for stress trajectories and displacements of the membrane elements in the floor, walls, and ceiling. Because of the large size of the wall membrane elements, walls containing too few elements had less than minimal information to develop a stress plot. Output results for all elements of the structure are available in the computer output sheets (available upon request at Southwest Research).

The before and after stress results of the analysis (Condition I, Loads 1 and 2 are shown in Figures 30 - 33. Inspection of the plots for the gravity load case shows significantly more areas of higher stress concentrations than T-2A. Although the structural components were modeled identically for the T-2A and T-2B, the latter has very little wall support along the left side of the unit (see Figure 21). Hence, the stress patterns were developed along a different path. This has greatly increased the stresses on the exterior face, or right side, of the unit.

A comparison of maximum stresses between Load Cases 1 and 2, taken from the ANSYS output plot data, shows stress increases of +2 percent tensile, +7 percent compressive in the floor; +5 percent tensile, +5 percent compressive in the ceiling; +12 percent tensile, +3 percent compressive in the right side; and +3 percent tensile, +5 percent compressive in the front side. Since the second load case for T-2A and T-2B was the same except for the directional sense of the lateral load, these results detail the net effect of opening one side of the unit and allowing the other side to accept a greater share of the load.

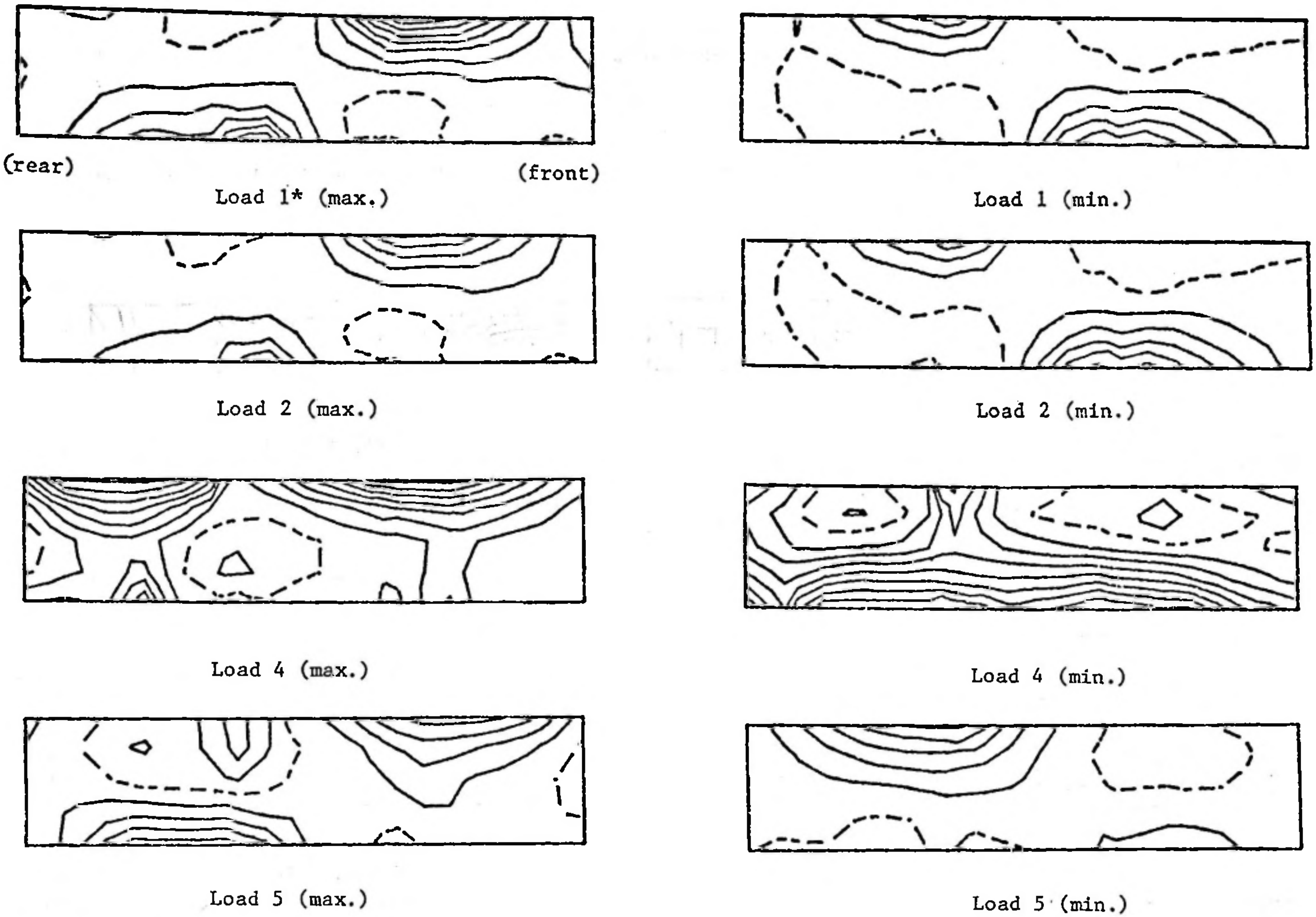
---

*See Appendix C for method of interpretation.



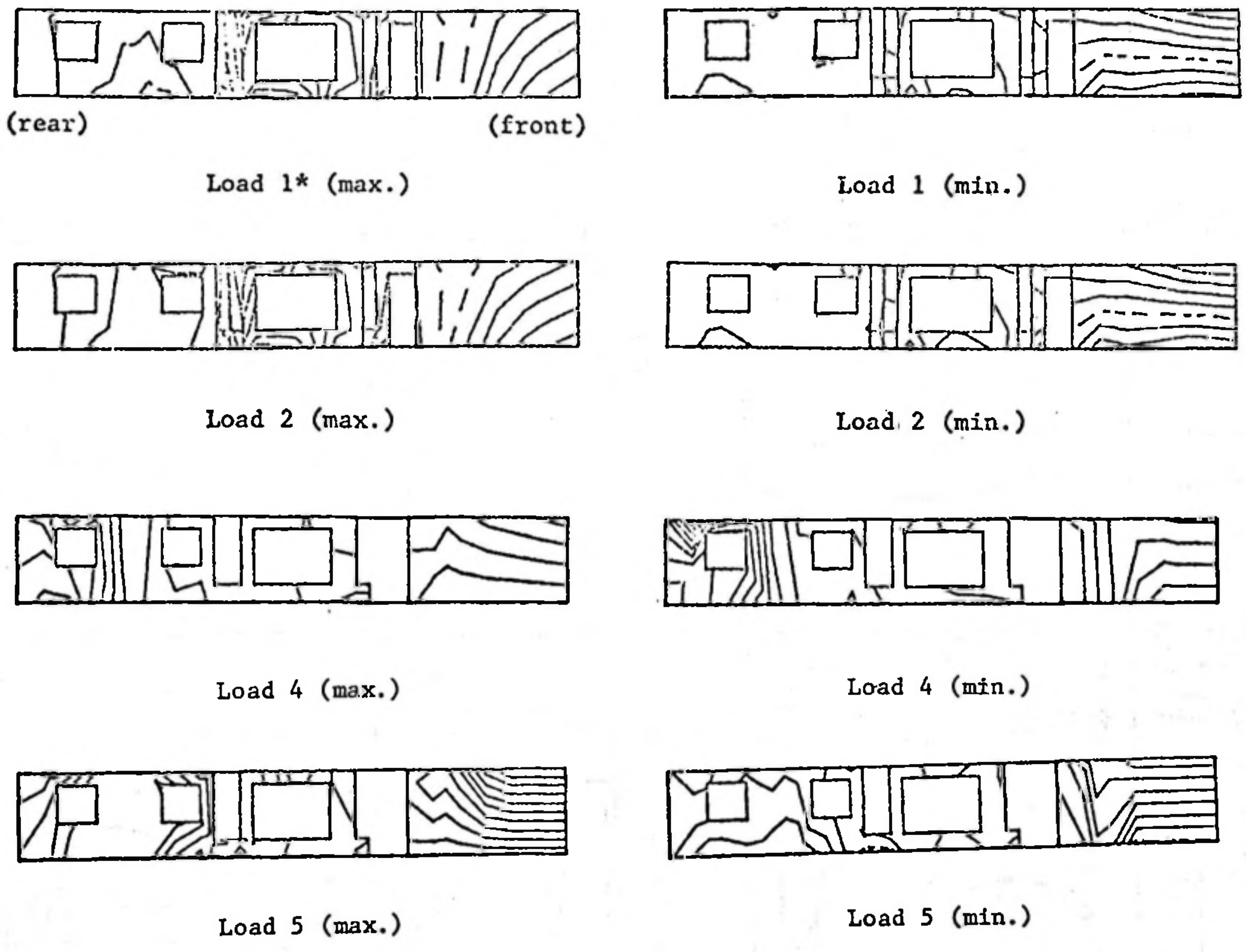
*See Table 3 for load descriptions.

FIGURE 30. COMPARISON OF T-2B STRESS PLOTS - FLOOR



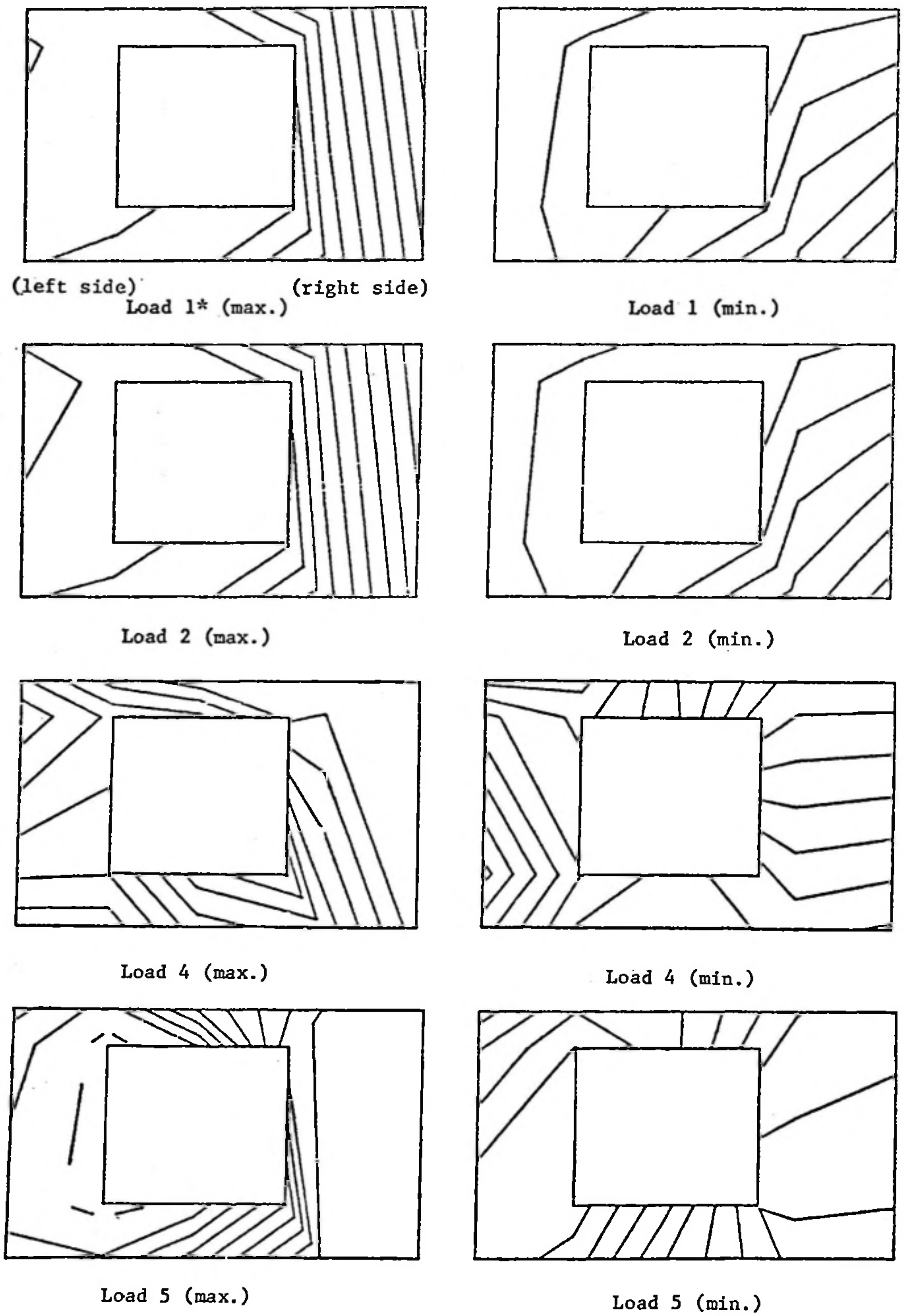
*See Table 3 for load descriptions.

FIGURE 31. COMPARISON OF T-2B STRESS PLOTS - CEILING



*See Table 3 for load descriptions.

FIGURE 32. COMPARISON OF T-2B STRESS PLOTS - RIGHT SIDE



*See Table 3 for load descriptions.

FIGURE 33. COMPARISON OF T-2B STRESS PLOTS - FRONT END

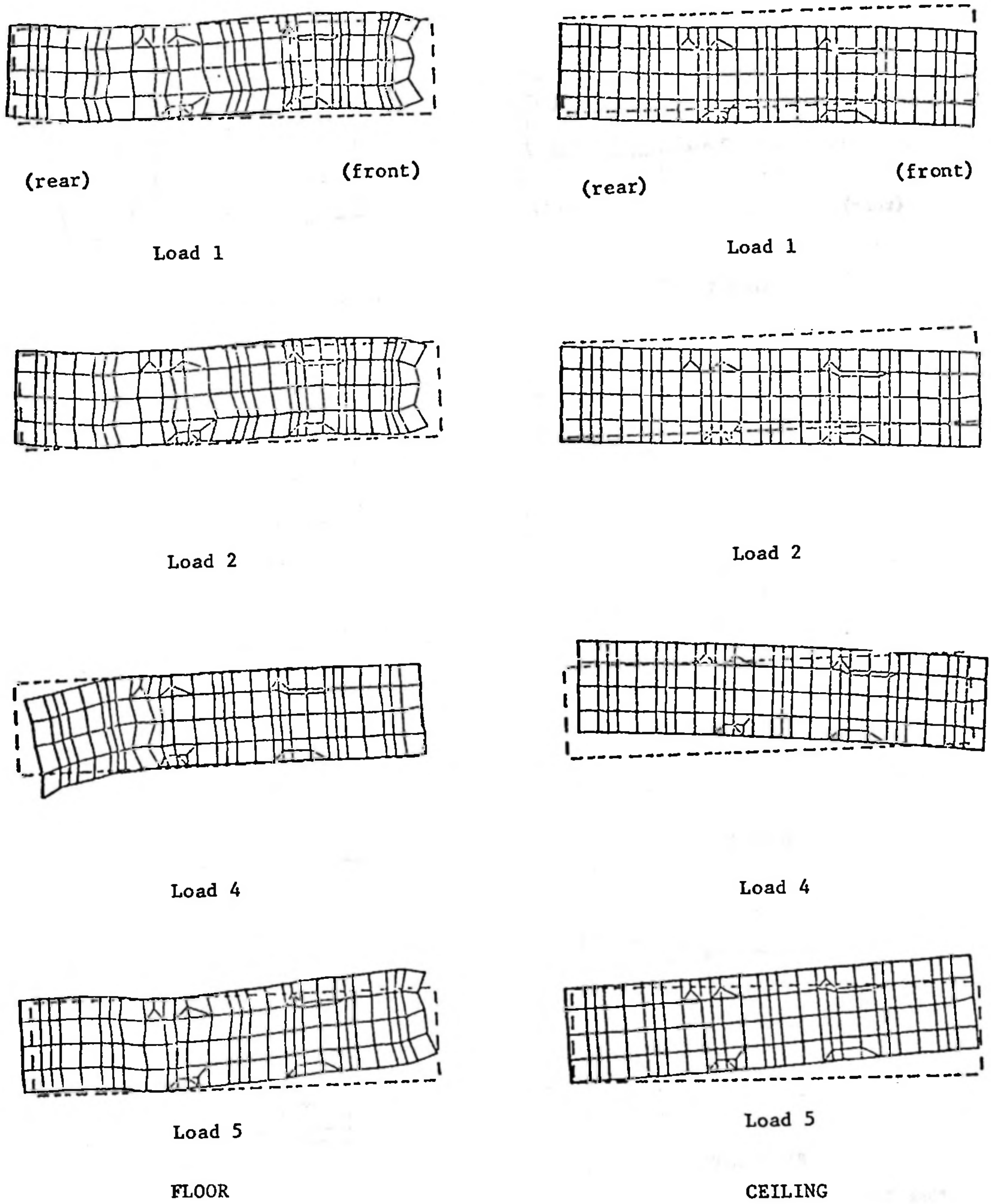
Results of the displacement plots are shown in Figures 34 and 35. A summary of the maximum deflections is compiled in Table 6. These deformation data were derived from the same load cases used to calculate the stress data. However, the elasticity modulus of the wall panels was reduced as detailed in the T-5 mobile home computer model correlation.

Examining the results of these two load cases, it was found that vertical deflections maximize at the left front area of the unit as in the T-2A model. In this model, there is no wall support existing along this area of the unit. Also, a problem area exists along the right sidewall because of a large window opening between the axles and front hitch. (Figure 35)

Through comparison of the results of the load cases, it again appears that the "torsional" deflection of the unit increased due to the lateral loads. As expected, however, the rotation of the ceiling and right sidewall were both in the direction of the applied lateral load.

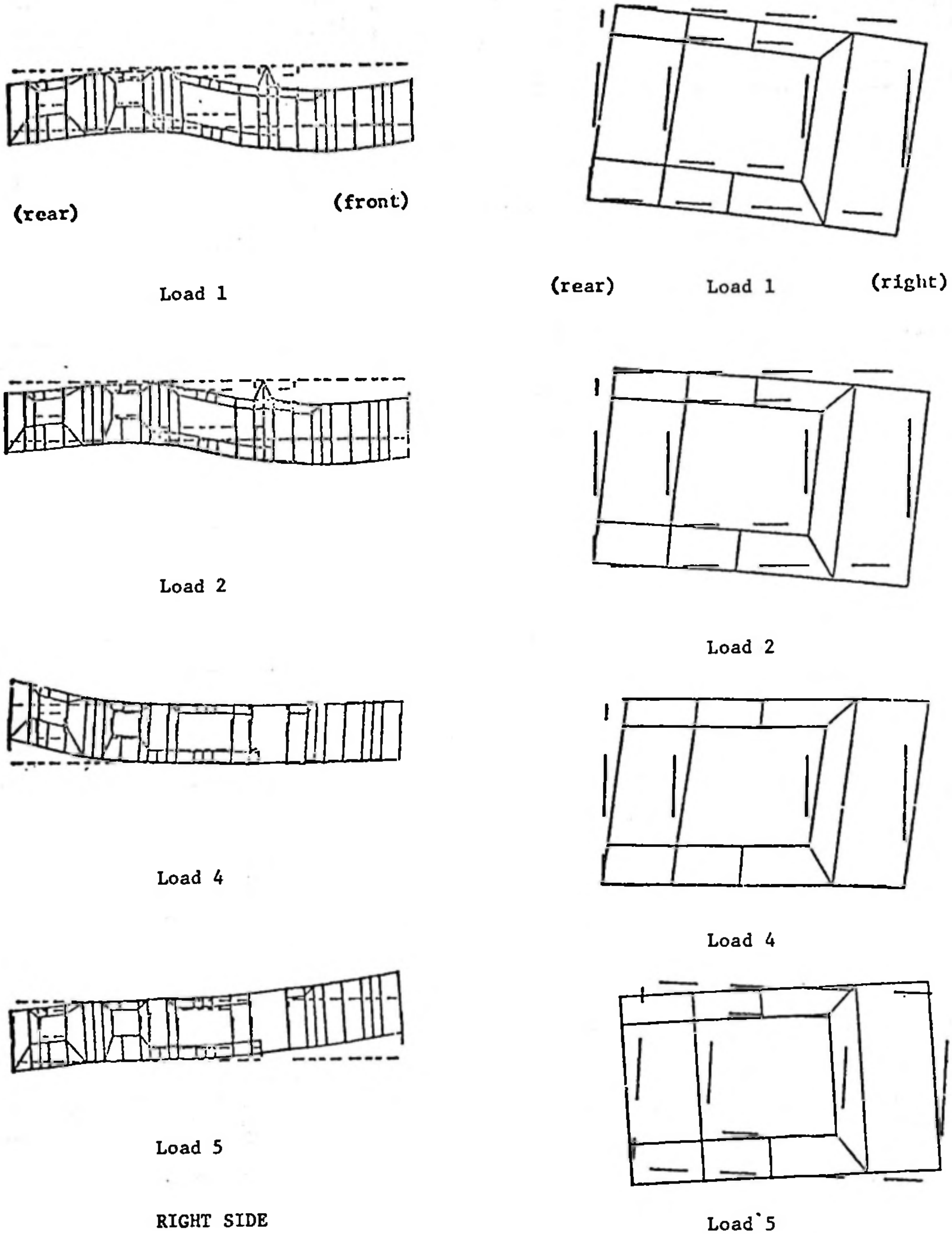
The stress and displacement plots of Load Cases 4 and 5 accompany those of Load Cases 1 and 2 in Figures 30 through 33. The plots for Load Case 4 show the results of a counter-clockwise twist at the rear of the mobile home about the forward axis resulting from the simulated right rear jacking load. This loading condition created stress concentrations in the floor at that corner as indicated by the crowded isostress lines of Figure 30. Over the right side of the axles the floor also experienced high stresses. The displacement plots of Figures 34 and 35 show why these stresses occur. Almost all of the floor displacement occurred rearward of the axles. Other points of high stress for Load Case 4 were along the left side of the ceiling and around windows and doors.

The worst dynamic condition, Load Case 5, is also presented in the figures. Displacement plots show the mobile home to be uplifted to the left in the front and slightly down in the rear. This situation concentrates stresses in the floor over the left side of the axles and at the forward end of the right wall, and especially about the window in the front end wall.



*See Table 3 for load descriptions.

FIGURE 34. COMPARISON OF T-2B DISPLACEMENT PLOTS - FLOOR AND CEILING



*See Table 3 for load descriptions.

FIGURE 35. T-2B DISPLACEMENT PLOTS -- RIGHT SIDE AND FRONT END

TABLE 6

SUMMARY OF T-2B MAXIMUM DISPLACEMENTS

Mobile Home Component	Maximum Deflection (In.)/Node Location†							
	Load Case 1*		Load Case 2		Load Case 4		Load Case 5	
	Lateral**	Vertical**	Lateral	Vertical	Lateral	Vertical	Lateral	Vertical
Floor	0.005/257	-0.600/221	0.004/257	-0.742/221	-0.0196/101	1.31/101	0.0319/257	-2.75/261
Ceiling	-0.256/654	-0.586/609	-0.458/654	-0.742/613	0.396/500	1.305/500	3.354/650	-2.75/654
Left Sidewall	-0.091/409	0.182/400	-0.127/409	-0.167/400	0.389/401	0.385/401	0.389/409	-0.793/400
Right Sidewall	-0.251/395	-0.600/381	-0.452/395	-0742/381	0.396/301	1.306/300	3.354/395	1.996/394
Rear Sidewall	-0.058/702	-0.337/701	-0.071/703	-0.351/701	0.396/702	1.306/701	0.00583/710	-0.793/709
Front Sidewall	-0.256/768	-0.391/752	-0.458/768	-0548/752	-0.118/764	-0.0130/752	3.35/752	-2.75/768

*For load descriptions, see Figure 27 or Table 3.
†For node point locations, see Figure 21.
**For displacement directional sense, see Figure 23.

X. CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the static modeling of the single-wide (T-1) and the double wide (T-2A and B) mobile homes the following tentative conclusions can be drawn:

- A reduced modulus of elasticity was developed for the wall panel elements to simulate more closely the stiffness of the actual mobile home structural system.
- Stress concentrations were most predominant around window and door openings, over the axles and above the front hitch.
- The stress concentrations were not sensitive to the wall thickness designated for the wall panels.
- The "torquing" effect resulting from lateral loads significantly increases the lateral deformations and stresses associated with that type of load.
- The jacking mode develops stress relief in some areas of the unit, and increased stress concentrations in other sections of the unit.
- In the double-wide units, the elimination of an interior wall along the "marriage" joint increases vertical deflections in the unit, and increases stresses along the remaining exterior walls due to the transportation mode.
- The resulting loads and stresses in the unit due to the transportation and setup/takedown modes appear low. This is a static case, however, and the effects of cyclic loading should continually be considered.

It has been shown how mobile home structures are idealized and analyzed by application of the ANSYS program. Although the process of model development (i.e., mesh generation, member size and dimension determinations, and material property characterizations) is not difficult to accomplish, it requires a painstaking, time-consuming effort to generate and punch the required input data. Meticulous care must be exercised in coding the data for ANSYS input, and the computer runs are expensive because of the large size of the problem. (See the appendix for a typical computer run.) The problems might be reduced by developing a special purpose program with large wall panel elements (modules) that typically represent solid panels, panels with window openings, or panels with door openings. The development, however, would be a major undertaking, particularly if the plot capability were included.

The finite element analysis is a static analysis methodology. It is not the intent of the finite element analysis to predict the consumed life of the mobile home unit. It can be used in the "predictive analysis" only as a static checkpoint by analyzing the structure at any point in the degradation cycle. A more complete method of analyzing degradation would be to compare the structure at two different points in the cycle. For a set of given conditions developed in the dynamic analysis, it can be used to locate areas of stress concentration and determine what effect the equivalent static loads caused by the transport or the loads caused by setup and takedown procedures have on the structure. Such an analysis can be of importance in establishing areas of a unit that need stiffening to resist these loads. Remedial changes, however, in the structural configuration require input modifications and a complete rerun of the program to determine how the stresses are redistributed.

As previously mentioned, the volume of calculations and computer printout developed to complete the analysis of each finite element model was too large to include as part of this report. However, all records pertaining to the analysis of each mobile home unit, including the punch card computer decks, are on file at Southwest Research and are available on request.

APPENDIX A

ANSYS COMPUTER PROGRAM DEVELOPMENT

ANSYS COMPUTER PROGRAM DEVELOPMENT

This appendix is included to provide a basic understanding of the ANSYS computer program used to develop the static analysis computer models. This is accomplished in three steps: discussion of the problem-solving technique of the ANSYS program, a brief explanation of how a typical model was developed, and most importantly, an example using a typical computer run with input and output data.

1. ANSYS Analysis Methodology

The ANSYS computer program is a large scale general purpose computer program for the solution of several classes of engineering analysis problems. For the computer model of this report, the static analysis capabilities were utilized.

For the static analysis, the matrix displacement method of analysis based upon finite element idealization was employed to develop a solution. The structure analyzed was approximated as an assembly of discrete structural elements connected at a finite number of points (called nodal points). Knowing the force-displacement relationship for each of these discrete structural elements (the element "stiffness matrix"), the force-displacement relationship for the entire structure was assembled using standard matrix methods.

When sufficient boundary conditions were given for the displacement matrix to guarantee a unique solution, a solution was generated that obtained the nodal point displacements at each node in the structure. From these displacements, forces and stresses within each structural element were calculated.

2. Model Development

The static analysis of each mobile home unit (T-1, T-2A and T-2B) was developed under the same procedures for each finite element model. First, each unit was accurately measured and detailed. With this information, the layout of each unit was drawn to scale.

From the layout of each section of the unit (floor, walls, ceiling, etc.), a finite element mesh was developed for each component. As detailed in Figures A.1 and A.2, each component was idealized as a series of finite or discrete elements. Each element was connected to a set of nodes. Since all nodes were located within a three-dimensional orthogonal coordinate system, the elements, therefore, were properly defined and located within the system.

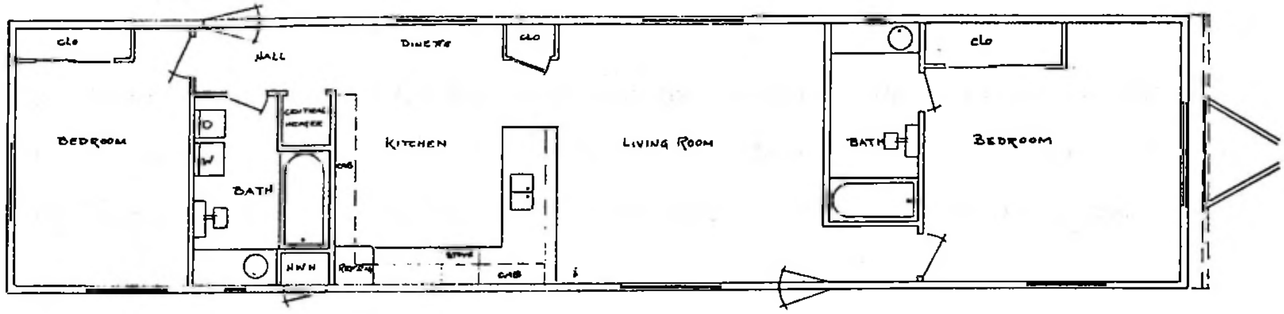
With the elements located, the next step was to define each type of element. For each analysis, all elements were either membrane (or shell) elements for the floor, wall and ceiling panels, elastic beam elements for the floor joists and wall studs, or tapered, unsymmetrical beam elements for the chassis outriggers and roof trusses. During this step in the analysis, it was also important to define the cross-sectional and material properties of each element.

Next, each section of the unit (floor, walls, ceiling, etc) was "pinned", or connected, together by coupling the translational degrees of freedom at the wall stud/floor joist and wall stud/roof truss connect points. This type of joint connection models more closely to the way the unit is constructed.

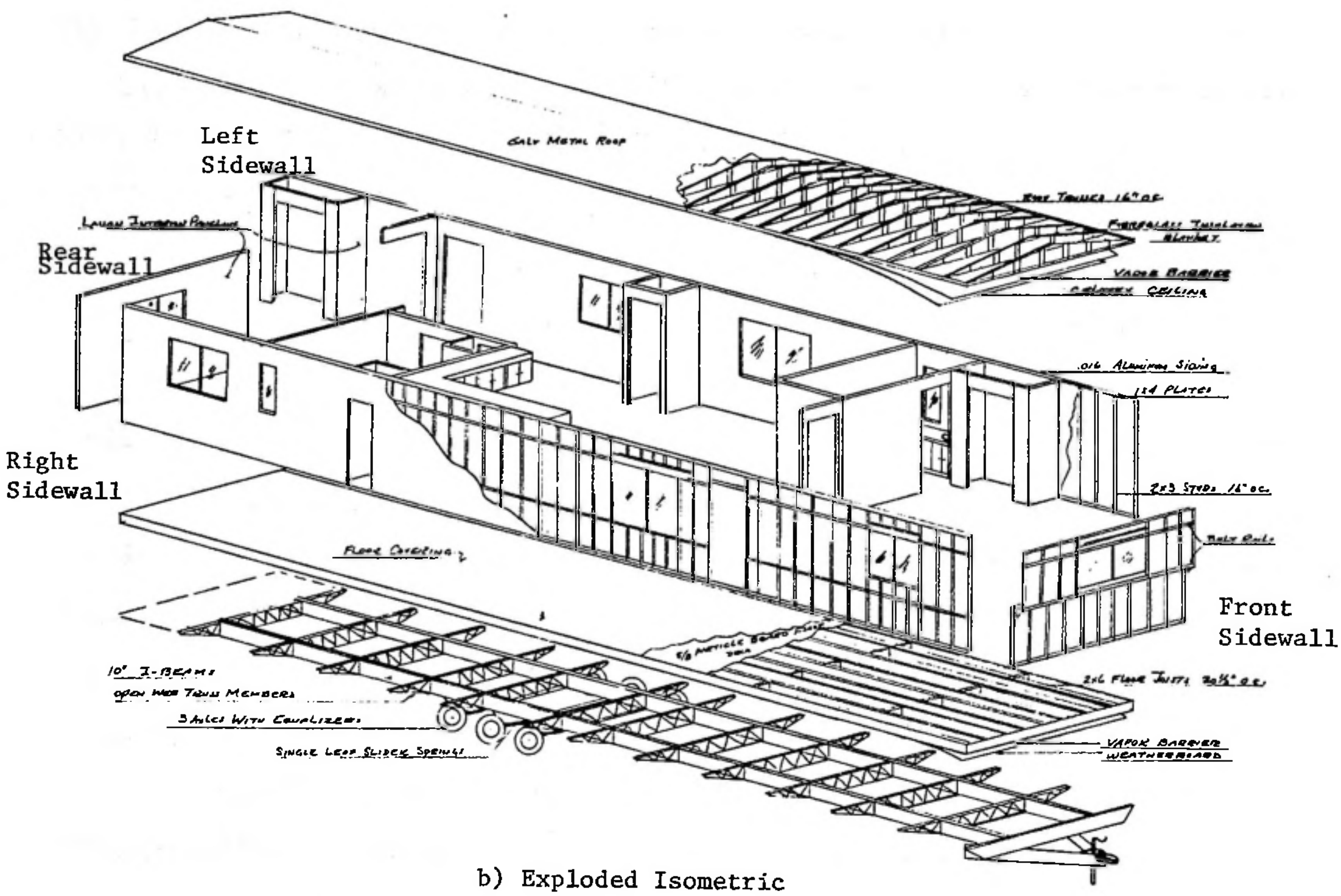
The remainder of the input data required to model each unit was for boundary and loading conditions. For the boundary restrictions, the translational displacement were defined as zero for the nodes at the hitch and at the axle/chassis I-beam connection points.

The basic loading condition for all load cases was the unit's own weight and furnishing loads. The weight of the unit was developed by introducing a 1.0 g vertical acceleration to all elements in the model. Based on the material densities, this was equivalent to a static loading based on the weight of the unit.

Furnishing loads were applied as concentrated loads. The actual weight of each furnishing was applied equally to all nodes on which it rested.

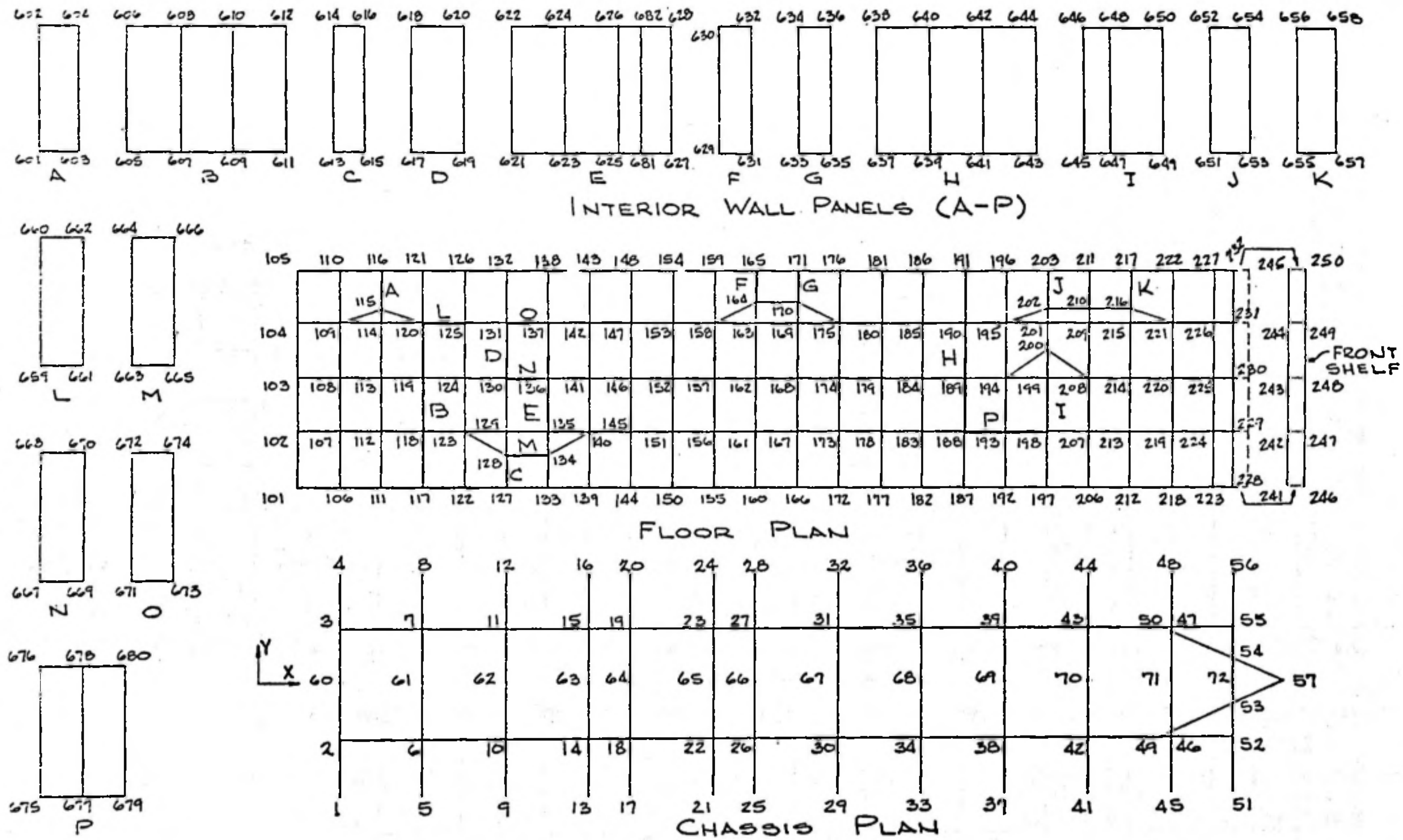


a) Floor Plan



b) Exploded Isometric

FIGURE A.1. T-1 MOBILE HOME LAYOUT



NOTE: Numbers shown indicate nodal point locations.

FIGURE A.2. TYPICAL FINITE ELEMENT COMPUTER MODEL (T-1)

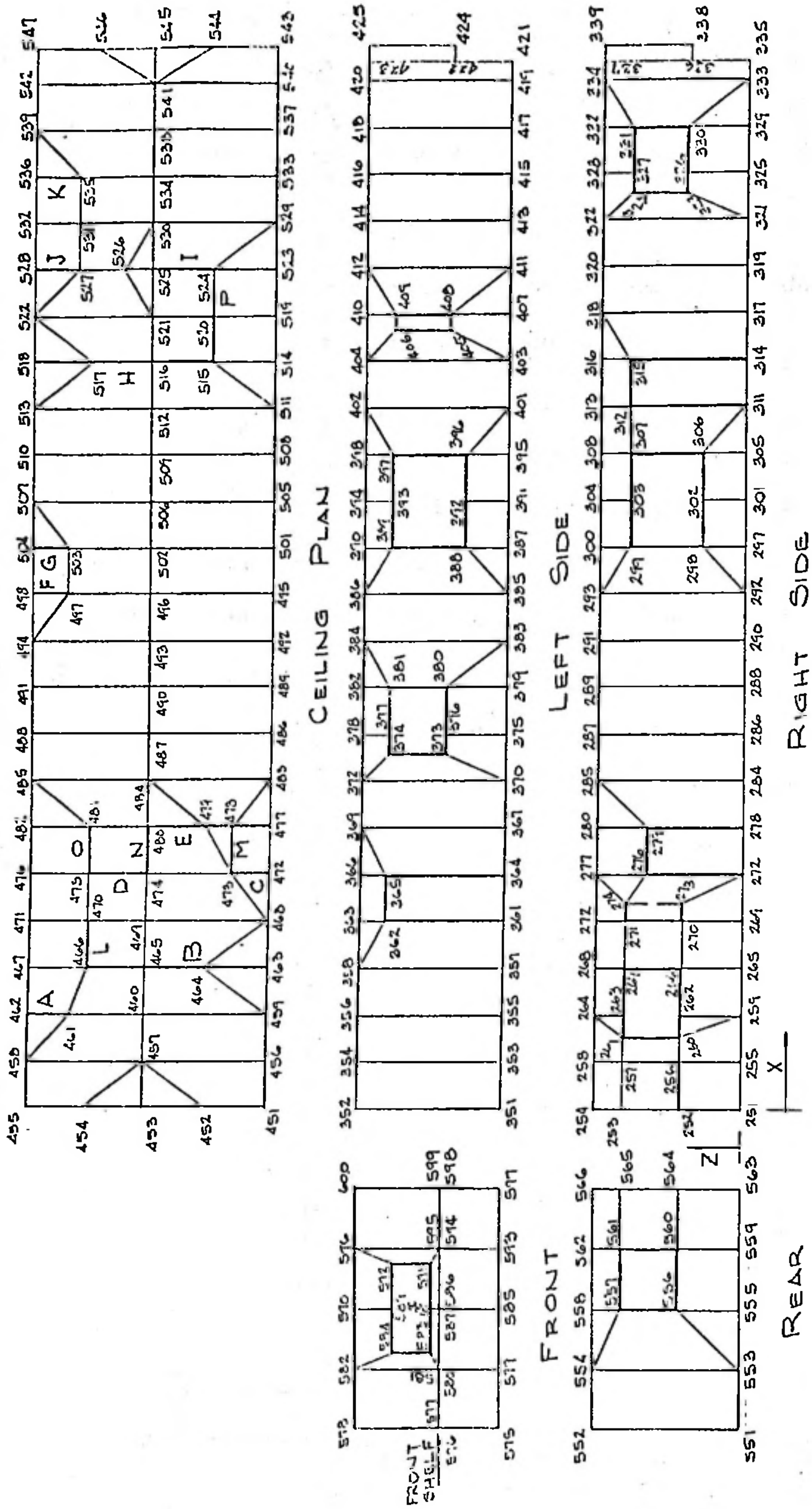


FIGURE A.2 (Cont'd)

Pertaining to the equivalent static loads, this system of concentrated loads was calculated based on the accelerations developed along the unit from the dynamic analysis in Task I, Volume I. Additional concentrated loads, acting vertically and laterally, were applied at the ceiling level of each wall section due to weight of the roof. Other concentrated loads were those caused by accelerations acting vertically and laterally on appliances, bathroom fixtures, and heating and water heater units.

3. Typical Input and Output Computer Data

This section of the appendix contains a typical computer run of the static model developed using the ANSYS analysis technique. Because of its length, however, only partial listings of many sections of the data are presented. All data for this example are taken from the T-1 mobile home model (see Figures A.1 and A.2), Load Case 1. Although the entire analysis is not presented, the segments presented contain elements common to each step of the analysis.

***** ANALYSIS OPTIONS (CARDS C1 AND C2) *****

	VALUE	VARIABLE NAME	COLUMNS					
NUMBER OF LOAD STEPS	3	NSTEPS	1-4					
ANALYSIS TYPE	0	K20	5-7					
COUPLED DEGREES OF FREEDOM KEY	1	KCDF	10					
ELEMENT CONSTANT TABLE . . .	24	KTB	11-12					
BOUNDARY CONDITION KEY. . . .	-0	K17	18					
POST-RUN PROCESS KEY	5	KYPOST	27-28					
REFERENCE TEMPERATURE	70.00	TREF	1-12					
UNIFORM TEMPERATURE	70.00	TUNIF	13-24					
PLOT DEVICE TYPE.	4	KPDV	79-80					
BLOCK SIZES	500	500	1500	500	500	500	0	0
CORE SIZE REQUESTED(OCTAL). .	00247700							

These cards (C1 and C2) defined the analysis options used in the solution of problem. These options included the "type" of analysis (static for this analysis), the number of loading cases, plotting options. a checking option, etc.

FIGURE A.3. ANSYS INPUT DATA, ANALYSIS OPTIONS

```
          ***** ELEMENT TYPES (CARD D) *****

TYPE  STIF       DESCRIPTION                  KEYSUB OPTIONS        KC   INOTPR
                                           1B 1A  1   2B 2A  2

 1     4    ELASTIC BEAM, 3-D     8/05/74  -0  0  0   -0  0  0      0      0
 2    41    QUAD FLAT MEMBR SHELL1/30/73   -0  0  0   -0  0  0      0      0
 3    44    3-D TAPERED BEAM     10/20/72  -0  0  0   -0  0  0      0      0


          ***** TABLE OF ELEMENT REAL CONSTANTS (CARD D2) *****
 NO.

Outriggers
 1    .84000    .36000    .26000    1.3250    1.0000    7.3000    .84000    17.400
       .25000    1.2700    5.0000    0.        0.        1.0000    0.        0.
      5.0000    0.        0.        0.        .55000    1.0000    .48000    5.0000
 2    .84000    .36000    .26000    .55000    1.0000    7.3000    .84000    17.400
       .25000    .48000    5.0000    0.        0.        -1.0000   0.        0.
      -5.0000   0.        0.        0.        1.3250    1.0000    1.2700    5.0000
Lauan Plywood
 7    .15625
Floor Joists
 8    13.700    6.8000    36.200    5.6250    2.4400    0.        0.        19.800
```

Card Set D defines the elements used from the ANSYS element library. In this particular case, the 3-D elastic beam element was used for elements such as wall studs and floor joints. The 3-D quadralateral flat membrane shell element, which has membrane stiffness but no bending stiffness, was used for the particle board floor, plywood walls and metal roof. The 3-D tapered beam was utilized for members contained in the chassis and the roof trusses.

