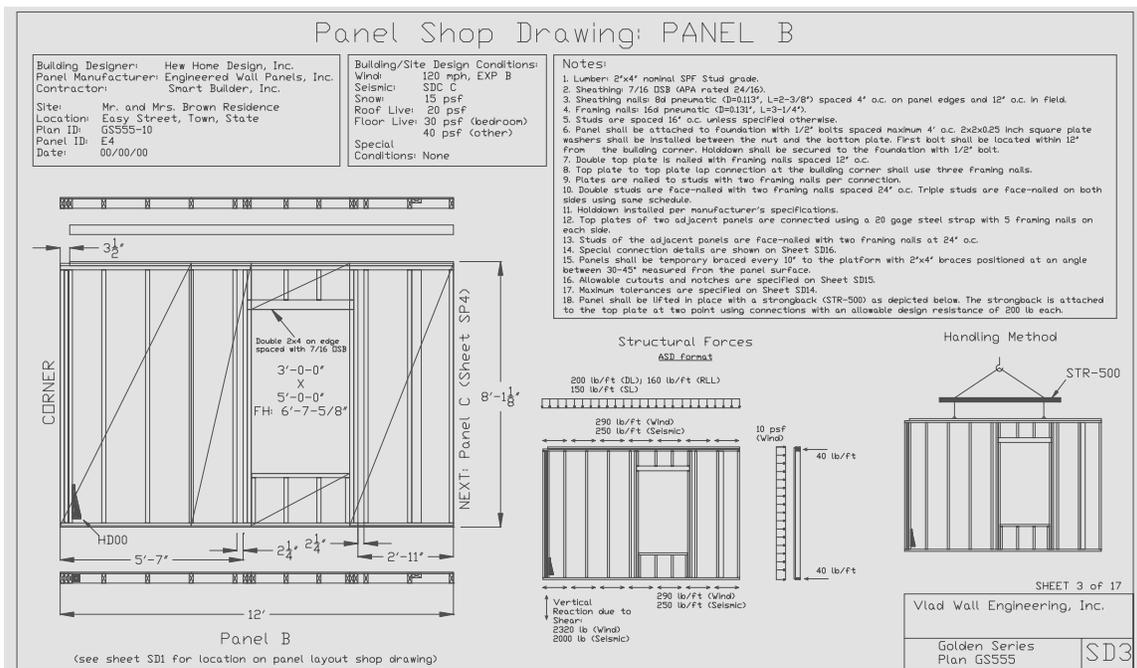




**U.S. Department of Housing and Urban Development  
Office of Policy Development and Research**

# Model Guidelines for Design, Fabrication, and Installation of Engineered Panelized Walls



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Prepared for

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

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by

NAHB Research Center, Inc.  
Upper Marlboro, Maryland

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## **FOREWORD**

This guide serves as a resource document for the housing and building component industries and as a comprehensive guideline for design, fabrication, and installation of panelized wall construction. More importantly, it provides a starting point for development of an industry standard which, through a reference in future building codes, could advance panelized wall construction as a safe and affordable housing technology.

This guide is based on compilation of current building practices and research information relevant to panelized wall construction. State-of-the-art methods provide the fabricator, designer, and builder with a set of tools for efficient design of residential structures and other buildings. The document is organized in four sections covering general issues, responsibilities, quality guidelines, and structural evaluation. Appendices provide useful supplemental data and design examples.

It is hoped that existing and innovative methods of wall panelization will be encouraged and improved by implementation of this document.

Harold L. Bunce  
Deputy Assistant Secretary for  
Economic Affairs



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## 1.0 GENERAL

### 1.1 PURPOSE

This guide provides technical information and specifications for the design and construction of panelized light-frame walls that are produced and delivered as engineered, prefabricated structural assemblies.

*The provisions include guidelines for quality, loads, structural evaluation, and material specification – similar to the provisions used for wood trusses as standardized in TPI 1-95. In addition, appendices are included to give supplemental information on the determination of loads, methods of load distribution and structural analysis, and supplemental design data for light-frame wall design.*

### 1.2 APPLICABILITY

The provisions of this guide apply to the design, fabrication, and installation of panelized light-frame wall systems that include framing members, sheathing, fastenings, openings for doors and windows, and other elements necessary to form a complete structural wall system. Although this guide focuses on a manufactured assembly approach, the provisions also include specific guidance that is applicable to site-built wall constructions. The provisions are intended to be applied by qualified design professionals, manufacturers, and contractors in accordance with all applicable regulations, governing building codes, and accepted practices.

*This guide is not intended to be applied specifically to pre-manufactured shear wall segments or other components that, alone, do not comprise a complete wall structural system. However, such wall components may be included as a part of a complete wall design in accordance with this guide.*

### 1.3 SCOPE

These provisions address the structural design, fabrication, and installation of light-frame walls, including its components and subassemblies, fabricated using wood or cold-formed steel members in platform-frame building constructions. The guidelines do not address non-structural and other design considerations such as thermal insulation, exterior and interior finishes, fire resistance ratings, or sound transmission ratings.