The D2 cards were used to define the element real constants. A new set of constants was defined for each member type (i.e., outriggers, hitch beam, roof truss, wall panel) utilized in the model. In the example above, set numbers 1 and 2 were used for tapered beams, where properties must be defined at each end of the element; set number 7 for a typical membrane element; and set number for the cross-sectional properties of a 3-D elastic beam element. For this particular model, a total of 29 element real constant sets were computed and submitted as part of the ANSYS analysis.

FIGURE A.4. ANSYS INPUT DATA, ELEMENT TYPES AND REAL CONSTANTS

***** ELEMENT DEFINITIONS (CARD E) *****

ELEMENT	NODES				MAT	TYPE	ELEMENT REAL CONSTANTS					
							THK1	THK2	THK3	THK4	THET	
49	258	254	253	257	2	2	.156	-0.	-0.	-0.	0.	
50	257	253	252	256	2	2	.156	-0.	-0.	-0.	0.	
51	256	252	251	255	2	2	.156	-0.	-0.	-0.	0.	
							3-D	BEAM	CONS			
52	1	2	102		1	3	.840	.360	.260	1.33	1.00	7.30
							.840	17.4	.250	1.27	5.00	0.
							0.	1.00	0.	0.	5.00	0.
							0.	0.	.550	1.00	.480	5.00
							AREA	IZ	IY	THKZ	THKY	THET
								IP				
53	106	111			3	1	13.7	6.80	36.2	5.63	2.44	0.
							0.	19.8				
							THK1	THK2	THK3	THK4	THET	
120	266	262	261	265	2	2	.156	-0.	-0.	-0.	0.	
							3-D	BEAM	CONS			
121	5	6	102		1	3	.840	.360	.260	1.33	1.00	7.30
							.840	17.4	.250	1.27	5.00	0.
							0.	1.00	0.	0.	5.00	0.
							0.	0.	.550	1.00	.480	5.00
							AREA	IZ	IY	THKZ	THKY	THET
								IP				
122	117	122			3	1	13.7	6.80	36.2	5.63	2.44	0.
							0.	19.8				

This card set defined the nodes to which each element was connected and referenced the material type (see Figure A.8), element type (see Figure A.4) and the real constants (see Figure A.4) associated with each element type. In this example, elements 51 and 121 represent quadrilateral flat membrane shell elements, elements 52 and 122 represent 3-D tapered beam elements, and elements 53 and 123 are examples of 3-D elastic beam elements. (See Figure A.2 for element locations.)

FIGURE A.5. ANSYS INPUT DATA, ELEMENT DEFINITIONS

***** NODE DEFINITIONS (CARD F) *****

	LOCATION			ROTATION (DEGREES)		
NODE	X	Y	Z	THXY	THYZ	THXZ
1	32.000	-82.000	0.	-0.	-0.	-0.
2	32.000	-41.000	0.	-0.	-0.	-0.
3	32.000	41.000	0.	-0.	-0.	-0.
4	32.000	82.000	0.	-0.	-0.	-0.
5	96.000	-82.000	0.	0.	0.	0.
6	96.000	-41.000	0.	0.	0.	0.
102	0.	-41.000	0.	0.	0.	0.
103	0.	0.	0.	0.	0.	0.
104	0.	41.000	0.	0.	0.	0.
105	0.	82.000	0.	0.	0.	0.
106	32.000	-82.000	0.	0.	0.	0.
111	64.000	-82.000	0.	-0.	-0.	-0.
117	96.000	-82.000	0.	-0.	-0.	-0.
118	96.000	-41.000	0.	0.	0.	0.
119	96.000	0.	0.	0.	0.	0.
120	96.000	41.000	0.	0.	0.	0.
121	96.000	82.000	0.	0.	0.	0.
122	128.00	-82.000	0.	0.	0.	0.
251	0.	-82.000	0.	-0.	-0.	-0.
252	0.	-82.000	41.000	-0.	-0.	-0.
253	0.	-82.000	80.000	-0.	-0.	-0.
254	0.	-82.000	96.000	-0.	-0.	-0.
255	32.000	-82.000	0.	0.	0.	0.
256	32.000	-82.000	41.000	0.	0.	0.
261	64.000	-82.000	0.	-0.	-0.	-0.
262	64.000	-82.000	41.000	-0.	-0.	-0.
263	64.000	-82.000	80.000	-0.	-0.	-0.
264	64.000	-82.000	96.000	-0.	-0.	-0.
265	96.000	-82.000	0.	0.	0.	0.
266	96.000	-82.000	41.000	0.	0.	0.

This card set was used to define the nodal point coordinates and local axis specifications for all the nodal points in the structure. During the development of this model, approximately 650 nodal points were generated to define the model. (These nodes are shown in Figure A.2)

FIGURE A.6. ANSYS INPUT DATA, NODE DEFINITIONS

```
                  95.0  97.0  0.   0.   1.   5          4 2
      -83.  -81.              0.   -1.  0.   5          4 2
      81.0  83.0              0.   -1.  0.   5          4 2
-1.   1.                      -1.  0.   0.   5          4 2
```

(a) Input Listing for Geometry Plots (Card Set G)

```
RANGE =      0.0000  756.0000  -82.0000   82.0000   -1.0000    1.0000    VIEW =     0.00    0.00    1.00
  KTYPE = 5     DIST =     -0.00    KSTART,KSTOP =     1   795    KPDV =   4    IELPT =  2    KSIZE =-0

  CUMULATIVE PLOT NUMBER     4
                                                                            GEOMETRY  ANSYS

RANGE =      0.0000  756.0000  -82.0000   82.0000   95.0000   97.0000    VIEW =     0.00    0.00    1.00
  KTYPE = 5     DIST =     -0.00    KSTART,KSTOP =     1   795    KPDV =   4    IELPT =  2    KSIZE =-0

  CUMULATIVE PLOT NUMBER     5
                                                                            GEOMETRY  ANSYS

RANGE =      0.0000  756.0000  -83.0000  -81.0000    0.0000   96.0000    VIEW =     0.00   -1.00    0.00
  KTYPE = 5     DIST =     -0.00    KSTART,KSTOP =     1   795    KPDV =   4    IELPT =  2    KSIZE =-0

  CUMULATIVE PLOT NUMBER     6
                                                                            GEOMETRY  ANSYS

RANGE =      0.0000  756.0000   81.0000   83.0000    0.0000   96.0000    VIEW =     0.00   -1.00    0.00
  KTYPE = 5     DIST =     -0.00    KSTART,KSTOP =     1   795    KPDV =   4    IELPT =  2    KSIZE =-0

  CUMULATIVE PLOT NUMBER     7
                                                                            GEOMETRY  ANSYS
```

(b) Output Listing for Geometry Plots

This card set defined the geometry plot request. These plots, which can contain expanded plots for local regions and rotated and/or perspective views, were used to develop a clear definition of the model. Due to the complexity of this model, geometry plots were developed in the data check run, serving as an inexpensive method to identify the correct location of all elements in the model.

FIGURE A.7. ANSYS INPUT AND OUTPUT DATA, GEOMETRY PLOTS

```
***** MATERIAL PROPERTIES (CARD H) *****

                 MATERIAL  1
Steel              EX   =      .290000E+08
                   ALPX =      0.
                   NUXY =      .300000
                   DENS =      .283000
                 MATERIAL  2
Lauan              EX   =      .150000E+07
Plywood            NUXY =      .250000
                   ALPX =      0.
                   DENS =      .462000E-01
                 MATERIAL  3
Douglas            EX   =      .192000E+07
Fir                ALPX =      0.
                   NUXY =      .300000
                   DENS =      .208000E-01
                 MATERIAL  4
Particle           EX   =      800000.
Board              NUXY =      .250000
                   ALPX =      0.
                   DENS =      .289000E-01
```

NOTE: Exponential Notation

This card set was used to define the material properties of each element in the model. These properties were assigned to their respective elements with Card Set E, as shown in Figure A.5. (In this listing, EX equals the elastic modulus, ALPX equals the coefficient of thermal expansion, NUXY equals Poisson's ration, and DENS equals the mass density of the element being defined.)

NOTE: The elastic modulus for the Lauan Plywood was 1.5 x 10^6 psi when calculating element stresses, and 5.0 x 10^4 psi when determing deflection data.

FIGURE A.8. ANSYS INPUT DATA, MATERIAL PROPERTIES

***** COUPLED DEG. OF FR. DEFINITIONS (CARD J) *****

SET	D.O.F.	NUMBER	COUPLED NODES			
1	UX	3	101	251	563	
2	UY	3	101	251	563	
3	UZ	3	101	251	563	
4	UX	2	102	559		
5	UY	2	102	559		
6	UZ	2	102	559		
7	UX	3	60	103	555	
8	UY	3	60	103	555	
9	UZ	3	60	103	555	
10	UX	2	104	553		
11	UY	2	104	553		
12	UZ	2	104	553		
13	UX	3	105	351	551	
14	UY	3	105	351	551	
15	UZ	3	105	351	551	
16	UX	3	106	1	255	
17	UY	3	106	1	255	
18	UZ	3	106	1	255	
19	UX	2	111	261		
20	UY	2	111	261		
21	UZ	2	111	261		
22	UX	4	117	265	5	611
23	UY	4	117	265	5	611
24	UZ	4	117	265	5	611
25	UX	2	122	269		
26	UY	2	122	269		
27	UZ	2	122	269		

This card set was used to specify the sets of "coupled" degrees of freedom. As described previously in the text, each section of the model was developed separately. These units (floor, ceiling, interior walls, etc.) were then combined with the specification of this card set. In this example, the translational degrees of freedom (UX, UY, and UZ) were coupled at the wall stud/floor and wall stud/ceiling connect points. This is, however, only a partial listing. The total number of coupled sets for this example was 591.

FIGURE A.9. ANSYS INPUT DATA, COUPLED DEGREES OF FREEDOM DEFINITIONS

LOAD STEP NUMBER = 1

***** LOAD STEP OPTIONS (CARDS L AND M) *****

	VALUE	VARIABLE NAME	COLUMNS	
LOAD STEP KEY	1	KDIS	2-3	
TEMPERATURE KEY	0	KTEMP	4-6	
NUMBER OF ITERATIONS.	1	NITTER	7-9	
STRESS PRINTOUT FREQUENCY . .	1	NPRINT	10-12	
TIME AT END OF LOAD STEP. . .	0.	TIME	13-24	
ITERATION FREQ. OF PLOT DATA.	1	KPLOT(1)	50-51	(CARD M)
DISPL. PRINTOUT FREQUENCY . .	1	NDPRNT	71-72	(CARD M)
COORDINATE ACCELERATIONS	-0.0000	-0.0000	1.0000	

Card Sets L and M were used to define the type of load step (or loading condition) and boundary conditions that were used for each load case. One set of L and M cards was included for each load case submitted with an analysis.

***** SPECIFIED DISPLACEMENTS (CARD N) *****

NO.	NODE	DIRECTION	VALUE
1	14	UX	0.
2	14	UY	0.
3	14	UZ	0.
4	15	UX	0.
5	15	UY	0.
6	15	UZ	0.
7	18	UX	0.
8	18	UY	0.
9	18	UZ	0.
10	19	UX	0.
11	19	UY	0.
12	19	UZ	0.
13	22	UX	0.
14	22	UY	0.
15	22	UZ	0.
16	23	UX	0.
17	23	UY	0.
18	23	UZ	0.
19	57	UX	0.
20	57	UY	0.
21	57	UZ	0.

Card Set N defined the displacement boundary conditions to be included in the analysis. For this unit, these boundary conditions were used to simulate the restraints on the unit at the hitch and at the axles. Zero displacements were defined to restrict the translation of these points (UX, UY, UZ) with respect to the global coordinate system. Rotational restraints were not provided at these nodal locations.

FIGURE A.10. ANSYS INPUT DATA, LOAD STEP OPTIONS AND SPECIFIED DISPLACEMENTS

***** SPECIFIED FORCES (CARD O) *****

NO.	NODE	DIRECTION	VALUE
1	101	FZ	-14.0000
2	102	FZ	-14.0000
3	103	FZ	-14.0000
4	106	FZ	-14.0000
5	107	FZ	-14.0000
6	108	FZ	-14.0000
7	111	FZ	-14.0000
8	112	FZ	-14.0000
9	113	FZ	-14.0000
10	117	FZ	-17.0000
11	118	FZ	-42.0000
12	119	FZ	-25.0000
13	122	FZ	-17.0000
14	123	FZ	-42.0000
15	124	FZ	-25.0000
16	127	FZ	-37.5000
17	128	FZ	-74.5000
18	129	FZ	-37.0000
19	130	FZ	-95.0000
20	131	FZ	-75.0000
21	133	FZ	-107.500
22	134	FZ	-57.5000
23	135	FZ	-90.0000
24	136	FZ	-95.0000
25	137	FZ	-75.0000
26	139	FZ	-70.0000
27	140	FZ	-70.0000
28	144	FZ	-45.0000
29	145	FZ	-45.0000
30	150	FZ	-75.0000
31	151	FZ	-75.0000
32	152	FZ	-30.0000

Card Set O was used to specify force boundary conditions. Forces were specified only at nodal points. The system of forces for this example was used to simulate loads due to the furnishings contained in the unit. (In subsequent computer runs, where equivalent static loads were included, this data was input into the model under this card set, being simulated as forces acting externally on the unit).

FIGURE A.11. ANSYS INPUT DATA, SPECIFIED FORCES

```
                    **********  ANSYS INPUT DATA LISTING  **********

         6     12     18     24     30     36     42     48     54     60     66     72     78
         V      V      V      V      V      V      V      V      V      V      V      V      V
        -1
              00.     0.     1.           11                              1   4
                            -5.     5.
              10.     0.     1.           11                              1   4
                            91.   101.
              10.    -1.     0.           11                              1   4
               -87.   -77.
              10.    -1.     0.           11                              1   4
               77.    87.
              1-1.    0.     0.           11                              1   4
  -5.     5.
              1-1.    0.     0.           11                              1   4
 715.   737.
```

See Figure A.15

This listing contains a sample set of input data contained for the R Card Set. Due to the post-processing routine selected for this problem (see Figure A.3, variable name: KYPOST), this card set was used to develop stress contours from the output of the analysis. For this particular post-processing subroutine, only the results for the shell elements (floor, wall and ceiling panels) were able to be plotted. (Each contour line connects points within the specified geometric profile which have equal values for the quantity being plotted).

In addition to the stress plots, this subroutine was also capable of plotting the distorted geometry (or displacements) of the model for specified geometric profiles.

FIGURE A.12. ANSYS INPUT DATA, POST-PROCESSING ROUTINE

***** DISPLACEMENT SOLUTION ***** TIME = 0. LOAD STEP= 1 ITERATION= 1 CUM. ITER.= 1

NODE	UX	UY	UZ	ROTX	ROTY	ROTZ
1	.392891E-02	-.958122E-02	-.337666	-.147148E-02	-.138054E-02	.793686E-04
2	.109267E-02	-.988205E-02	-.396381	-.134697E-02	-.138368E-02	.487555E-04
3	-.342373E-03	-.958597E-02	-.365215	.472869E-05	-.998442E-03	-.104891E-04
4	-.217598E-02	-.942682E-02	-.365116	-.264170E-05	-.100693E-02	.722783E-04
5	.400587E-02	-.738900E-02	-.302146	.346758E-04	-.170918E-02	.132428E-03
6	-.158840E-03	-.709959E-02	-.301505	-.160905E-04	-.171868E-02	.397689E-04
102	.114847E-02	-.107531E-01	-.357782	-.134168E-03	.144117E-02	.369735E-04
103	-.368159E-03	-.101524E-01	-.362529	-.945117E-04	.351823E-03	.169635E-04
104	-.450160E-03	-.100911E-01	-.365462	-.545671E-04	.292639E-03	.112649E-04
105	-.202642E-02	-.101201E-01	-.366966	-.252140E-04	-.370320E-04	.341461E-04
106	.392891E-02	-.958122E-02	-.337666	-.123062E-03	-.508828E-03	.305451E-04
111	.409986E-02	-.873911E-02	-.320483	-.829423E-04	-.557176E-03	.267217E-04
117	.400587E-02	-.738900E-02	-.302146	-.428223E-04	-.592472E-03	.680880E-04
118	-.158840E-03	-.709959E-02	-.301505	-.569902E-04	-.335066E-02	.601070E-04
119	-.964738E-03	-.692935E-02	-.300070	-.145832E-03	-.189619E-02	.608327E-04
120	-.851157E-03	-.662517E-02	-.299026	-.194104E-03	.537892E-04	.606345E-04
121	-.304939E-02	-.606862E-02	-.361093	-.175664E-03	-.264244E-04	.741121E-04
122	.363650E-02	-.451153E-02	-.282148	-.270240E-05	-.666827E-03	.972619E-04
251	.382916E-02	-.110209E-01	-.351575	-.106629E-03	-.365494E-03	0.
252	-.116901E-01	-.683607E-02	-.351573	-.929481E-04	-.368225E-03	0.
253	-.259560E-01	-.349827E-02	-.351586	-.838711E-04	-.377356E-03	0.
254	-.321055E-01	-.213910E-02	-.351597	-.854860E-04	-.387841E-03	0.
255	.392891E-02	-.958122E-02	-.337666	-.112053E-04	-.415354E-03	0.
256	-.121617E-01	-.912180E-02	-.337460	-.112053E-04	-.346653E-03	0.
261	.409986E-02	-.873911E-02	-.320483	.269135E-04	-.365927E-03	-.736041E-04
262	-.130520E-01	-.996513E-02	-.320625	.358817E-04	-.523164E-03	-.736041E-04
263	-.235334E-01	-.130490E-01	-.321715	.636214E-04	-.539128E-03	-.122681E-03
264	-.317232E-01	-.140524E-01	-.321730	.622557E-04	-.498233E-03	-.122681E-03
265	.400587E-02	-.738900E-02	-.302146	.125557E-03	-.443185E-03	-.844613E-04
266	-.124339E-01	-.124143E-01	-.301418	.116589E-03	-.316542E-03	-.844613E-04

Note: Exponential Notation

This listing contains part of the displacement solution, providing translational and rotational displacements for each nodal point in the model. (The nodal points listed can be located on Figure A.2.). UX and ROTX are, respectively, the displacement in the X direction and rotation (in radians) about the X axis. UY/ROTY and UZ/ROTZ are related to the respective axis in a similar manner.

FIGURE A.13. OUTPUT DATA, DISPLACEMENT SOLUTION

```
***** ELEMENT STRESSES *****  TIME =   0.           LOAD STEP=   1   ITERATION=  1   CUM. ITER.=   1

LINE ELEMENT STRESSES ASSUME WEIGHT IS CONCENTRATED AT NODAL POINTS
REACTION FORCES AND ELEMENT FORCES ASSUME DISTRIBUTED WEIGHTS

MEMB. SHELL   51  NODES=  256  252  251  255  MATERIAL= 2  STRESS INT.=     63.  SIGEFF=     54.
 AREA=1312.00000  XC= 16.00  YC=-82.00  ZC= 20.50 T=  70. XY STR=    -10.      1.     31.
MAX-MIN STR=     27.    -36.      31. A= 40.1

3-D TAPERED BEAM    52   NODES    1    2  MAT=  1   TEMP=   70.   TTOPZ=  70.0   TBOTY=  70.0
 END      DIRECT    SYBOT     SYTOP     SZBOT     SZTOP    SYB-ZB    SYB-ZT    SYT-ZB    SYT-ZT
  1         118.     394.     -158.      118.      118.     394.      394.     -158.     -158.
  2         117.    -175.      410.       61.      138.    -232.     -154.      353.      431.

3-D BEAM    53   NODES  106  111   MAT   3   TEMP=   70.   TTOPZ,TBOTY=  70.0  70.0   DIR1,DIR2=    10.    10.
BZ1=   -10.  BY1=    -1.  MAX1=    22.  MIN1=    -1.    BZ2=    -2.  BY2=     1.  MAX2=    13.  MIN2=     7.

MEMB. SHELL  120  NODES=  266  262  261  265  MATERIAL= 2  STRESS INT.=    212.  SIGEFF=    185.
 AREA=1312.00000  XC= 80.00  YC=-82.00  ZC= 20.50 T=  70. XY STR=     16.     15.    106.
MAX-MIN STR=    122.    -91.     106. A= 45.2

3-D TAPERED BEAM   121   NODES    5    6  MAT=  1   TEMP=   70.   TTOPZ=  70.0   TBOTY=  70.0
 END      DIRECT    SYBOT     SYTOP     SZBOT     SZTOP    SYB-ZB    SYB-ZT    SYT-ZB    SYT-ZT
  1          79.     263.     -105.       79.       79.     263.      263.     -105.     -105.
  2          78.     193.      -37.      -93.      142.      22.      258.     -208.       27.

3-D BEAM   122   NODES  117  122   MAT   3   TEMP=   70.   TTOPZ,TBOTY=  70.0  70.0   DIR1,DIR2=   -22.   -22.
BZ1=    -6.  BY1=     5.  MAX1=   -11.  MIN1=   -33.    BZ2=   -15.  BY2=    -1.  MAX2=    -6.  MIN2=   -39.
```

This listing contains sample output stress data. As specified in the input (Card Set L, M, Figure A.9), a complete listing of stress information was requested for every element in the system. The sample listing above contains two examples of each type of element input into the model: the 3-D beam, the membrane shell, and the 3-D tapered beam. These results refer back to the elements defined on Figure A.4 and shown in Figure A.1. A complete explanation of terms for this data is contained in the ANSYS User's Manual.

NOTE: Although it is not listed, the output also includes a list of the forces and moments acting on each node for each member in the model.

FIGURE A.14. ANSYS OUTPUT DATA, ELEMENT STRESSES

```
**** SURFACE STRESS PLOT OF PLATES AND SHELLS (POST5) ****

ILIST =          KNEW =     0    VIEW =     0.0000    0.0000    1.0000
PLOT KEYS = -0-0-0 1 1-0-0-0-0-0-0-0    IEMIN =     1    IEMAX =    808    NLIST =   -0
KZONE =  1     KPDV =     4    KLINE = -0    KTITLE = -0

REGION PLOTTED =      -0.0000   -0.0000      -0.0000   -0.0000      -5.0000    5.0000
XSIZE =     10.0000     YSIZE =     10.0000

LOAD STEP =   1     ITERATION =   1     TIME =     0.00000    NNODES =   129    NNELS =   106

MAX. NO. OF ELEMENTS ALLOWED =  2051    QUANTITIES STORED PER ELEMENT =    11


 CUMULATIVE PLOT NUMBER     1
SANDPOINTE-T1                                                          MAX STRESS(MIDDLE)    ANSYS

       MAX STRESS(MIDDLE)

 MAX =      77.7140      X

 MIN =     -19.6822      0

 ISOSTRESS LINES      -10.000        0.           10.000        20.000        30.000
                       40.000       50.000        60.000        70.000

 CUMULATIVE PLOT NUMBER     2
SANDPOINTE-T1                                                          MIN STRESS(MIDDLE)    ANSYS

       MIN STRESS(MIDDLE)

 MAX =      9.43912      X

 MIN =     -96.9120      0

 ISOSTRESS LINES      -90.000       -75.000       -60.000       -45.000       -30.000
                      -15.000       .15348E-11
```

This output information describes, in summary, the output data displayed in detail on the stress contour plots which were defined in Card Set R, Figure A.12. This particular set of data was developed for the floor of the unit. The more important details included with this information are the confirmation of the region plotted, the direction from which the region is viewed, the stress boundaries for the region, and the values for the contour lines.

FIGURE A.15. ANSYS OUTPUT DATA, SURFACE STRESS PLOTS

APPENDIX B

INTERPRETATION OF NODE FORCE OUTPUT FROM ANSYS FINITE ELEMENT COMPUTER PROGRAM

INTERPRETATION OF NODE FORCE OUTPUT FROM ANSYS FINITE ELEMENT COMPUTER PROGRAM

This appendix is included to provide an example and an explanation of the application of the nodal forces calculated by the ANSYS finite element program. A longitudinal I-beam in the chassis of T-1 is selected to demonstrate how these data can be used to examine the total stresses on a single member of the finite element model.

The model used to simulate the structure represents each structural member as a combination of elements connected at nodes. The I-beam of interest is represented by the elements and nodes below.

```
   55    124    200  272  300  348 376    439   495   562    628 629 688
2     6     10     14 18     22 26    30    34    38     42    49 46    52
Rear                                                                Front
```

A partial listing of a typical run of the ANSYS program is presented in Figure B.1. (See also Figure A.14). This section of output, entitled "Element Stresses," details the stress information as calculated by the finite element program for each element of the structure. The nodal forces listed are the forces in each of the three directions and the moments about each of the three axes transmitted to the node by the element. In order to investigate the elemental forces and moments, the signs of the nodal forces and moments are reversed. Tabulated here are elemental values for a pair of adjacent elements that make up the longitudinal I-beam.

Element	Node	F_x(lbs)	F_y(lbs)	F_z(lbs)*	M_x(in-lbs)	M_y(in-lbs)	M_z(in-lbs)
376	26	2356.21	30.0196	1658.17	184.140	-96425.1	928.002
	30	-2356.21	-30.0196	-1610.18	-184.140	8162.1	993.251
439	30	-7152.63	37.3235	1543.84	227.651	9989.48	1203.79
	34	7152.63	-37.3235	-1495.84	-227.651	-1072.59	1184.85

TABLE B.1. COMPUTER CALCULATED STRESSES FOR ELEMENTS 376 and 439 (Compiled from Figure B.1)

*Errors due to roundoff.

```
***** ELEMENT STRESSES *****  TIME =    0.                LOAD STEP=   1   ITERATION=  1   CUM. ITER.=   1

LINE ELEMENT STRESSES ASSUME WEIGHT IS CONCENTRATED AT NODAL POINTS
REACTION FORCES AND ELEMENT FORCES ASSUME DISTRIBUTED WEIGHTS

3-D TAPERED BEAM  376   NODES    26    30  MAT=  1    TEMP=    70.   TTOPZ=  70.0   TBOTY=  70.0
 END      DIRECT     SYBOT     SYTOP      SZBOT      SZTOP     SYB-ZB    SYB-ZT    SYT-ZB     SYT-ZT
  1        -889.     10019.   -11797.     -2935.      1157.     7972.     12065.   -13843.     -9751.
  2        -889.     -3454.     1681.      1301.     -3079.    -1269.     -5649.     3871.      -509.
FORCES ON NODE    26  -.235621E+04  -.300196E+02  -.165817E+04  -.184140E+03   .964251E+05  -.928002E+03
FORCES ON NODE    30   .235621E+04   .300196E+02   .161018E+04   .184140E+03   .816210E+04  -.993251E+03

3-D TAPERED BEAM  439   NODES    30    34  MAT=  1    TEMP=    70.   TTOPZ=  70.0   TBOTY=  70.0
 END      DIRECT     SYBOT     SYTOP      SZBOT      SZTOP     SYB-ZB    SYB-ZT    SYT-ZB     SYT-ZT

  1        2699.      6020.     -622.        45.      5353.     3366.      8675.    -3277.      2032.
  2        2699.     -6514.    11913.      5312.        87.    -3902.     -9127.    14525.      9300.
FORCES ON NODE    30   .715263E+04  -.373225E+02  -.154384E+04  -.227651E+03  -.998448E+04  -.120379E+04
FORCES ON NODE    34  -.715263E+04   .373225E+02   .149584E+04   .227651E+03   .107259E+06  -.118485E+04
```

FIGURE B.1. ANSYS OUTPUT DATA, ELEMENT STRESSES

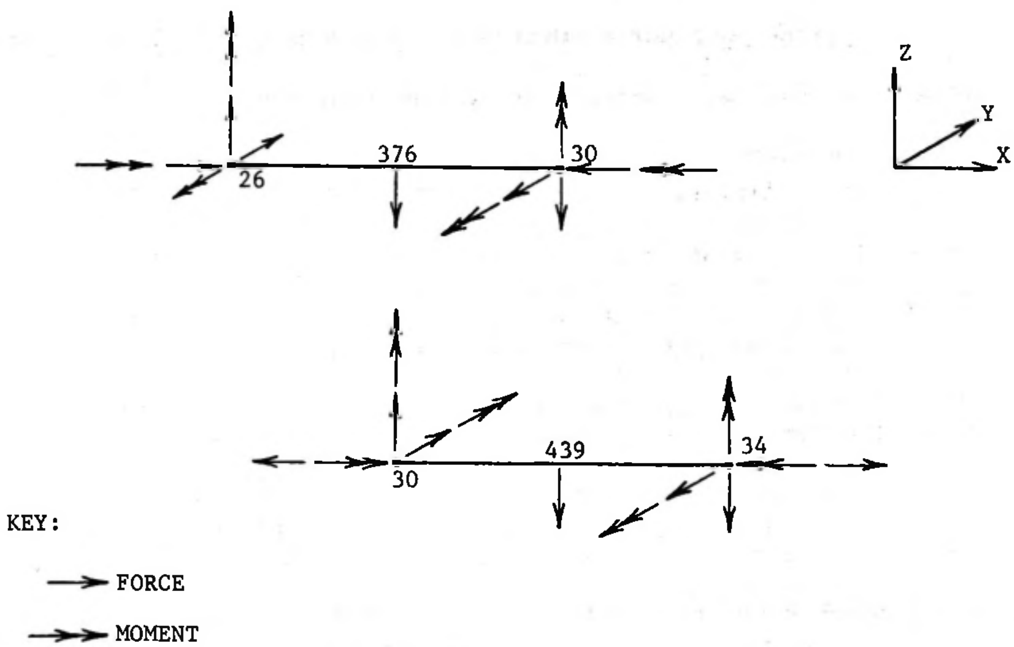


FIGURE B.2. FREE BODY DIAGRAMS OF ELEMENTS
376 AND 439

The freebody diagrams, Figure B.2, of these elements, 376 and 439, show the above stresses applied to the elements. Also included in the diagrams are the weight forces (48 lbs) of each element acting at their centroids in the negative (-)z directions. Both elements are 64-in. long.

A. STATIC MEMBERS

To prove that the forces tabulated are all those exerted on the element, the sums of the forces in each direction and the sum of the moments about each axis are taken for each element and for the entire I-beam. If these quantities are zero, the member is static, thereby, proving the point.

1. Stresses on a Single Element

First consider element 376. The sums of its forces and moments approach 0 as follows. Moments are taken about node 30 and include the effect of the weight.

$$\Sigma F_x = 2356.21 - 2356.21 = 0$$

$$\Sigma F_y = 30.0196 - 30.0196 = 0$$

$$\Sigma F_z = 1658.17 - 1610.18 - 48.0 = -0.01$$

$$\Sigma M_x = 184.140 - 184.140 = 0$$

$$\Sigma M_y = \Sigma M_{yi} + \Sigma L_i F_{zi} + \ell(wt)$$

$$= [-96425.1 - 8162.1] + [64\ (1658.17) + 32\ (-48)] = -0.32$$

$$\Sigma M_z = \Sigma M_{zi} + \Sigma L_i F_{yi}$$

$$= [928.002 + 993.251] + [-64\ (30.0196)] = -\ 0.0014$$

Some round-off error is present and accounts for the - 0.0014 and - 0.32 values.

2. Stresses on a Pair of Adjacent Elements

Programming the same activity with the adjacent elements 376 and 439 produces the same results. Here moments are taken about node 34 Again some round-off error is apparent.

$$\Sigma F_x = 2356.21 - 2356.21 - 7152.63 + 7152.63 = 0$$

$$\Sigma F_y = 30.0196 - 30.0196 + 37.3235 - 37.3235 = 0$$

$$\Sigma F_z = 1658.17 - 1610.18 + 1543.84 - 1495.84 - 2\ (48) = -0.01$$

$$\Sigma M_x = 184.140 - 184.140 + 227.651 - 227.651 = 0$$

$$\Sigma M_y = \Sigma M_{yi} + \Sigma L_i F_{zi} + \Sigma \ell_i\ (wt)$$

$$= [-96425.1 - 8162.1 + 9989.48 - 107259.] + [128\ (1658.17)$$

$$+ 64\ (-1610.18 + 1543.84)] + [96\ (-48) + 32\ (-48)] = -0.72$$

$$\Sigma M_z = \Sigma M_{zi} + \Sigma L_i F_{yi}$$

$$= [928.002 + 993.251 + 1203.79 + 1184.85] - [128\ (30.0196)$$

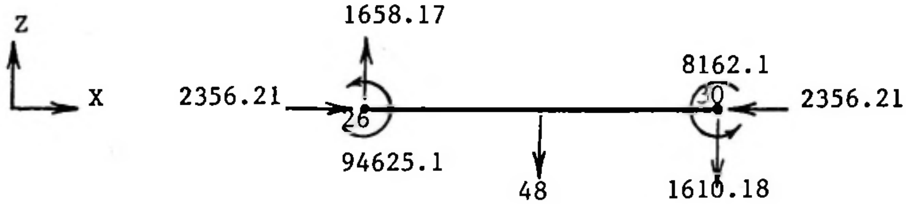
$$+ 64\ (-30.0196 + 37.3235)] = -0.065$$

3. Stresses on Entire I-Beam

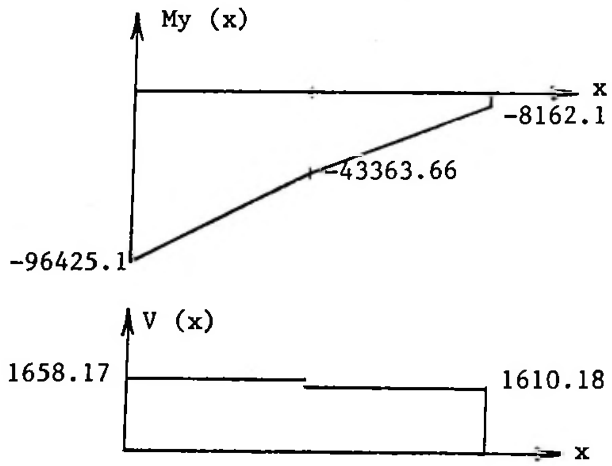
Similarly, the above quantities can be calculated for all the elements which make up the I-beam. Table B.2 lists and sums the elemental forces and moments as calculated by a typical ANSYS finite element program. The total force in the z direction is equal to the opposing weight force of the beam. The sums of the total moments about the y- and z- axes take into account moment inducing eccentric forces in the Z and Y directions, respectively. Due to round-off errors magnified by the number of terms and length of the beam neither moment sum (29.997 or -0.0214) vanishes completely.

B. SHEAR AND MOMENT DIAGRAMS

These data produced by the ANSYS Finite Element Computer Program can also be used to calculate stresses throughout the beam or in any particular element. To demonstrate this, again consider element 376 of the longitudinal I-beam and its stresses in Table B.1. The stresses on the element in the X-Z plane are diagrammed in the freebody diagram in Figure B.3a. From these values the shear and moment diagrams in Figure B.3b are derived.



a.) X-Z Plane Freebody Diagram, Element 376



b.) Shear and Moment Diagrams

FIGURE B.3. FREEBODY, SHEAR, AND MOMENT DIAGRAMS OF ELEMENT 376

TABLE B.2. SUMMATION OF NODAL FORCES AND MOMENTS

Element	Node	Element Weight	L_i *	F_{x_i}	F_{yi}	F_{zi}	M_{xi}	M_{yi}	M_{zi}	L_iF_{zi}	L_iF_{yi}
55	2	48	344	-367.5	-9.52593	229.627	-59.2	1482.03	-291.164	76991.688	-3276.9199
	6		280	367.5	9.52593	-181.630	59.2	-14642.6	-318.496	-50836.40	2667.2604
124	6	48	250	1604.6	-18.8723	-744.207	-112.8	16311.6	-573.966	-208377.96	-5284.244
	10		216	-1604.6	18.8723	792.204	112.8	32853.5	-633.862	171116.06	4076.4168
200	10	48	216	12235.1	-24.7304	-3077.34	-158.0	-32171.2	-860.270	-664705.44	-5341.7664
	14		152	-12235.1	24.7304	3125.34	158.0	230657.0	-722.472	475051.68	3759.0208
272	14	24	152	13967.5	-48.5655	7506.60	-264.7	-230716.0	-737.569	1141003.2	-7381.956
	18		120	-13967.5	48.5655	-7482.60	264.7	-9111.33	-816.529	-897912.0	5827.86
300	18	48	120	9297.3	-15.4008	-2571.96	-94.7	9102.79	446.482	-308635.2	-1848.096
	22		56	-9297.3	15.4008	2619.96	94.7	157039.0	-539.171	146717.76	862.4448
348	22	24	56	9493.2	20.9630	1844.05	117.0	-156413.0	238.224	103266.80	1173.928
	26		24	-9493.2	-20.9630	-1820.05	-117.0	97787.7	432.591	-43681.20	-503.112
376	26	48	24	2356.2	30.0196	1658.17	184.1	-96425.1	928.002	39796.08	720.4704
	30		-40	-2356.2	-30.0196	-1610.18	-184.1	-8162.10	993.251	64407.20	1200.784
439	30	48	-40	-71526.0	37.3225	1543.84	227.7	9989.48	1203.79	-61753.60	-1492.90
	34		-104	71526.0	-37.3225	-1495.84	-227.7	-107259.0	1184.85	155567.36	3551.54
495	34	48	-104	-14261.7	21.9824	783.818	135.1	108711.0	730.839	-81517.072	-2286.1696
	38		-168	14261.7	-21.9824	-735.821	-135.1	-157339.0	676.035	123617.92	3693.0432
562	38	48	-168	-15984.8	1.34193	-272.207	10.0	158416.0	61.8202	45730.776	-225.44424
	42		-232	15984.8	-1.34193	320.203	-10.0	-139459.0	24.0632	-74287.096	311.32776
628	42	42.75	-232	-13305.5	-52.8058	-624.026	-284.3	140639.0	-1261.86	144774.03	12250.945
	49		-259	13305.5	52.8058	666.774	284.3	-103851.0	-1748.08	-192697.68	-15260.876
629	49	5.75	-269	-10083.4	1459.23	-3785.26	7330.0	87584.0	4083.03	1093940.1	-421717.47
	46		-296	10083.4	-1459.23	3790.51	-7330.0	-61068.8	6131.57	-1121990.8	431932.08
688	46	36	-296	-3206.4	-21.5847	-1353.35	-111.9	66079.7	-591.441	400591.60	6389.0712
	52		-344	3206.4	21.5847	1389.35	111.9	-254.967	-444.623	-477936.4	-7425.1368
TOTALS -	-	516	-	0	0	516	0	-194.297	6702.0804	22[illegible].294	6702.1018

* L_i = Length From Node To I-Beam C.G.

TABLE B.2.

$\Sigma M_y = \Sigma M_{yi} + \Sigma L_i F_{zi} = 26.997$ ✓ (Round-Off Error)
About C.G.

$\Sigma M_z = \Sigma M_{zi} + \Sigma L_i F_{yi} = .0214$ ✓
About C.G.

APPENDIX C

INTERPRETATION OF STRESS PLOTS

INTERPRETATION OF STRESS PLOTS

One of the output options with the ANSYS finite element analysis program is the plotting of shell and plate stresses. These are the maximum and minimum in-plane stresses calculated by ANSYS for each element of the model. Given information specifying a particular shell or surface of the model, the routine plots the surface and its isostress lines which are contour lines connecting points within the geometric profile having equal stress values. Stress plots are similar to topographic maps; they indicate lines of constant stress rather than constant elevation.

Along with other information in the element summaries produced by ANSYS, the calculated maximum and minimum stresses are tabulated. Similarly, both maximum and mimimum stresses can be plotted as they are in this volume. A maximum stress plot presents lines connecting the maximum stresses of all the elements of the desired surface. These lines may be either tensile or compressive stresses since the maximum stress of an element completely in compression would be a compressive stress. Similarly, a minimum stress plot indicates lines of constant stresses which are the minimums of the elements shown and could be tensile as well as compressive. In both cases, dashed stress lines indicate the boundary of tensile and compressive stresses, that is, the line of zero stress. Although in this volume the signs of the stresses are not indicated, they can be determined by comparing the plots of maximum and minimum stresses. Lines parallel in both plots are of the same sign; perpendicular, of opposite sign.

The stress contours, or lines, of the plots are drawn at equal intervals of stress such that each line indicates an increase or decrease of, for example, 100 psi over its neighbor. Where isostress lines are spaced widely, stresses change gradually, similar to how a rolling plain is indicated on a topographic map. As stress lines become more crowded stress concentrations, akin to cliffs topographically, occur. The concentrations may be of compressive or tensile stresses.

EXPLODED ISOMETRICS

EXPLODED ISOMETRICS
OF SELECTED MOBILE HOME STRUCTURE

Prepared by

C. R. Ursell, II
E. O. Wiles

ABSTRACT

Exploded isometric drawings of selected areas of the mobile home structures are presented in this volume. Essentially, the drawings are freebody diagrams of elements of the finite element model depicting loads imposed upon these elements by various static and dynamic load conditions and the resulting in-plane stresses. The elements diagramed from the various areas of the structure are those with the greatest stresses - compressive as well as tensile - as computed by the finite element analysis.

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DEFINITIONS

The following pages contain definitions of words or terms used in this document.

ANSYS - A large-scale general purpose computer program developed by Swanson Analysis Systems, Incorporated, Elizabeth, Pennsylvania. Analysis capabilities of the program include: (1) static and dynamic, (2) plastic, creep and swelling, (3) small and large deflection, (4) steady state and transient heat transfer, and (5) steady state fluid flow types of problems. The matrix displacement method of analysis based on finite element idealization of the structure is employed in the program. The library of finite element types in the program numbers more than 40 for static and dynamic analyses and 10 for heat transfer analyses. This variety of elements gives the program user the capability of analyzing frame structures, piping systems, two-dimensional plane and axisymmetric solids, flat plates, three-dimensional solids, axisymmetric and three-dimensional shells, and nonlinear problems. In this study, the program is used for static analysis of the mobile home structure, idealized as an assemblage of bar, beam, and membrane elements.

ELEMENT - A component part of a structure for which the relationships between forces and displacements at a finite number of points (or nodes) on the element are known. In this study, elements used are bars, prismatic beams, tapered beams, and membranes.

NODAL POINT - A point in space where two or more elements are connected in the idealization of the structure.

DEGREE OF FREEDOM - The direction of force or displacement at a node. For example, the three-dimensional elastic beam element used in the study has two nodes, one at each end. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes.

BOUNDARY CONDITIONS - Specified external loads and/or displacements applied at the nodes of the idealized structure.

RESTRAINT - A displacement boundary condition specified as zero in ANSYS. For example, if the node at the hitch is assumed stationary, displacements in the x, y, and z directions are all specified as zero.

MODULUS OF ELASTICITY - The slope of the stress-strain diagram of a material in the elastic range.

MASS DENSITY - The mass of a body per unit volume. When multiplied by the acceleration of gravity, the mass density becomes the specific weight in pounds per unit volume.

GRAVITY LOAD - Load applied to the structure by the weight of a component part.

EQUIVALENT STATIC LOAD - The load obtained by multiplying the weight of a structural component by its root-mean-square acceleration, as determined from the dynamic analysis (32 percent probability of not being exceeded or multiply by a factor of 3 to obtain 99.9 percent probability).

MAXIMUM/MINIMUM IN-PLANE STRESSES - The maximum and minimum principal stresses acting in the plane of a membrane element. (Note that a membrane element is not capable of resisting a force component applied perpendicular to the plane of the element).

STRESS CONTOUR PLOT - A plot of a membrane element showing contours (or lines) of constant maximum or minimum stress levels.

EXPONENTIAL - Standard form of presentation of a number in E format, showing the number of places the indicated decimal must be moved to the right (plus exponent) or left (negative exponent). For examples, 1.4 E

+ 03 - 1400., and 1.4 E - 02 = 0.014.

CARD SET - A group of input cards used in ANSYS for common input data (e.g., card set D defines the element types and card set E defines the nodes to which the elements are connected). The total conglomorate of all the various card sets forms the specified input data required to conduct a run of the program.

ISOTROPIC - Characteristic of a material that has identical properties in all directions.

I. INTRODUCTION

The dynamic and finite element static analyses have been demonstrated as an effective approach to analyze the structural behavior of the mobile home. The main purpose of this part of Task I was to investigate the effects of transportation on a unit through the use of exploded isometric drawings of selected areas of the mobile home structure. The dynamic analysis determined the accelerations generated during the transportation mode. The finite element static analysis generated the resulting stresses and displacements based on structure weight and the equivalent static loads developed in the dynamic analysis.

In this study, the aforementioned isometrics for mobile homes T-1, T-2A and B were made indicating the type of structure and method of assembly.* These isometrics are used to display transportation and site installation stresses and forces not only on separate components or structural systems of a mobile home, but also on the integrated structure of the unit, where possible. Tables preceding the isometrics present the maximum and minimum in-plane stresses (i.e., greatest tensile and compressive stresses) of individual components of interest. These values were calculated in the finite element analysis for each load case developed. A summary of load case descriptions is shown in Table 1. In addition to the stresses, the finite element analysis can generate, upon request, the deflection and corner loads for each element, as well as the deflection for the overall unit. (Task I, Volume III.) The analysis, however, cannot generate cumulative damage of individual or isolated joints because:

- The basic conditions or parameters associated with each joint are not known at the start of each test.

* The stresses and forces indicated in the isometrics are those present in the test units and are not to be interpreted as typical for all mobile homes.

TABLE 1

DESCRIPTION OF LOAD CASES AND LOAD CONDITIONS

CONDITION I	LOAD CASE 1	Gravity Load - Weight of Mobile Home Unit With Furnishings Included
	LOAD CASE 2	Furnishings Added With Dynamic Loading Induced by Well-Paved Road at 45 mph (Test Run No. 1)
	LOAD CASE 3	Furnishings Added With Dynamic Loading Induced by Well-Paved Road at 45 mph (Test Run No. 5)
CONDITION II	LOAD CASE 4	Setup/Takedown (Jackup) Loading with Furnishings Included
	LOAD CASE 5	Worst Case Condition - Furnishings Plus Dynamic Loading Induced by Paved, Secondary Road

- As each joint degrades it is supported by the adjacent joints to which the unabsorbed load is transferred. Therefore, the stability or integrity of each joint is indeterminate by this method.

- Individual joint analysis for cumulative damage would be the source of a completely separate study requiring development of degradation curves that involve load, frequency, displacement and time from typical laboratory tests. Once such "joint-curves" were available, the loads or stresses and frequencies generated by the finite element analysis would be applied to the curves for the degree of degradation or the remaining useful life of each particular joint. Such a family of curves would have to assume a certain standard of integrity for each joint, although we know the integrity of joints varies considerably because of the construction/assembly methodology used for mobile home production.

In this program, it is important to note that the entire mobile home has been analyzed as an integrated structural unit via the dynamic and finite element methods. To develop the loads and stresses in each unit, the finite element analysis method divided each mobile home into hundreds of small elements to form a mesh. There exists a trade-off with regard to the mesh size: the finer the mesh, the more detailed and accurate the analysis, but the more points there are to analyze and the more costly the program to run.

The computer printout of the finite element program furnishes data over the entire unit. Results for particular components of the unit - such as windows, doors, door openings, corner joints, wall attachments, etc. - are accessible from the data. If you want to investigate the effects of loads at any point in the structure, choose the element that represents this point from the mesh and follow through the computer printout (as indicated in Volume III) to determine the stresses and deflection for that particular loading condition. The stresses for the exploded isometrics were handled in this manner. For concentrated weight items - such as the central heater, refrigerator or toilet - the equivalent static load was obtained by applying the acceleration in the area of the item developed from the dynamic analysis to the c.g. of the component. A designer can use these equivalent static loads to provide adequate attachments for each component. In addition to the latter loads, the frequency of vibrations of the component generated by road and speed conditions should be considered by a designer since this kind of stress has proven to be more damaging than that of the static loads. A frequency of between 5 and 10 Hz has been recorded as the average for the mobile homes tested. This frequency seems low, but when augmented by accelerations of 0.3 to 1.0 g's, these repetitive loadings can be damaging. An example is a toilet with only two hold-down screws that are inadequately anchored and improperly located. The screws are inserted into a plastic ring which is screwed into a particle board floor. The c.g. of the heavy unit is not located above the screws but toward the tank creating an eccentric loading condition. Because of vibrations, the soft wax seal cold flows and develops leaks. Two hold-down screws are inadequate to prevent this situation, which could result even on site as well as during transportation.

II. DISCUSSION

The exploded isometrics present selected areas of the mobile home structure and heavy-weight components listed as follows:

Structure

- Roof:
  - (1) At the connection of the roof trusses to sidewall framing;
  - (2) At the roof membrane/sidewall interface;
  - (3) At the top and bottom chords of the roof trusses; and
  - (4) On top of the furnace vent outlet.
- Ceiling: At attachment to roof trusses.
- Exterior Walls:
  - (1) At sidewall and endwall joint;
  - (2) At sidewall interface with window and doors;
  - (3) At window glazing; and
  - (4) On exterior siding panels.
- Interior Walls and Electrical:
  - (1) On sidewall and endwall paneling;
  - (2) On partition walls;
  - (3) Juncture of sidewalls and ceiling; and
  - (4) On selected snap-in type wall receptacles.
- Floor:
  - (1) Over axle area;
  - (2) Along the hall or corridor;
  - (3) At joist splices and large notches; and
  - (4) At sliding doors, doors, and window cutouts.
- Frame (Chassis) and Running Gear:
  - (1) On the large, longitudinal I-beam;
  - (2) On the cross-members;
  - (3) On the outriggers above the axles;
  - (4) On axles, wheels, tires, brakes and spring suspension; and
  - (5) On drawbar and coupling mechanism.
- Plumbing:
  - (1) On the sink, tub and toilet; and
  - (2) On the water heater.
- Heating & Cooling:
  - (1) On the connection of the furnace vent at the furnace;
  - (2) At the supply duct connection with the furnace; and
  - (3) At the air conditioning unit (if internal A-frame mounted).

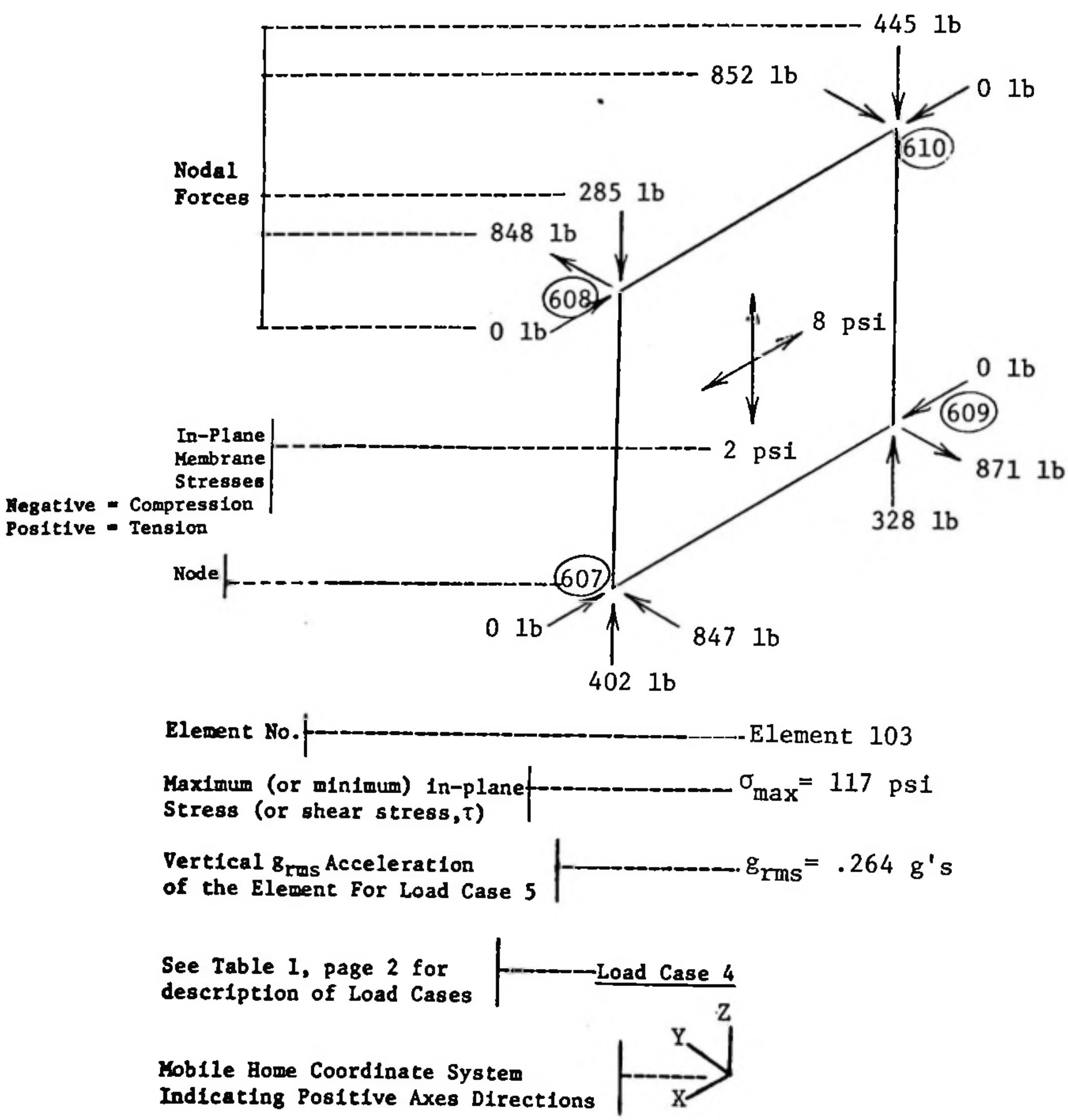
These items are detailed in the following sketches. A table is presented with those sketches of areas of the unit structure that have been modeled as elements in the finite element analysis; specifically, areas of the exterior and interior walls and the floor. The stresses, σ_{max}, σ_{min}, and τ_{max}, in the latter isometrics, are the prinicipal in-plane stresses. The calculations that support the drawings and the tabulated data are contained in the dynamic and finite element analysis in Task I, Volumes II and III.*

No tables accompany the sketches of areas of the mobile home and heavyweight components that have not been modeled in the analysis. Note that the celotex ceiling was not considered a load carrying item of the structure because data obtained in testing the module indicated that the installation, using staples and interlock attachments, offers little resistance as a panel, particularly in the torsion mode.

*The finite element computer printouts as well as the computer card program for T-1, T-2A and T-2B are available at SwRI.

EXPLODED ISOMETRIC DRAWINGS

The freebody diagrams on the following pages are of the form below. This figure is intended as a guide with which to interpret the later diagrams. Units are indicated here for forces and stresses. In-plane membrane stresses are parallel to the mobile homes axes in most cases. From these, the maximum and minimum stresses, σ_{max} and σ_{min}, are rotated at some angle within the plane. RMS g accelerations are given for the dynamic Load Case 5 only -- not the static Load Case 4. These accelerations are in the vertical direction. Lateral accelerations are 3/4 of the vertical accelerations.



T-1

14 x 64 SINGLE-WIDE
MOBILE HOME UNIT

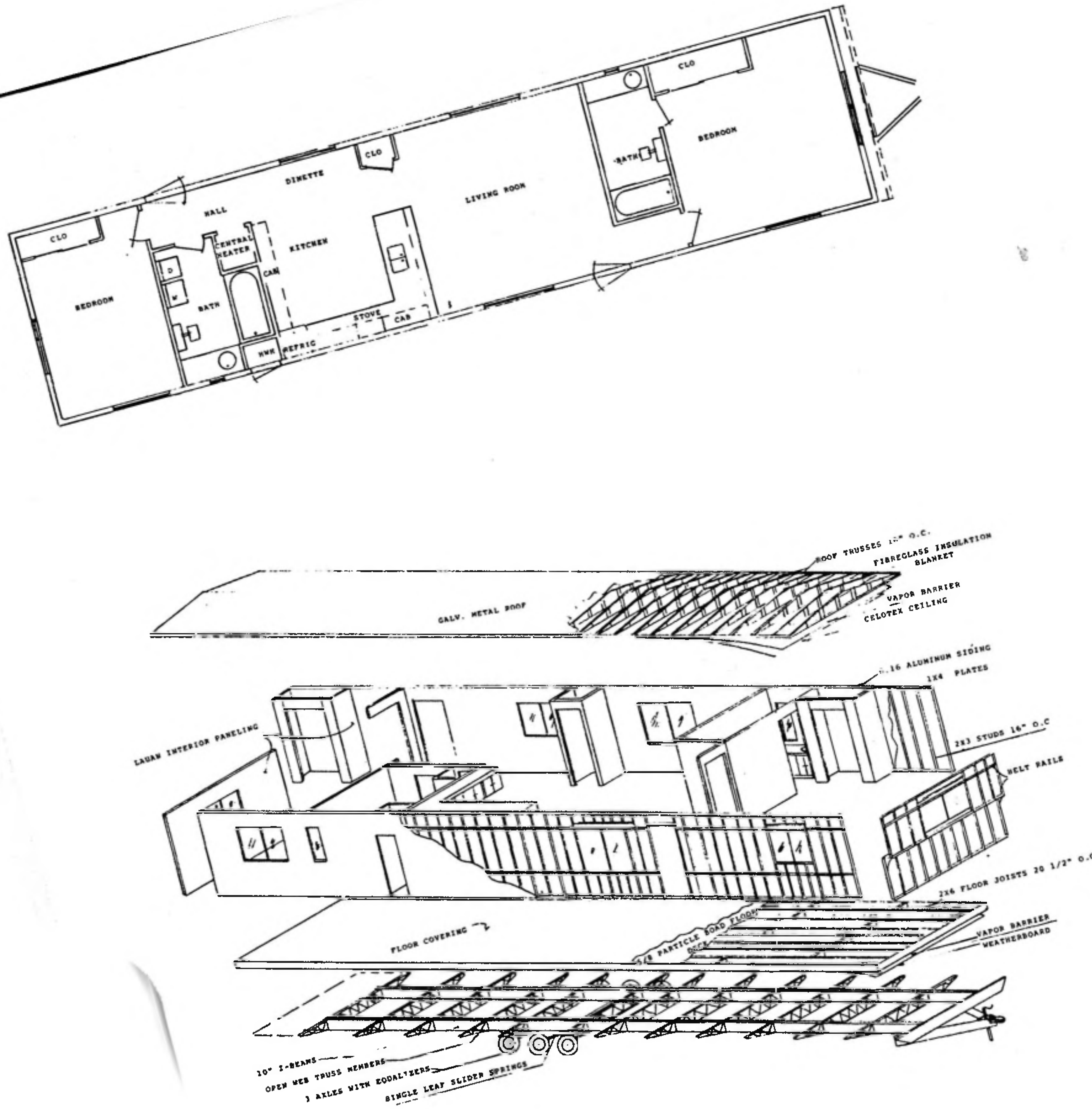


FIGURE 1. T-1 MOBILE HOME EXPLODED ISOMETRIC

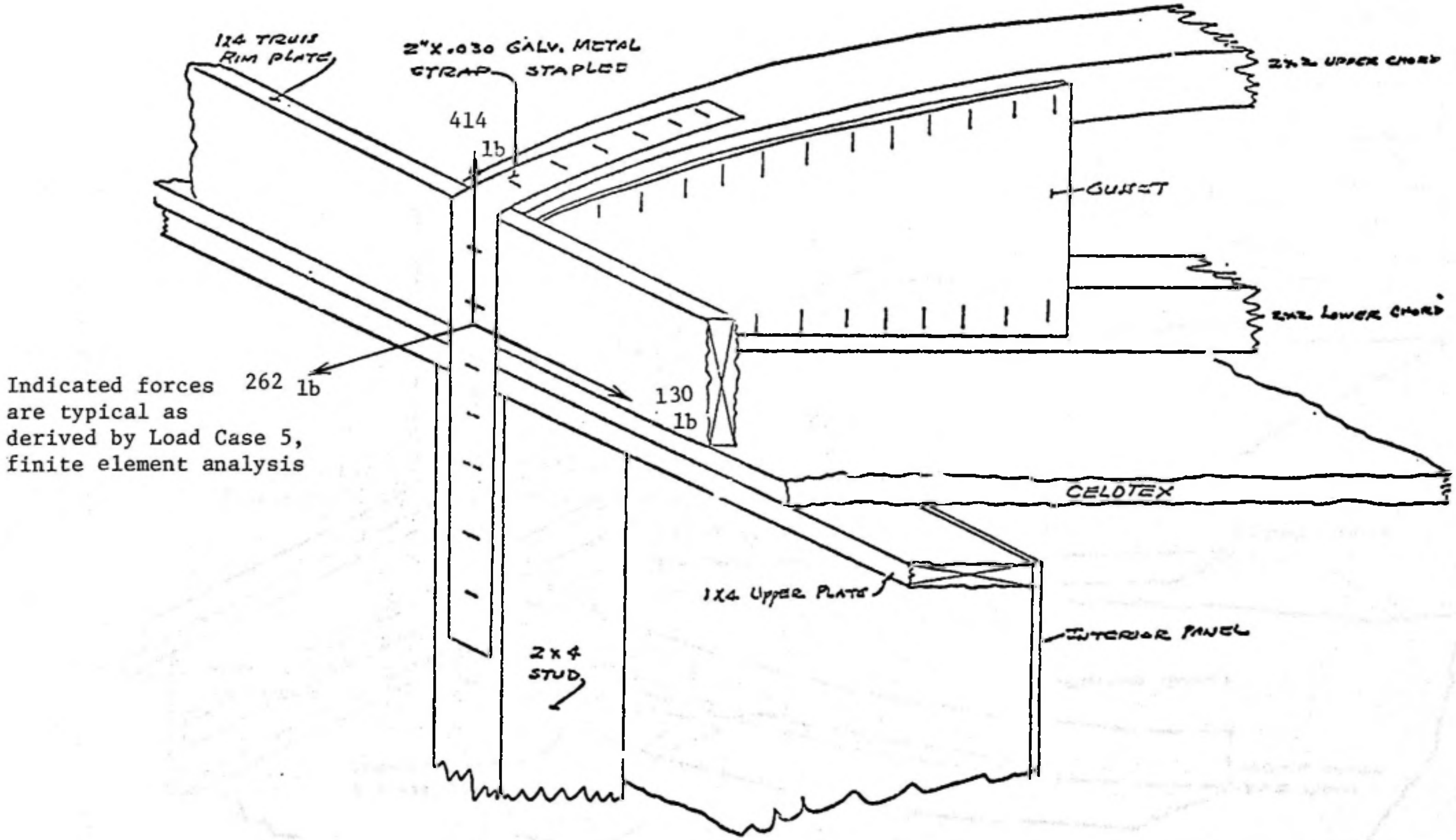


FIGURE 2. T-1 - ROOF TRUSS TO SIDEWALL FRAMING

Indicated in-plane stresses are maximum tensile and compressive ones as derived by Load Case 5, finite element analysis

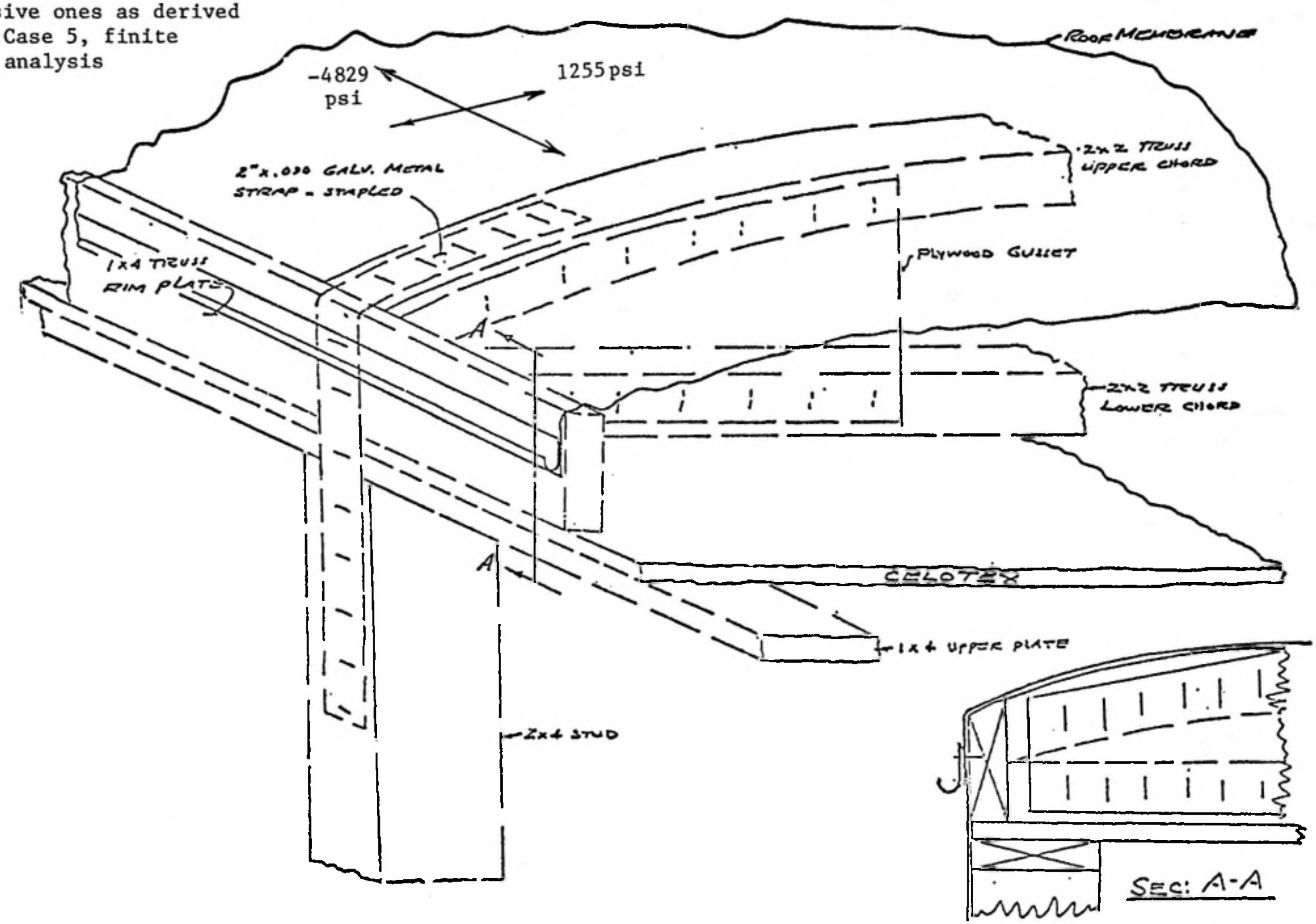
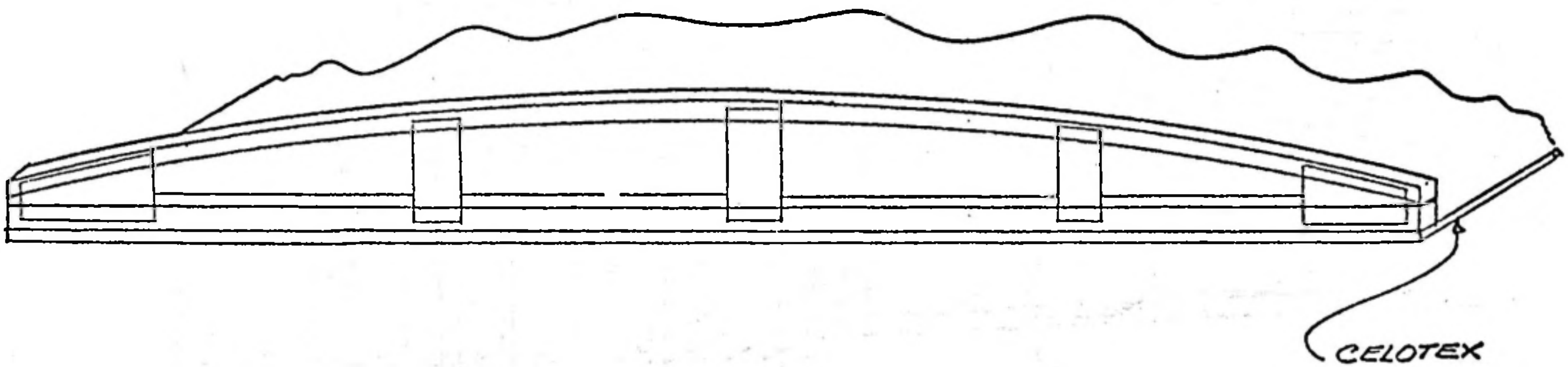
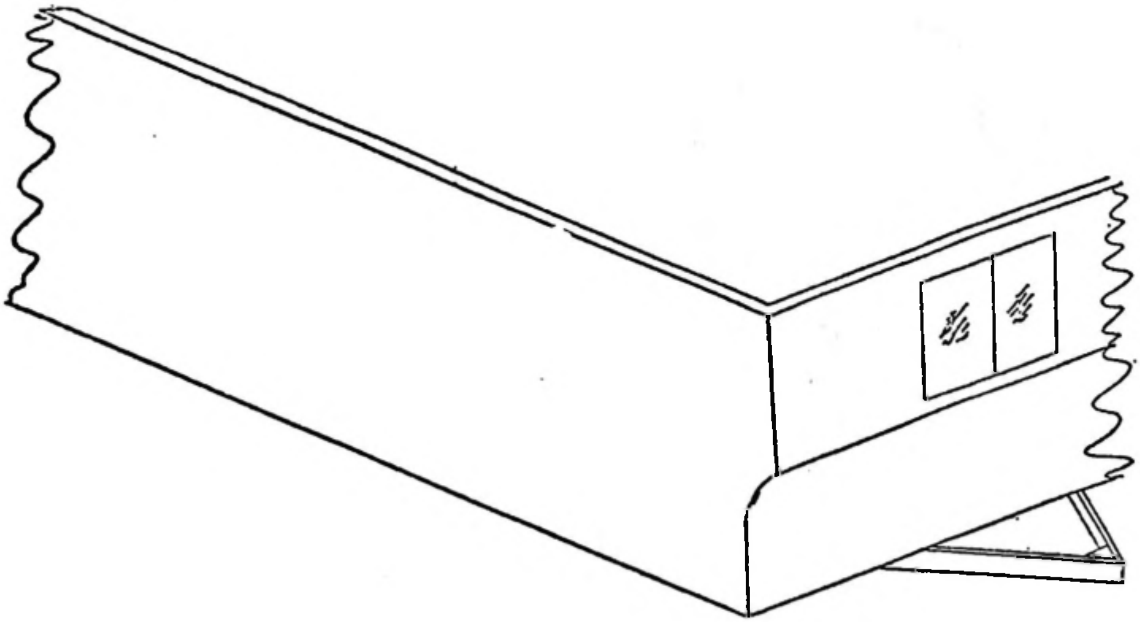


FIGURE 3. T-1 - ROOF MEMBRANE/SIDEWALL INTERFACE



The celotex was not considered as a structural component in the development of the finite element analytical model.

FIGURE 4. T-1 - ROOF TRUSS TO CEILING ATTACHMENT

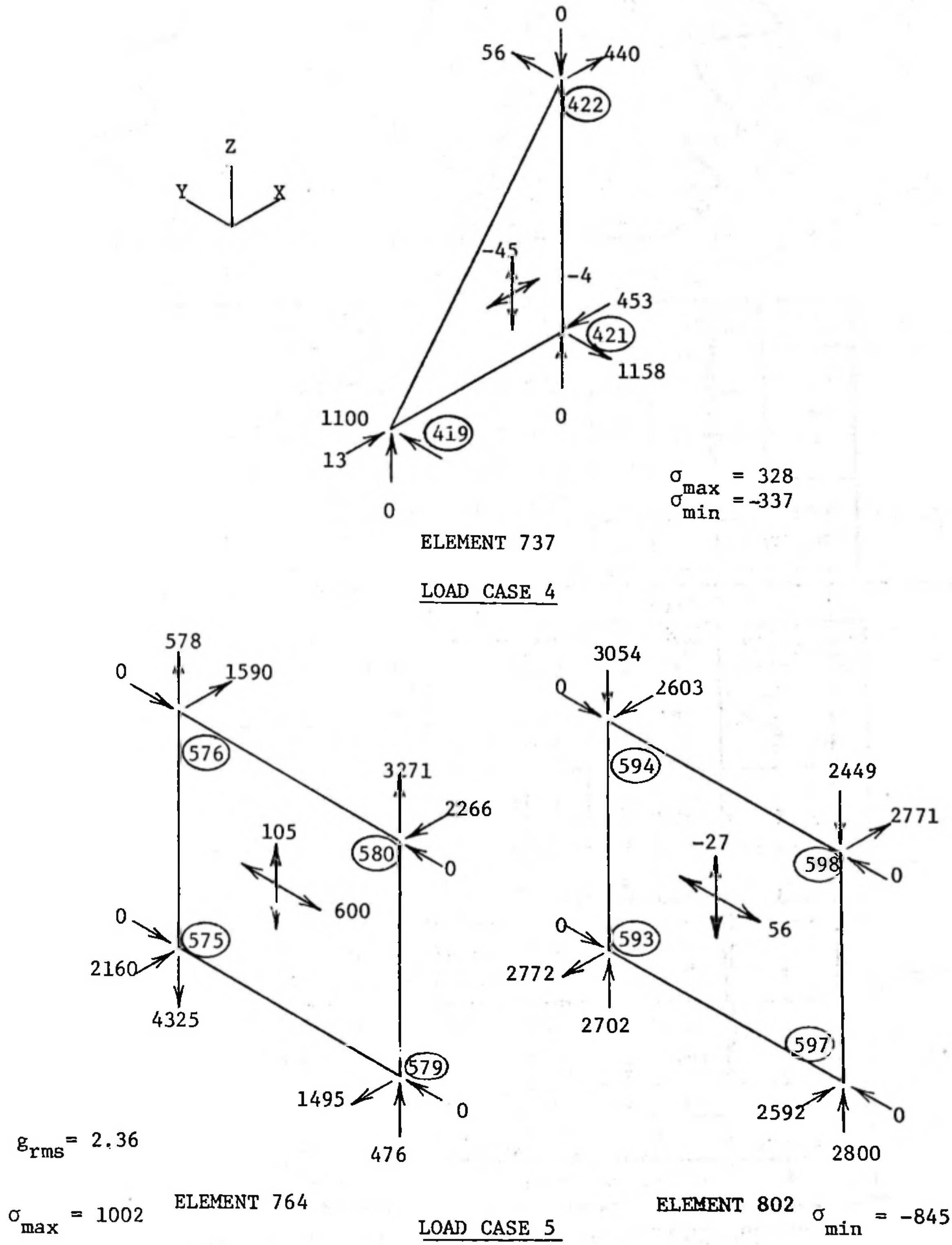


For interior panel elements along the interface:

Loading Condition	Load Case ****	Max (PSI)	Elem.	Element Location *	Min (PSI)	Elem.	Element Location
Cond. I	1	** 449	764	Lower Left Front	*** -358	802	Lower Right Front
	2	502	764	-	-408	802	-
	3	505	764	-	-409	802	-
Cond. II	4	328	737	Forward Left Side	-337	737	Forward Left Side
	5	1002	764	-	-845	802	-

* Element locations are detailed in Table 2 and Figure 35.
** Positive stress value signifies tension on the element
*** Negative stress value signifies compression on the element
**** See Table 1 for details

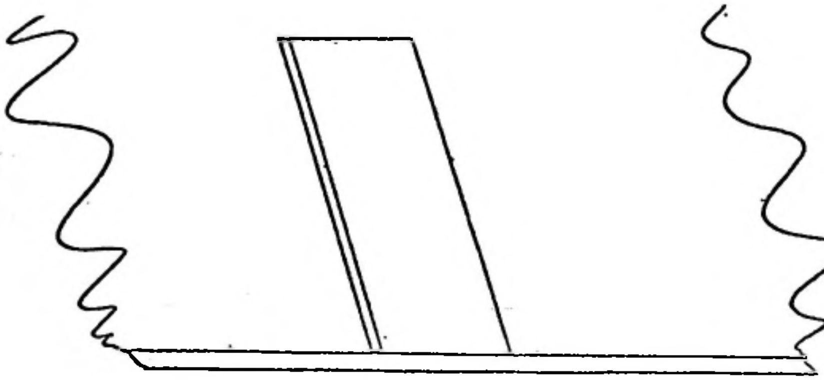
FIGURE 5. T-1 - SIDEWALL/ENDWALL INTERFACE



g_{rms} = 2.92

FIGURE 6. FREEBODY DIAGRAMS
T-1 SIDE WALL/END WALL INTERFACE

(XXX) -NODE



LEFT SIDEWALL:

Loading Condition	**** Case	σ Max (PSI)	Elem.	Element Location*	Min σ (PSI)	Elem.	Element Location*	Max τ (PSI)	Elem.	Element Location*
Cond. I	1	** 111	229	Rear Left Side	*** -49	228	Rear Left Side	72	229	Rear Left Side
	2	132	229	Rear Left Side	-46	228	Rear Left Side	79	229	Rear Left Side
	3	133	229	Rear Left Side	-45	228	Rear Left Side	78	229	Rear Left Side
Cond. II	4	61	175	Rear Left Side	-83	229	Rear Left Side	63	175	Rear Left Side
	5	299	229	Rear Left Side	-50	228	Rear Left Side	148	229	Rear Left Side

RIGHT SIDEWALL, REAR:

Loading Condition	**** Load Case	σ Max (PSI)	Elem.	Element Location*	σ Min (PSI)	Elem.	Element Location*	Max τ (PSI)	Elem.	Element Location*
Cond. I	1	333	267	Center Right Side	-211	192	Rear Right Side	219	192	Rear Right Side
	2	371	267	Center Right Side	-232	192	Rear Right Side	140	192	Rear Right Side
	3	374	267	Center Right Side	-234	192	Rear Right Side	242	192	Rear Right Side
Cond. II	4	134	186	Rear Right Side	-139	192	Rear Right Side	112	192	Rear Right Side
	5	726	267	Center Right Side	-430	186	Rear Right Side	430	267	Rear Right Side

RIGHT SIDEWALL, FRONT:

Loading Condition	**** Load Case	σ Max (PSI)	Elem.	Element Location*	Min σ (PSI)	Elem.	Element Location*	Max τ (PSI)	Elem.	Element Location*
Cond. I	1	159	524	Forward Right Side	-277	524	Forward Right Side	215	524	Forward Right Side
	2	227	524	Forward Right Side	-355	524	Forward Right Side	291	524	Forward Right Side
	3	231	524	Forward Right Side	-360	524	Forward Right Side	296	524	Forward Right Side
Cond. II	4	64	524	Forward Right Side	-208	524	Forward Right Side	136	524	Forward Right Side
	5	614	524	Forward Right Side	-854	524	Forward Right Side	734	524	Forward Right Side

* Element locations are detailed in Table 2 and Figure 35.
** Positive stress value signifies tension on the element
*** Negative stress value signifies compression on the element
**** See Table 1 for details

FIGURE 7. T-1 - DOOR FRAME INTERFACE WITH SIDEWALL

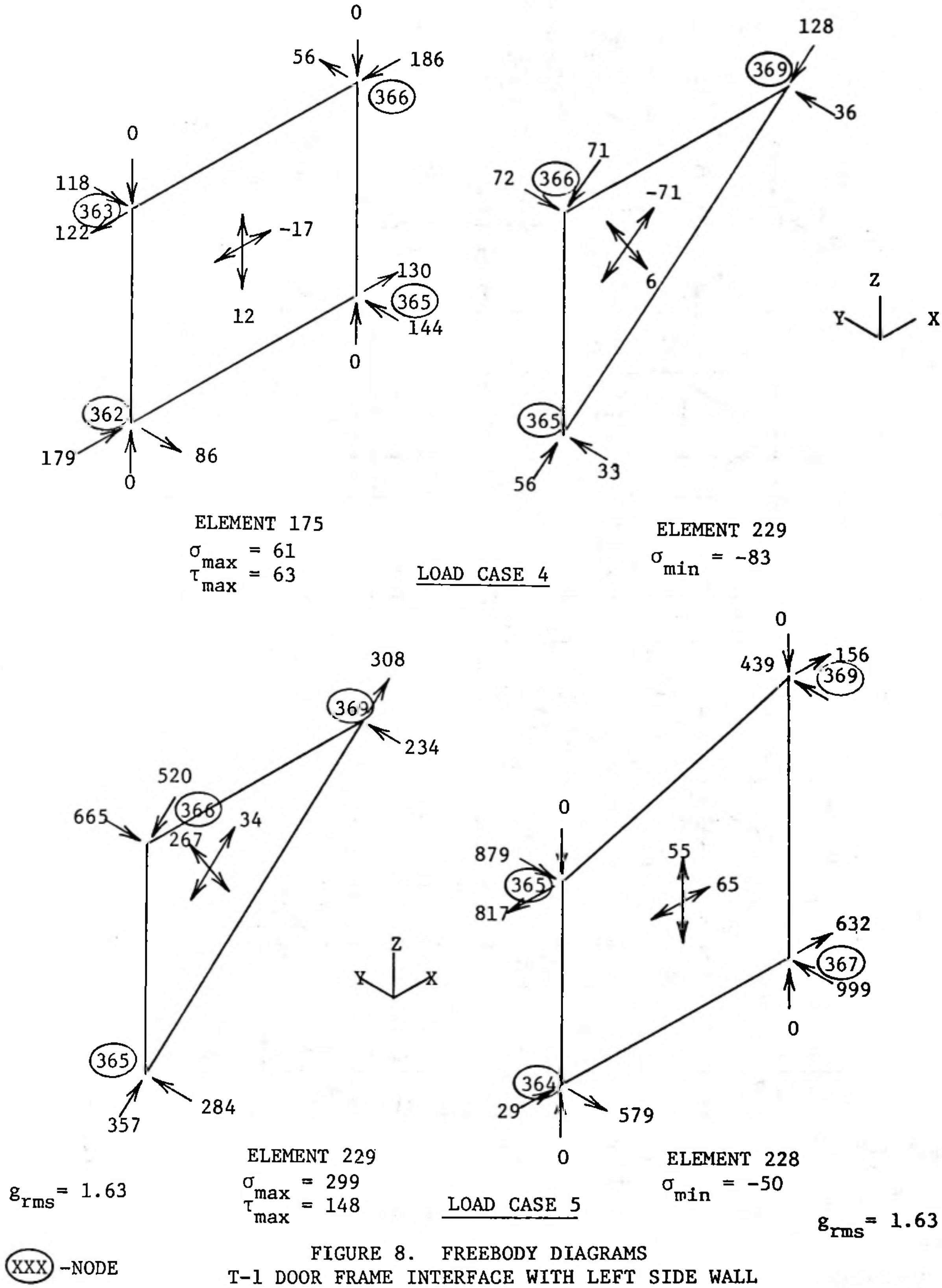


FIGURE 8. FREEBODY DIAGRAMS
T-1 DOOR FRAME INTERFACE WITH LEFT SIDE WALL

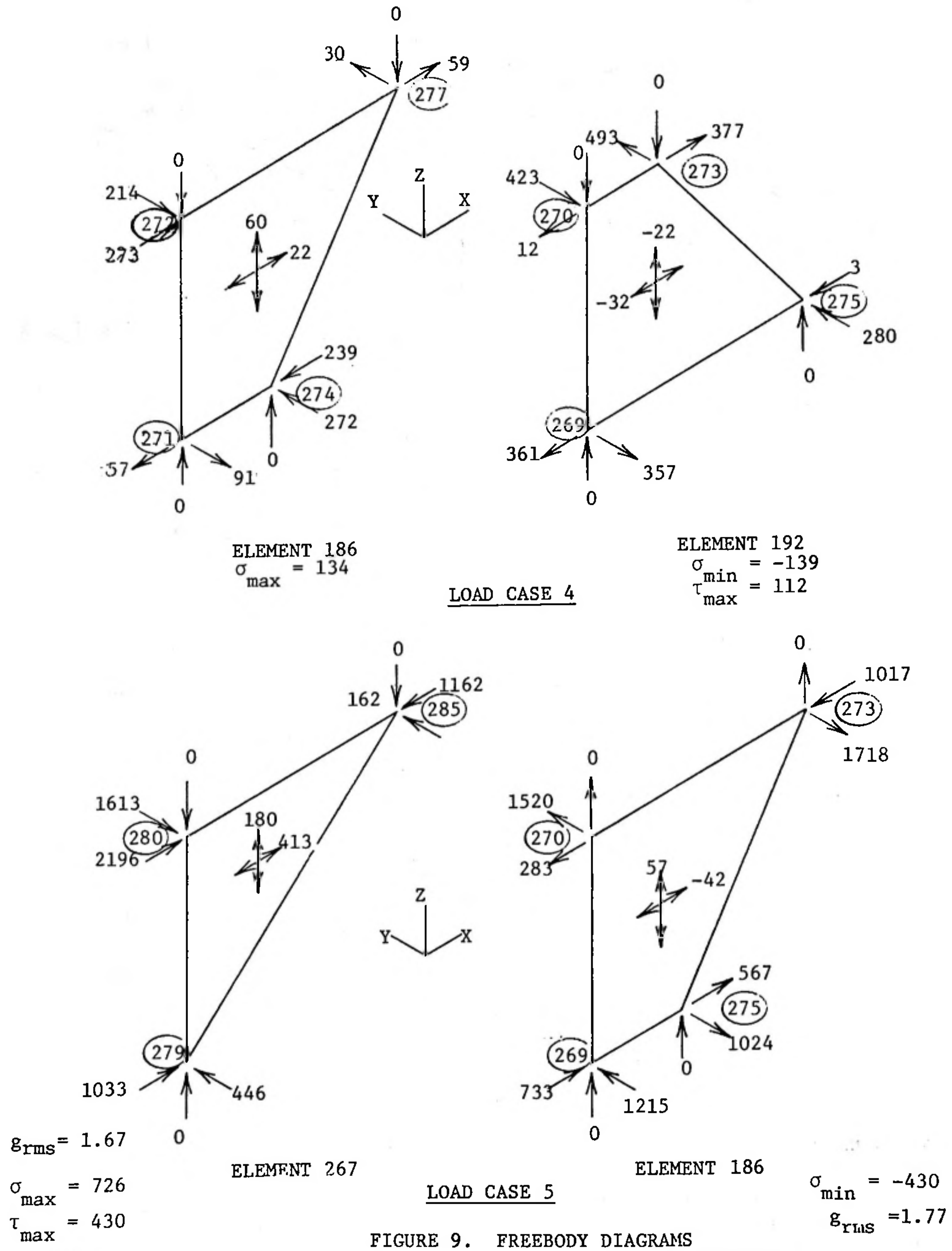
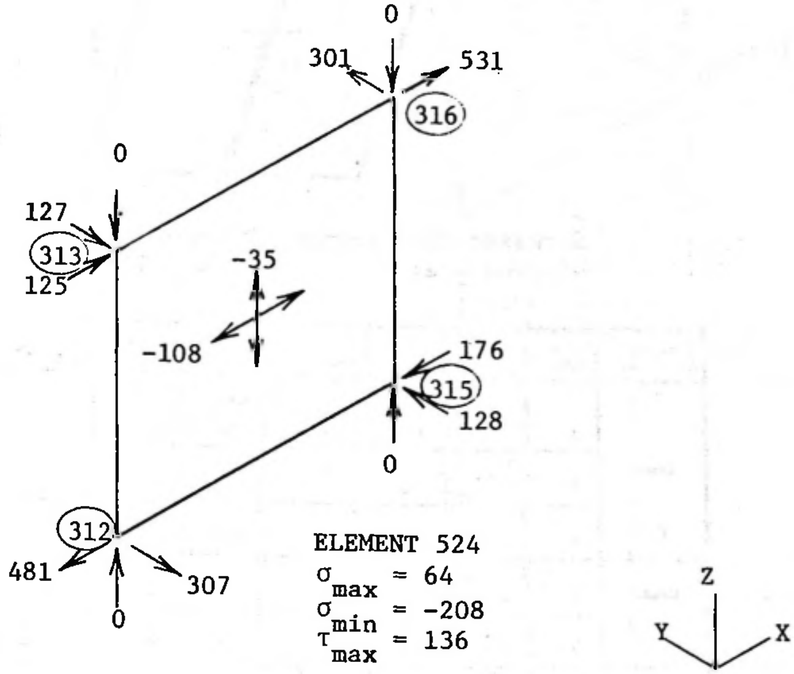
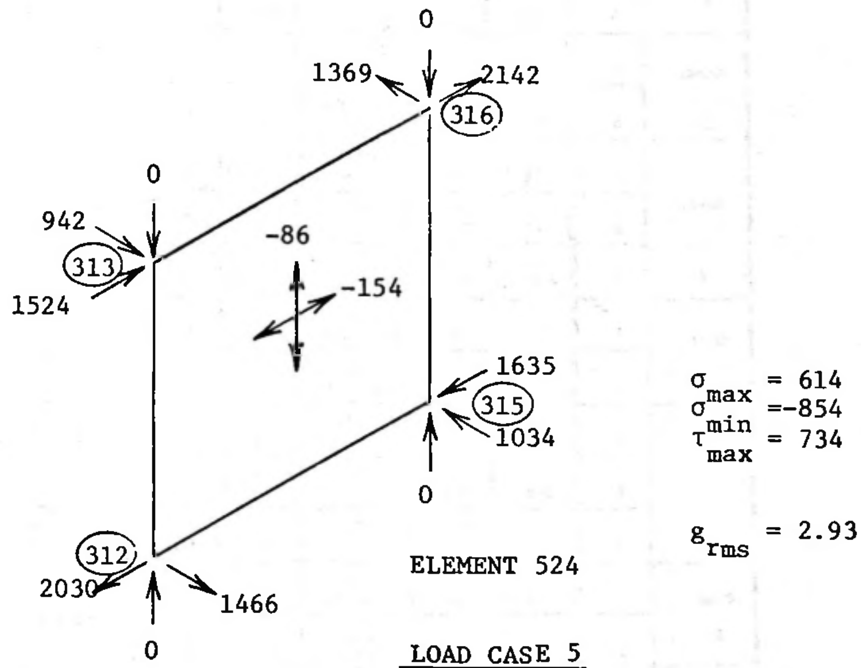