*Light-frame wall systems use repetitive vertical framing members (i.e., studs) that are generally spaced not more than 24 inches on center. Platform framing is a method of constructing light-frame walls such that the walls are not continuous between story levels and the tops and bottoms of the walls are “plated” with horizontal members that adjoin floor, roof, or foundation systems. Depending on the design conditions, additional connections can be installed to provide an adequate transfer of forces within the wall and between other building systems.*

*Panelized walls can be used as exterior and interior load bearing walls that are designed to resist gravity loads or lateral loads or both. The wall panels can be fabricated as “open” or “closed” assemblies. In the latter case, the on-site inspections need to be replaced with in-factory inspections and quality assurance procedures need to be established. These in-factory quality measures should be approved by and performed in coordination with the authority having jurisdiction.*

## **1.4 BUILDING CODE COMPLIANCE**

These provisions allow several options for attaining building code compliance, including the use of the governing building code provisions or prescriptive construction provisions for light-frame walls. The user is responsible for assuring compliance with the governing building code. Where the provisions of this guide depart from the governing building code, the user shall be responsible to make all necessary modifications to attain compliance or to seek the necessary approval as an alternate means and method.

*This document is not written as a regulatory document; however, the information presented is considered to be technically sound and in compliance with the intent of existing model codes in the United States. As such, the guide may be a useful resource in obtaining local regulatory approval for means and methods contained herein that are not otherwise recognized in the governing building code. This document is not currently referenced by a national model code and, while developed with review provided by selected experts in the subject matter, it does not currently comply with consensus standard development procedures such as those accredited by the American National Standards Institute (ANSI).*

## **1.5 ALTERNATE METHODS**

The provisions in this guide are not intended to preclude the use of equivalent materials, processes, and methods of design or construction.

## **1.6 REFERENCE DOCUMENTS**

The following reference documents are recommended for evaluation, design, fabrication, and installation of panelized walls.

*National Design Specification for Wood Construction and Supplement (ANSI/AF&PA NDS-1997), American Forest & Paper Association, Washington, DC, 1997.*

*National Design Standard for Metal Plate Connected Wood Truss Construction (ANSI/TPI 1-1995), Truss Plate Institute, Madison, WI, 1995.*

*This Guide is not intended to be a comprehensive document that covers all aspects associated with the use of the panelized walls, rather it establishes principal guidelines and methods that are currently unavailable to the panelized wall industry or scattered among numerous documents and publications. The user may implement selected concepts presented in the guide in combination with the provisions from the governing standards and codes unless the two contradict each other. For example, the lateral load path may be designed using methods presented in Appendices B, C, and D, whereas studs may be designed to resist gravity loads using methodology and reference data from the NDS-1997 (a code-approved design specification).*

*Specification for the Design of Cold-Formed Steel Structural Members (AISI-96)*, 1996 Edition, American Iron and Steel Institute (AISI), Washington, DC, 1997.

*Minimum Design Loads for Buildings and Other Structures*, ASCE 7-98, American Society of Civil Engineers, Reston, VA, 2000.

ASTM E 564-95 *Standard Method of Static Load Tests for Shear Resistance of Framed Walls for Buildings*, American Society of Testing and Materials (ASTM), West Conshocken, PA.

ASTM E 72-95 *Standard Test Methods of Conducting Strength Tests of Panels for Building Construction*, American Society of Testing and Materials (ASTM), West Conshocken, PA.

ASTM D6555-00 *Guidelines for Evaluating System Effects in Repetitive-Member Wood Assemblies*, American Society of Testing and Materials (ASTM), West Conshocken, PA.

*Power Driven Fasteners Staples and Nails for Use in All Types of Building Construction (NER-272)*, National Evaluation Service, Inc., Falls Church, VA, 1997.

*Quality Assurance System for Wood Framing Contractors*, U.S. Department of Housing and Urban Development, Washington, D.C., 2000.

*International Building Code (IBC)*, International Code Council (ICC), Inc., Falls Church, VA, 2000.

*International Residential Code (IRC)*, International Code Council (ICC), Inc., Falls Church, VA, 2000.

*International One- and Two-Family Dwelling Code*, International Code Council (ICC), Inc., Falls Church, VA, 1998.

*One- and Two-Family Dwelling Code (OTFDC)*, Council of American Building Officials (CABO), Falls Church, VA, 1995 and earlier editions.

*Wood Frame Construction Manual for One- and Two family Dwellings* (WFCM), American Forest and Paper Association and American Wood Council, Washington, DC, 1995.

*Uniform Building Code* (UBC), International Conference of Building Officials, Whittier, CA, 1997 and earlier editions.

*Standard Building Code* (SBC), Southern Building Code Congress International (SBCCI), Birmingham, AL, 1999 and earlier editions.

*National Building Code* (NBC), Building Officials and Code Administrators International, Inc., Country Club Hills, IL, 1999 and earlier editions.

*Structural Design Loads for One- and Two-Family Dwellings*, U.S. Department of Housing and Urban Development, Washington, DC, 2001.

*Residential Structural Design Guide*, U.S. Department of Housing and Urban Development, Washington, DC, 2000.

## 1.7 NOTATIONS AND SYMBOLS

$A_o$  = total area of openings in a perforated shear wall;

$B$  = sheathing panel width;

$C_N$  = capacity of a single nail connection;

$F$  = reduction parameter estimated using perforated shear wall method;

$F_b'$  = allowable bending stress;

$F_v$  = tabulated shear stress;

$H$  = shear wall height;

$J$  = torsional moment of inertia of a story;

$l$  = length of a shear wall segment;

$L$  = length of a shear wall line;

$M$  = total number of nails along the end stud of a shear wall segment;

$M_T$  = torsional moment;

- n = number of shear wall segments in a shear wall line;
- r = sheathing area ratio;
- R = uplift restraint force applied to the end stud of shear wall that can include contribution of partial overturning restraint, gravity load, corner effect, and other system effects;
- $r_i$  = distance from the wall to the center of story stiffness;
- V = characteristic shear resistance value adjusted for end use conditions;
- v = characteristic unit shear resistance value adjusted for end use conditions;
- $V_T$  = torsional component of shear load on the wall line due to diaphragm rotation;
- x = horizontal coordinate of a fastener relative to the panel center;
- y = vertical coordinate of a fastener relative to the panel center;
- $\Sigma K$  = geometric characteristic of fastening schedule of a sheathing panel;
- $\gamma$  = (H/l) = aspect ratio of a shear wall segment;
- $\beta$  = angle between the diagonal and the vertical edge of individual sheathing panel;
- $\alpha$  = shear wall strength reduction factor as defined in Appendix C for use with the Ni-Karabeyli method.

## 1.8 DEFINITIONS

ALLOWABLE STRESS DESIGN (ASD). A format of design whereby adequate structural performance is attained through use of (1) safety factors applied to characteristic material property values and (2) a series of nominal or design load combinations.

CHARACTERISTIC (REFERENCE) MATERIAL PROPERTY. A strength property at the design limit (reference) state before application of adjustment factors and reduction factors.

*Characteristic resistance is typically a mean or a percentile value of the assembly/component maximum strength measured by testing or estimated analytically.*

**ENGINEERED WALL.** A wall designed by a licensed professional to resist the design loads determined in accordance with this Guide or the governing building code.

*If the wall is constructed using prescriptive provisions as permitted by the governing building code, it is considered to be designed or “deemed-to-comply” per prescriptive requirements.*

**LOAD AND RESISTANCE FACTOR DESIGN (LRFD).** A format of design whereby adequate structural performance is attained by use of resistance factors applied to characteristic material property values and a series of factored load combinations.

**OVERTURNING RESTRAINT.** An element or assembly of elements that resist the wall overturning force resulting from an in-plane shear load.

**PANELIZED WALL.** A portion of a wall or an entire wall that is manufactured in a factory to be delivered to the construction site for installation. Also see **WALL ASSEMBLY**.

**RESISTANCE FACTOR.** A factor used with the LRFD format to reduce a characteristic resistance value to a factored resistance value.

**REDUCTION FACTOR. (RECIPROCAL OF SAFETY FACTOR).** A factor that is used with the ASD format to reduce a characteristic resistance value to an allowable design value.

*Safety factors and resistance factors do not include adjustments for the end-use conditions. Therefore, the reference resistance values should be adjusted for inconsistencies, if any, between assumed standard conditions and the actual end-use conditions. For example, the reference resistance of wood members are subject to adjustment for load duration effects.*

**SEGMENT ASPECT RATIO.** A ratio of a shear wall segment height to its length.

**SHEAR WALL LINE.** A series of shear wall segments located on the same wall line.

**SHEAR WALL SEGMENT.** A portion of a shear wall that is fully sheathed from the bottom plate (or track) to the top plate (or track).

*A shear wall without openings is also a shear wall segment for the purpose of shear wall design.*

**WALL ASPECT RATIO.** A ratio of the wall height to its overall length.

WALL ASSEMBLY. A portion of a wall or an entire wall that includes framing, sheathing, and fastening. A wall assembly provides a load path for lateral and gravity loads. Also see PANELIZED WALL.

## **2.0 RESPONSIBILITIES**

### **2.1 WALL DESIGNER**

The *Wall Designer* is a qualified individual or organization having responsibility for the design of a wall system. This qualification shall be in accordance with the statutes and regulations governing the professional registration and certification of architects and engineers at the location of the proposed construction. The responsibility includes, but is not limited to, designing walls, including associated components and connections, to resist required loads and to meet the serviceability criteria, if any, specified by the building designer. The wall designer shall analyze the wall performance under in-plane and out-of-plane forces due to all applicable load combinations specified in Section 4.3. The wall designer shall specify, if necessary, means and methods for panel handling, stacking, and special packaging requirements. Walls designed using prescriptive construction provisions shall comply with the governing building code for residential construction.

*The responsibilities of the wall designer can be adjusted to facilitate the design process based on a mutual agreement between the wall designer and the building designer. For example, the wall designer may calculate the wall loads based on information about the building characteristics and the site conditions provided by the building designer. If using prescriptive provisions, the wall designer need not carry a professional registration unless otherwise required by the local statutes.*

### **2.2 BUILDING DESIGNER**

The *Building Designer* is a qualified individual or organization having responsibility for overall building design in accordance with the statutes and regulations governing the professional registration and certification of architects and engineers at the location of the proposed construction. The responsibility includes, but is not limited to, selection of design format and design basis, determination of design loads, foundation design, structural member sizing, fastening schedule, construction detailing, and compliance of the

*Building designer and wall designer can be one and the same. If using prescriptive provisions, the building designer need not carry a professional registration unless otherwise required by the local statutes.*

building design with the governing building codes. The building designer shall provide for quality control and quality assurance of the design process in accordance with this guide and the governing building code. Buildings designed using prescriptive construction provisions for residential construction shall comply with the governing building code regulating the use of such provisions.