FIGURE 9. FREEBODY DIAGRAMS
T-1 DOOR FRAME INTERFACE WITH REAR RIGHT SIDE WALL

XXX -NODE



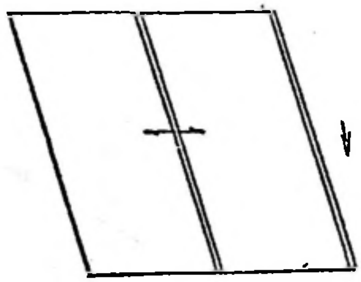
LOAD CASE 4



LOAD CASE 5

XXX - NODE

FIGURE 10. FREEBODY DIAGRAMS
T-1 DOOR FRAME INTERFACE WITH FRONT RIGHT SIDE WALL



Stresses in elements adjacent to the windows are:

Loading Condition	**** Load Case	Max σ (PSI)	Elem.	Element Location*	Min σ (PSI)	Elem.	Element Location*	Max τ (PSI)	Elem.	Element Location*
Cond. I	1	*** 272	285	Rear Left Side	*** -282	338	Center Left Side	250	314	Center Left Side
	2	287	285	"	-290	338	"	258	314	Center Left Side
	3	284	285	"	-285	338	"	254	314	Center Left Side
Cond. II	4	162	285	"	-223	481	Center Left Side	148	314	Center Left Side
	5	466	285	"	-488	589	Forward Left Side	376	314	Center Left Side
Cond. I	1	233	190	Rear Right Side	-245	657	Forward Right Side	188	154	Rear Right Side
	2	260	435	Forward Right Side	-255	657	"	240	192	Rear Right Side
	3	269	435	"	-255	657	"	244	435	Forward Right Side
Cond. II	4	161	684	Forward Right Side	-208	657	"	154	684	Rear Right Side
	5	722	435	"	-658	466	Center Right Side	626	466	Center Right Side
Cond. I	1	38	18	Right Rear Center	-38	18	Right Rear Center	38	18	Right Rear Center
	2	47	17,18	"	-49	18	"	48	18	Right Rear Center
	3	46	17,18	"	-47	18	"	46	18	Right Rear Center
Cond. II	4	37	13	Upper Rear Side	-63	10	Lower Rear Side	45	10	Lower Rear Side
	5	104	17	Lower Right Rear	-107	18	Right Rear Center	105	10	Right Rear Center
Cond. I	1	82	796	Right Front Side	-123	794	Center Front	63	794	Center Front
	2	104	796	"	-152	794	"	90	794	Center Front
	3	103	796	"	-151	794	"	90	794	Center Front
Cond. II	4	58	786	Left Front Side	-44	796	Right Front Side	31	796	Right Front Side
	5	283	796	Right Front Side	-298	794	Center Front	187	794	Center Front

* Element locations are detailed in Table 2 and Figure 35.
** Positive stress value signifies tension on the element
*** Negative stress value signifies compression on the element
**** See Table 1 for details

FIGURE 11. T-1 - WINDOW GLAZING

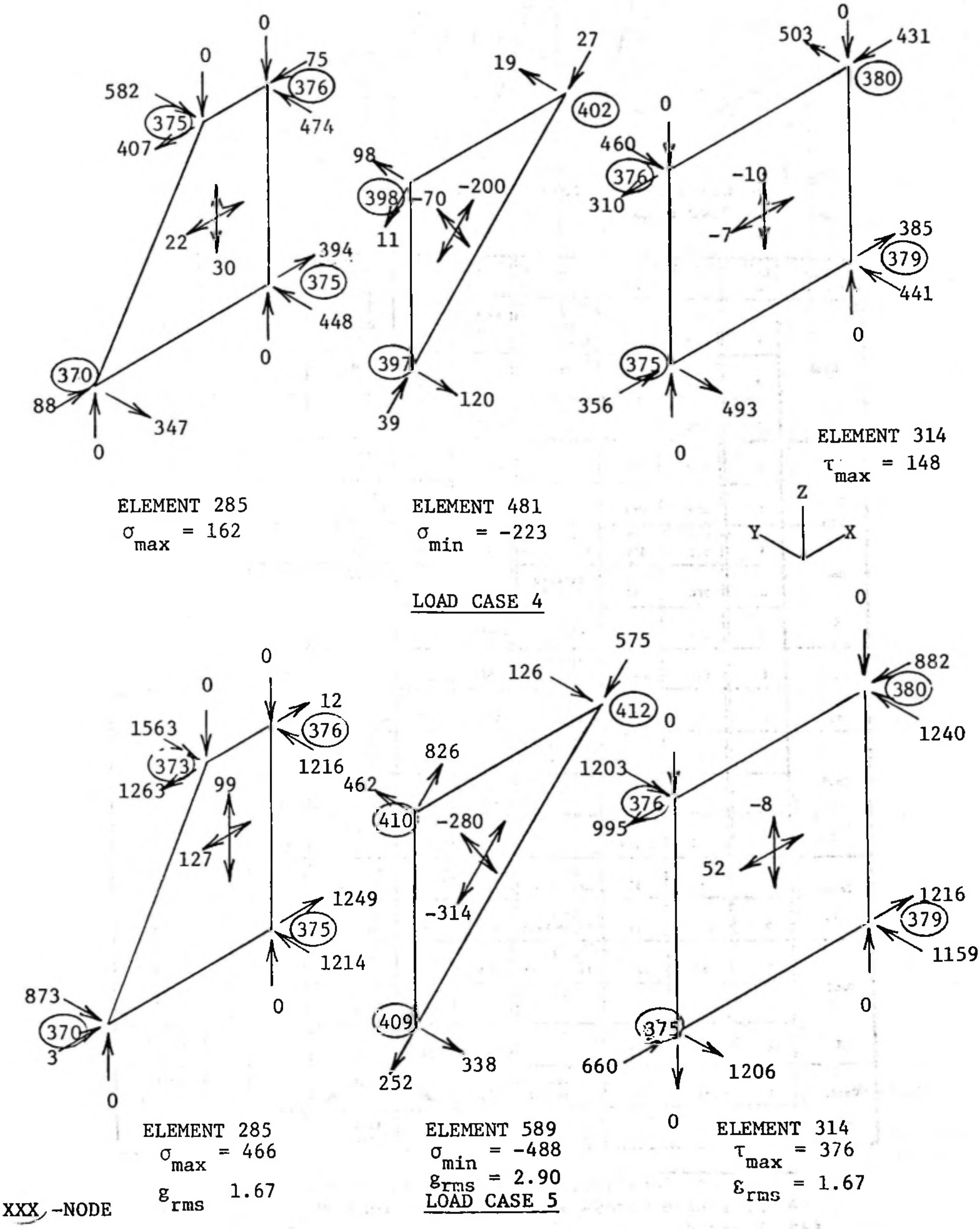
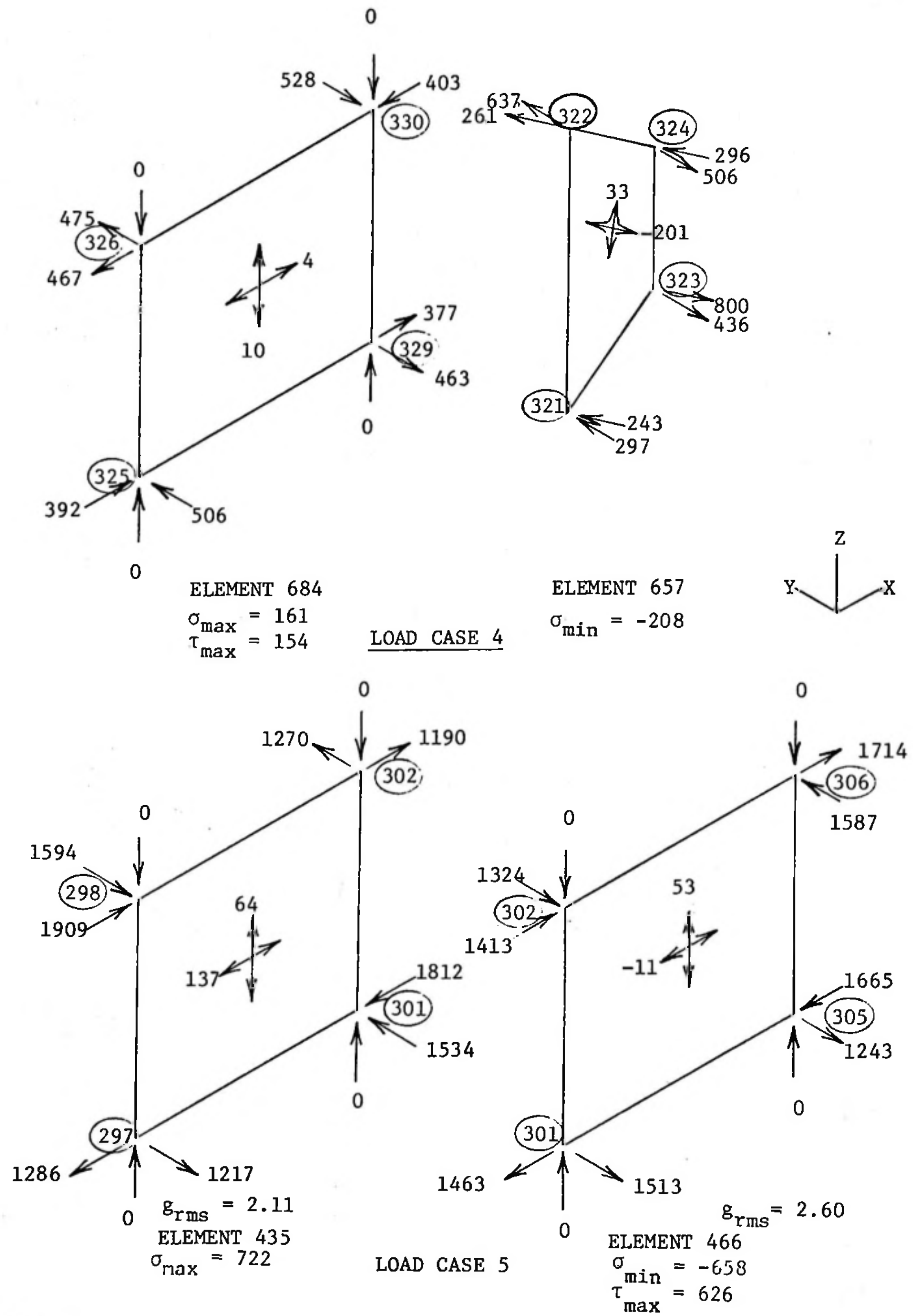
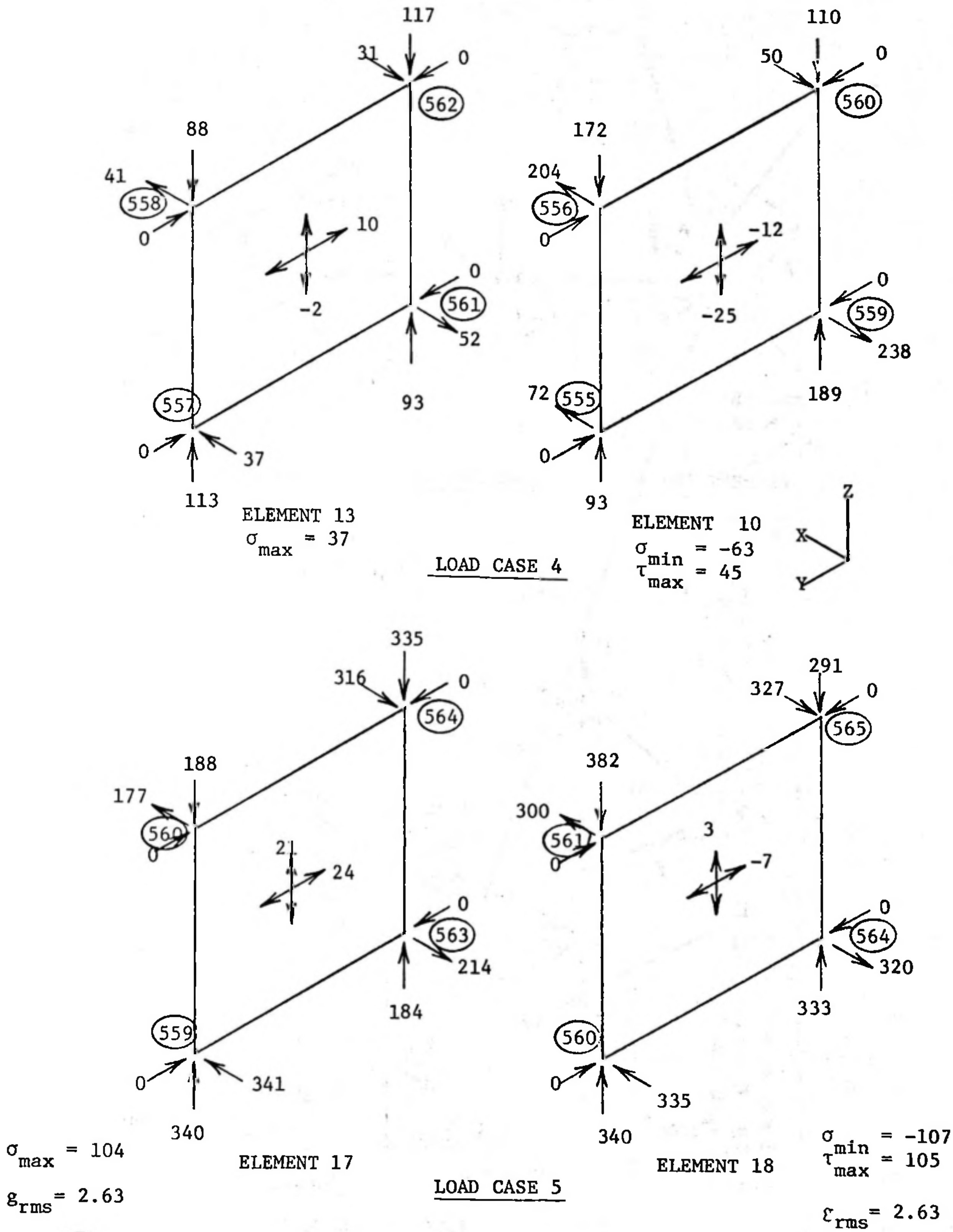


FIGURE 12. FREEBODY DIAGRAMS
T-1 LEFT SIDE WALL ADJACENT TO WINDOW



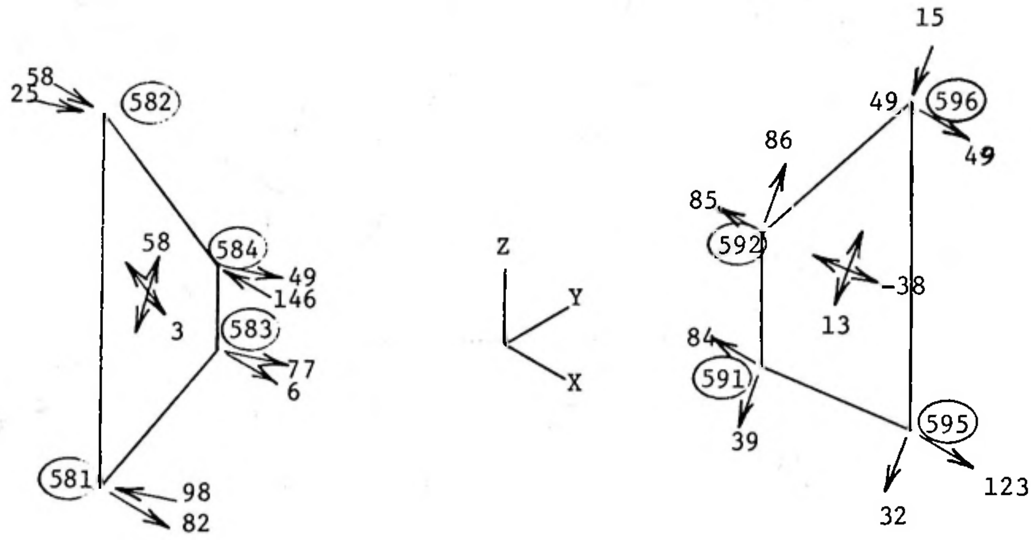
XXX -NODE

FIGURE 13. FREEBODY DIAGRAMS
T-1 RIGHT SIDE WALL ADJACENT TO WINDOW



XXX -NODE

FIGURE 14. FREEBODY DIAGRAMS
T-1 REAR WALL ADJACENT TO WINDOW



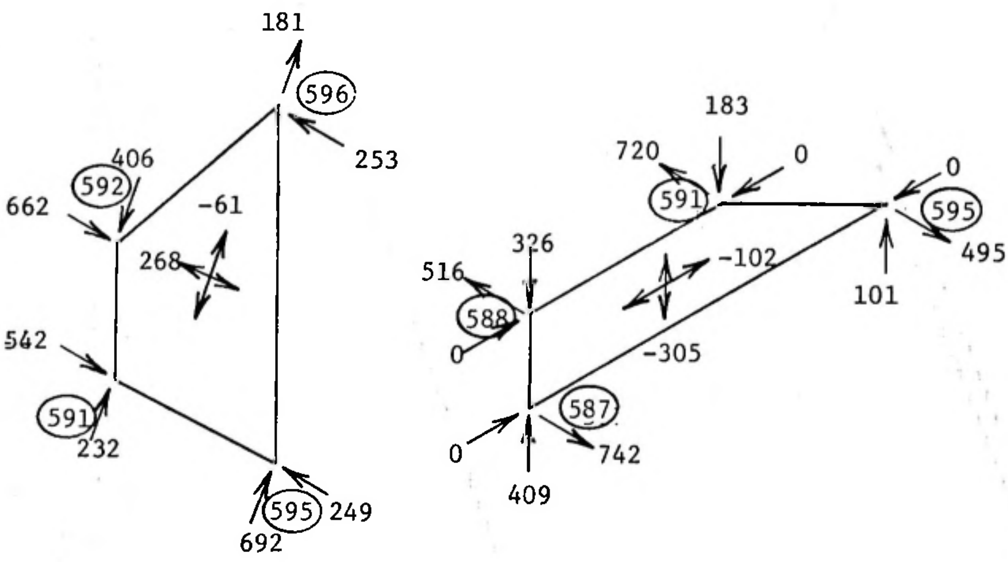
ELEMENT 786

σ_{max} = 58

LOAD CASE 4

ELEMENT 796

σ_{min} = -44
τ_{max} = 31



ELEMENT 796
σ_{max} = 283

g_{rms}= 2.49

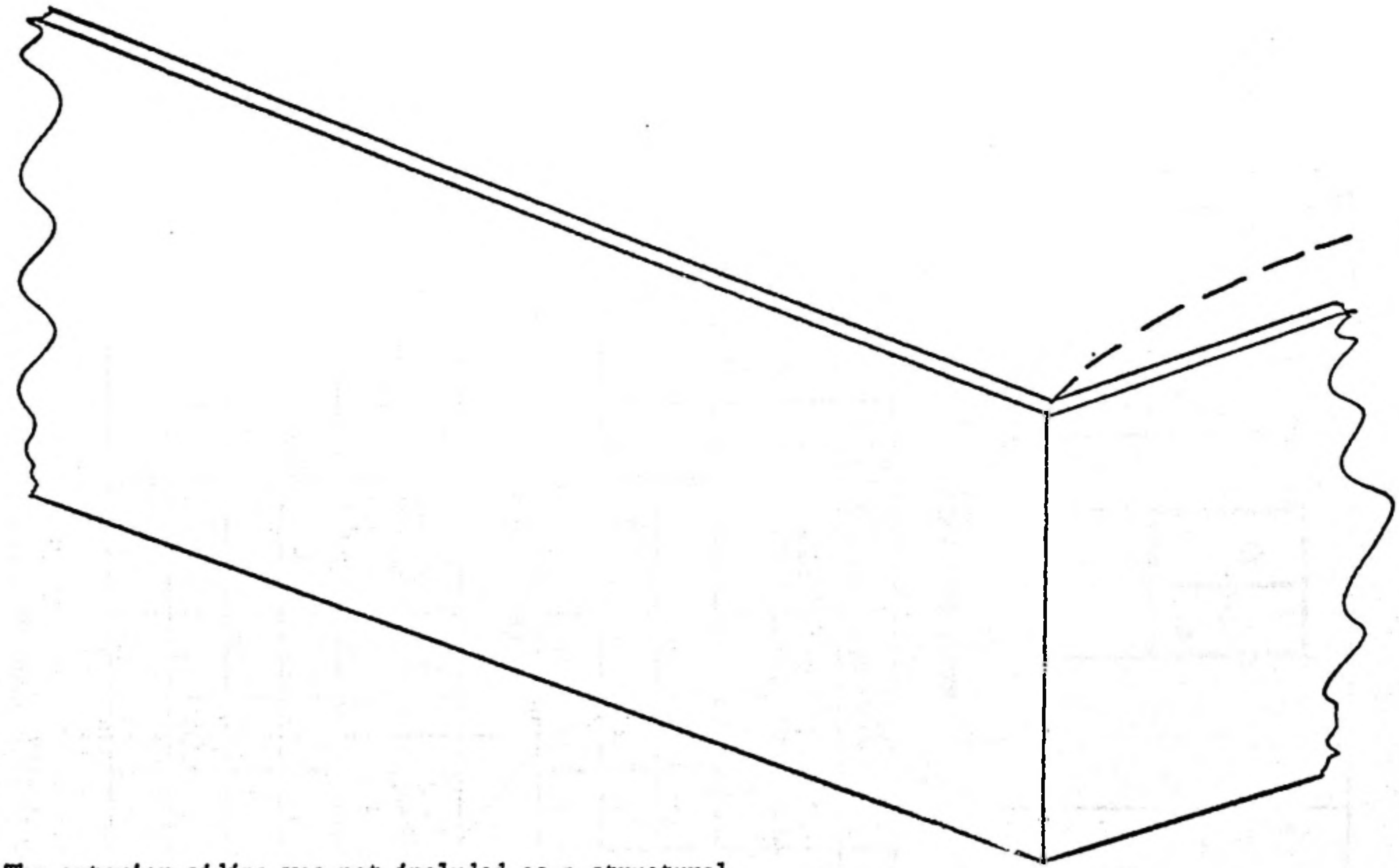
LOAD CASE 5

ELEMENT 794
σ_{min} = -298
τ_{max} = 187

g_{rms}= 2.49

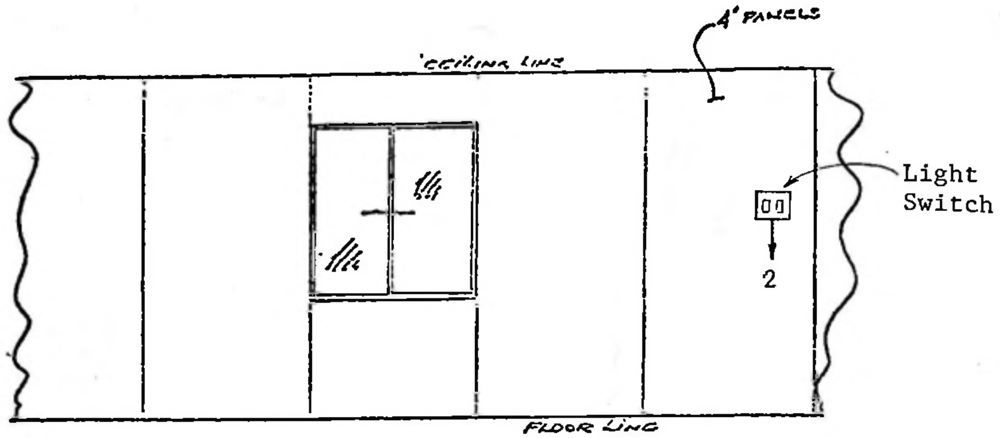
XXX -NODE

FIGURE 15. FREEBODY DIAGRAMS
T-1 FRONT WALL ADJACENT TO WINDOW



The exterior siding was not included as a structural component in the development of the finite element computer model.

FIGURE 16. T-1 - EXTERIOR SIDING AT FORWARD SIDE



RIGHT SIDE WALL:

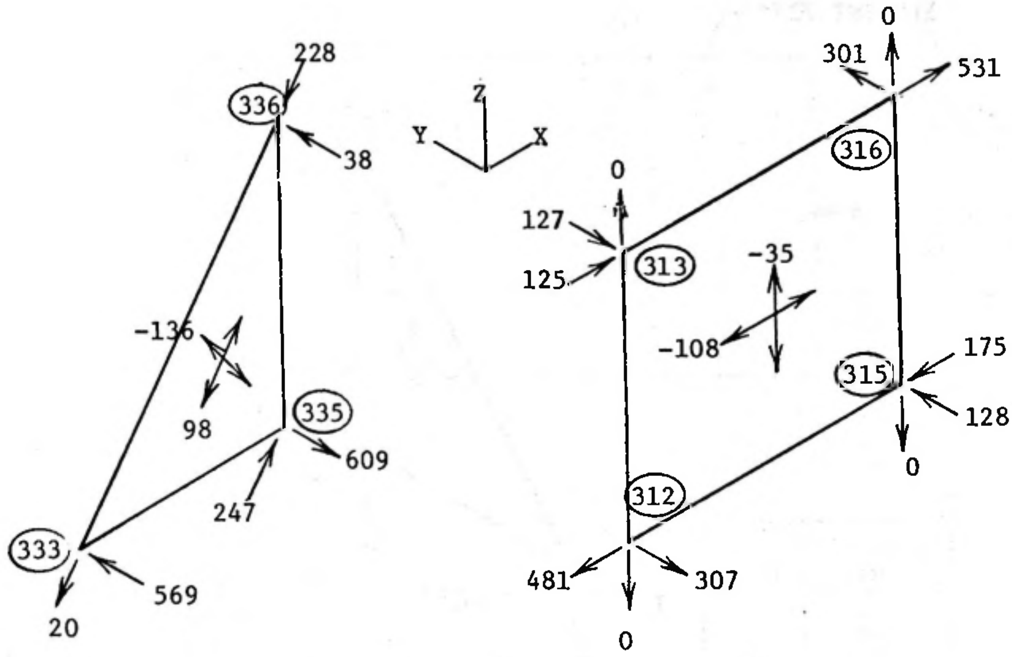
Loading Condition	Load Case ****	▽ Max (PSI)	Elem.	Element Location*	▽ Min (PSI)	Elem.	Element Location
Cond. I	1	333	** 267	Center Right Side	*** -283	754	Front Right Side
	2	371	267	-	-355	524	Forward Right Side
	3	364	267	-	-360	524	-
Cond. II	4	164	756	Forward Right Side	-203	524	-
	5	726	267	-	-854	524	-

LEFT SIDE WALL:

Loading Condition	Load Case ****	Max (PSI)	Elem.	Element Location*	Min (PSI)	Elem.	Element Location
Cond. I	1	285	737	Forward Left Side	-294	737	—
	2	323	737	—	-334	737	-
	3	325	737	—	-335	737	—
Cond. II	4	328	737	—	-377	737	—
	5	659	737	—	-710	737	—

* Element locations are detailed in Table 2 and Figure 35 .
** Positive stress value signifies tension on the element
*** Negative stress value signifies compression on the element
**** See Table 1 for details

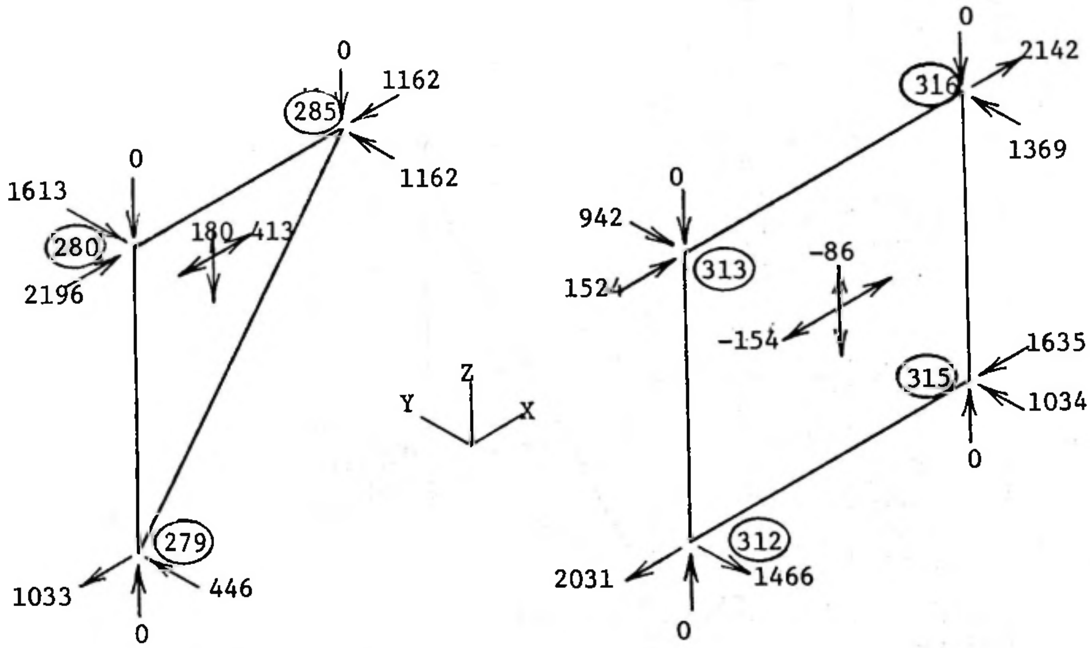
FIGURE 17. T-1 - SIDEWALL PANELING - INTERIOR



ELEMENT 756
σ_{max} = 164

LOAD CASE 4

ELEMENT 524
σ_{min} = -208



g_{rms} = 1.67
ELEMENT 267
σ_{max} = 726

LOAD CASE 5

g_{rms} = 2.93
ELEMENT 524
σ_{min} = -854

(XXX) -NODE

FIGURE 18. FREEBODY DIAGRAMS
T-1 RIGHT SIDE WALL PANELING INTERIOR

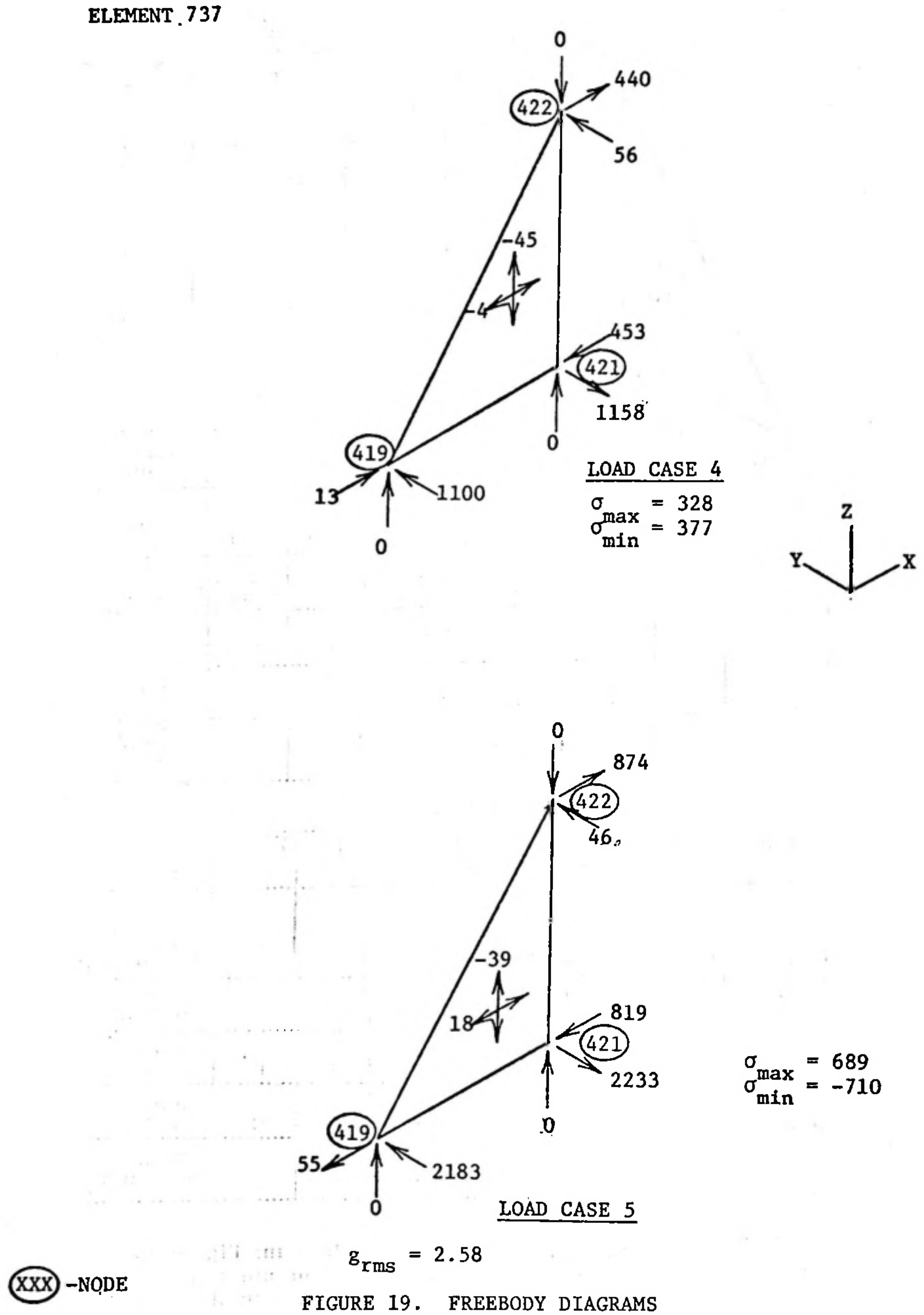
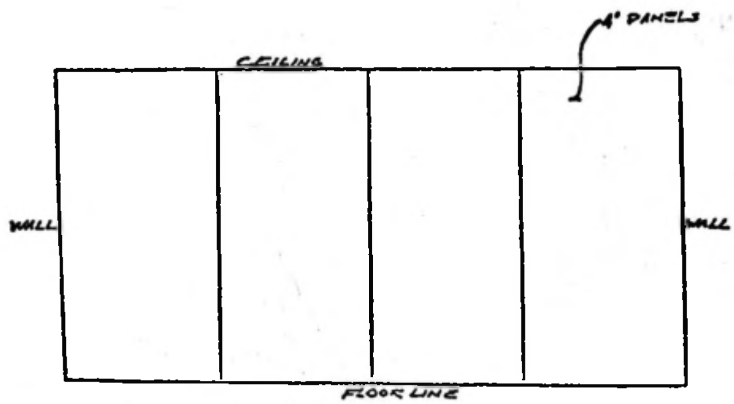


FIGURE 19. FREEBODY DIAGRAMS
T-1 LEFT SIDE WALL PANELING INTERIOR



FRONT WALL:

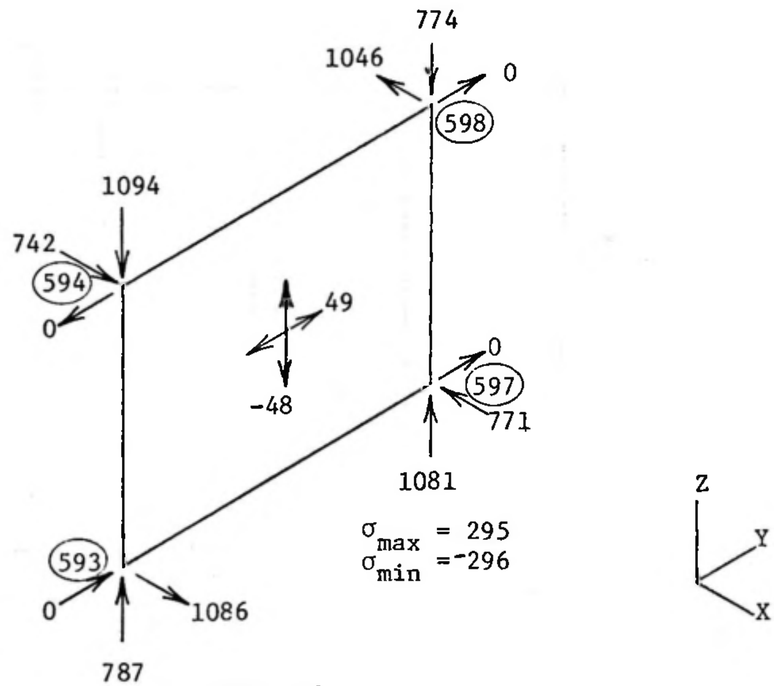
Loading Condition	**** Case	σ Max (PSI)	Elem.	Element Location*	σ (PSI)	Elem.	Element Location*
Cond. I	1	** 449	764	Lower Left Front	*** -367	778	Front Bottom
	2	502	764	Lower Left Front	-409	778 & 802	Front Bottom
	3	505	764	Lower Left Front	-403	779	Front Bottom
Cond. II	4	296	802	Lower Right Front	-295	802	Front Bottom
	5	1002	764	Lower Left Front	-845	802	Front Bottom

REAR WALL:

Loading Condition	**** Case	σ Max (PSI)	Elem.	Element Location*	Min (PSI)	σ Load Case	Element Location *
Cond. I	1	38	18	Right Rear Center	-38	18	Right Rear Center
	2	47	17 & 18	Right Rear Center	-49	18	Right Rear Center
	3	46	17 & 18	Right Rear Center	-47	18	Right Rear Center
Cond. II	4	37	13	Upper Rear Side	-63	10	Lower Rear Side
	5	104	17	Lower Right Rear	-107	18	Right Rear Center

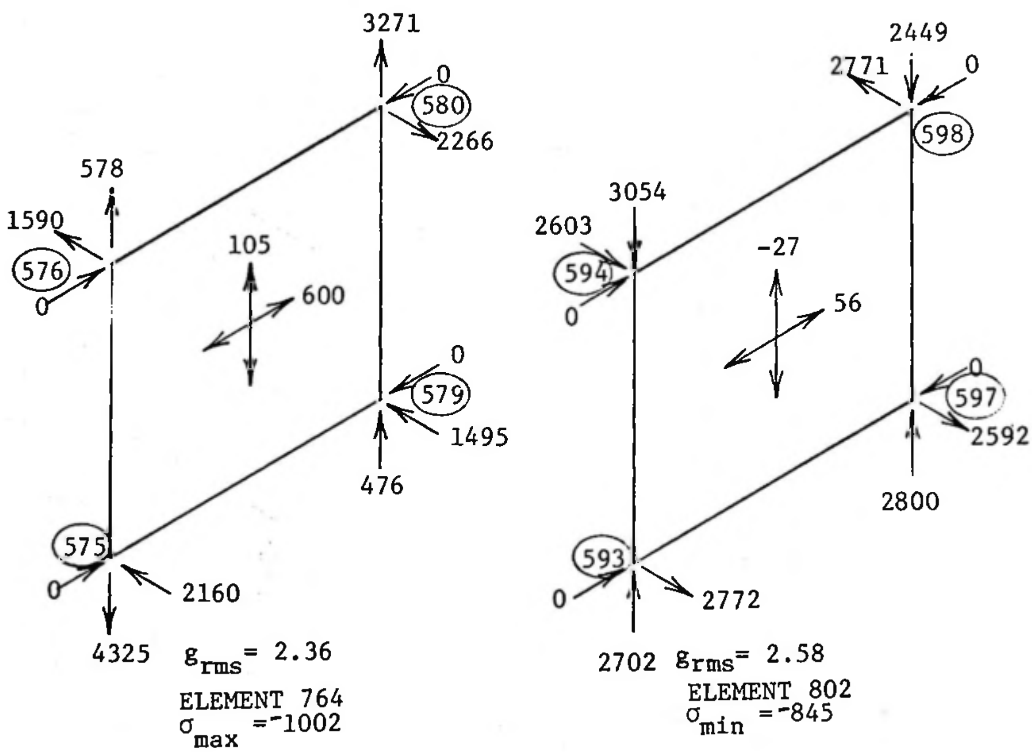
* Element locations are detailed in Table 2 and Figure 35.
** Positive stress value signifies tension on the element
*** Negative stress value signifies compression on the element
**** See Table 1 for details

FIGURE 20. T-1 - ENDWALL PANELING



ELEMENT 802

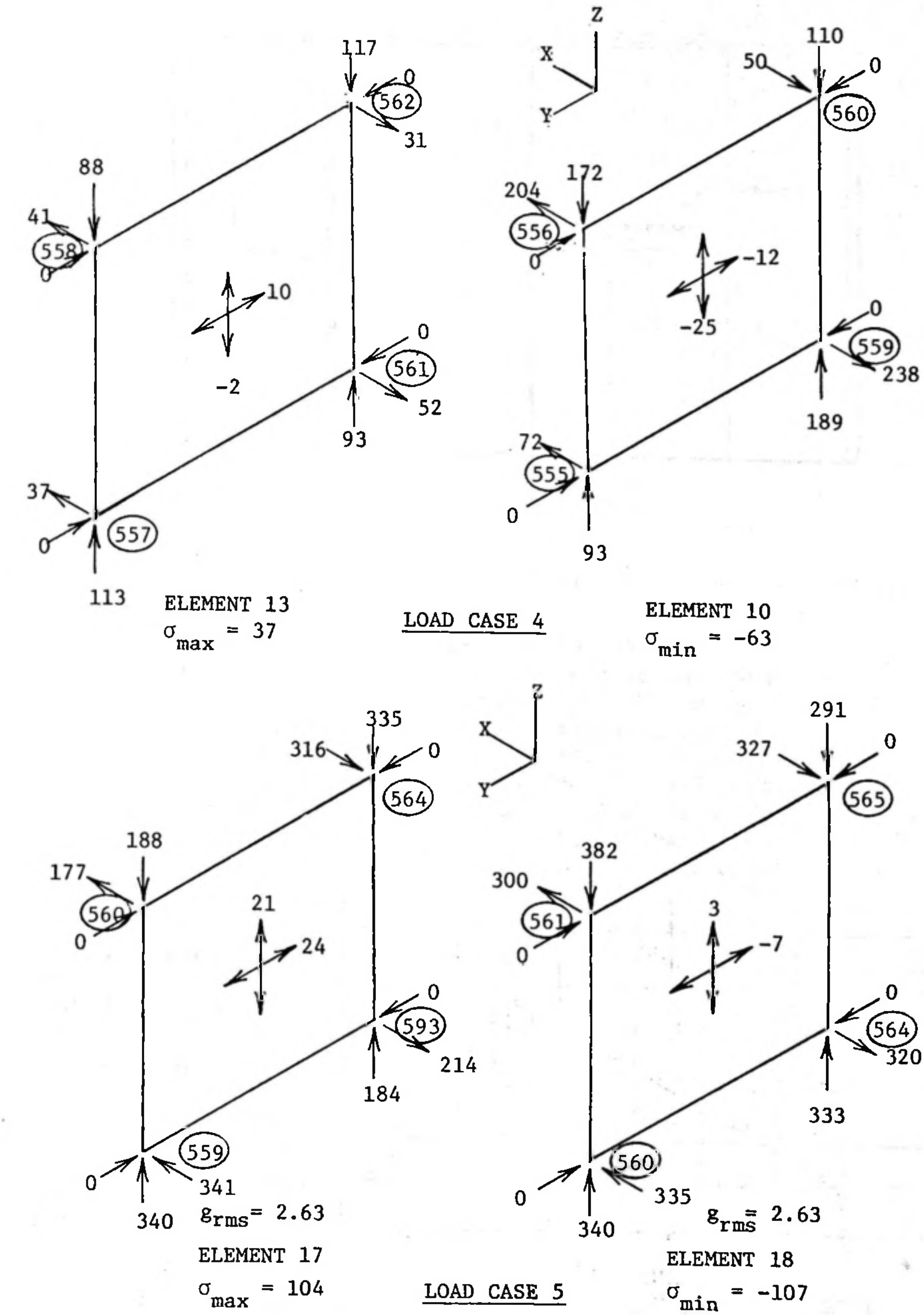
LOAD CASE 4



(XXX) -NODE

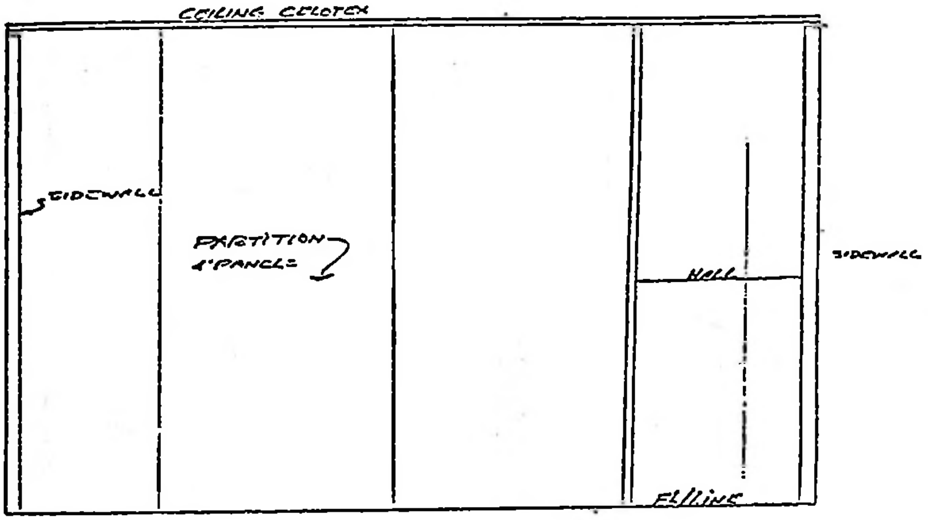
LOAD CASE 5

FIGURE 21. FREEBODY DIAGRAM
T-1 FRONT END WALL PANELING



(XXX) -NODE

FIGURE 22. FREEBODY DIAGRAMS
T-1 REAR END WALL PANELING

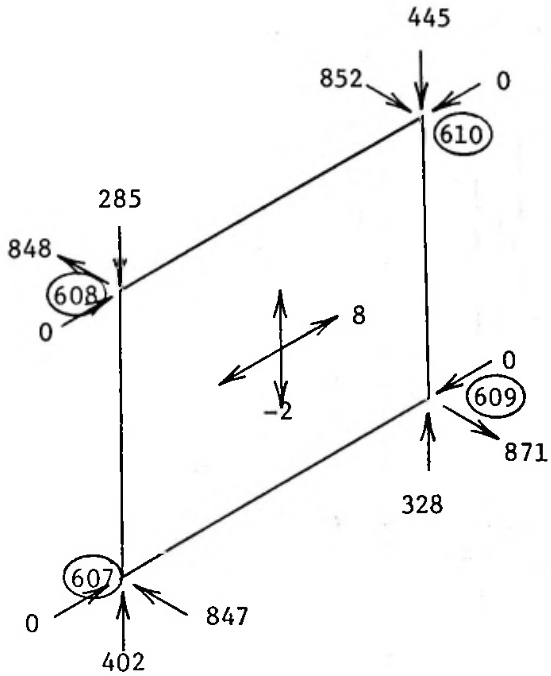


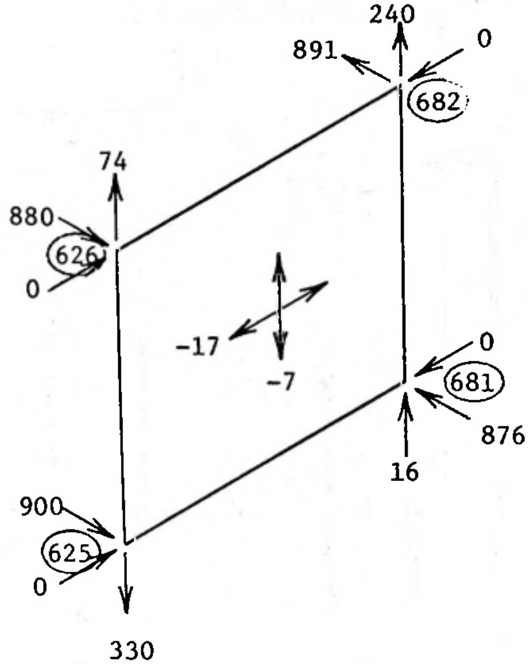
In the finite element model, the different sections of the unit (floor, sidewalls, ceiling, etc.) were "pinned" at the nodal points at the floor and ceiling lines to simulate the unit's stiffness. The shear stresses, therefore, for this model will be zero along the partition/sidewall and partition/ceiling interfaces. Values for the individual wall panels do exist, however.