### **2.3 WALL MANUFACTURER**

The *Wall Manufacturer* is an individual or organization responsible for the fabrication of panelized walls in accordance with the wall design (shop drawings). The wall manufacturer shall provide for quality control and quality assurance of the panel fabrication process in accordance with this guide and the governing building code. The wall manufacturer shall provide for proper handling, stacking and packaging of the panels, as specified by the wall designer, to prevent mechanical or environmental damage to the panels during factory storage and transportation to the installer.

*The panel manufacturer may also serve as the building designer and wall designer. Each responsibility must be carried out in accordance with governing regulations associated with the location of the proposed site.*

### **2.4 INSTALLER**

The *Installer* is an individual or organization (i.e., contractor, builder, or construction company) responsible for the on-site installation of panelized walls in accordance with the building design (plans and specifications) and the individual wall designs (shop drawings). The installer shall use methods and means of handling wall panels as specified by the wall designer. The installer shall provide for quality control and quality assurance of the construction process in accordance with this guide and the governing building code. The installer shall provide temporary wall bracing, if necessary, to avoid panel damage or collapse during the construction process.

*Multiple roles, including installation, can be performed by a single entity to offer a streamlined service to the customer.*

## 2.5 DESIGN INFORMATION AND DOCUMENTATION

### 2.5.1 Wall Design by Engineering Analysis

– The wall designer shall provide engineered shop drawings and calculations for each wall in accordance with the loading requirements specified by the building designer. The design documentation shall be furnished to the building designer, panel manufacturer, and wall installer. The shop drawings shall indicate the following:

1. Reference to the building plan and the building designer.
2. Location of each shop-drawn wall with respect to the building plan.
3. Wall framing layout, material specifications, connection details within the wall assembly, allowable cut-out and notching specifications, and allowable tolerances.
4. Connection methods that will be used to attach the wall to the adjacent assemblies in the building.
5. Methods of panel handling during shipping and installation, special packaging and stacking requirements, if necessary.
6. The design uniform loads (in-plane and out-of-plane), concentrated loads, and reaction loads or forces along the perimeter (boundaries) of the wall based on loading conditions, building configuration, and connection detailing approach (i.e., load transfer) specified by the building designer. The design format (ASD or LRFD) that was used to estimate the loads and type of loading (wind, seismic, etc.) shall be specified.

*Appendix F includes an example of a wall shop drawing following design by engineering analysis (Section 4.0).*

*Wall design, unlike truss design, is integral to the building design and is iterative in nature when stiffness based design approaches are used for lateral building load distribution (Appendix C). Therefore, it is often difficult to separate the wall designer's and the building designer's responsibilities in a traditional sense. If the building designer does no engineering analysis and only specifies basic loading conditions (i.e., basic design wind speed, snow load, live load, etc.), then the wall designer must calculate the loads based on the applicable load combinations for applicable failure modes (shear, bending, compression, or combinations thereof) and distribute these loads between the elements or assemblies. Alternatively, the building designer can provide loads acting on each floor and the wall designer distribute them to the walls.*

*This level of involvement in making design assumptions and calculations regarding the "whole building" has traditionally been assumed by the building designer in the engineered wood truss industry. However, for a wall designer, the design of a load-bearing wall is much more integral with the design of the rest of the building.*

*There may be instances where the building designer will need to revise wall layouts, wall openings, and other features associated with the building design in coordination with the wall designer. If the building designer and the wall designer are one and the same, then this issue of coordination and division of responsibility is more easily managed. Also, if the wall design and building design are based on prescriptive construction provisions for residential construction, this issue diminishes in significance.*

*The wall designer is not responsible for partition wall design, floor system design, roof system design, foundation design, window and door specifications, weatherization, and other aspects of design not directly associated with the structural design of load bearing walls.*

### **2.5.2 Wall Design by Prescriptive Method**

– If walls are designed in accordance with prescriptive construction provisions of the governing building code for residential buildings, the relevant building code provisions shall be referenced on the shop drawings in lieu of engineering calculations. The shop drawing should include the information required in Section 2.5.1 except item 6.

*Most areas of the United States base residential building designs on prescriptive code provisions which do not require the services of a licensed design professional. Engineering analysis may be required or may be beneficial for buildings in high hazard areas (earthquakes and hurricanes), for structural conditions that exceed the intended limits of prescriptive methods, or when prescriptive solutions may be enhanced to meet requirements for higher performance levels.*

**2.5.3 Building Design by Engineering Analysis** – The building designer shall provide the following design information and documentation to the wall designer:

1. Complete construction documents including drawings and specifications showing detailed building plans and elevations with location of wall openings for windows and doors, foundation conditions, material specifications, and appropriate references to the governing building code and its provisions.
2. Information on the wall interior and exterior finishes that can alter the structural response or durability characteristics of the walls.
3. The design loads applied to the building including dead, live, snow, wind, seismic, and other loads as required by the specific use conditions and the governing building code in accordance with Section 4.3 of this guide.
4. Design format (ASD or LRFD) that was used to calculate the loads.
5. Any special conditions or requirements such as concentrated loads and the temperature and moisture environment expected for the end use.

**2.5.4 Building Design by Prescriptive Method** – If the building design is in accordance with prescriptive construction provisions of the governing building code, the building designer shall designate this method of design on the construction documents provided to the wall designer in accordance with Section 2.5.3. The design information required in items 3 and 4 of Section 2.5.3 shall be provided to the extent necessary to allow for correct application of the prescriptive construction provisions.

### **3.0 QUALITY GUIDELINES**

#### **3.1 GENERAL**

This section provides quality guidelines for design, fabrication, and installation of panelized walls as defined by the scope of this guide. It does not address appropriate means of quality assurance (i.e., assurance of compliance with these quality guidelines) through certified quality assurance programs, construction inspections, or other processes. Quality assurance measures shall be in accordance with the requirements of the governing building code and the applicable provisions of Section 4 of this Guide.

*Quality assurance in installation and manufacturing can be provided by the normal construction inspection requirements of the governing building code and local building authority. Alternatively, quality assurance in the manufacturing of walls may be accomplished by periodic audits or inspection provided by a certified third-party quality assurance organization or by other means considered acceptable and in compliance with the governing building code.*

#### **3.2 DESIGN**

**3.2.1 General** – Wall designs and building designs shall be prepared in accordance with Section 2.

**3.2.2 Design Criteria** – The minimum acceptable design criteria specified in Section 4 of these provisions shall be used to the extent that they are consistent with or otherwise deemed compliant with the intent of the governing building code.

*The wall designer is afforded some latitude in establishing an appropriate means and method of design based on judgment and the conditions of a particular project or application. Where discrepancies are identified between the wall designer's approach and the provisions of this guide, the governing building code, or local accepted practice, the wall designer should clearly indicate the discrepancy and identify the method used in the wall design with a reasonable justification. For example, a building code may require a header to be designed using the NDS with certain limitations on the various adjustment factors. However, the wall designer*

*may use the system adjustment factors found in Appendix B of this guide for specific systems or for other systems determined by testing in accordance with Section 4.4.2. Any variance from previously accepted practice as dictated by the governing building code should be clearly evidenced in the wall design documentation. Similarly, the wall designer may elect to use a particular lateral force distribution method in Appendix D because it better models a particular building's expected structural response (or the nature of the application is such that a more simplistic and less accurate approach is justified). If the method is not addressed in the governing building code, the wall designer should provide documentation and justification as suggested above. Finally, the design may be based directly on test data provided in accordance with the provisions of Section 4.*

*In effect, the building designer has full responsibility to provide a design that is in compliance with the governing building code or that has received approval as an alternate means and method. In any case, the building design must ultimately perform to a level consistent with the intent of the governing building code. The determination of "meeting the intent of the code" in matters of design usually requires the certification of a design professional and approval of the local building authority.*

### **3.2.3 Design Corrections and Revisions –**

Design defects that are identified in the design phase, the manufacturing phase (Section 3.3), or during installation (Section 3.4) shall be corrected. All corrections shall be incorporated into revised design documentation. Depending on the nature of the defect and revisions to the wall or building plans, the building designer shall promptly notify the local building authority for appropriate revision of and obtain approval of the revised construction documents as required.

## **3.3 WALL FABRICATION**

**3.3.1 General** – Components of the wall shall be assembled in accordance with the wall shop drawings in regard to dimensions, materials, and details.

### 3.3.2 In-Plant Inspection and Corrections –

Each wall panel shall be a subject to a documented inspection that assures compliance with design documentation, identifies potential manufacturing defects, and provides an effective mechanism to correct deviations from the wall design. The inspection shall be performed by a competent employee of the wall manufacturer. The inspection document shall contain the following: date of wall fabrication, date of inspection, inspector name, shift manager name, reference to building design documentation and building designer, and pass or fail statement. The wall panels that failed the inspection shall be discarded or repaired. In the latter case, the inspection shall be repeated and, if the defect affected the structural integrity of the wall panel, the nature of the repair shall be described in the inspection document.

In-plant inspections are not required for wall panels fabricated according to the prescriptive provisions of the governing building code.

**3.3.3 Acceptability Criteria (Tolerance Limits)** – Tolerance limits to evaluate the acceptability of wall panel construction and to detect non-compliances shall be established in agreement between the wall manufacturer, the wall designer, and building designer. The tolerance limits shall be identified on the wall shop drawings in a performance format, prescriptive format, or both. Noncompliances that reduce the structural integrity of the wall relative to the design specifications shall be corrected as set forth in Section 3.3.2. Recommended tolerance limits are as follows:

- Overall wall dimensions shall not vary from design by more than 1/4 inch per eight feet of the corresponding wall dimension.