Loading Condition	Load Case ****	Max (PSI) σ	Elem.	Element Location*	Min (PSI) σ	Elem.	Element Location*	Max (PSI) τ	Elem.	Element Location*
Cond. I	1	** 294	224	Interior Wall E	*** -324	224	Interior Wall E	309	224	Interior Wall E
	2	314	224	Interior Wall E	-361	224	Interior Wall E	337	224	Interior Wall E
	3	318	224	Interior Wall E	-268	224	Interior Wall E	343	224	Interior Wall E
Cond. II	4	117	103	Interior Wall B	-130	224	Interior Wall E	118	224	Interior Wall [illegible]
	5	578	224	Interior Wall B	-751	224	Interior Wall E	665	224	Interior Wall E

* Element locations are detailed in Table 2 and Figure 35.
** Positive stress value signifies tension on the element
*** Negative stress value signifies compression on the element
**** See Table 1 for details

FIGURE 23. T-1 - INTERIOR PARTITION TO CEILING AND SIDEWALL

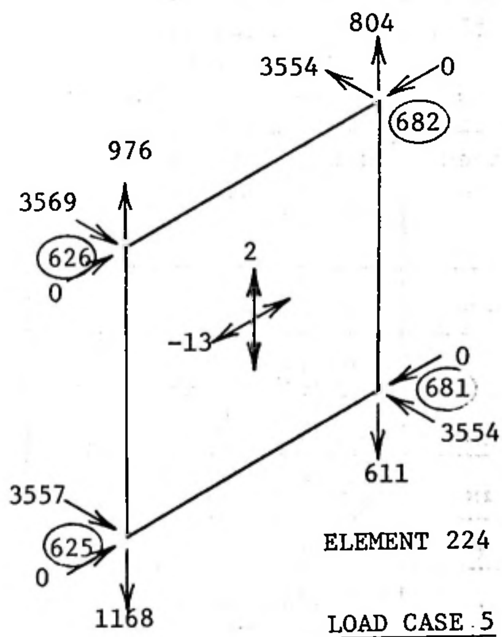


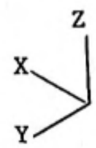


ELEMENT 103
$\sigma_{max} = 117$

LOAD CASE 4

ELEMENT 224
$\sigma_{min} = -130$
$\tau_{min} = 118$





ELEMENT 224

LOAD CASE 5

$\sigma_{max} = 578$

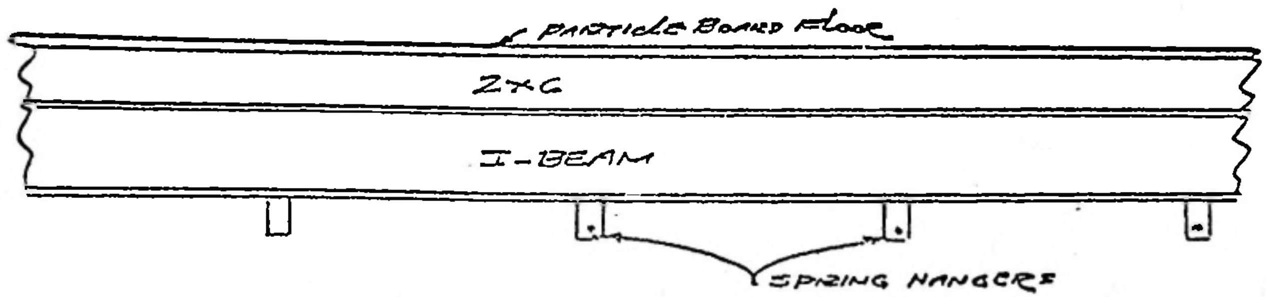
$\sigma_{min} = -751$

$\tau_{max} = 665$

$\varepsilon_{rms} = 1.71$

(XXX) -NODE

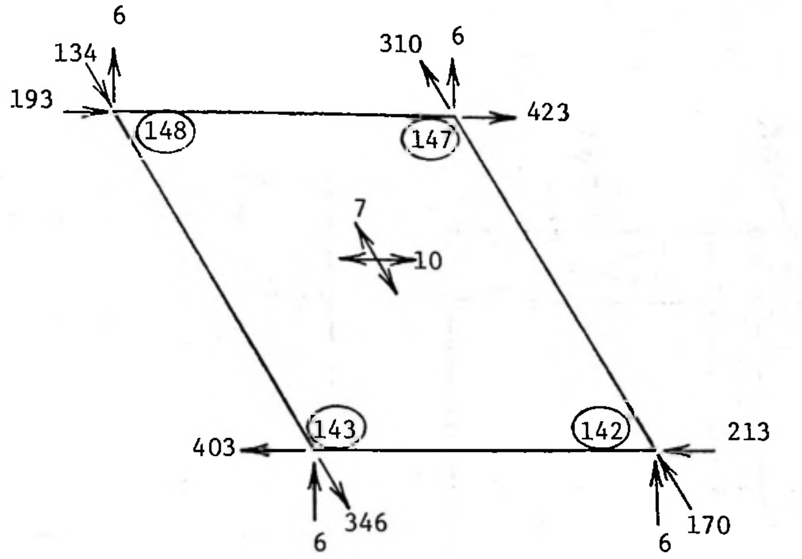
FIGURE 24. FREEBODY DIAGRAMS
T-1 INTERIOR PARTITION TO CEILING AND SIDE WALL



Loading Condition	****Load Case	σ Max (PSI)	Elem.	Element * Location	σ Min (PSI)	Elem.	Element Location
Condition I	1	55**	245	Right Side	-39***	245	-
	2	57	245	-	-38	245	-
	3	59	245	-	-38	245	-
Condition II	4	33	281	Left Side	-15	281	-
	5	170	250	Left of Ctr.	-181	250	-

* Element locations are detailed in Table 2 and Figure 35.
** Positive stress value signifies tension on the element
*** Negative stress value signifies compression on the element
**** See Table 1 for details

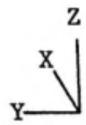
FIGURE 25. T-1 - FLOOR OVER AXLE

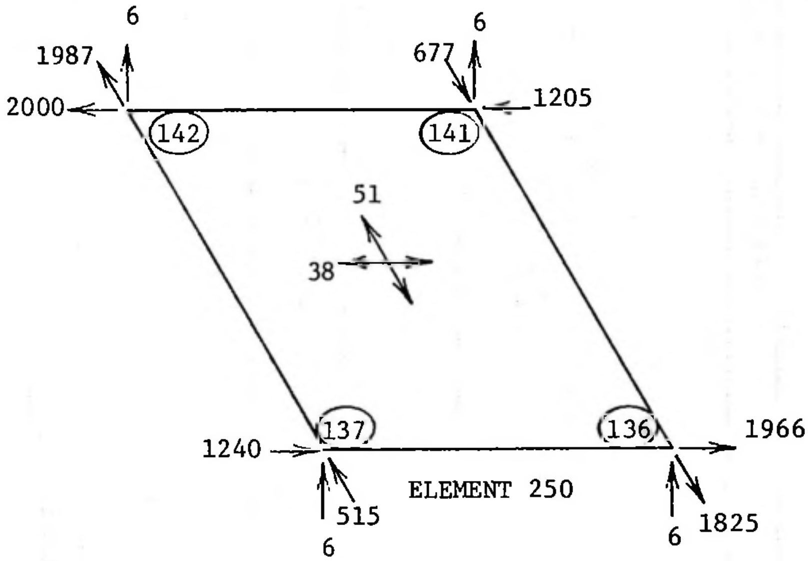


ELEMENT 281

LOAD CASE 4

$\sigma_{max} = 33$
$\sigma_{min} = -15$





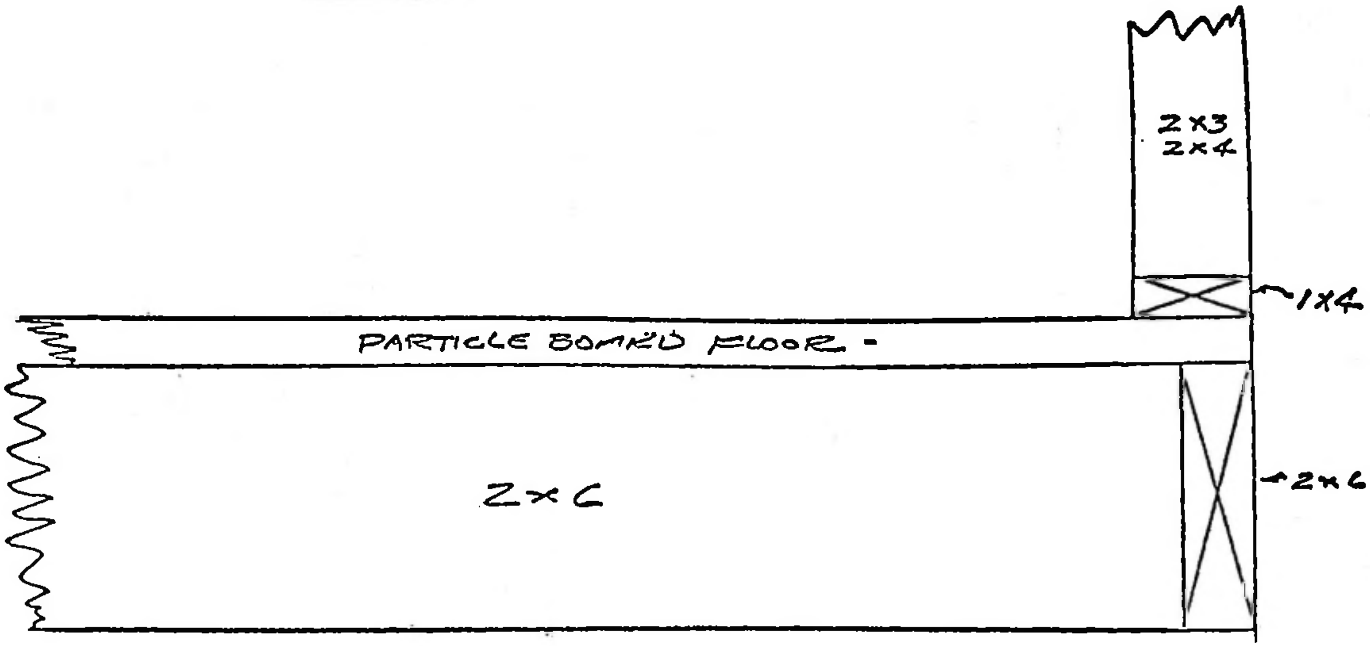
$\sigma_{max} = 170$
$\sigma_{min} = -181$

$g_{rms} = 1.67$

XXX -NODE

LOAD CASE 5

FIGURE 26. FREEBODY DIAGRAMS
T-1 FLOOR OVER AXLES



Loading Condition	Load Case	Max (PSI)	Elem.	Element Location*	Min (PSI)	Elem.	Element Location
Cond. I.	**** 1	26 **	215	Behind Axles	*** -39	164	Behind Axles
	2	27	215	-	-34	164	-
	3	25	215	-	-32	164	-
Cond. II.	4	14	215	-	-18	164	-
	5	47	215	-	-24	97	Left Rear

* Element locations are detailed in Table 2 and Figure 35.
** Positive stress value signifies tension on the element
*** Negative stress value signifies compression on the element
**** See Table 1 for details

FIGURE 27. T-1 - HALL FLOOR OVER OUTRIGGERS

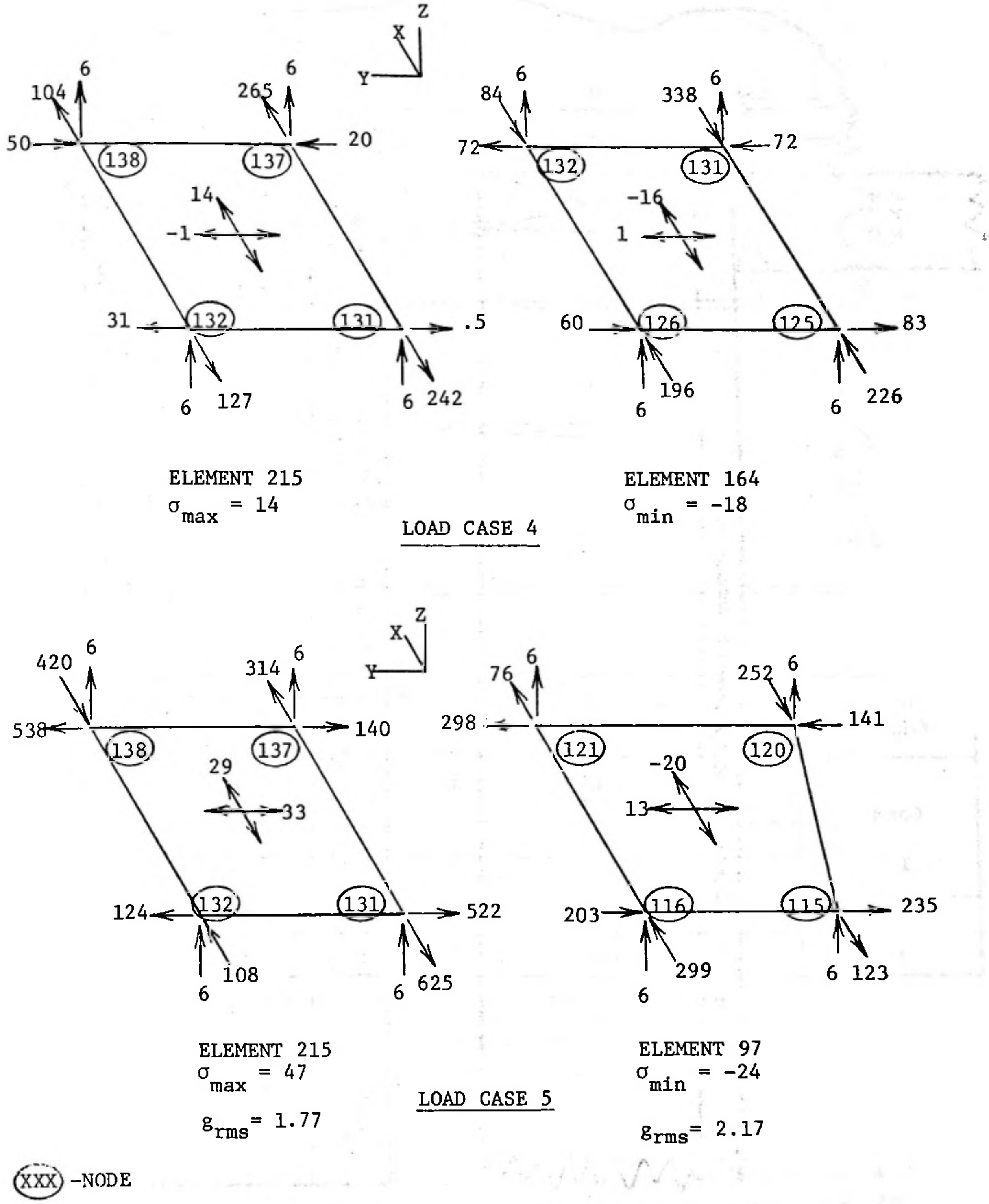
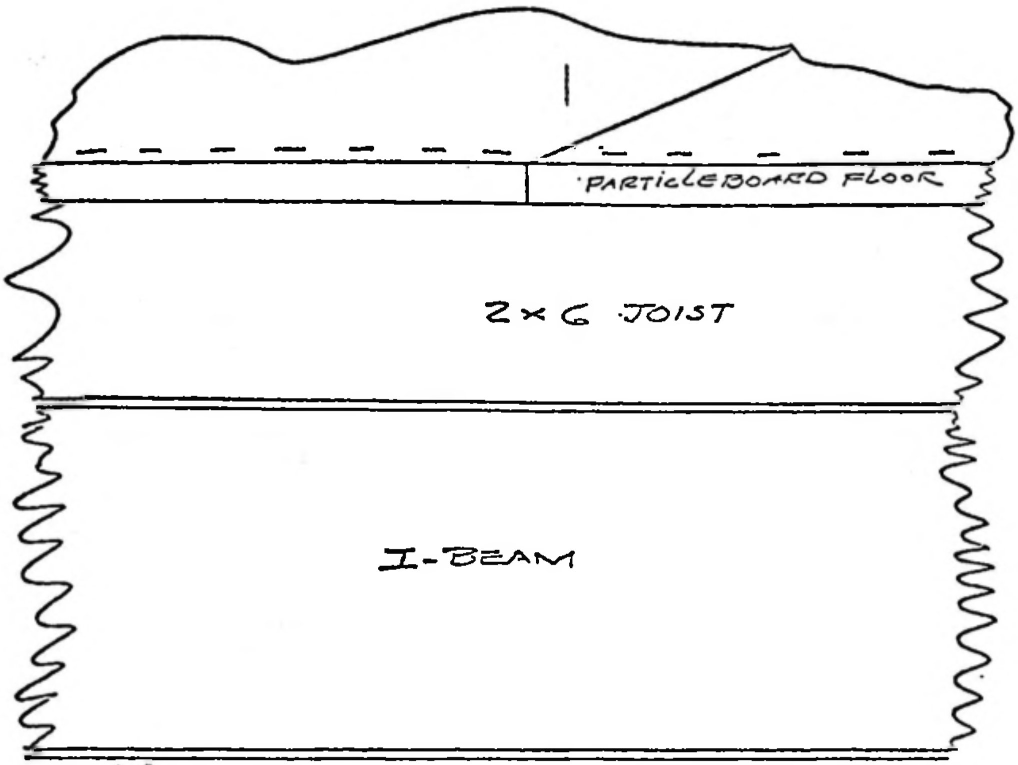


FIGURE 28. FREEBODY DIAGRAMS
T-1 HALL FLOOR OVER OUTRIGGERS



Loading Condition	Load Case ****	σMax (PSI)	Elem.	Element* Location	σMin (PSI)	Elem.	Element Location
Cond. I	1	117**	357	Forward of Axles	- 86***	158	Behind Axles
	2	121	357	-	-107	158	-
	3	119	357	-	-111	158	
Cond. II	4	55	357	-	- 84	158	-
	5	180	357	-	-282	158	-

NOTE: σ_{max} and σ_{min} are the in-plane principal stresses.

* Element locations are detailed in Table 2 and Figure 35.
** Positive stress value signifies tension on the element
*** Negative stress value signifies compression on the element
**** See Table 1 for details

FIGURE 29. T-1 - FLOOR JOINT

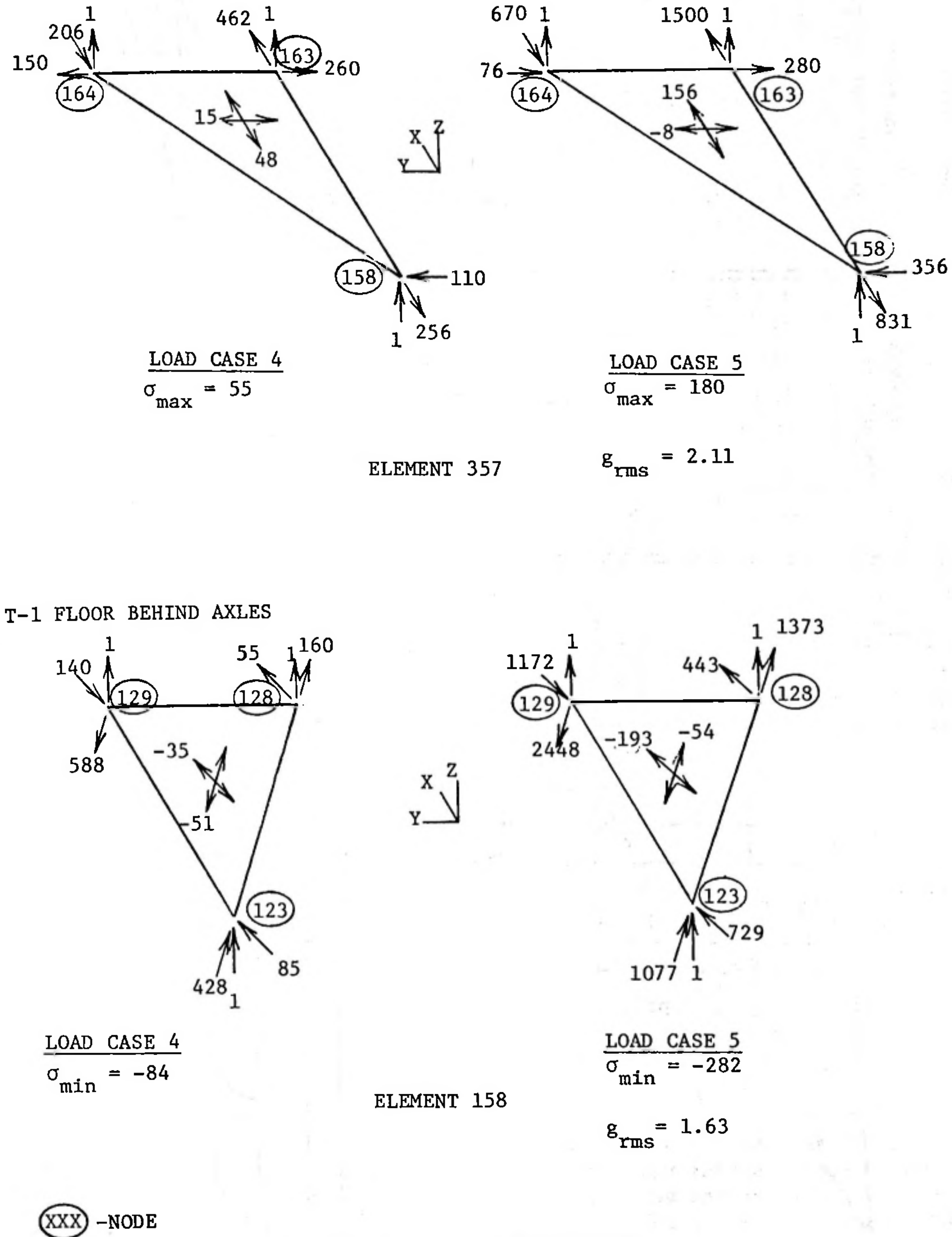


FIGURE 30. FREEBODY DIAGRAMS
T-1 FLOOR JOINT

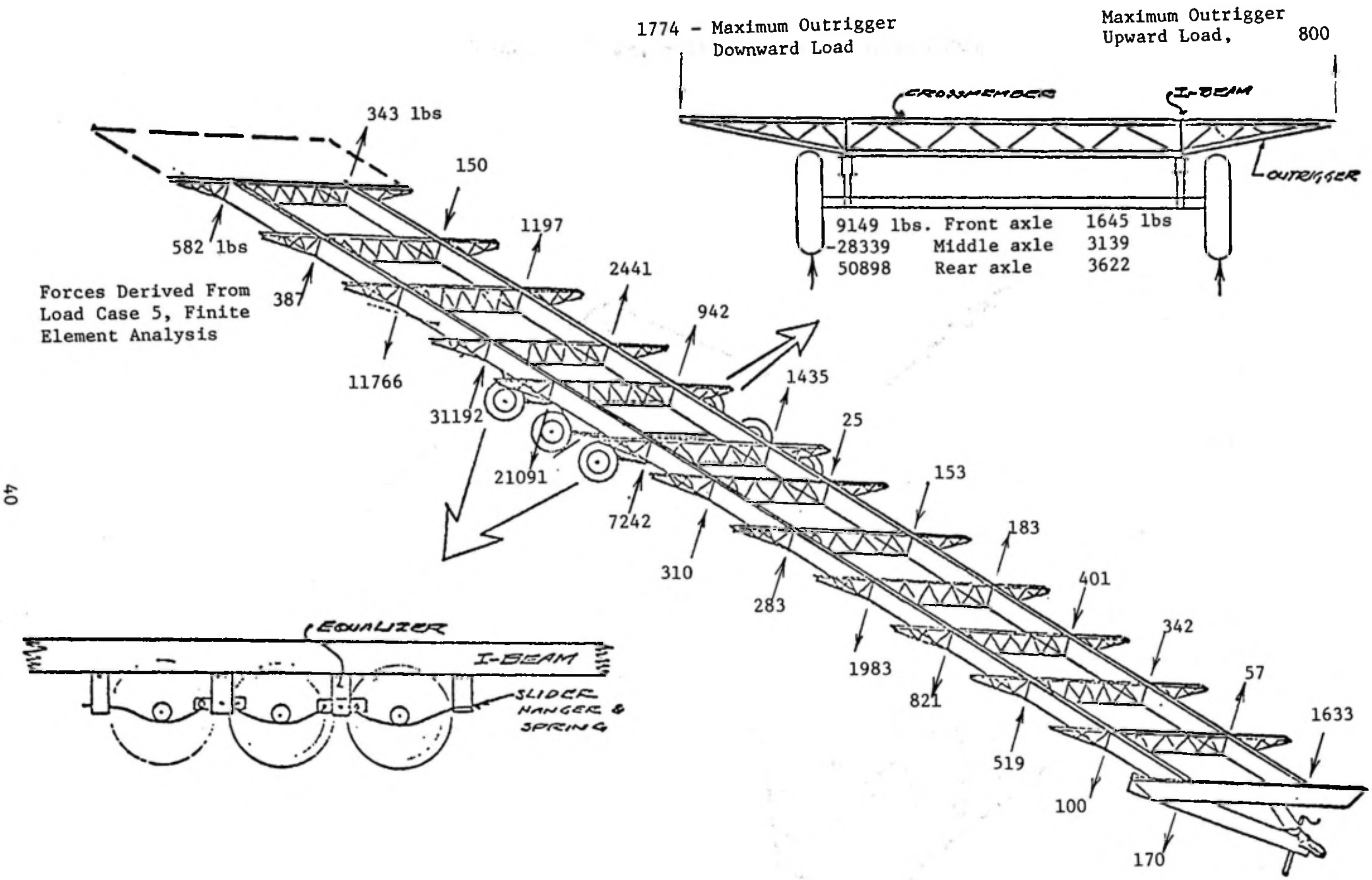
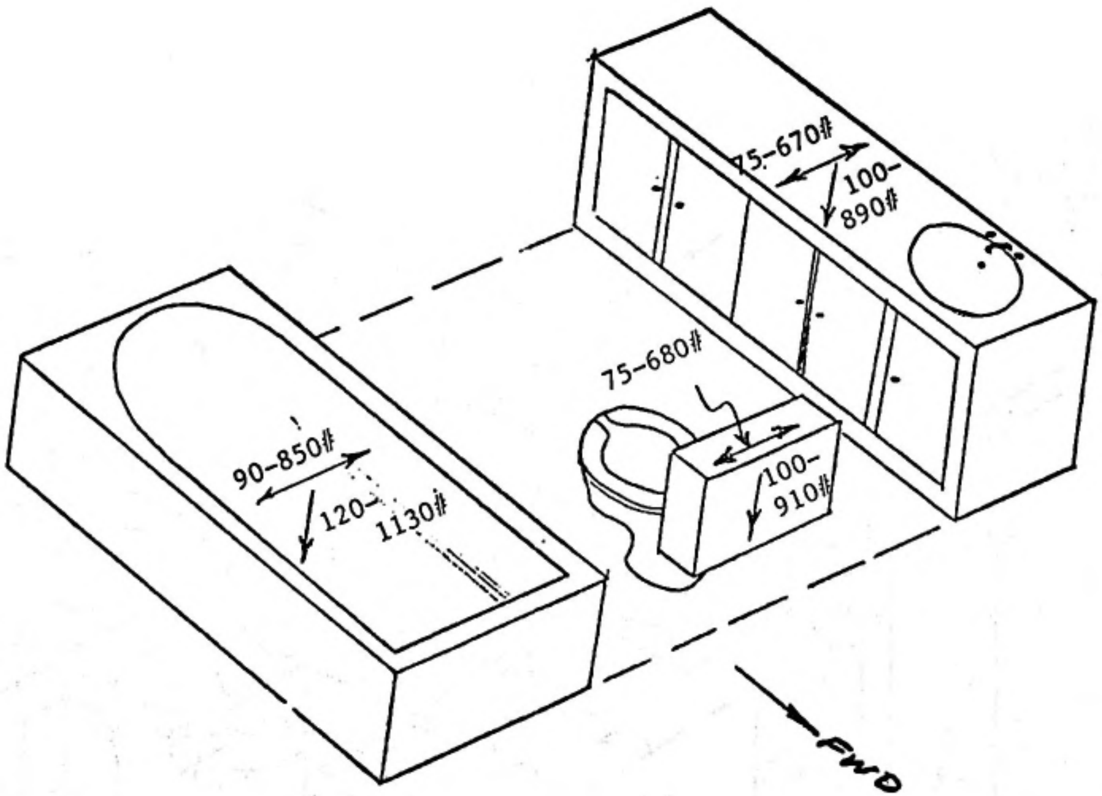


FIGURE 31. CHASSIS AND RUNNING GEAR



g_{rms} = 2.67 to 3.14 g's

FIGURE 32. T-1 - FRONT BATH AND COMPONENTS

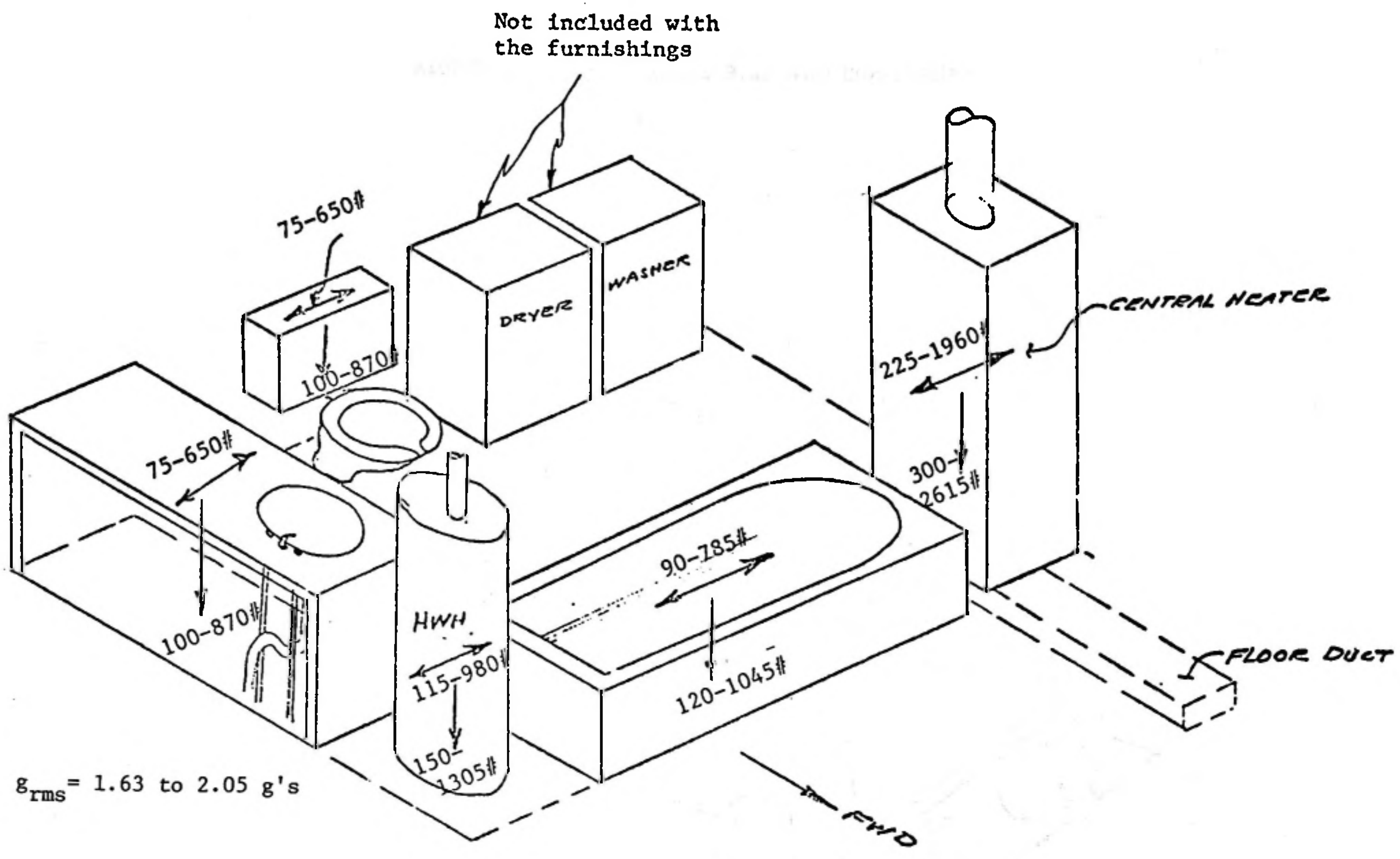
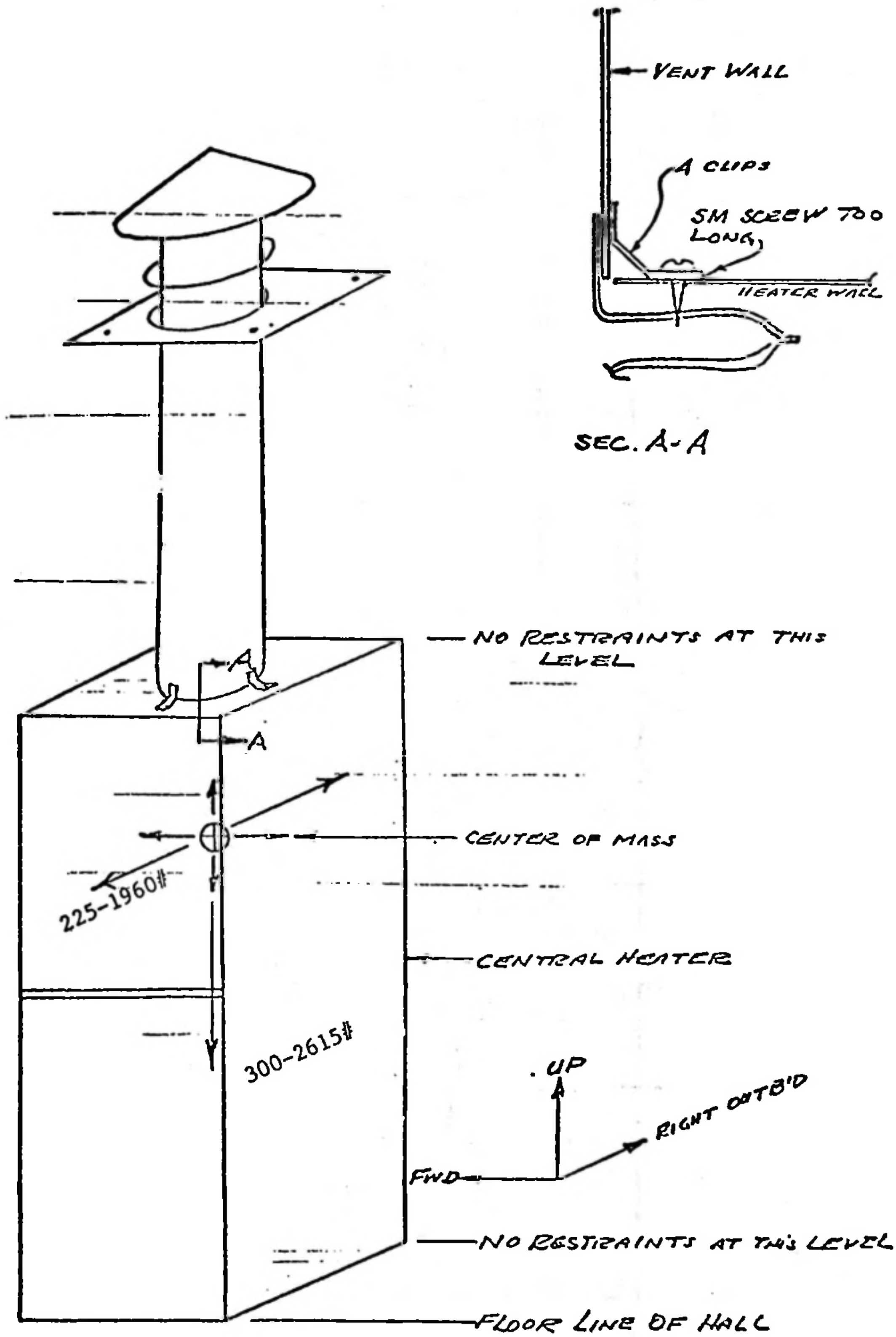


FIGURE 33. T-1 - REAR BATH AND RELATED COMPONENTS



g_{rms}= 1.63 to 1.71 g's

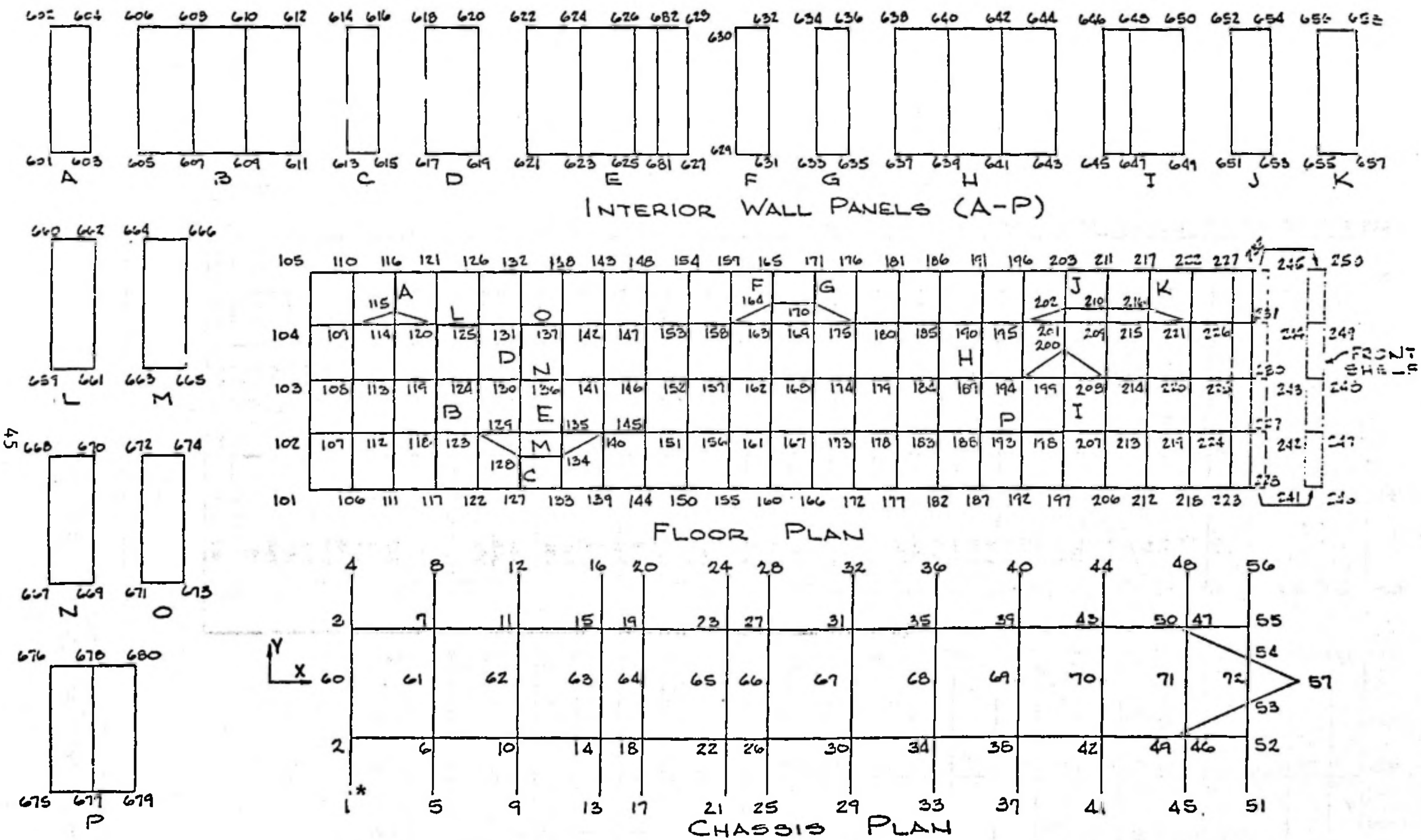
FIGURE 34. T-1 - CENTRAL HEATER TO VENT

TABLE 2

T-1 ELEMENT DIRECTORY

ELEMENT NO.	NODAL CONNECT POINTS*			
	I**	J**	K**	L**
10	555	559	560	556
13	557	561	562	558
17	559	563	564	560
18	560	564	565	561
96	114	120	115	115
97	115	120	121	116
103	607	609	610	608
136	120	125	126	121
153	272	268	267	271
154	271	267	266	270
158	123	128	129	129
164	125	131	132	126
175	362	365	366	363
180	474	469	468	473
186	277	272	271	274
190	276	274	273	275
192	273	270	269	275
215	131	137	138	132
224	625	681	682	626
228	364	367	369	365
229	365	369	366	366
235	479	473	478	478
241	280	277	276	279
245	134	140	135	135
250	136	141	142	137
267	285	280	279	279
281	142	147	148	143
285	370	375	376	373
314	375	379	380	376
338	381	384	382	382
357	158	163	164	164
435	302	298	297	301
466	306	302	301	305
481	397	402	398	398
524	316	313	312	315
546	406	409	410	404
589	409	412	410	410
657	324	322	321	323
684	330	326	325	329
733	226	231	232	227
737	419	421	422	422
754	337	334	333	336
756	336	333	335	335
764	575	579	580	576
778	579	585	586	580
786	581	583	584	582
794	587	595	591	588
796	591	595	596	592
802	593	597	598	594

*See Figure 35 for nodal point locations.
**Computer reference symbols



*Numbers on the model indicate nodal point locations.

FIGURE 35. T-1 - FINITE ELEMENT MODEL

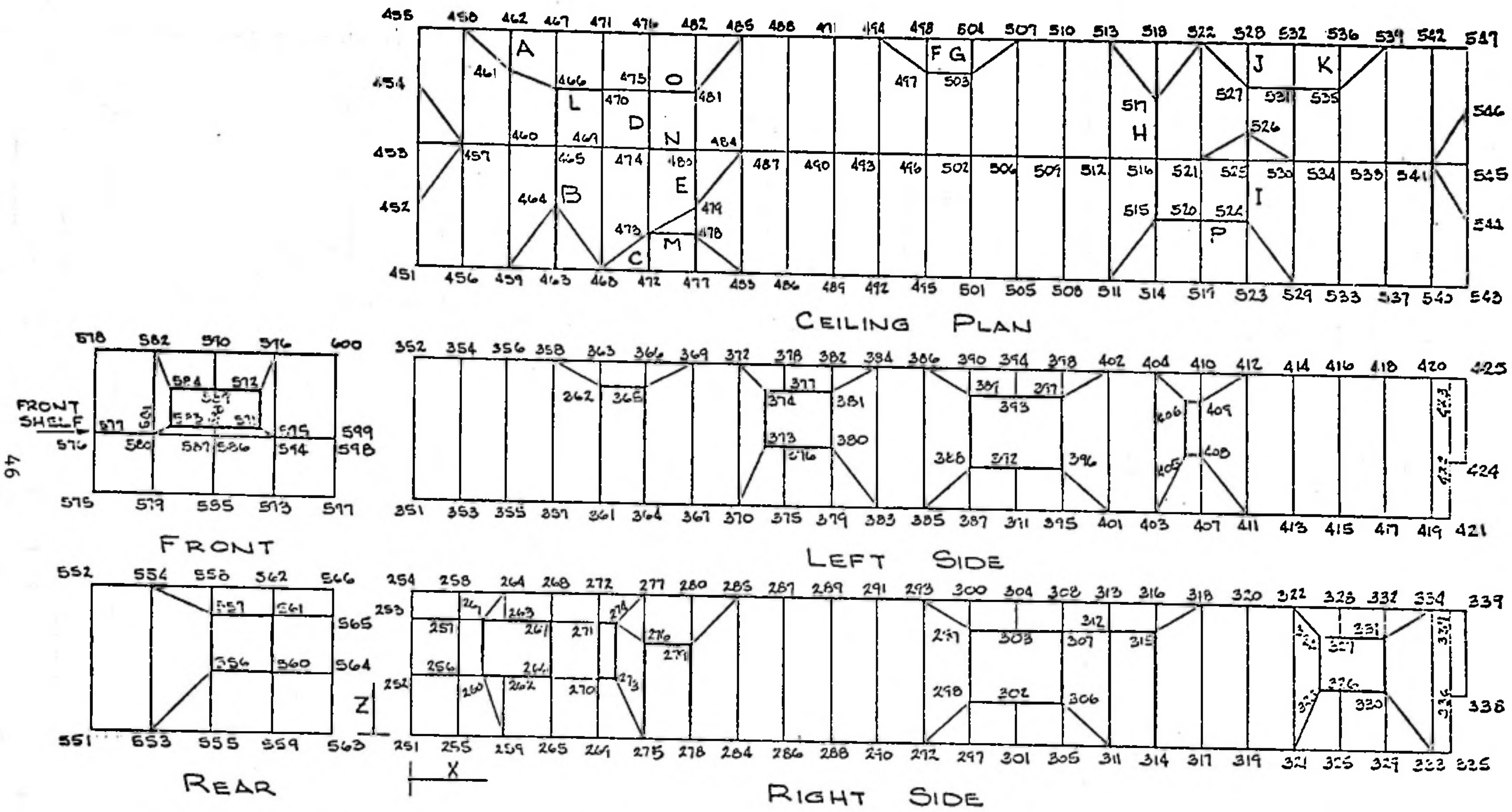


FIGURE 35 (Cont'd)

T-2 24 x 56 DOUBLE WIDE MOBILE HOME UNIT

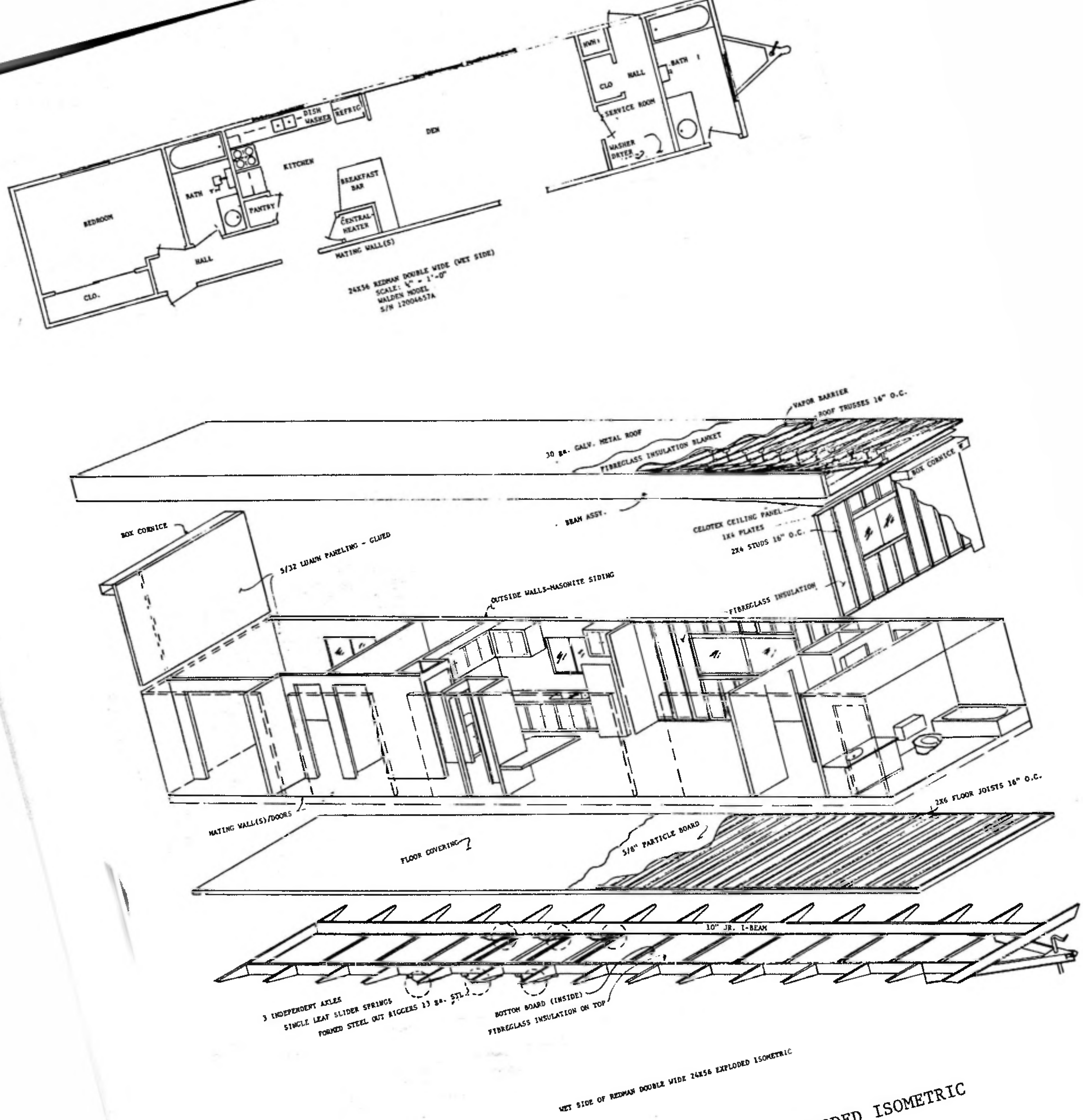


FIGURE 36. T-2A (WET SIDE) DOUBLE WIDE - EXPLODED ISOMETRIC

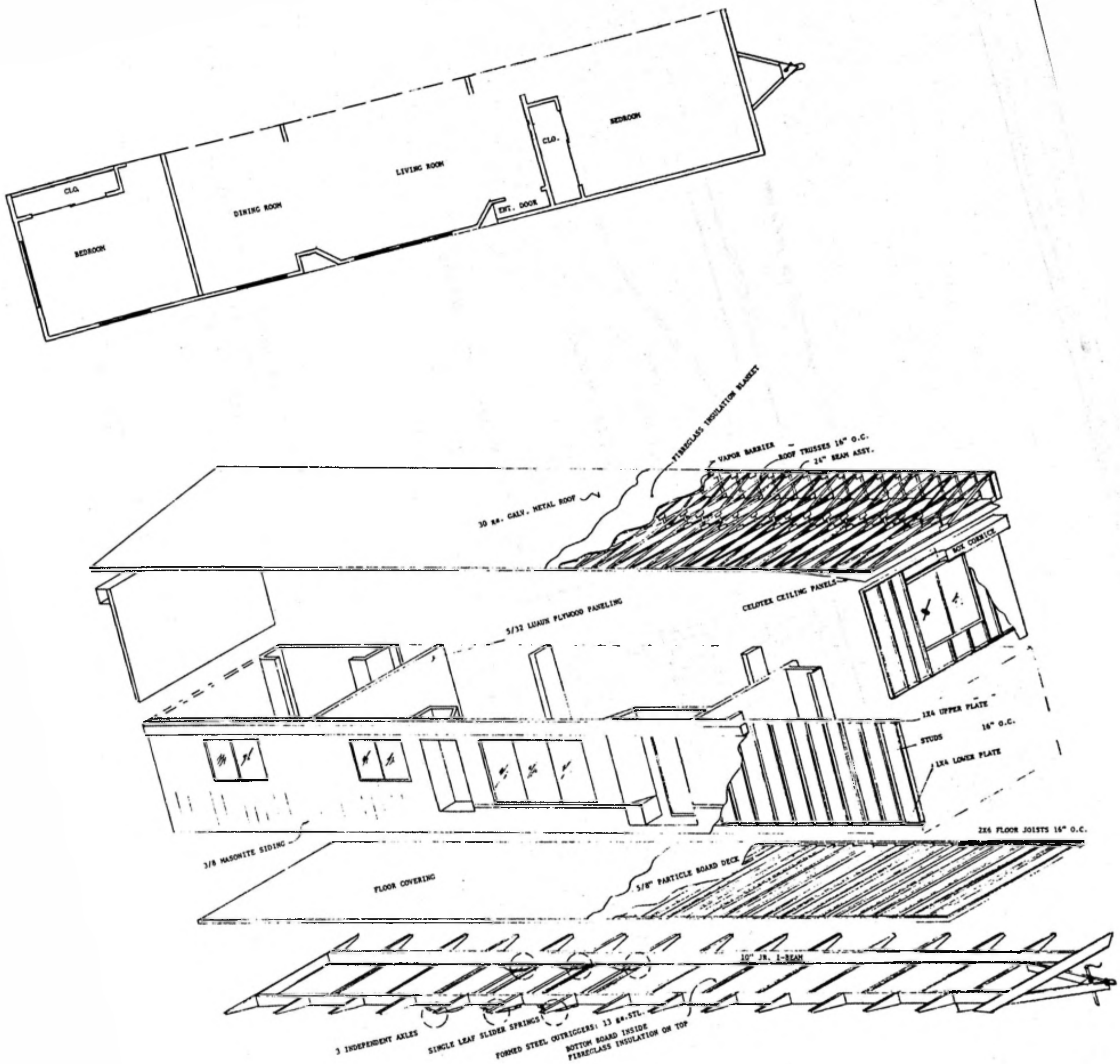
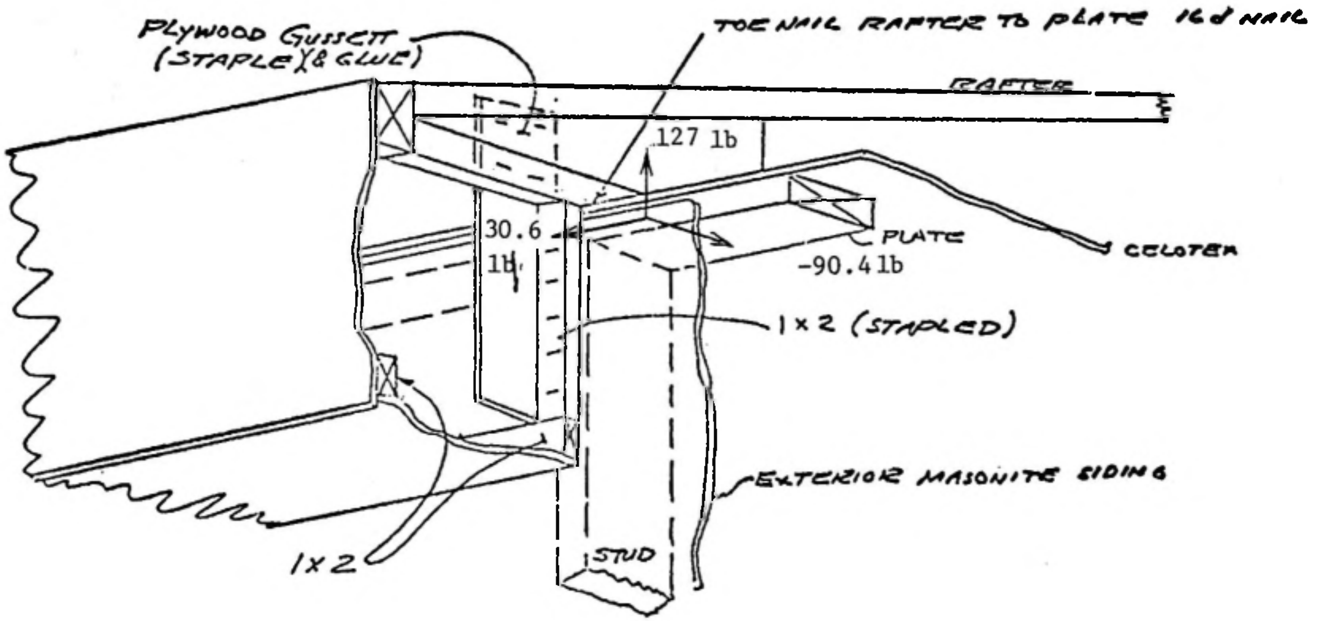


FIGURE 37. T-2B DOUBLE WIDE - EXPLODED ISOMETRIC



Forces indicated are typical ones for Load Case 5, finite element analysis.

FIGURE 38. T-2A/B DOUBLE-WIDE - ROOF TO SIDEWALL FASTENINGS

Forces indicated are typical
ones for Load Case 5
finite element analysis.

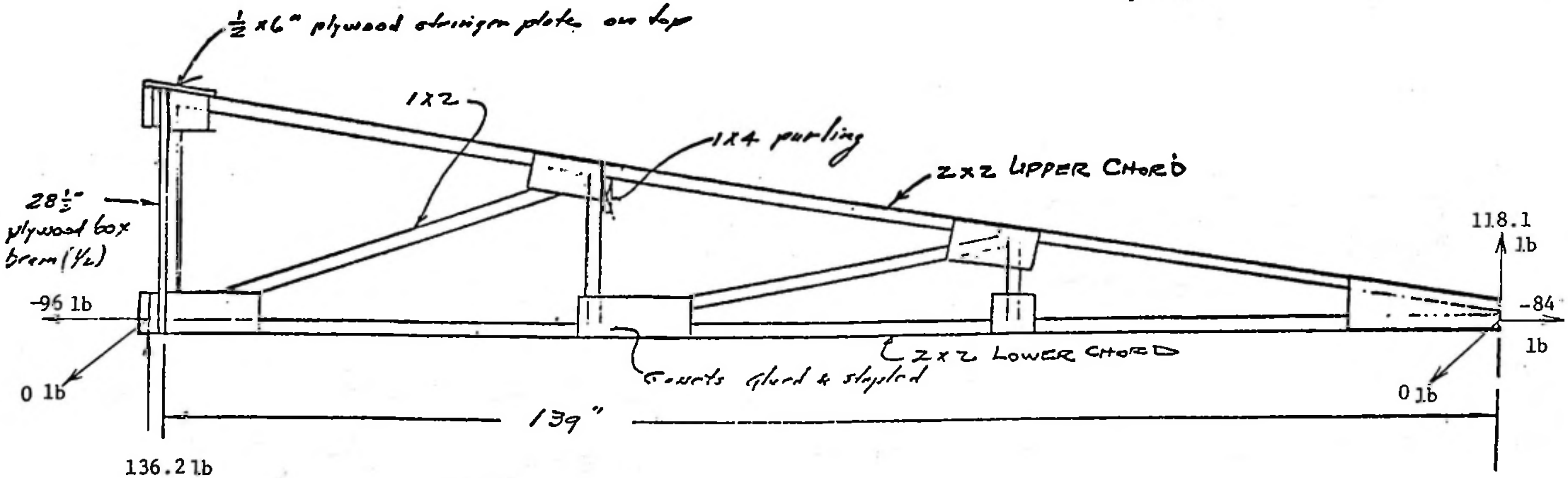


FIGURE 35. T-2A/B DOUBLE WIDE - ROOM ASSEMBLY

The ceiling was not considered as a structural component in the development of the finite element analytical model.

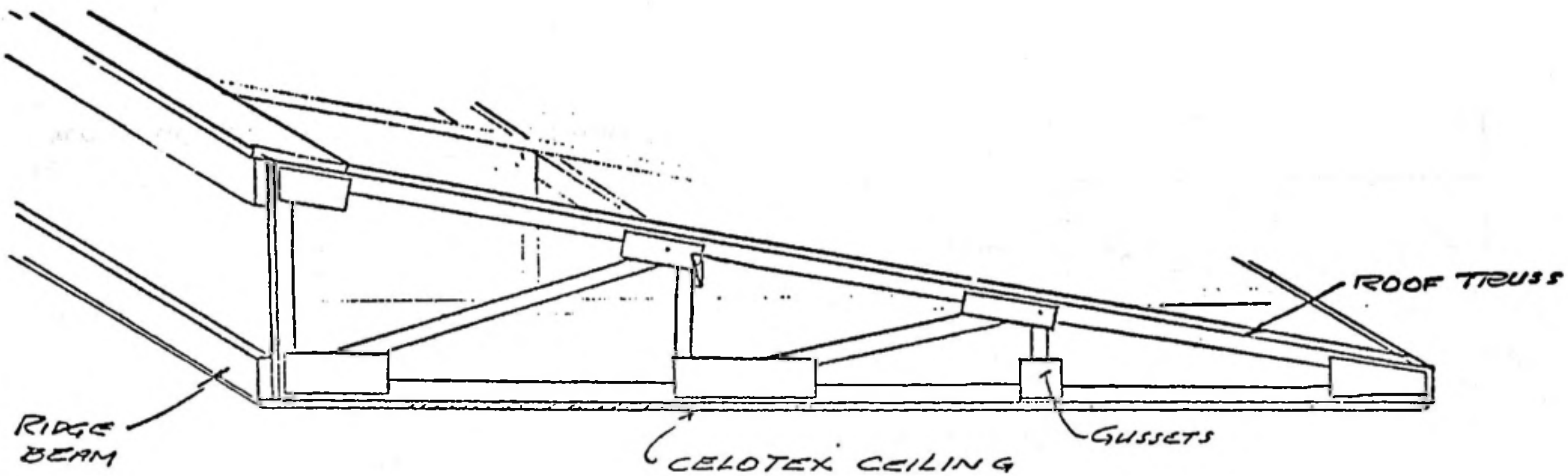
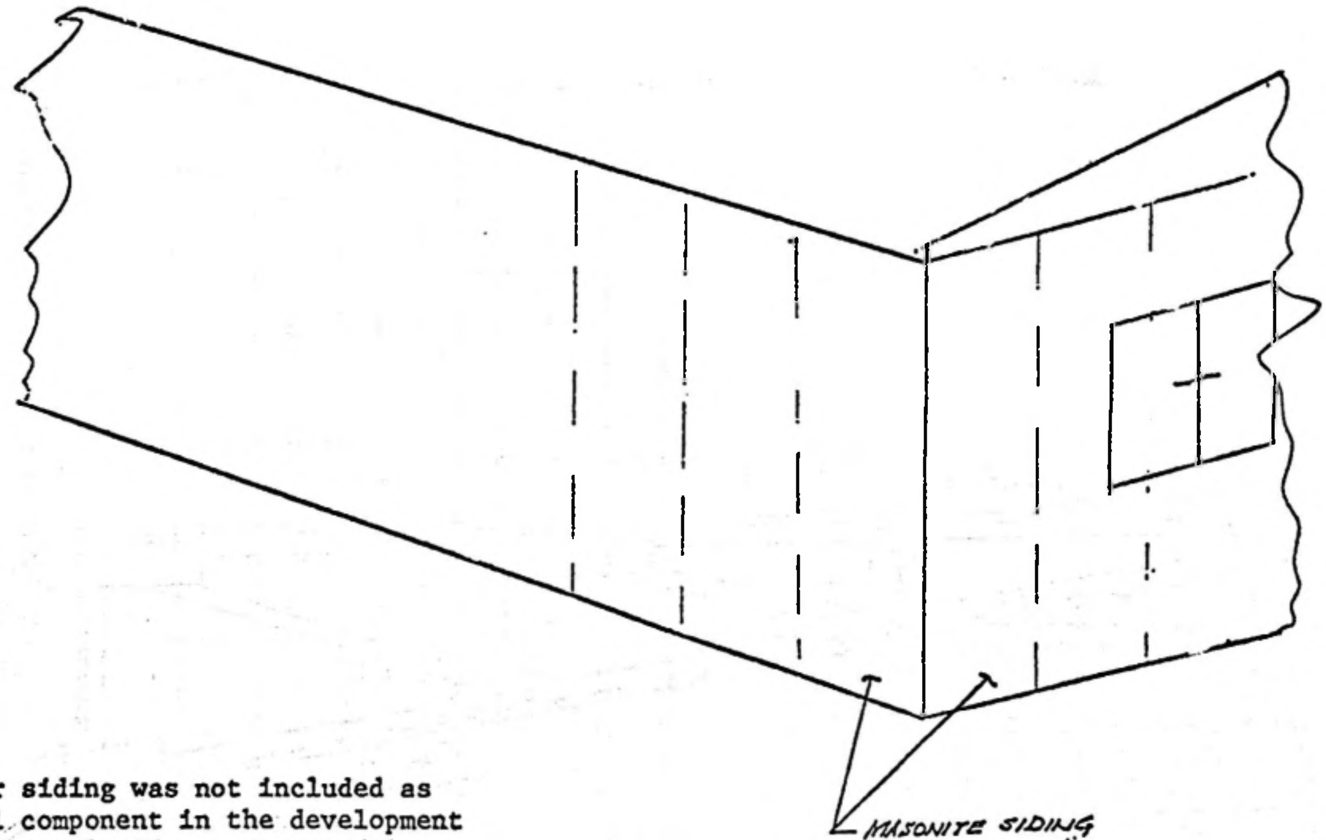
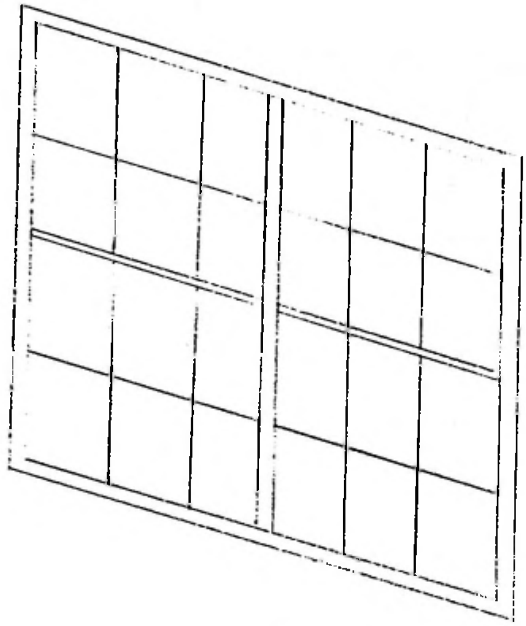


FIGURE 40. T-2A/B DOUBLE-WIDE - ROOF TRUSS TO CEILING ATTACHMENT



The exterior siding was not included as a structural component in the development of the static analysis computer model.

FIGURE 41 . T-2B DOUBLE-WIDE - EXTERIOR SIDING AT FORWARD SIDE



Stress in elements adjacent to the windows are:

Load Case ****	σ max (PSI)	Elem.	Element Location*	σ min (PSI)	Elem.	Element Location	max τ (PSI)	Elem.	Element Location
1	** 251	391	Center Right Side	*** -238	470	Center Right Side	234	469	Center Right Side
2	281	391	Center Right Side	-266	470	Center Right Side	261	469	Center Right Side
4	19	527	Center Right Side	-25	527	Center Right Side	22	527	Center Right Side
5	38	389	Center Right Side	-31	390	Center Right Side	34	390	Center Right Side

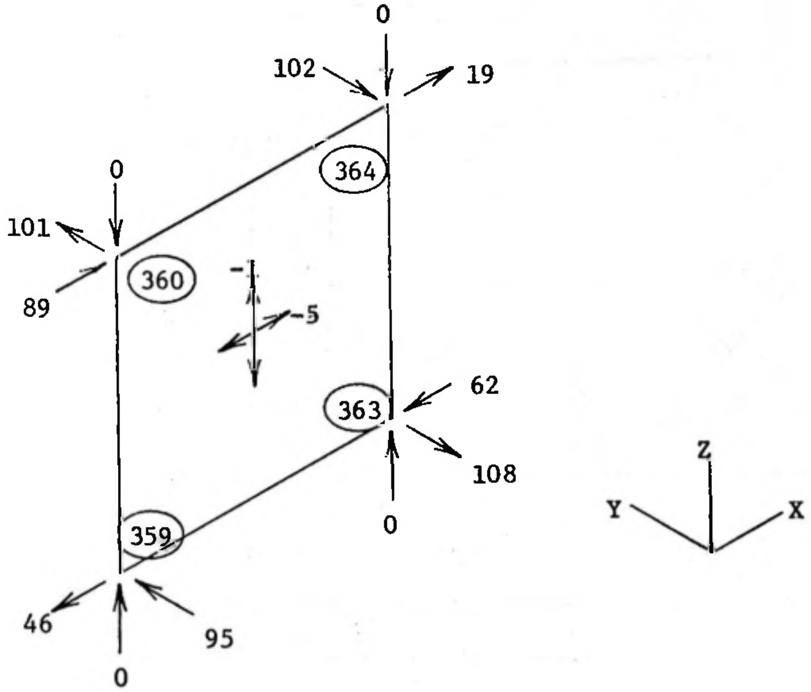
* Element locations for T-2A are detailed in Table 3 and Figure 69; for T-2B, Table 4 and Figure 70.

** Positive stress value signifies tension on the element.

*** Negative stress value signifies compression on the element

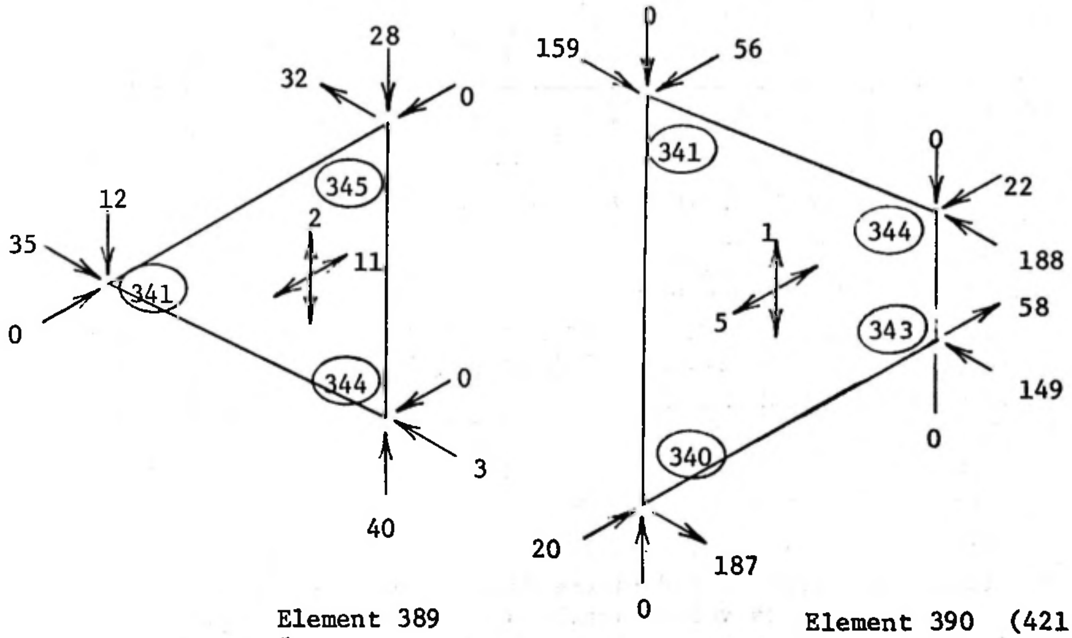
**** See Table 1 for details.

FIGURE 42. T-2B DOUBLE-WIDE - WINDOW GLAZING - LIVING ROOM



ELEMENT 527
σ max = 19 σ min = -25

LOAD CASE 4



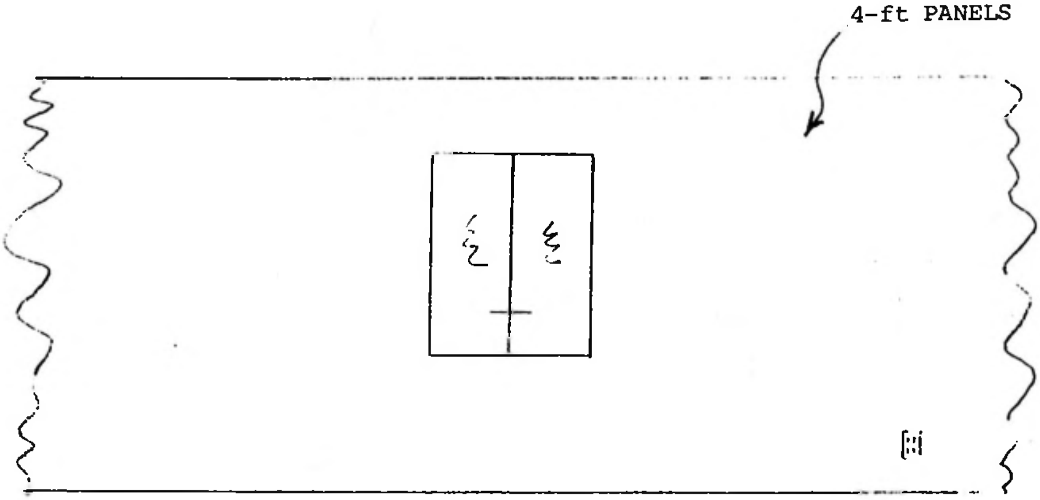
Element 389
σ max = 38
g_{rms} = 1.67

LOAD CASE 5

Element 390 (421, 422)
σ min = -31
g_{rms} = 1.67

(XXX) - NODE

FIGURE 43. FREEBODY DIAGRAMS
T-2B WINDOW GLAZING, LIVING ROOM



RIGHT SIDEWALL:

	**** Load Case	σ max (PSI)	Elem.	Element Location*	σ min (PSI)	Elem.	Element Location
T-2A	1	** 194	853	Front Right Side	*** -85	852	Front Right Side
	2	205	853	Front Right Side	-92	852	Front Right Side
	4	77	48	Rear Right Side	-78	48	Rear Right Side
	5	103	327	Center Right Side	-119	327	Center Right Side
T-2B	1	251	391	Center Right Side	-238	470	Center Right Side
	2	281	391	Center Right Side	-238	729	Center Right Side
	4	123	88	Rear Right Side	-135	87	Rear Right Side
	5	115	362	Center Right Side	-125	362	Center Right Side

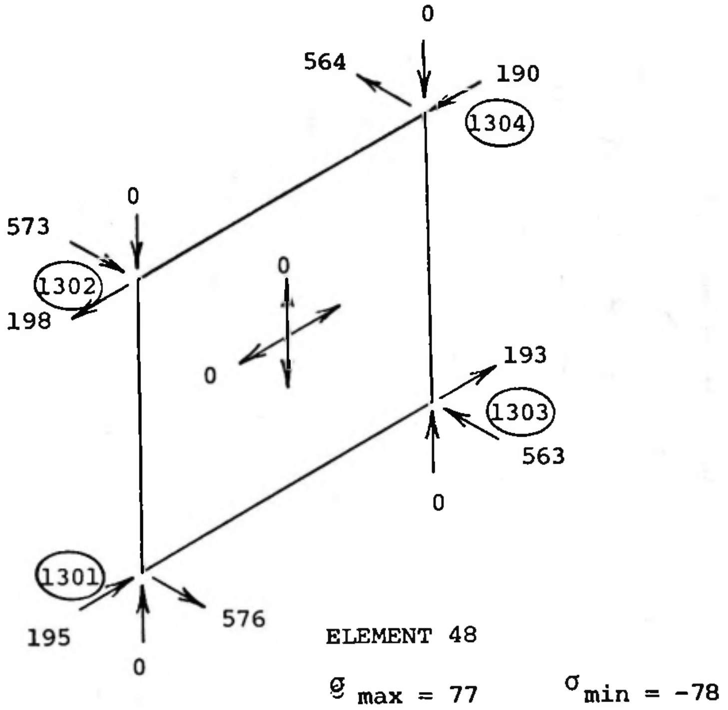
* Element locations for T-2A are detailed in Table 3 and Figure 69; for T-2B, Table 4 and Figure 70.

** Positive stress value signifies tension on the element

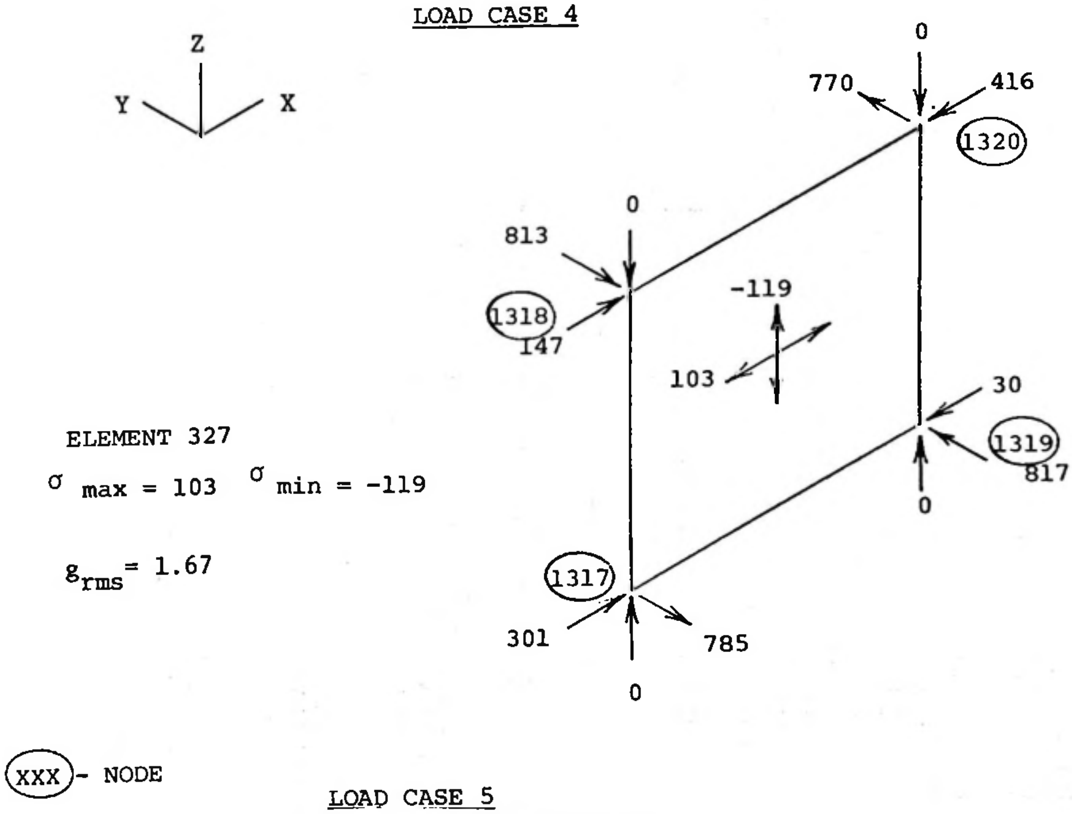
*** Negative stress value signifies compression on the element

**** See Table 1 for details.

FIGURE 44. T-2A/B DOUBLE-WIDE - RIGHT SIDE WALL PANELING



LOAD CASE 4



LOAD CASE 5

FIGURE 45. FREEBODY DIAGRAMS
T-2A RIGHT SIDE WALL PANELING

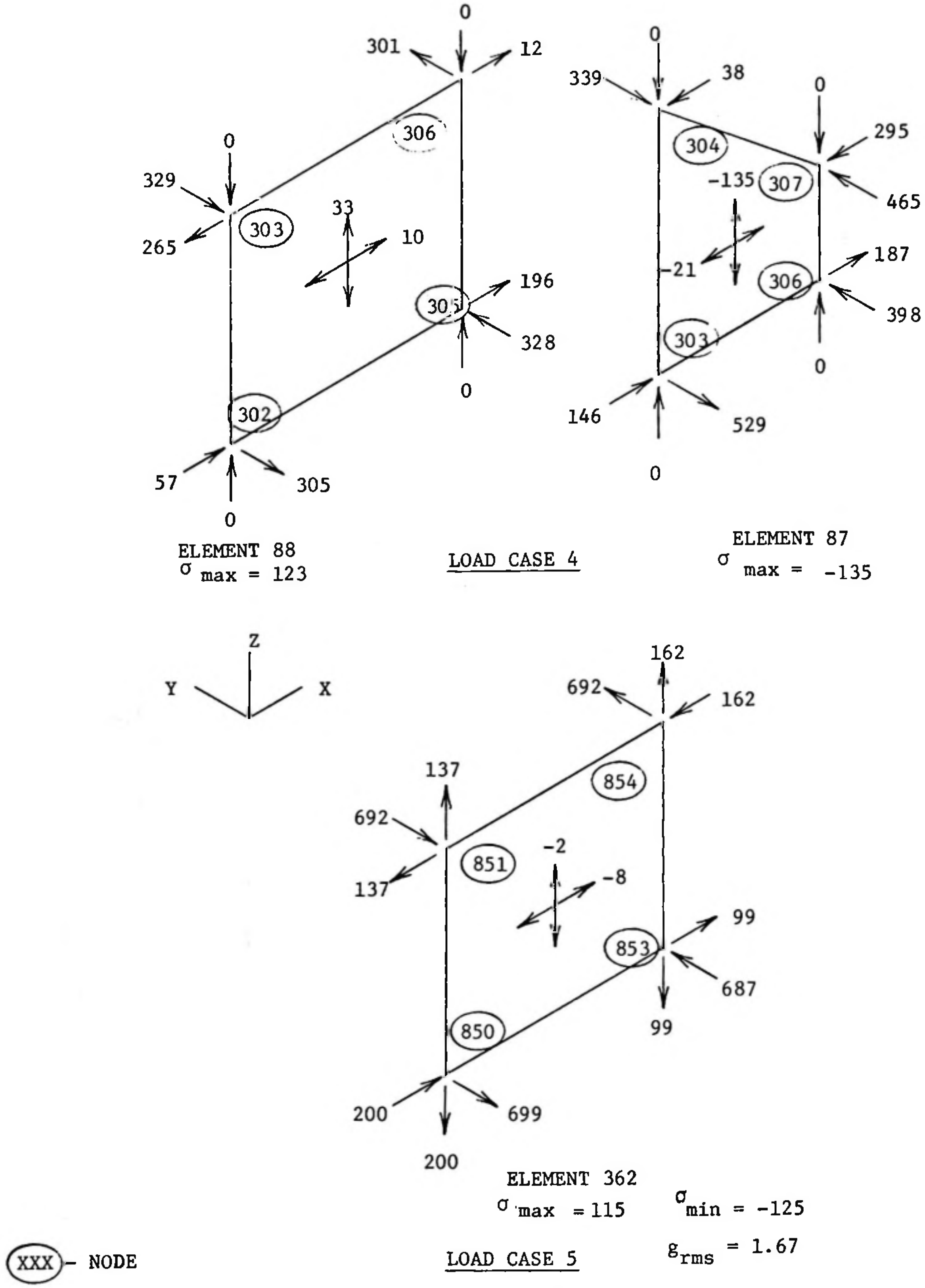
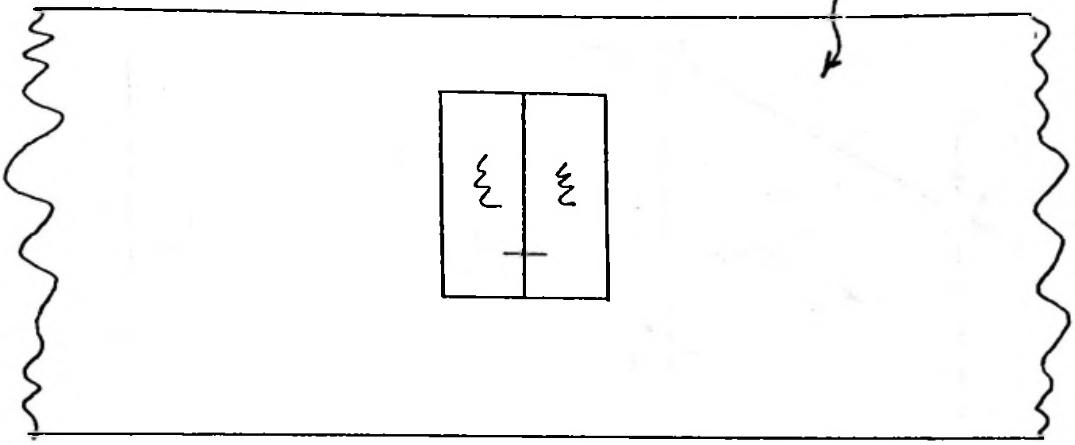


FIGURE 46. FREEBODY DIAGRAMS
T-2B RIGHT SIDE WALL PANELING



LEFT SIDEWALL

	Load Case	σ max (PSI)	Elem.	Element Location*	σ min (PSI)	Elem.	Element Location *
T-2A	1	** 144	410	Center Left Side	-153	834	Front Left Side
	2	152	410	Center Left Side	-158	834	Front Left Side
	4	68	307	Center Left Side	-184	410	Front Left Side
	5	446	410	Center Left Side	-169	834	Front Left Side
T-2B	1	62	103	Rear Left Side	-37	64	Rear Left Side
	2	76	103	Rear Left Side	-46	64	Rear Left Side
	4	8	103	Rear Left Side	-5	103	Rear Left Side
	5	102	103	Rear Left Side	-110	103	Rear Left Side

* Element locations for T-2A are detailed in Table 3 and Figure 69; for T-2B, Table 4 and Figure 70.
** Positive stress value signifies tension on the element
*** Negative stress value signifies compression on the element
**** See Table 1 for details