*In-plant quality-control methods and practices can be enhanced by periodic auditing by a third-party for quality assurance purposes. Due to the extensive historic experience associated with conventional construction practices, the walls constructed in accordance with the prescriptive building code provisions are exempted from the in-plant inspections. The quality of such walls is assured through on-site inspections conducted by a local building official in the same manner as required by the governing building code for walls constructed on-site (Section 3.4.3). However, the panel manufacturer is encouraged to implement consistent quality procedures for all manufactured wall panels.*

*Some examples of interpretation of these provisions are:*

- *tolerances on the location of intermediate studs shall be governed by the ability of the wall framer to nail or screw two adjacent sheathing panels to a common stud without splitting the stud and damaging the panel edges and, at the same time, to provide the required gap between the panel edges;*
- *crooked studs shall be oriented with the curvature in the same direction to minimize the affect on the appearance of the wall;*
- *in regard to the top and bottom plates, studs shall be positioned so that the stud edge is flush against the interior edge of the plate to provide a flat surface for interior sheathing; the tolerances on the exterior side of the wall shall not exceed 1/8 inch;*
- *gaps between studs and plates shall not exceed 1/8 inch to prevent excessive settling and stiffness reduction;*
- *sheathing fasteners should be installed no closer than 3/8 inch from panel edges and with a tolerance of 1/2 inch in respect to spacing;*
- *nail heads shall be flush with the fastened member or countersunk to a depth no greater than 15 percent of the member thickness;*

- Individual member tolerances shall conform with the provisions of the governing grading agency for lumber products and with applicable industry standards for cold-formed steel construction.
  - Tolerances on location of individual members and connections within the wall shall be such that the wall structural integrity, function, and attachment of other materials are not compromised.
  - Fasteners and fastening techniques shall not cause member splitting, buckling, joint separation, abnormal deformation, or other conditions that may weaken the connection or member capacity relative to that required by the design specifications.
  - Members showing excessive rust, rot, warping, splitting, buckling, or other forms of damage or excessive defect shall not be used.
  - Members not showing an appropriate grade stamp or certification of material properties and type shall not be used.
- missed fasteners should be compensated with new fasteners installed in the intended locations; and,
  - buckled steel members should be discarded or used for non-structural components.

*Variation from these tolerance limits is permissible depending on the end-use application, customer specification, or local accepted practice. Some of the tolerance limits are recommendations that must be established with the purchaser and verified by inspection during manufacturing. In general, members should be assembled in a manner that minimizes dimensional variation.*

**Exceptions:**

1. Members that must be cut shall be permitted to be used without a label on each cut piece provided that at least 25 percent of the pieces used in the wall contain a visible and legible grade stamp or certification.
  
2. As an alternative to individual member labeling, a certificate containing appropriate verification of specified material properties shall be retained with the manufacturer job records.

**3.3.4 Site-built Wall Fabrication** – For site-built wall constructions, the provisions of this section shall apply to the wall framing contractor and builder. On-site inspections of the completed wall construction shall be conducted as required by the local building authority.

*For additional information on quality assurance for wood or steel framing contractors (installers), refer to Quality Assurance System for Wood Framing Contractors (HUD, 2000).*

### **3.4 WALL INSTALLATION**

**3.4.1 General** – Walls shall be positioned and installed in accordance with the construction documents consisting of the wall shop drawings provided by the wall designer and the building plans and specifications provided by the building designer.

**3.4.2 Temporary Bracing** – Temporary bracing shall be provided, as required, to resist loads during the construction phase until a floor or roof diaphragm is constructed and attached to the walls according to the permanent fastening schedule specified by the building designer.

**3.4.3 Field Inspection** – Field inspection of installed walls shall be performed by the local building authority for compliance with approved construction documents and the governing building code. The wall construction shall be completed prior to the inspection including installation of the panels, fastening of the panels within the wall and between the walls, and anchorage of the panels to the underlying structures. Corrections and alterations performed after the inspection nullify the inspection results and require a re-inspection by the local building official.

**3.4.4 Corrections** – Any significant discrepancies between the as-built or field conditions and the construction documents shall be corrected. The determination of appropriate corrective actions, including repairs and design revisions, shall be the responsibility of the building designer. The building designer shall be responsible to coordinate corrective actions with the wall designer unless otherwise approved by the local building authority. The corrective measures shall be implemented by the wall installer and inspected and approved by the local building authority.

**3.4.5 Alterations** – Alterations to the walls including cutting and drilling beyond limitations specified on the construction documents shall not be permitted unless approved by the wall designer. Repairs as a result of cutting and drilling beyond the specified limits or other damage to the wall and its components, shall be approved by the wall designer unless otherwise approved by the local building authority.

**3.4.6 Acceptance Criteria (Tolerance Limits)**  
Recommended tolerances for on-site wall installation are as follows:

- Walls shall be no more than 1/4 inch out of plumb per 8 foot of wall height;
- Wall locations in plan shall be accurate to within  $\pm 1/2$  inch;
- Wall support conditions (i.e., floor or foundation dimensions) shall be accurate to within  $\pm 1/2$  inch relative to plan dimensions;
- Wall anchor locations shall comply with the construction documents and shall not exceed maximum spacing requirements;
- Field installed connections shall use specified types and amounts of fasteners, and shall be installed in specified members and locations in accordance with the construction documents;
- Where alignment of members, components, and connections is required for proper load transfer as specified in the construction documents, any misalignment that results in abnormal deformation or discontinuity in the load path shall be corrected to be in compliance with the construction documents as specified in Section 3.4.4 or 3.4.5.