FIGURE 47. T-2A/B DOUBLE-WIDE - LEFT SIDE WALL PANELING

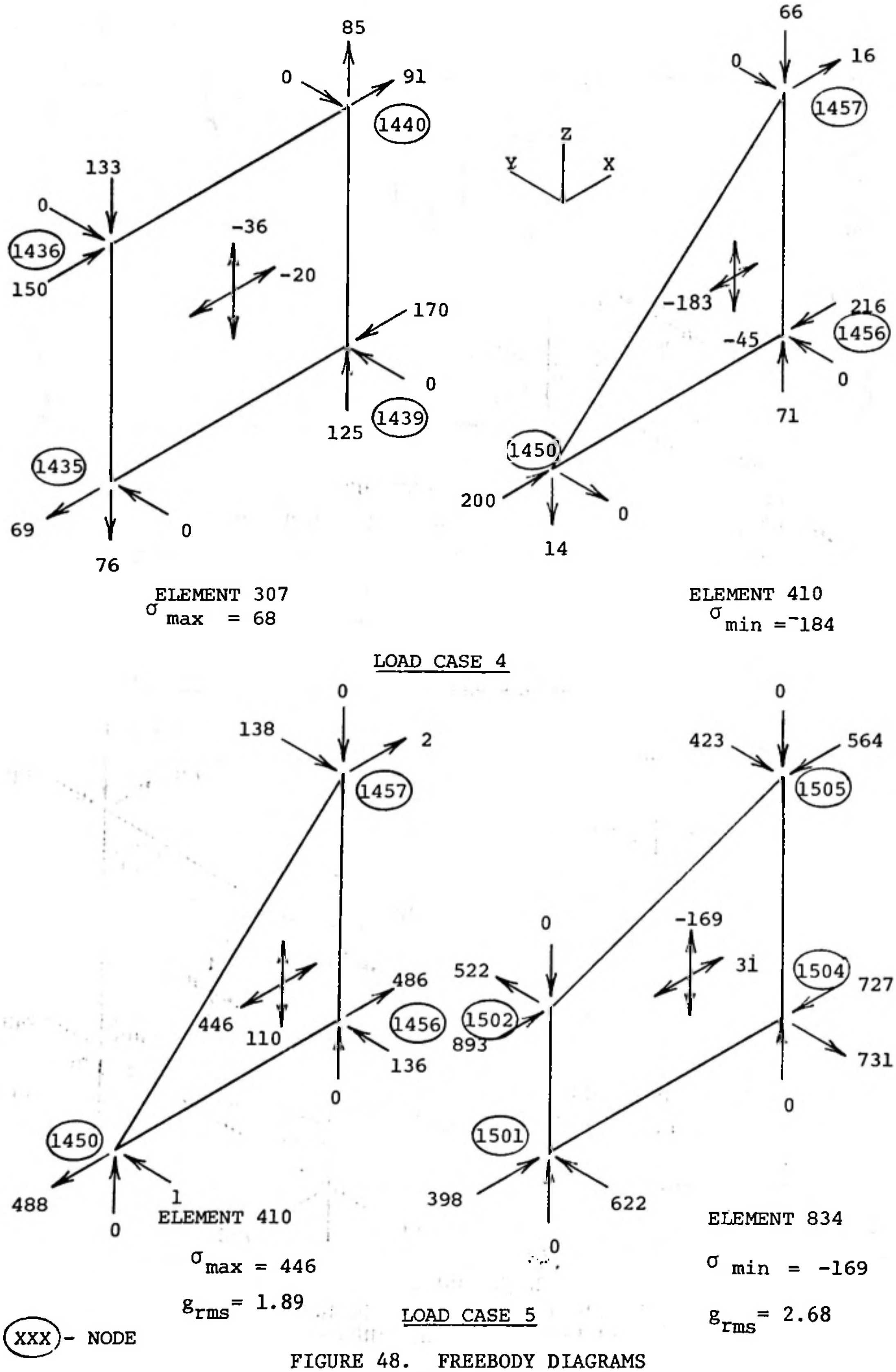
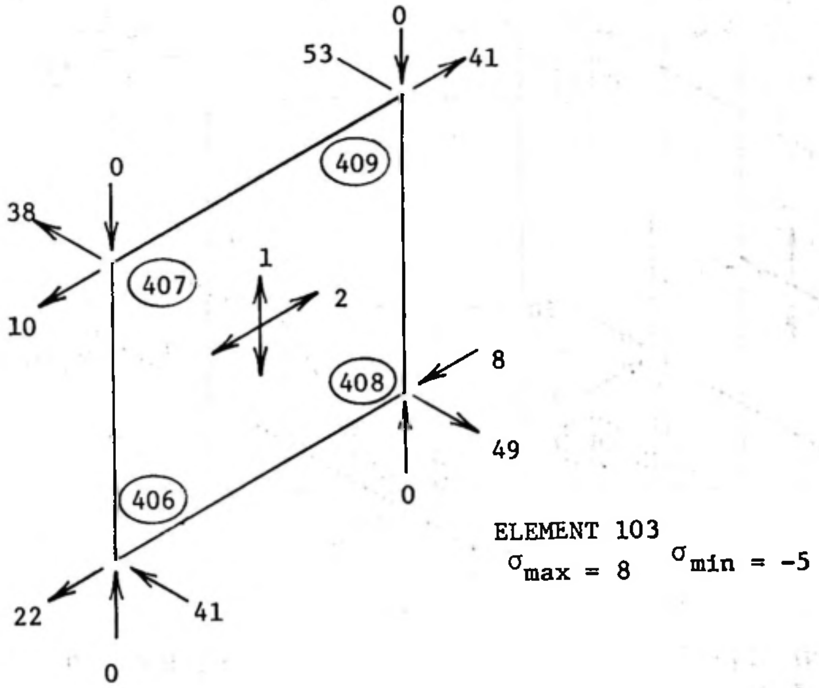
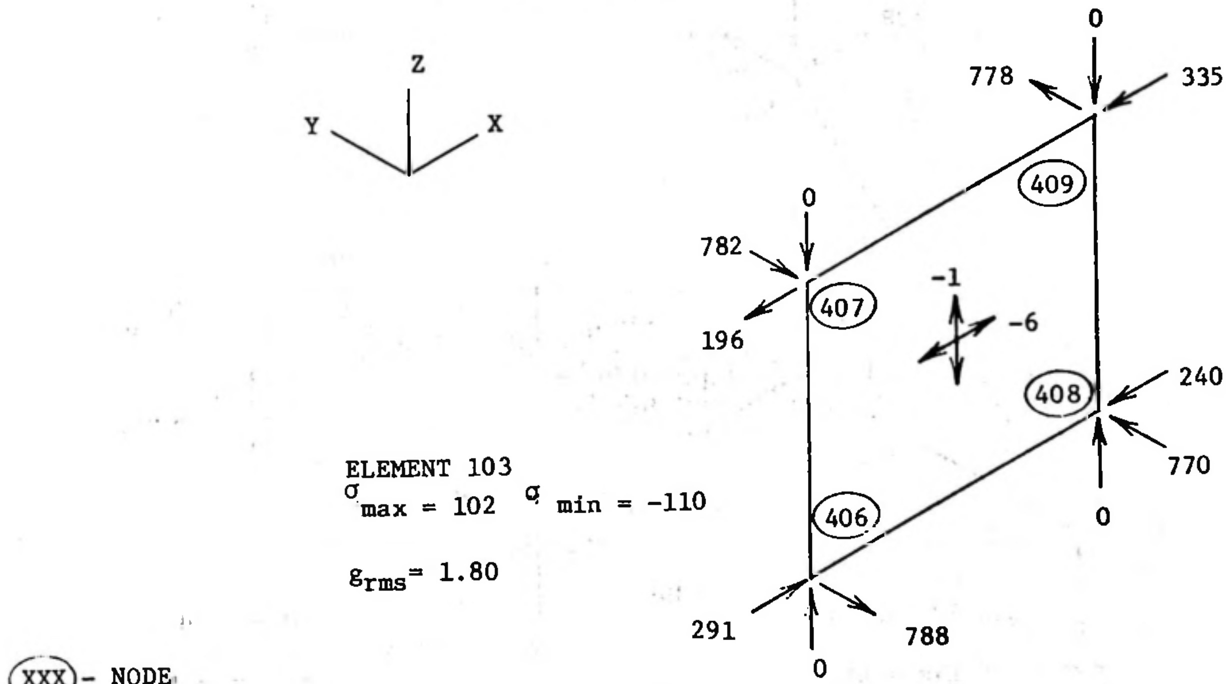


FIGURE 48. FREEBODY DIAGRAMS
T-2A LEFT SIDE WALL PANELING

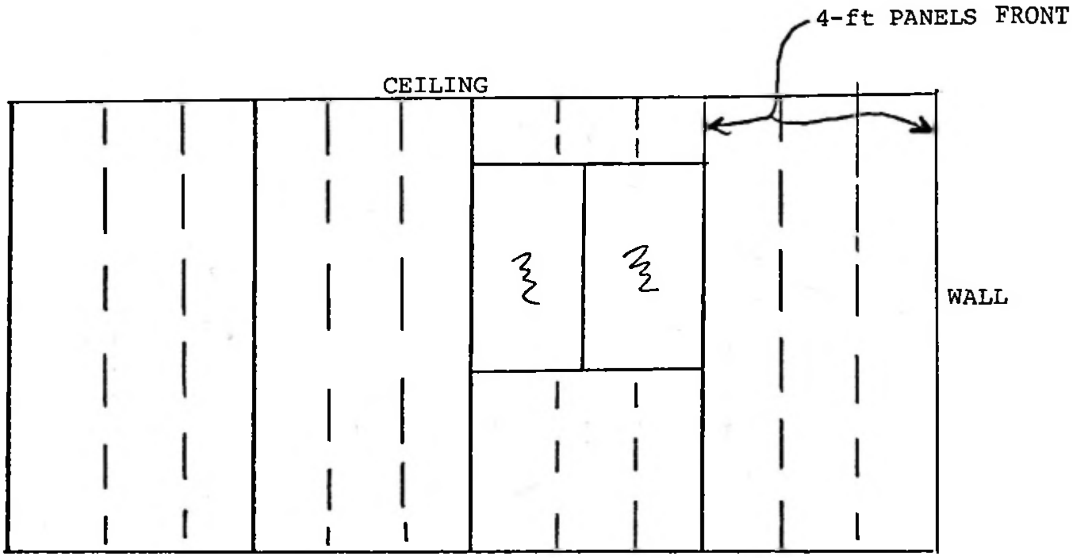


LOAD CASE 4



LOAD CASE 5

FIGURE 49. FREEBODY DIAGRAMS
T-2B LEFT SIDE WALL PANELING

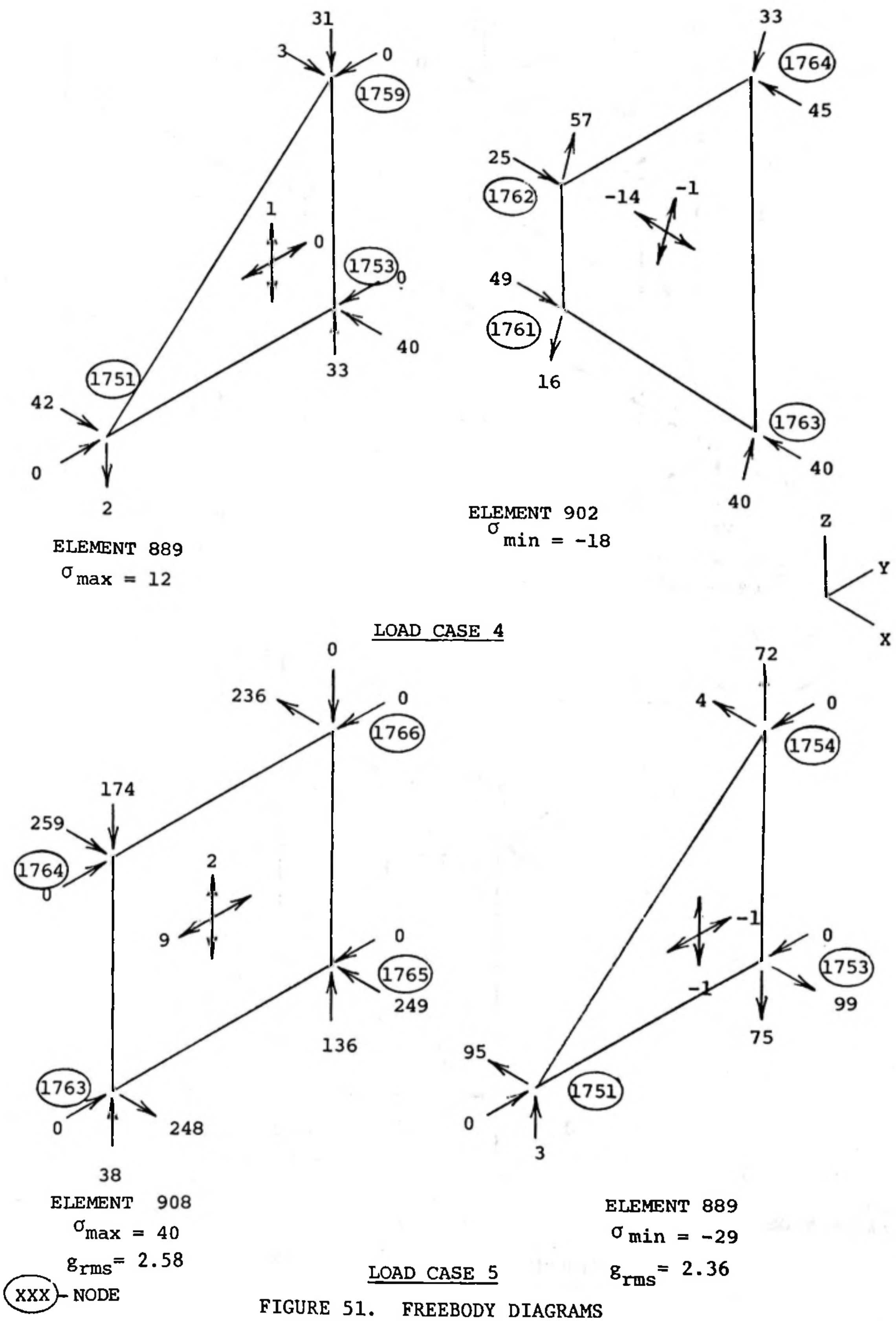


FRONT ENDWALL:

	**** Load Case	σ max (PSI)	Elem.	Element Location*	σ min (PSI)	Elem.	Element Location
T-2A	1	** 105	890	Lower Front	*** -168	889	Lower Front
	2	110	890	Lower Front	-177	889	Lower Front
	4	12	889+ 903	Lower Front	-18	902	Center Front
	5	40	908	Right Front	-29	889	Lower Front
T-2B	1	89	866	Lower Front	-124	871	Center Front
	2	92	866	Lower Front	-127	871	Center Front
	4	26	871	Center Front	-27	873	Upper Front
	5	65	866	Lower Front	-67	866	Lower Front

* Element locations for T-2A are detailed in Table 3 and Figure 69; for T-2B, Table 4 and Figure 70.
** Positive stress value signifies tension on the element
*** Negative stress value signifies compression on the element
**** See Table 1 for details

FIGURE 50. T-2A/B DOUBLE-WIDE - FRONT END WALL PANELING



LOAD CASE 4

LOAD CASE 5

FIGURE 51. FREEBODY DIAGRAMS
T-2A FRONT END WALL PANELING

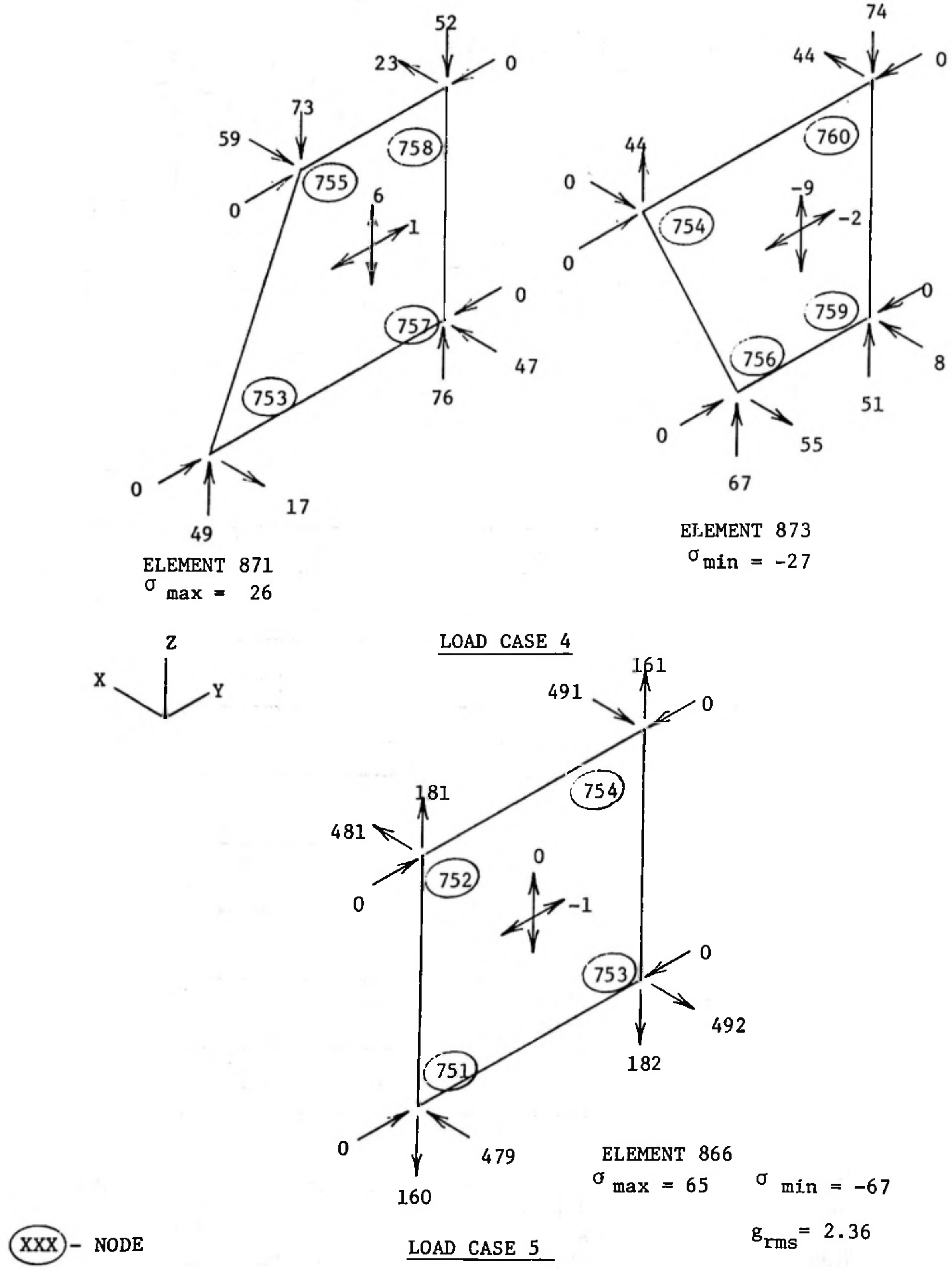
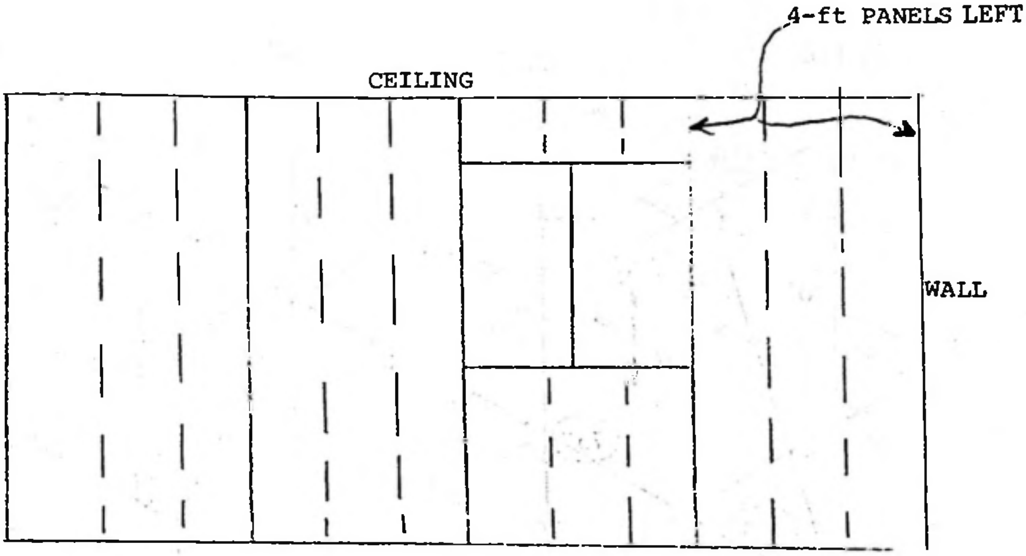


FIGURE 52. FREEBODY DIAGRAMS
T-2B FRONT END WALL PANELING



REAR ENDWALL:

	**** Load Case	σ min (PSI)	Elem.	Element Location*	σ min (PSI)	Elem.	Element Location
T-2A	1	19	2	Lower Rear	-19	2	Lower Rear
	2	21	2	Lower Rear	-21	2	Lower Rear
	4	48	8	Left Rear	-48	6	Center Rear
	5	197	2	Lower Rear	-194	2	Lower Rear
T-2B	1	19	6	Lower Rear	-20	6	Lower Rear
	2	17	9	Lower Rear	-18	9	Upper Rear
	4	58	9	Lower Rear	-59	9	Upper Rear
	5	6	6	Right Rear	-6	6	Right Rear

* Element locations for T-2A are detailed in Table 3 and Figure 69; for T-2B, Table 4 and Figure 70.
** Positive stress value signifies tension on the element
*** Negative stress value signifies compression on the element
**** See Table 1 for details

FIGURE 53. T-2A/B DOUBLE-WIDE - END WALL PANELING

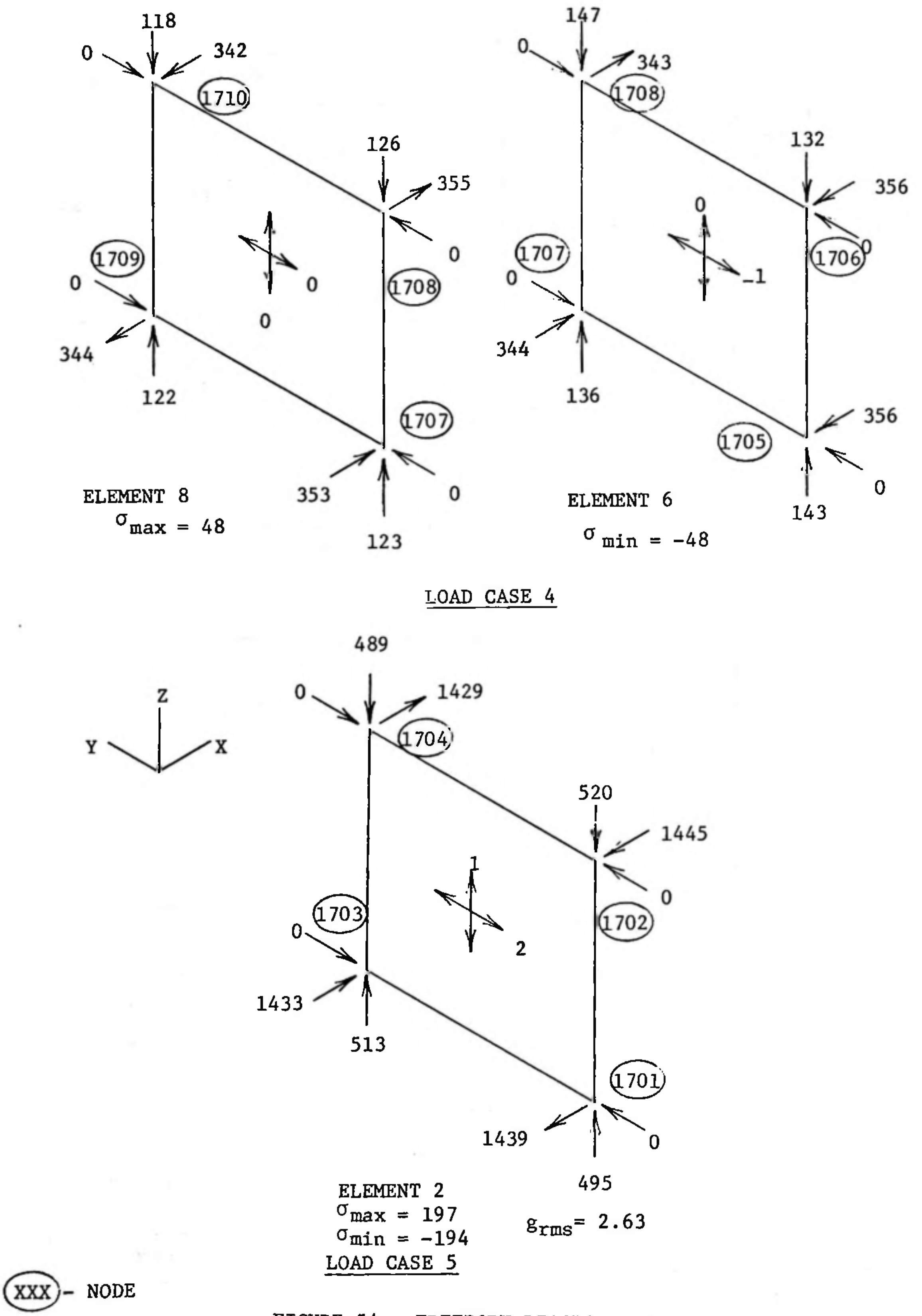
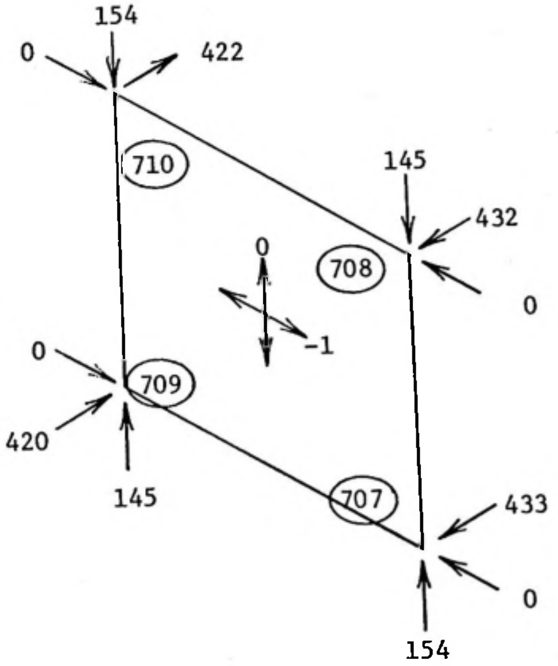
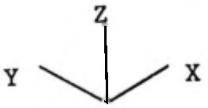


FIGURE 54. FREEBODY DIAGRAMS
T-2A REAR END WALL PANELING

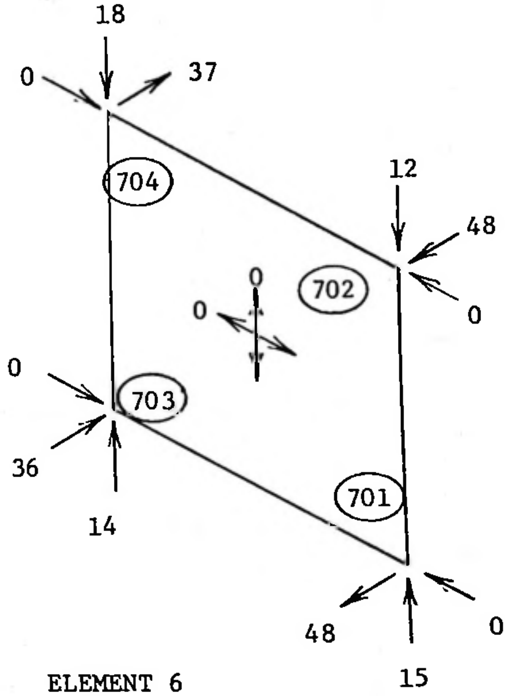


Element 9

$\sigma_{max} = 58$ $\sigma_{min} = -59$



LOAD CASE 4



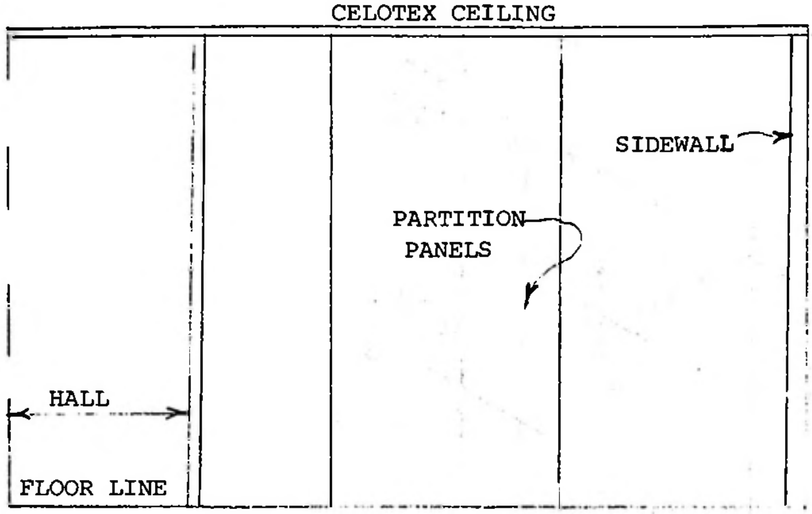
ELEMENT 6

$\sigma_{max} = 6$ $\sigma_{min} = -6$

LOAD CASE 5 $g_{rms} = 2.63$

(XXX) - NODE

FIGURE 55. FREEBODY DIAGRAMS
T-2B REAR END WALL PANELING



Having "pinned" all components of each unit at the wall/floor and wall/ceiling interfaces, the shear stresses along these surfaces will be zero. However, values for the individual wall panels do exist.

	Load Case ****	σ max (PSI)	Elem.	Element Location*	σ min (PSI)	Elem.	Element Location	max τ (PSI)	Elem.	Element Location
T-2A	1	** 75	791	Interior Wall I	*** -63	191	Interior Wall B	66	791	Interior Wall I
	2	78	791	Interior Wall I	-75	191+ 293	Interior Wall B	68	791	Interior Wall I
	4	146	349	Interior Wall J	-217	349	Interior Wall J	181	349	Interior Wall
	5	766	349	Interior Wall J	-1331	349	Interior Wall J	1048	349	Interior Wall
T-2B	1	63	659	Interior Wall F	-75	181	Interior Wall B	64	181	Interior Wall B
	2	69	659	Interior Wall F	-74	187	Interior Wall B	60	187	Interior Wall B
	4	57	667	Interior Wall K	-57	667	Interior Wall K	57	667	Interior Wall K
	5	202	667	Interior Wall K	-201	667	Interior Wall K	201	667	Interior Wall K

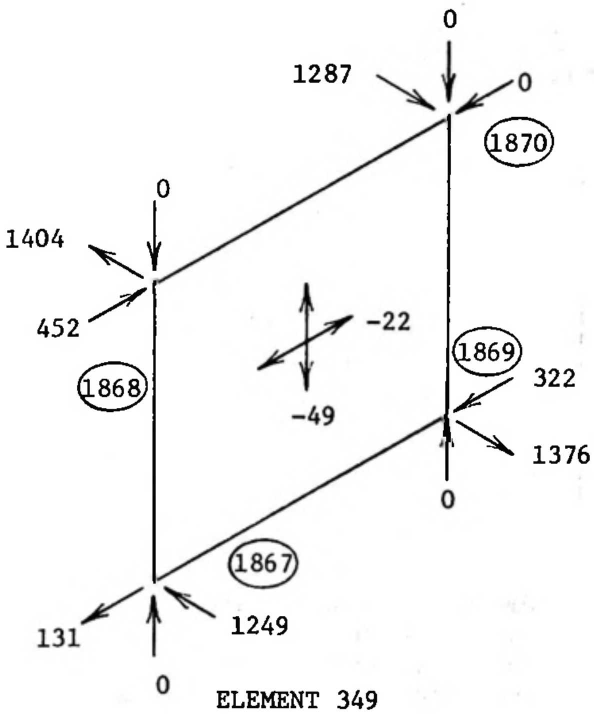
* Element locations for T-2A are detailed in Table 3 and Figure 69; for T-2B, Table 4 and Figure 70.

** Positive stress value signifies tension on the element

*** Negative stress value signifies compression on the element

**** See Table 1 for details

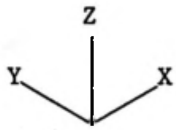
FIGURE 56. T-2A/B DOUBLE-WIDE - INTERIOR PARTITION TO CEILING AND SIDE WALL

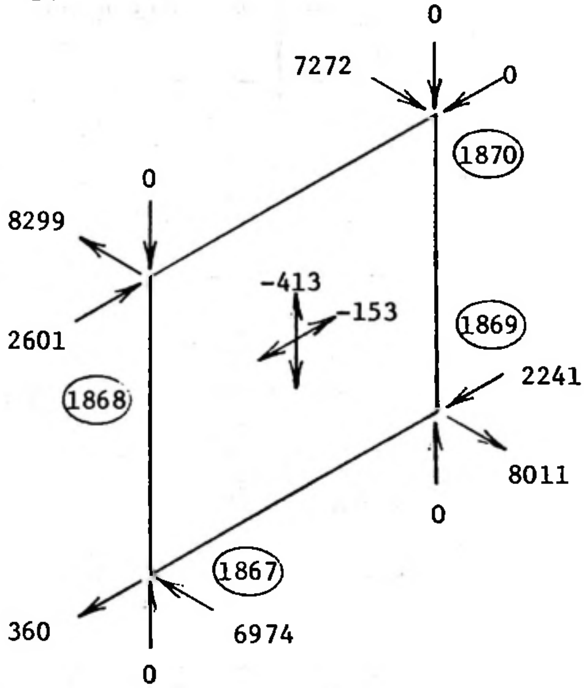


ELEMENT 349

$\sigma_{max} = 146$ $\sigma_{min} = -217$

LOAD CASE 4





ELEMENT 349

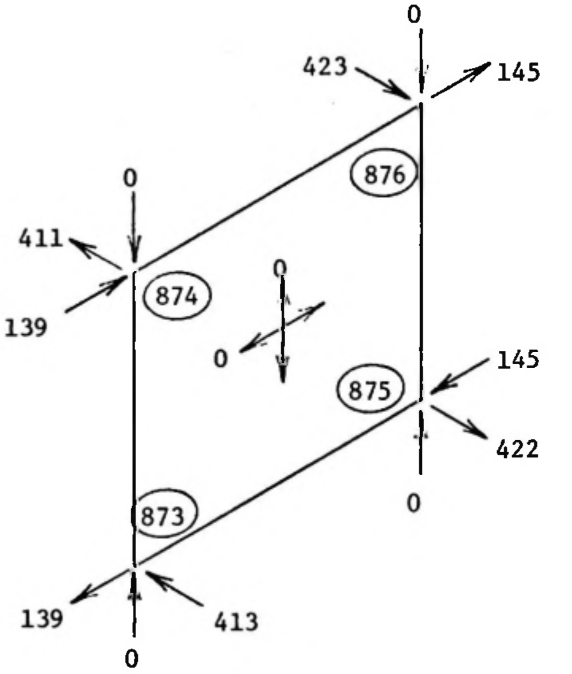
$\sigma_{max} = 766$ $\sigma_{min} = -1331$

$g_{rms} = 1.67$

(XXX) - NODE

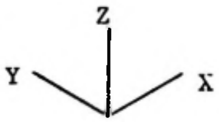
LOAD CASE 5

FIGURE 57. FREEBODY DIAGRAMS
T-2A INTERIOR PARTITION TO CEILING AND SIDE WALL



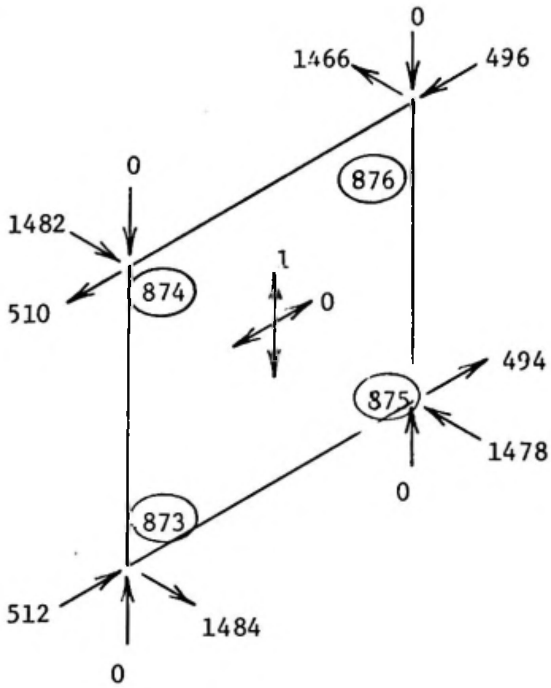
ELEMENT 667
$\sigma_{max} = 57$ $\sigma_{min} = -57$

LOAD CASE 4



Element 667
$\sigma_{max} = 202$ $\sigma_{min} = {}^{-}201$

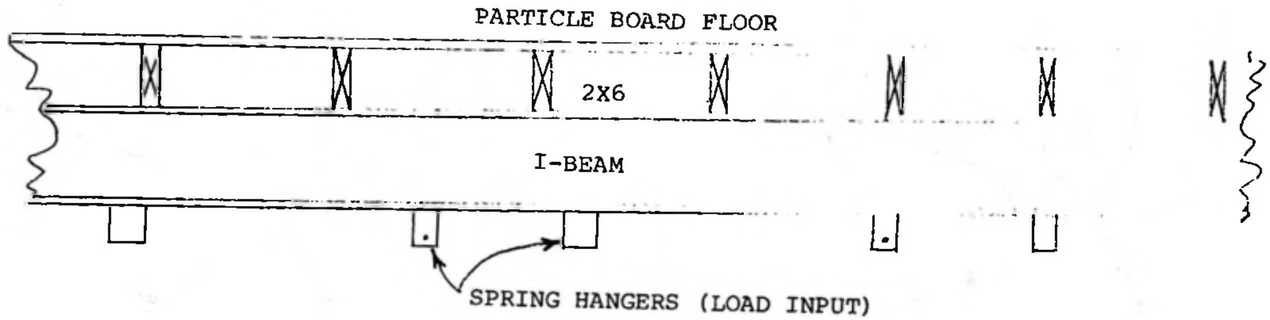
$g_{rms} = 3.03$



LOAD CASE 5

(XXX) - NODE

FIGURE 58. FREEBODY DIAGRAMS
T-2B INTERIOR PARTITION TO CEILING AND SIDE WALL



	**** Load Case	σ max (PSI)	Elem.	Element Location	σ min (PSI)	Elem.	Element Location
T-2A	1	** 45	359	Center Floor	*** -36	189	Rear Floor
	2	45	359	Center Floor	-40	189	Rear Floor
	4	169	348	Center Floor	-40	238	Rear Floor
	5	368	359	Center Floor	-543	238	Rear Floor
T-2B	1	84	297	Center Floor	-34	171	Rear Floor
	2	84	297	Center Floor	-35	171	Rear Floor
	4	130	297	Center Floor	-158	213	Rear Floor
	5	346	297	Center Floor	-39	252	Rear Floor

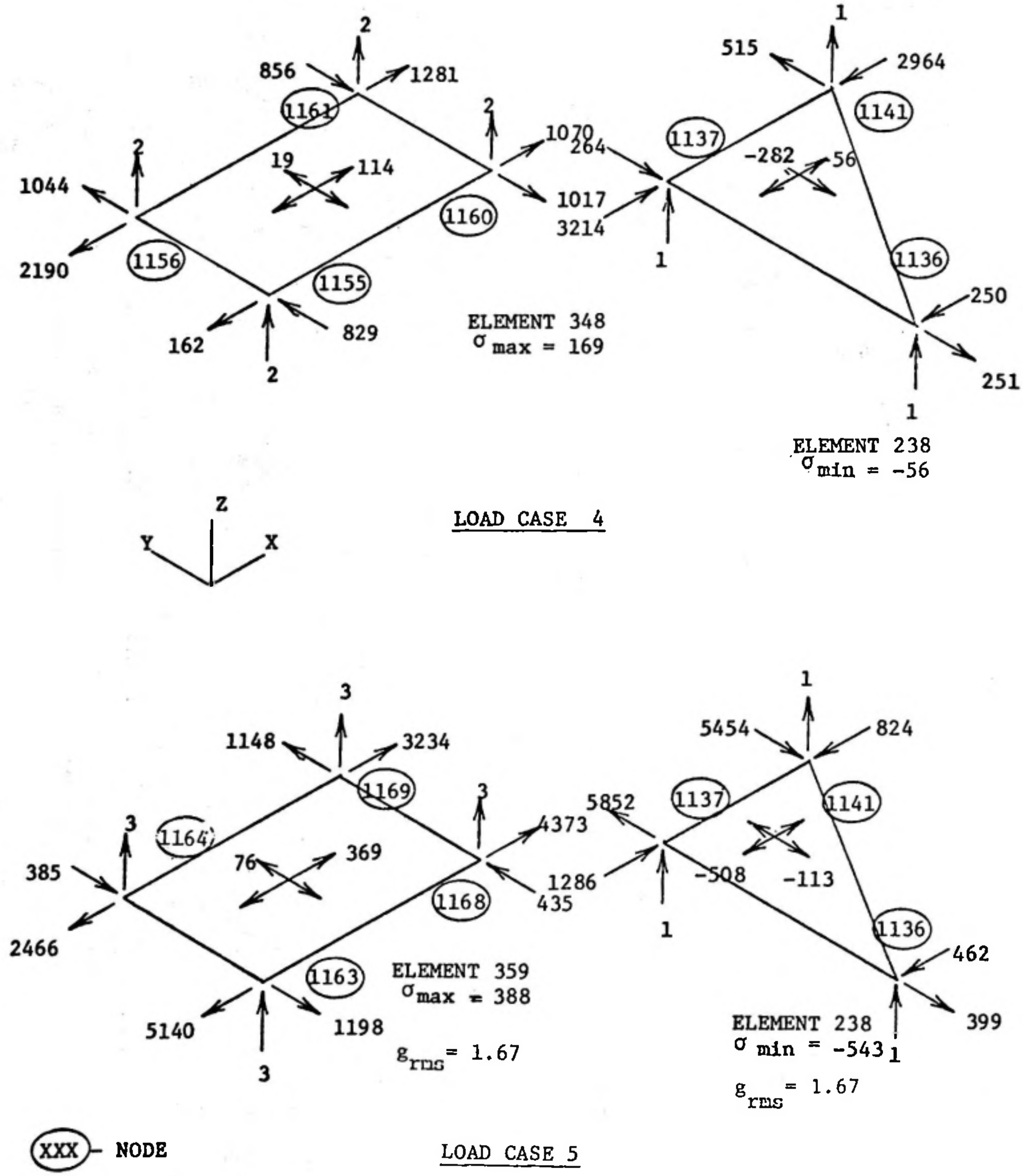
* Element locations for T-2A are detailed in Table 3 and Figure 69 for T-2B, Table 4 and Figure 70.