**3.5 Special Conditions** – The wall designer shall specify methods of panel handling that prevent degradation of structural components during panel manufacturing, transportation, and erection.

If necessary, the wall designer shall provide special guidelines for panel packaging and stacking to prevent environmental and mechanical degradation of wall components during panel storage and transportation.

*The wall panels shall be designed to resist forces resulting from temporary construction loads consistent with the methods of handling that will be used during wall manufacturing, transportation, and erection. During installation, a wall panel acts as a deep beam under gravity load. Therefore, the top and bottom plates (or track members) should be able to resist compression and tension forces. Depending on the wall size, configuration, and method of handling, the construction loads can degrade structural integrity or exceed capacity of the plates, splice joints in the plates, or sheathing joints. As an alternative, a strongback (lifting beam) can be used to distribute the load into the wall panel in a manner that prevents unfavorable loading conditions. Such handling problems may also be addressed by appropriate limits to panel size and weight relative to typical handling methods.*

## **4.0 STRUCTURAL EVALUATION**

### **4.1 APPLICABILITY**

This section applies to buildings, or portions thereof, designed in accordance with accepted engineering practice. Buildings, or portions thereof, designed in accordance with the prescriptive construction provisions permitted by the governing building code are exempted from this section.

*Appendix A includes a flow chart for design (structural evaluation) of panelized walls in accordance with this document. This flow-chart highlights the major design steps and provides design options available to the wall designer to meet the governing building code requirements.*

### **4.2 GENERAL**

Buildings and all parts thereof shall be designed by the building designer to resist loads determined in accordance with Section 4.3. Walls and all parts thereof shall be permitted to be designed by the wall designer to support loads determined in accordance with Section 4.3. Structural components, systems, and connections shall be designed such that a continuous load path is present and capable of transmitting lateral and vertical design loads through the structure and to the ground. Buildings shall be designed and detailed such that the local failure of any one component or element of the structural system will not precipitate immediate and catastrophic damage to the remaining structure.

### 4.3 DESIGN LOADS

Buildings, and all parts thereof, shall resist the structural actions and load effects resulting from the load combinations determined in accordance with one of the following:

1. governing building code;
2. *Minimum Design Loads for Buildings and Other Structures* (ASCE 7-98, ASCE 2000);
3. *Structural Design Loads for One- and Two-Family Dwellings* (HUD, 2001); or,
4. local accepted engineering practice.

### 4.4 STRUCTURAL RESISTANCE

Wall assemblies and components thereof, including connections within the walls and between the walls and adjacent assemblies, shall be designed to resist forces resulting from the load combinations determined in accordance with Section 4.3. The structural resistance of walls and components thereof shall be determined in accordance with the governing building code, or recognized material and design standards and specifications referenced in the governing building code. Alternatively, the methods of Section 4.4.1 or 4.4.2 shall be permitted to be used to evaluate structural performance of wall assemblies and components thereof.

**4.4.1 Design by Analysis** – Structural resistance of wall systems and components thereof shall be permitted to be determined by structural analysis methods including mechanics-based and empirical procedures. The ability of structural analysis procedures to adequately model structural response of the wall assemblies and components thereof shall be recognized in the governing building code, validated by extensive experience, or verified through structural testing in accordance with Section 4.4.2.

*Recognized design specifications for engineering analysis of light-frame steel and wood construction and assemblies are listed in Section 1.6. Supplemental design data is provided in Appendix B. Methods for distribution of lateral building loads and shear wall resistance analysis are provided in Appendices C and D, respectively. Appendix E includes an example of lateral design of a light-frame wood building.*

*Appendix B contains supplemental design data for use with recognized design methods such as the NDS-97 and the AISI-96. The data includes steel and wood framed shear wall values that may not be found in the governing building code. System factors for repetitive or built-up wood member design are also included for use with NDS-97. Other test data on connections, whole buildings, and other topics of design concern are also included and should be applied at the designer's discretion in accordance with the provisions of this Section. Reference documents are cited so that the designer and local code authority can independently assess the adequacy of technical substantiation.*

*Design procedures for specific methods and materials of construction that are beyond the current scope of the governing building code and recognized national standards may be substantiated by verification testing. A verification testing program intended to demonstrate the adequacy of a design method must address the range of conditions that are expected during the end use of the product. Such conditions include, but are not limited to, construction material types and dimensions, fastening methods and schedules, fabrication practices, wall configurations, failure mode, loading history, etc. The specimens should be tested to destruction in a manner that simulates the response during an anticipated in-service event under conditions representative of the end use conditions. The testing procedures from the reference documents listed in Section 1.6 or other documents recognized by the governing building code should be used to the extent practicable. In absence of standardized testing methods for evaluation of the proposed design procedures, a testing method should be developed and approved by an independent certified third-party testing organization. The design method should be used within the scope defined by the verification testing program.*

**4.4.2 Design by Structural Testing** – Structural resistance of wall systems or components thereof shall be permitted to be determined by testing. Specimens shall be tested to destruction in a manner that simulates the response during an anticipated in-service loading event under conditions representative of the end use conditions. Specimen size and configuration, assembly methods, and material properties (i.e., wood species and grade, steel yield strength, fastener type and dimensions, etc.) shall be identical to or representative of

*Evaluation by testing of individual members for the purpose of adjusting nationally recognized design values shall not be permitted. The design of individual members should be based on standardized design values in accordance with the governing building code. Evaluation of system performance effects for the purpose of developing generalized design rules (as oppose to testing of a specific construction configuration) should comply with the applicable provisions of the ASTM Standard D6555.*

the actual wall panel production and application. The testing procedures from the reference documents listed in Section 1.6 or other documents recognized by the governing building code shall be used. In absence of standardized testing procedures for measuring the performance of wall assemblies or components thereof, a testing method shall be developed and approved by an independent certified third-party testing organization. Design resistance values shall be determined from the test data in accordance with Section 4.4.3.

**4.4.3 Design Resistance Values** - The characteristic resistance values derived from testing conducted in accordance with Section 4.4.2 shall account for variability of the test sample in a manner that is consistent with applicable material design specifications listed in Section 1.6. In the absence of specific guidelines, recommended criteria for determining characteristic resistance values are provided in Table 4.1. Characteristic resistance values shall represent a lower bound test statistic based on the degree of variability experienced in the testing program.

*The characteristic resistance values for wood members subjected to bending, shear, tension, or compression should be reduced, as appropriate, for load duration effects using load duration factors in the table below. For example, with the exception of shear wall tests, wood member design values are generally established by dividing the characteristic resistance values (i.e., fifth percentile estimate of test data) by safety factor (i.e., 1.3 for bending) and the "ten minute" load duration factor (i.e., 1.6) to adjust the value to an assumed "normal" (live load) duration. The load duration factors in the NDS are then used to adjust to other load durations on a design-by-design basis. In addition, the characteristic resistance values shall be adjusted, if necessary, to account for differences between the standard test conditions and in-service conditions.*

**TABLE 4.1  
RECOMMENDED CRITERIA FOR  
ESTABLISHING CHARACTERISTIC  
RESISTANCE VALUES FROM STRUCTURAL  
TESTING**

Number of Test Repetitions	Observed Variability (COV)	Criteria for Characteristic Resistance
3	<10%	Use lowest tested value
	>10%	Increase number of test repetitions to 10
10	<20%	Use lowest tested value
	>20%	Increase number of test repetitions to 20
20	<30%	Use lowest tested value
	>30%	Use estimate of lower fifth percentile assuming normality

**LOAD DURATION FACTORS FOR USE WITH  
WOOD MEMBERS**

Load Duration	Load Type	Load Duration Factors
Permanent	Dead Load	0.9
Ten years	Occupancy Live Load	1.0
Two months	Snow Load	1.15
Seven Days	Construction Load	1.25
Ten Minutes	Wind/Earthquake	1.6

Design resistance values, for evaluation of loads determined in accordance with Section 4.3, shall be determined by multiplying the characteristic resistance value by an appropriate reduction factor in accordance with Table 4.2.

**TABLE 4.2  
ASD AND LRFD REDUCTION FACTORS  
FOR USE WITH CHARACTERISTIC  
RESISTANCE VALUES**

<b>Failure Mode/Application</b>	<b>Design Format</b>	
	<b>ASD</b>	<b>LRFD</b>
Light-frame shear walls and diaphragms		
- wind design	0.5	0.8
- seismic design	0.4	0.6
Bending, Tension, and Compression Members or Assemblies	0.5	0.8
Connections	0.4	0.65

**4.4.4 Serviceability Evaluation** – When required, the serviceability of walls and components thereof shall be evaluated in accordance with procedures and criteria provided by the governing building code and recognized design methods listed in Section 1.6. The serviceability criteria include, but are not limited to, considerations of short-term and long-term (creep) deformations or deflections, performance of exterior and interior finishes, function of nonstructural components (e.g., doors and windows), and others. The need for serviceability design and serviceability limit criteria shall be determined by the building designer.

**4.4.5 Quality Assurance** – The factory production process of panelized wall assemblies that are evaluated by testing (Section 4.4.2) shall be a subject to regular inspection in accordance with an approved periodic quality assurance program administered by an independent third-party quality assurance organization. The quality assurance program shall include periodic verification testing of wall panels randomly selected from the production line.

*The purpose of the factory inspection is to independently verify the compliance of the production process and panel product with the scope and intent of the testing program used to establish the performance characteristics of wall panels. The inspection should cover quality of the materials, conformance with design specifications, tolerances, fabrication practices, internal inspection procedures, and documentation. The verification testing should be performed periodically to assure that the panel performance is consistent with the original testing data, if applicable. The inspections are important for nontraditional systems because of limited experience with such systems.*

The in-house factory quality inspection programs administered by the panel manufacturer are required for assuring the quality of the engineered wall assemblies that fall into the categories specified in Sections 4.4.1 and 4.4.2 as stand-alone quality assurance programs or as a condition for compliance with the quality assurance programs administered by an independent certified third-party quality assurance agency.



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