** Positive stress values signifies tension on the element

*** Negative stress value signifies compression on the element

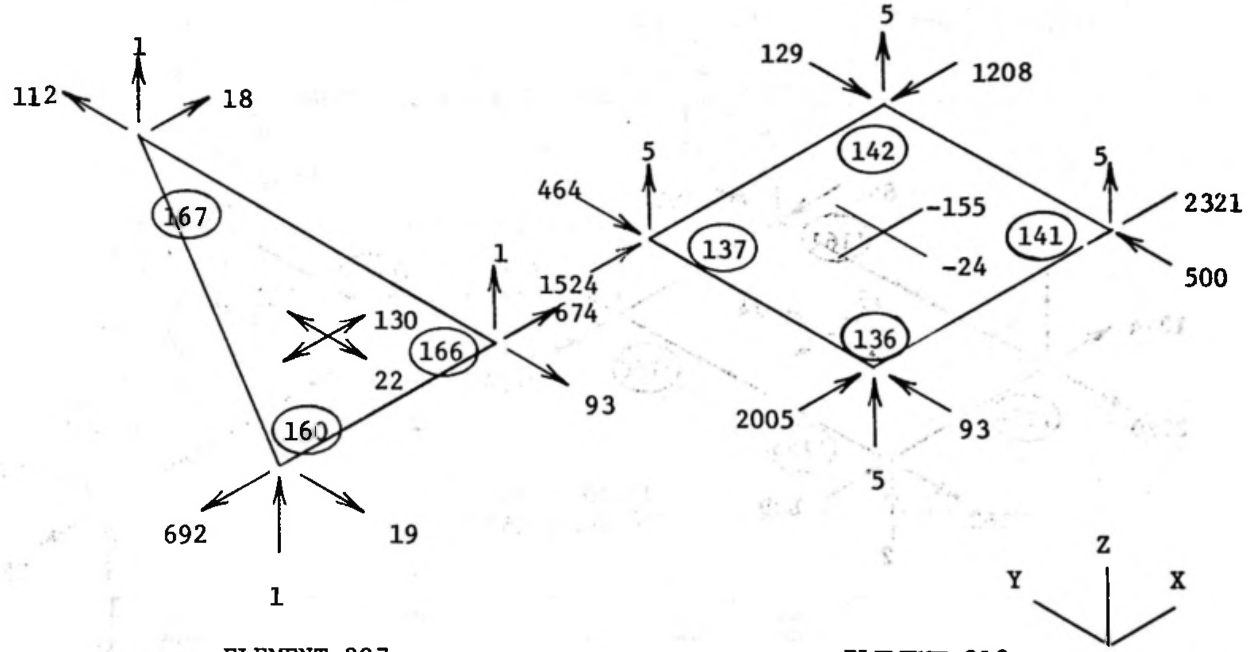
**** See Table 1 for details

Figure 59. T-2A/B DOUBLE WIDE - FLOOR OVER AXLE



LOAD CASE 5

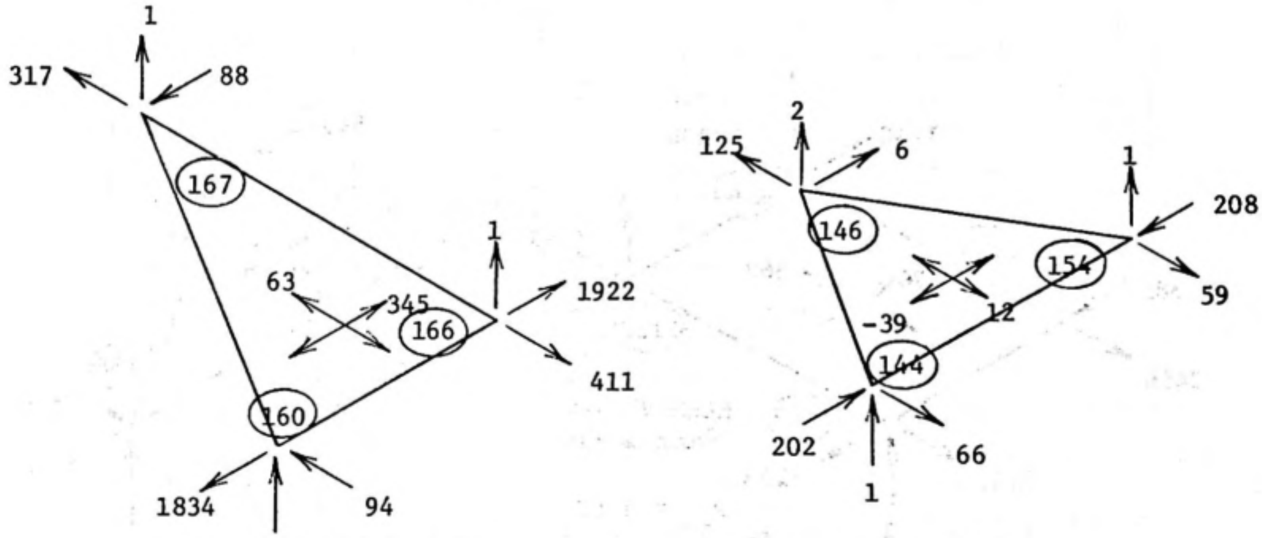
FIGURE 60. FREEBODY DIAGRAMS
T-2A FLOOR OVER AXLE



ELEMENT 297
σ max = 130

ELEMENT 218
σ min = -158

LOAD CASE 4



g_{rms}= 1.67

ELEMENT 297
σ max = 346

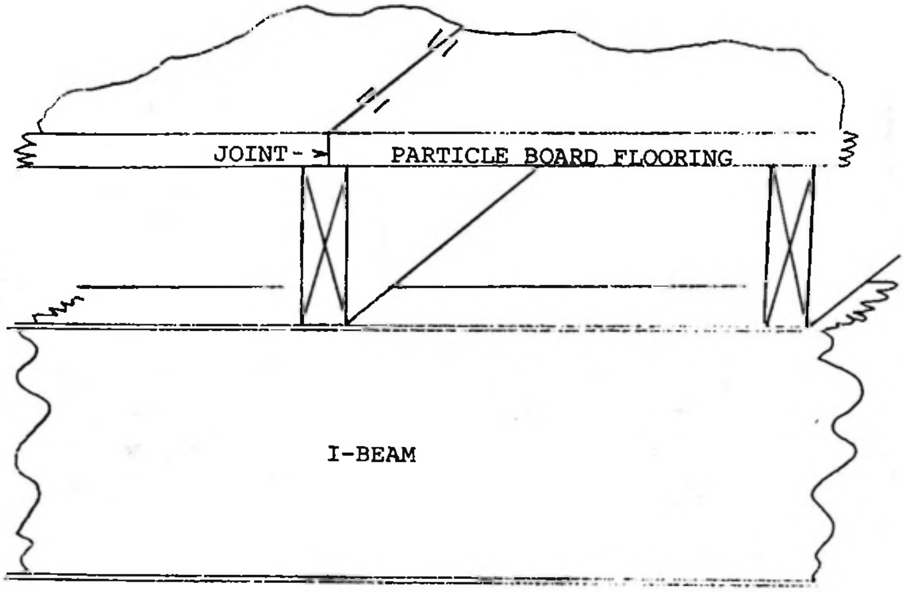
g_{rms}= 1.67

ELEMENT 252
σ_{min} = -39

LOAD CASE 5

(XXX) - NODE

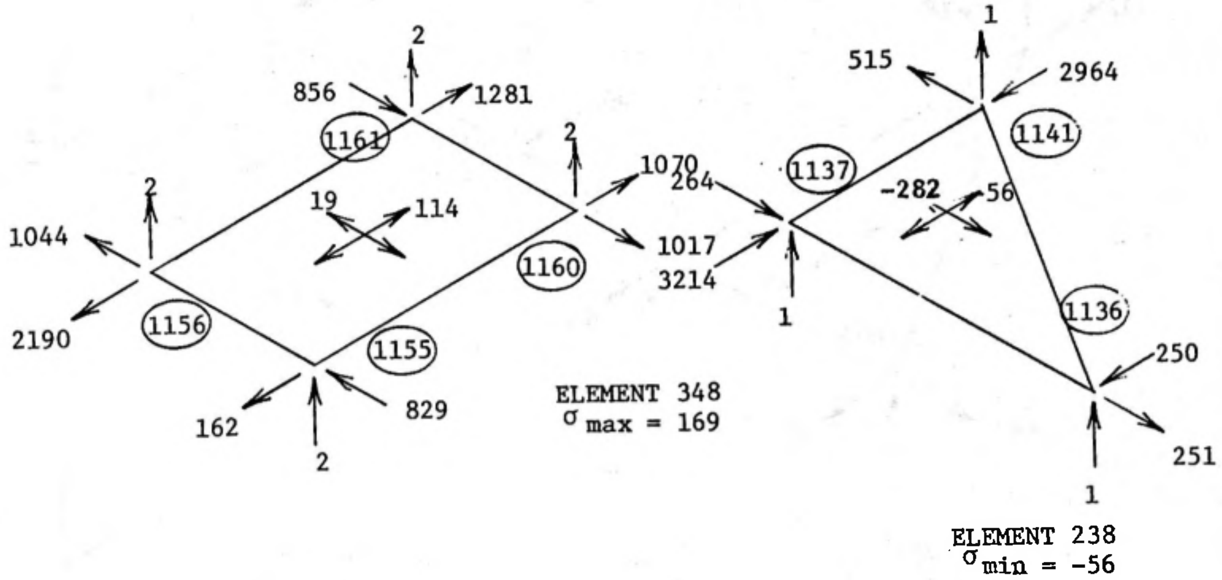
FIGURE 61. FREEBODY DIAGRAMS
T-2B FLOOR OVER AXLE

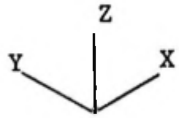


	**** Load Case	σ max (PSI)	Elem.	Element Location*	σ min (PSI)	Elem.	Element Location
T-2A	1	** 45	359	Center Floor	*** -40	188	Rear Floor
	2	48	359	Center Floor	-46	188	Rear Floor
	4	169	348	Center Floor	-298	238	Rear Floor
	5	388	359	Center Floor	-543	238	Rear Floor
T-2B	1	84	297	Center Floor	-47	803	Front Floor
	2	84	297	Center Floor	-50	803	Front Floor
	4	130	297	Center Floor	-158	218	Rear Floor
	5	346	297	Center Floor	-140	801	Front Floor

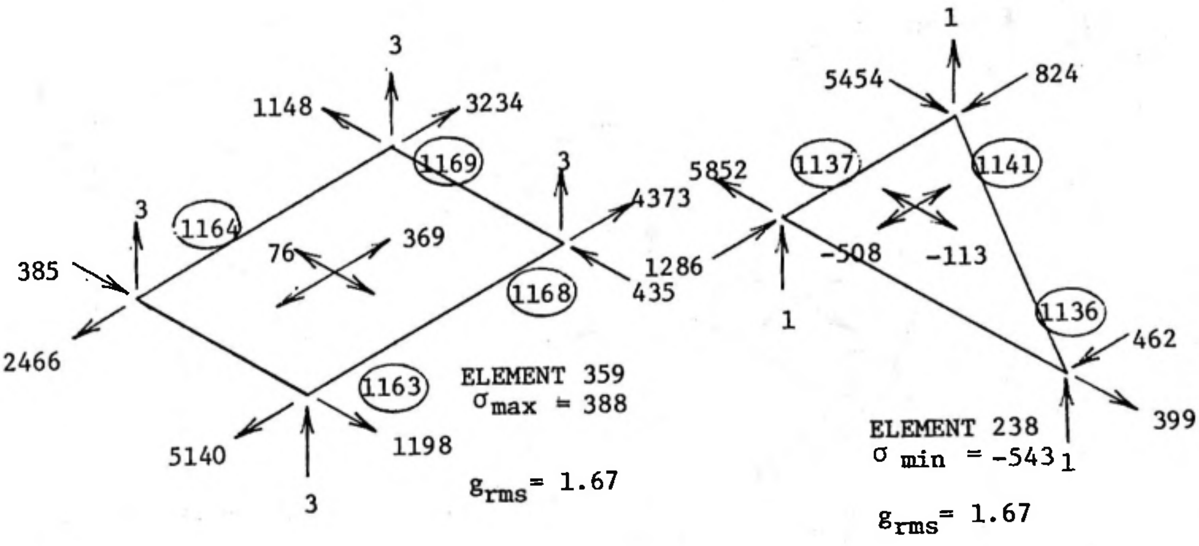
* Element locations for T-2A are detailed in Table 3 and Figure 69; for T-2B, Table 4 and Figure 70.
** Positive stress value signifies tension on the element
*** Negative stress value signifies compression on the element
**** See Table 1 for details

FIGURE 62. T-2A/B DOUBLE WIDE - FLOOR JOINT





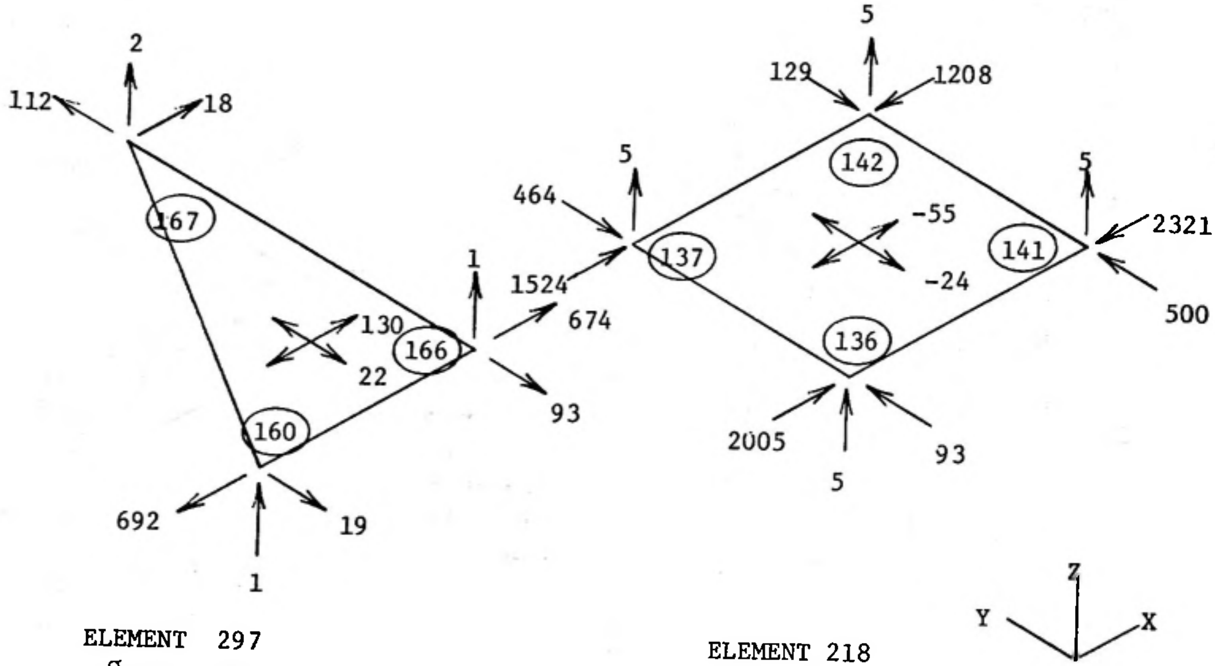
LOAD CASE 4



XXX - NODE

LOAD CASE 5

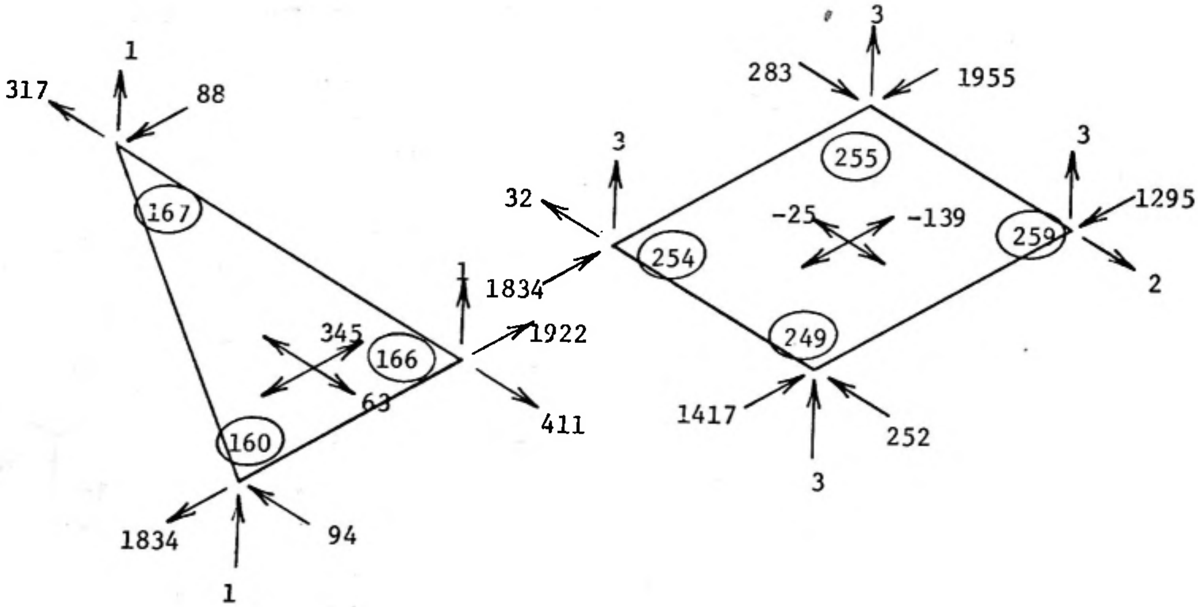
FIGURE 63. FREEBODY DIAGRAMS
T-2A FLOOR JOINT



ELEMENT 297
$\sigma_{max} = 130$

ELEMENT 218
$\sigma_{min} = -158$

LOAD CASE 4



ELEMENT 297
$\sigma_{max} = 346$
$g_{rms} = 1.67$

LOAD CASE 5

ELEMENT 801
$\sigma_{min} = -140$
$g_{rms} = 2.81$

XXX - NODE

FIGURE 64. FREEBODY DIAGRAMS
T-2B FLOOR JOINT

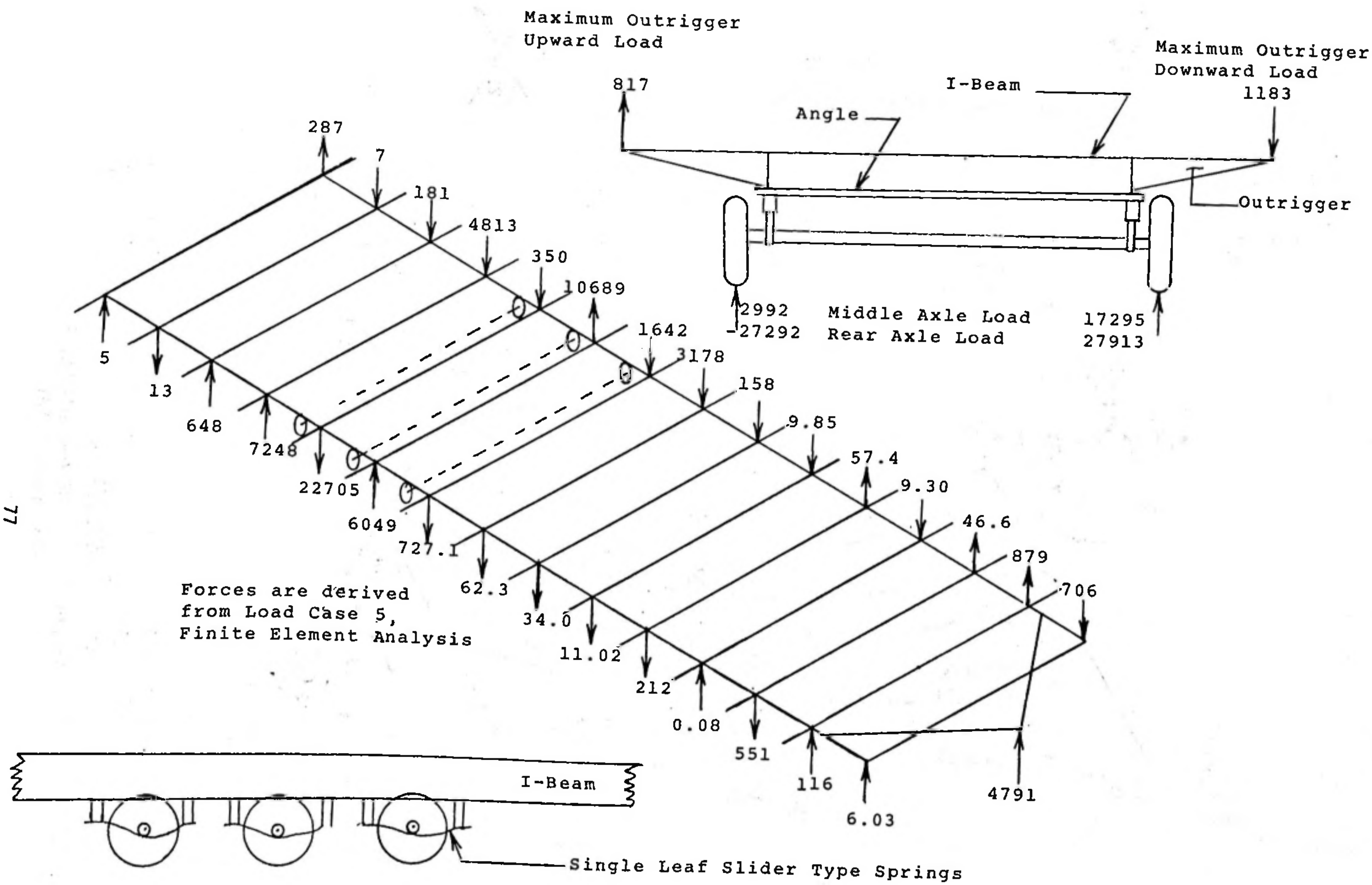
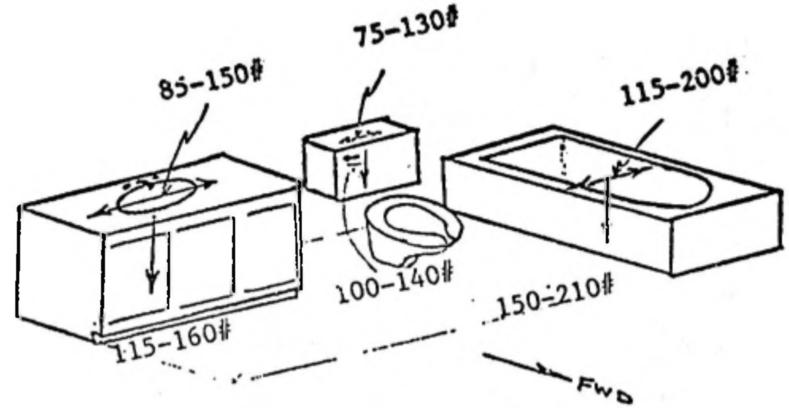
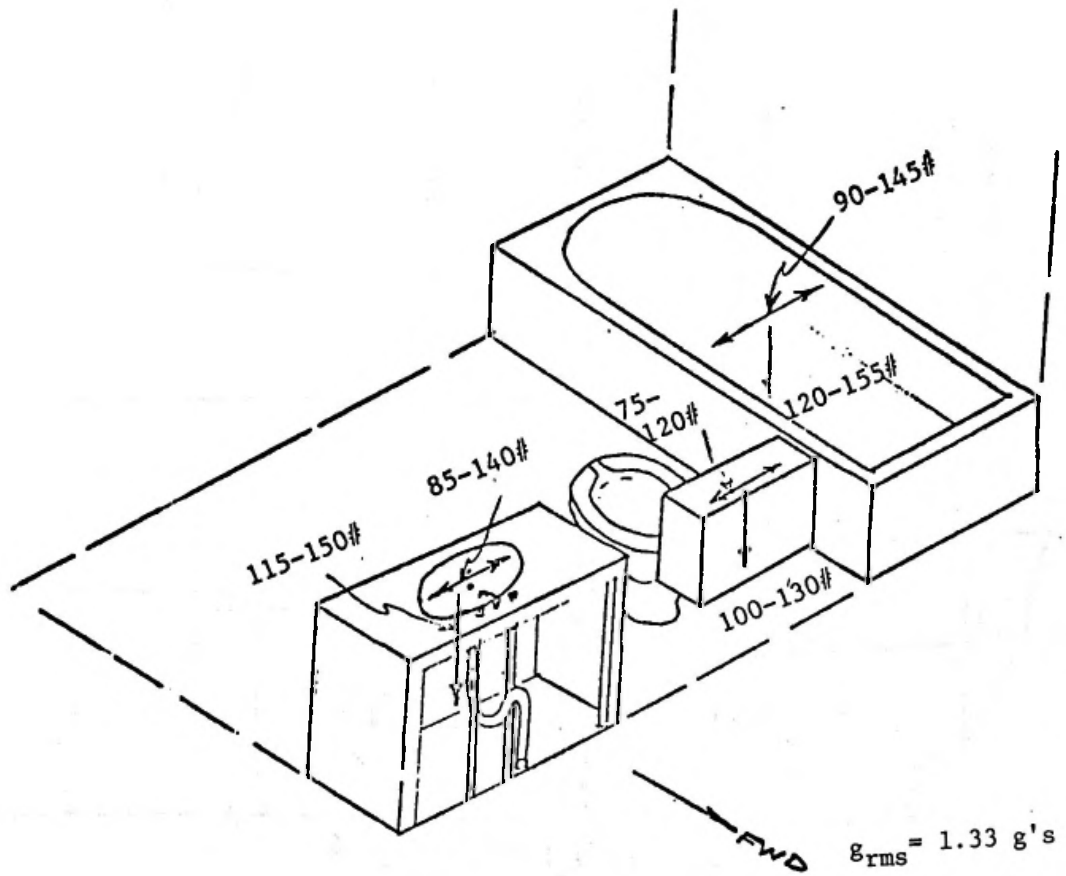


FIGURE 65. T-A DOUBLE-WIDE -- CHASSIS AND RUNNING GEAR



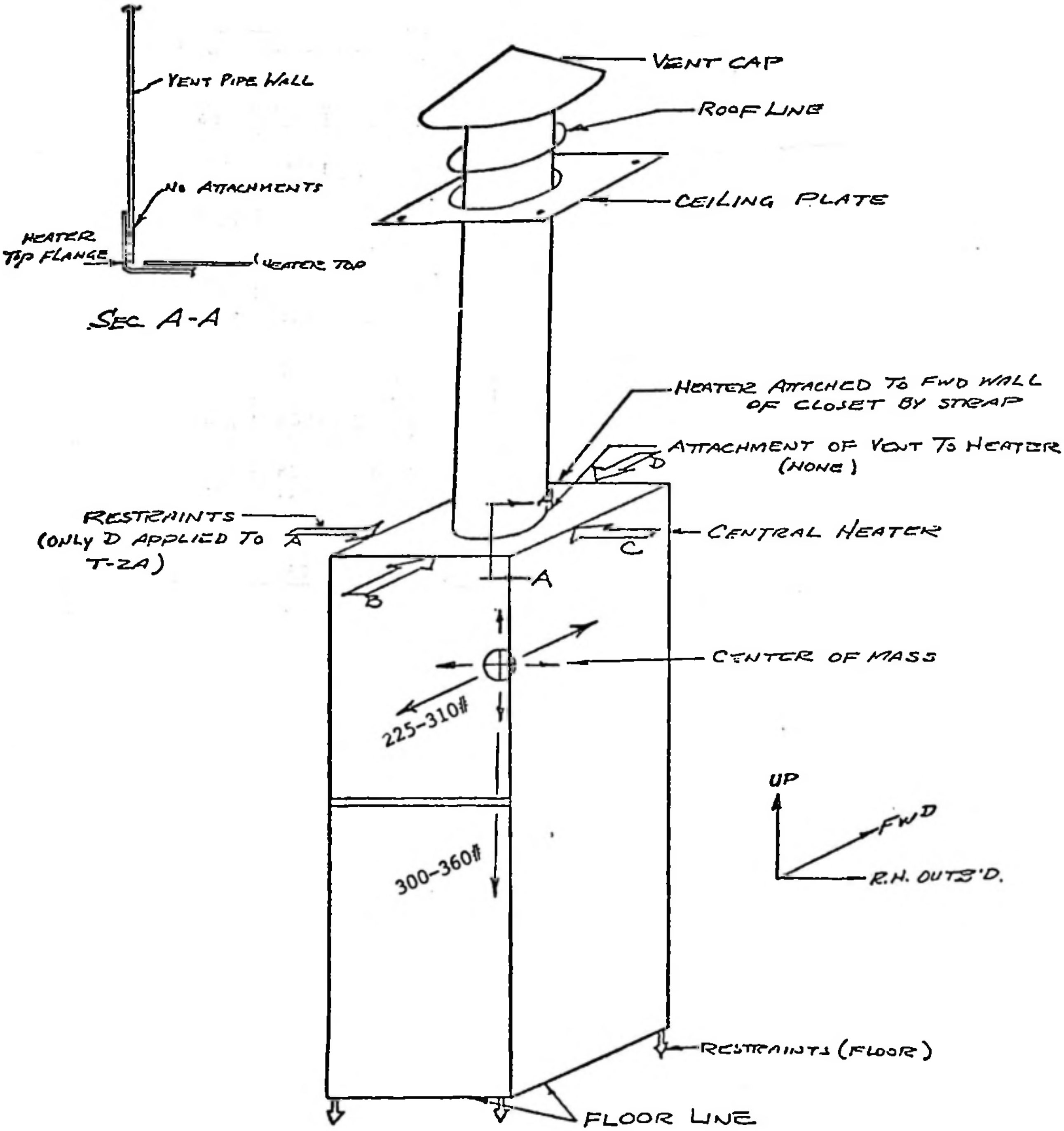
g_{rms}= 2.37 to 2.6 g's

FIGURE 66. T-2A DOUBLE-WIDE (WET SIDE) - FRONT BATH COMPONENTS



$g_{rms} = 1.33$ g's

FIGURE 67. T-2A DOUBLE-WIDE - REAR BATH AND COMPONENTS



g_{rms} = 1.33 to 1.77 g's

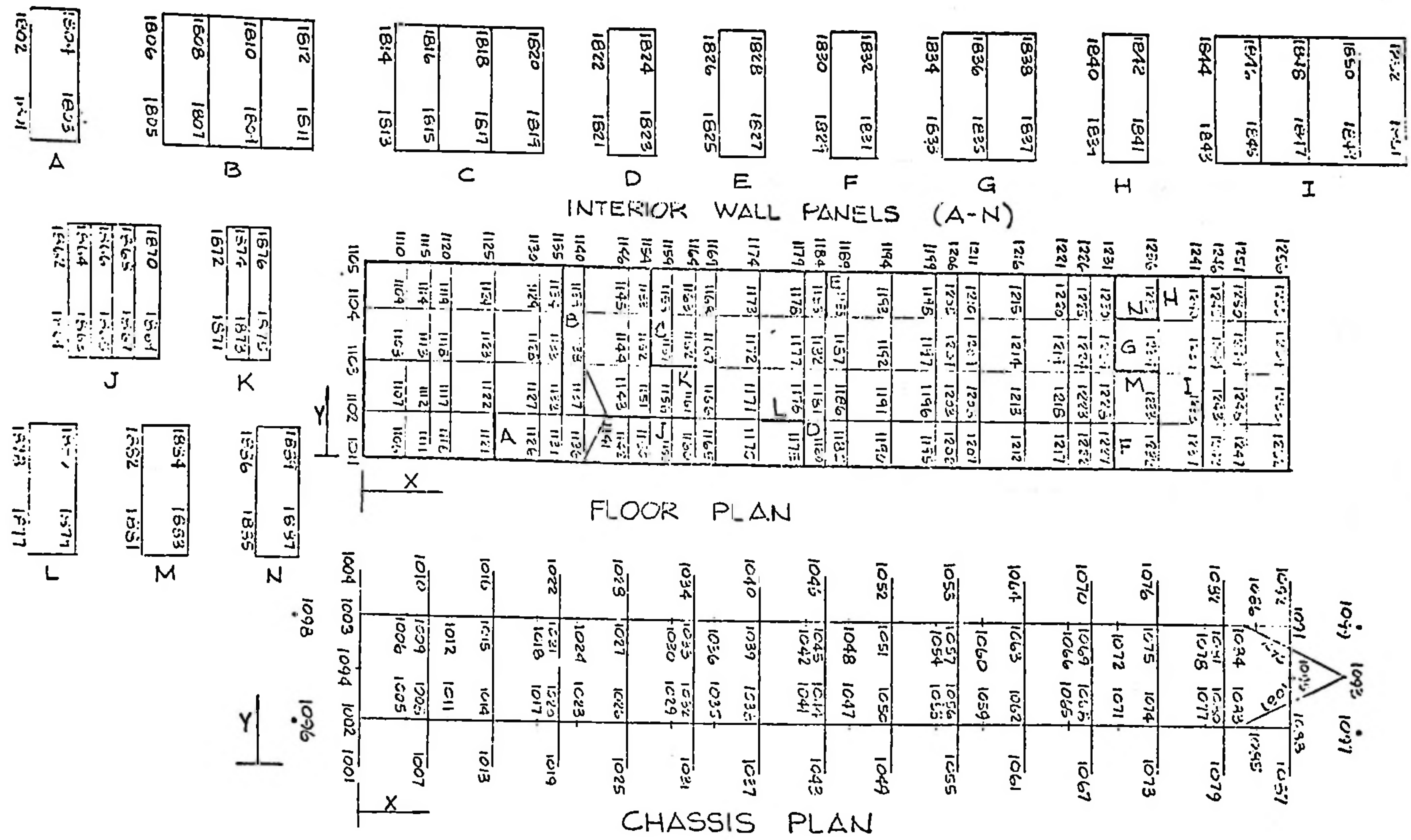
FIGURE 68. T-2A (WET SIDE) DOUBLE-WIDE - CENTRAL HEATER VENT

TABLE 3

T-2A ELEMENT DIRECTORY

ELEMENT NO.	NODAL CONNECT POINTS*			
	I **	J **	K **	L **
2	1703	1701	1702	1704
188	1129	1134	1135	1130
189	1134	1139	1140	1135
191	1809	1811	1812	1810
293	1817	1819	1820	1818
359	1163	1168	1169	1164
410	1450	1456	1457	1457
791	1843	1845	1846	1844
834	1501	1504	1505	1502
852	1349	1351	1352	1350
853	1351	1353	1354	1352
889	1751	1753	1754	1754
890	1751	1754	1755	1752

*See Figure 69 for nodal point locations.
**Computer reference symbols



Note: Numbers on the model indicate nodal point locations.

FIGURE 69. T-2A DOUBLE-WIDE - FINITE ELEMENT MODEL

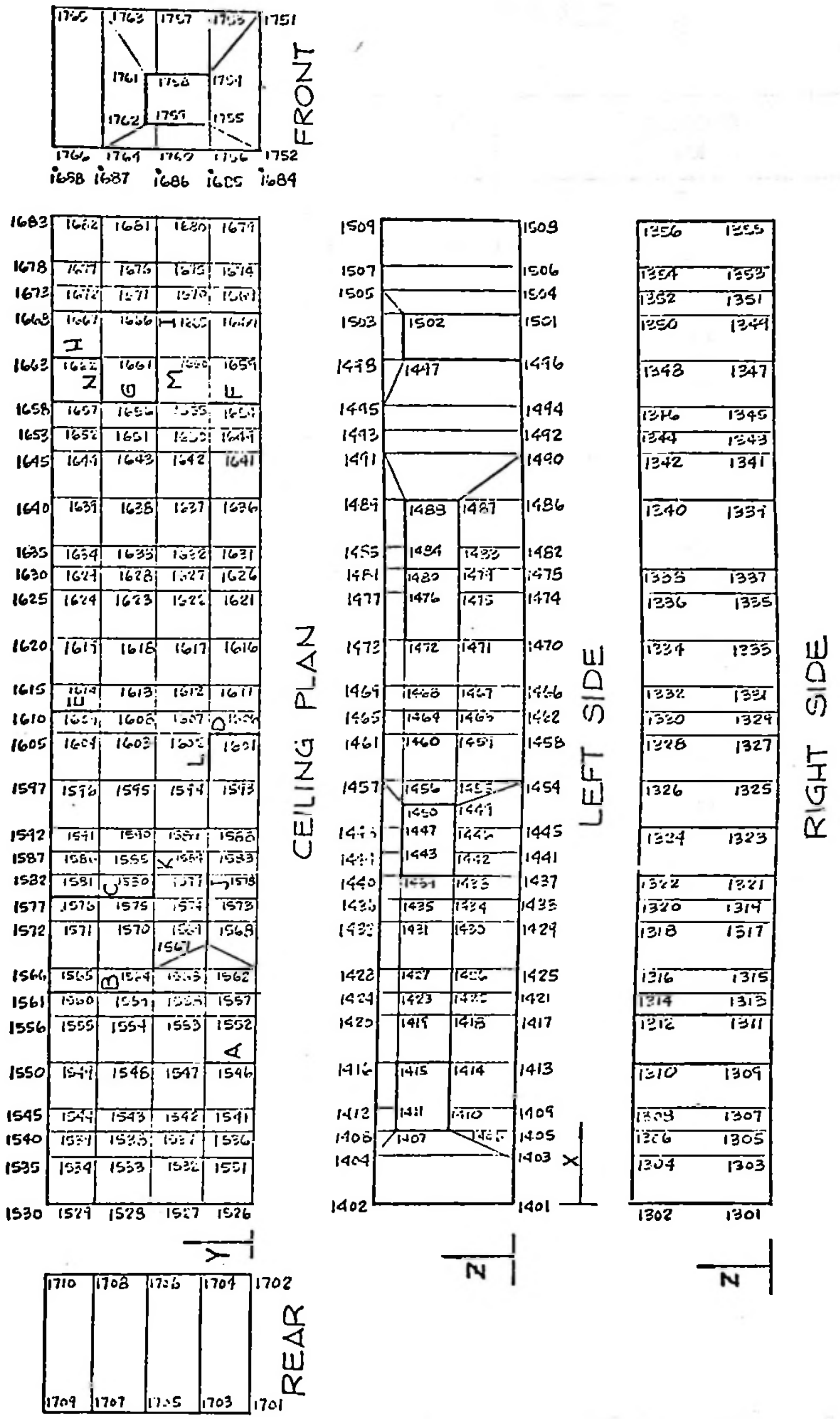


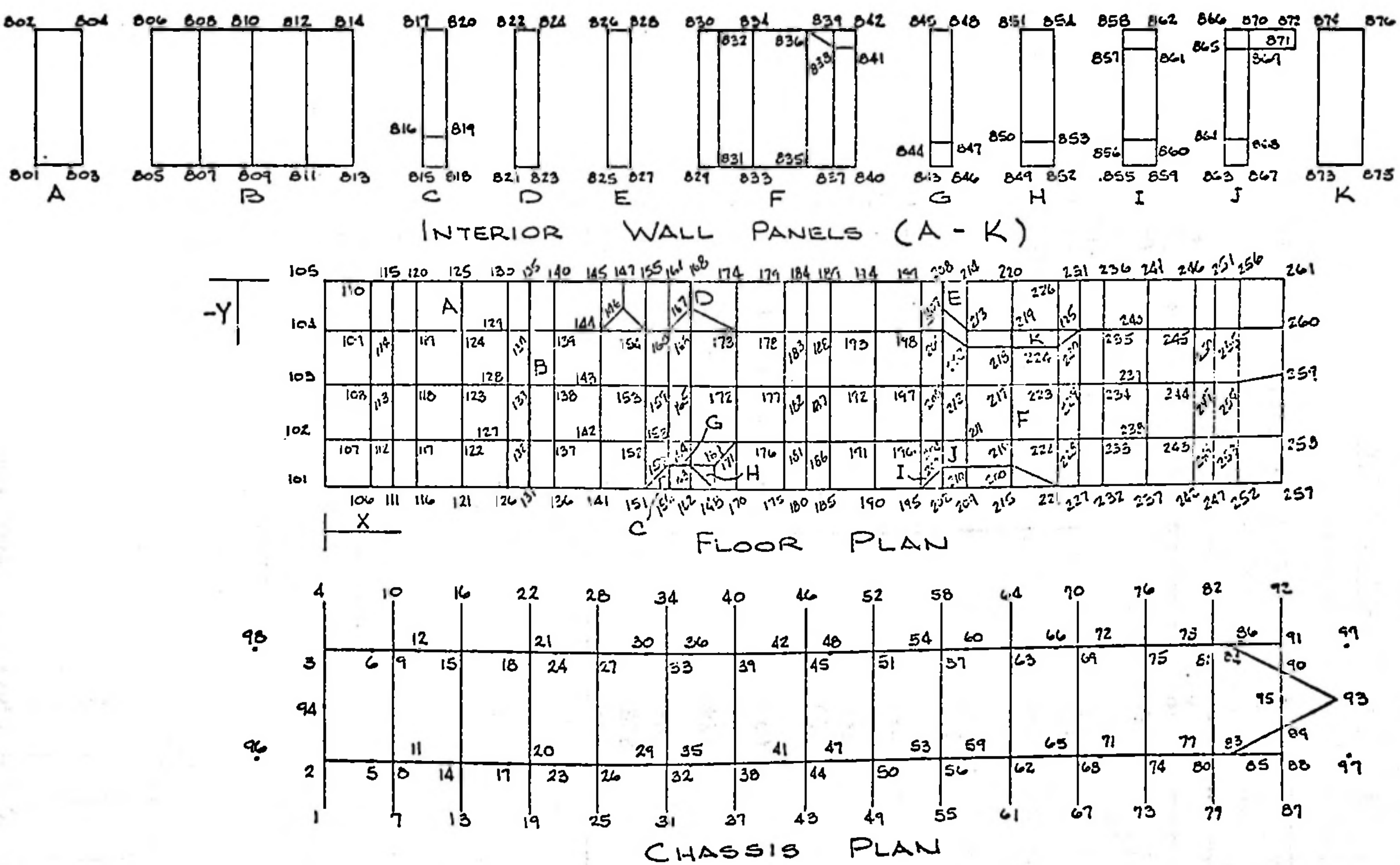
FIGURE 69. (Cont'd)

TABLE 4

T-2B ELEMENT DIRECTORY

ELEMENT NO.	NODAL CONNECT POINTS*			
	I	J	K	L
6	703	701	702	704
9	709	707	708	710
64	402	404	405	403
103	406	408	409	407
171	131	136	137	132
181	811	813	814	812
187	805	807	808	806
297	160	166	167	167
391	339	342	343	340
469	346	350	351	347
470	350	354	355	351
659	836	838	839	839
729	380	383	381	381
803	250	255	256	251
866	751	753	754	752
871	753	757	758	755

*See Figure 70 for nodal point locations.
**Computer reference symbols



Note: Numbers on the model indicate nodal point locations.

FIGURE 70. T-2B DOUBLE-WIDE - FINITE ELEMENT MODEL

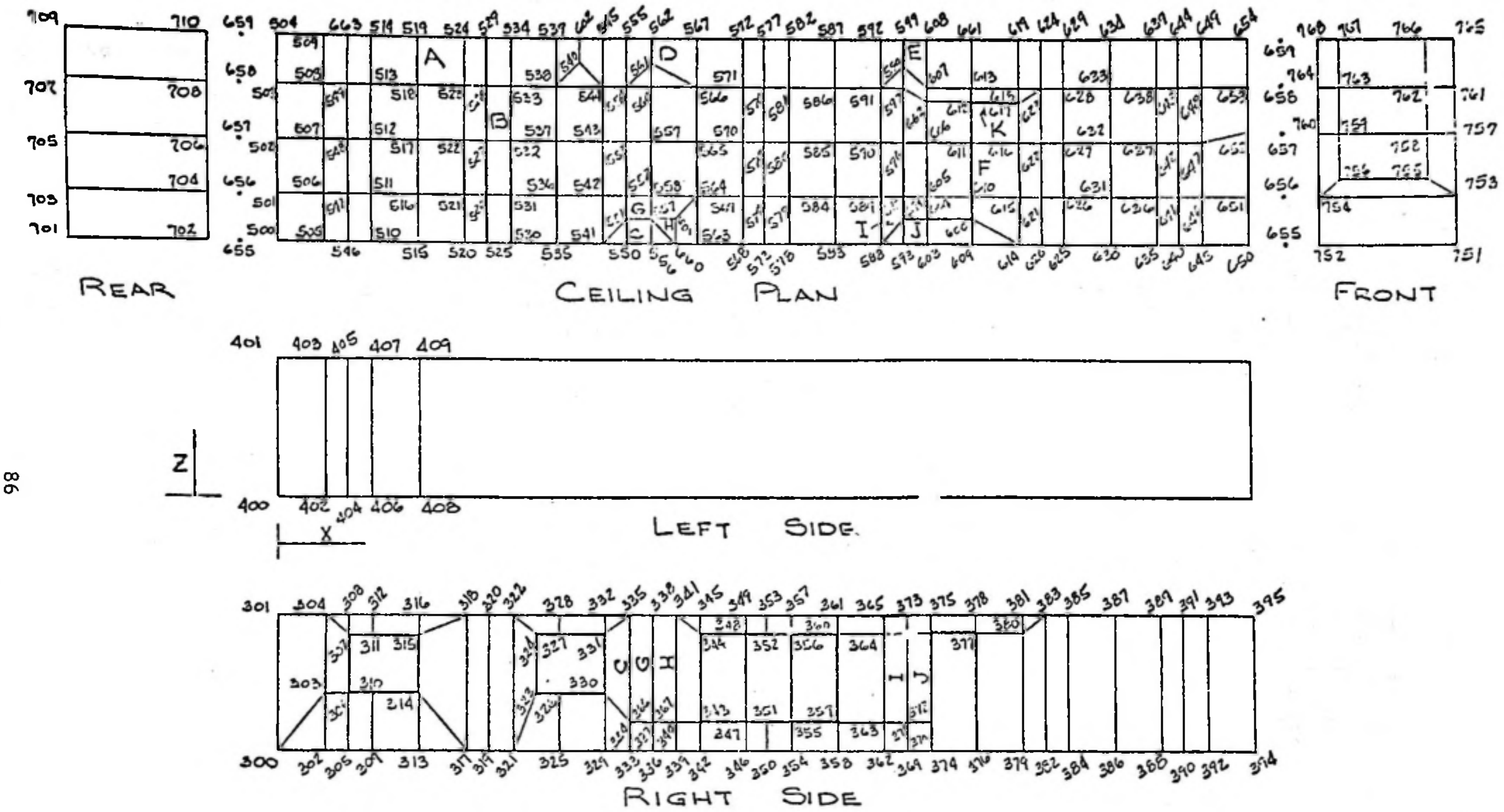


FIGURE 70. (Cont'd)

III. PERFORMANCE EVALUATION

At this point, the methodologies of the dynamic and finite element analyses have been revised and improved for the third time. Each program is now in a usable configuration. Task III will verify these analysis methodologies through the comparison of predicted data with that of the actual road tests.

Evaluation of the finite element analysis indicates areas of high stress, such as:

- Large openings like sliding glass doors and double windows;
- Front and rear doors;
- Maximum open spans (in the longitudinal direction);
- Joints that can be described as "soft" or "unstable" like the sidewall to roof joint with soft celotex in between or the sidewall to floor joint with asphalt or vinyl flooring in between;
- Over the axles, especially when large cutouts or doors are added in the sidewalls.

Of the above, the joints are believed to be the primary problem in the degradation of a mobile home. If one joint suffers a reduction in integrity or rigidity, then all or part of its load-carrying capability is transferred to the adjacent joints which, in turn, may be overloaded. This overloading of adjacent joints causes increased degradation within the joint and activates a sort of chain reaction of degradation along an entire length of joints, like the joints between the sidewalls and the roof trusses. For this reason, SwRI found torsion to be more critical in the degradation of a unit than the vertical bending mode. The application of adhesives significantly improved the integrity and rigidity of many of the joints in the mobile home system; but the remaining joints need to be similarly improved.

Furthermore, SwRI preliminary tests revealed that the galvanized metal roof cover of a mobile home offers no structural resistance to normal deflection of the unit structure during transportation. This lack of structural resistance to deflection is the result of the metal's tendency to wrinkle diagonally in either direction prior to becoming a tension member. Because the roof membranes are fastened with staples only around the folded down edges, any torsional deflections in the box structure introduce roof wrinkles in one direction, loading in tension at the edge attachments and shear at the lateral joints in the membrane. The repeated flexing and reversal of loading causes loosening of seals around vents, edge drop rails, lateral joints and edge attachments, inevitably causing water leaks in the ceiling and/or walls.

The use of plywood sheathing on roof trusses and under the galvanized metal membrane of mobile homes provides a significant increase in torsional rigidity in that such sheathing completes all sides of the torque box. The plywood then absorbs the loads the single metal membrane cannot, reducing the damage caused by the flexing metal roof.

For the most part, steel chassis strength is analyzed with respect to vertical loading. This is evidenced by the fact that "pre-cambering" of the longitudinal I-beams offsets vertical loading only. There are no calculations for the rigidity of the chassis in the torsional mode. In fact, many of the chassis have only lateral spacer angles between the I-beams - particularly if the unit employs lateral floor joists. There are no tests for torsion on the chassis or box structure.

However, torsion tests conducted on each mobile home did reveal the significance of nonsymmetry in the cross-section of the units. Torsion in the cross-section was noted to be directly proportionate to the degree of torsional resistance in the counterclockwise direction versus the clockwise direction. In the single-wide, where all but one shear wall are attached to one side and the corridor is placed along the opposite side, the difference in torsional resistance in the two directions was found to be significant. In the double-wide, the difference is further amplified by the lack of wall structure along the mating line. Even as a double-wide sits unsupported on the running gear, it indicates as much as 7 or 8 degrees asymmetrical loading in the direction of the exterior wall.

In tasks to follow, the concept, methodology, application, programs and results will be chronicled in the development and application of Task I's dynamic and finite element analyses.

*U.S. GOVERNMENT PRINTING OFFICE : 1980 0-625-542/1948

U.S. Department of Housing and Urban Development

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HUD-PDR-545-1