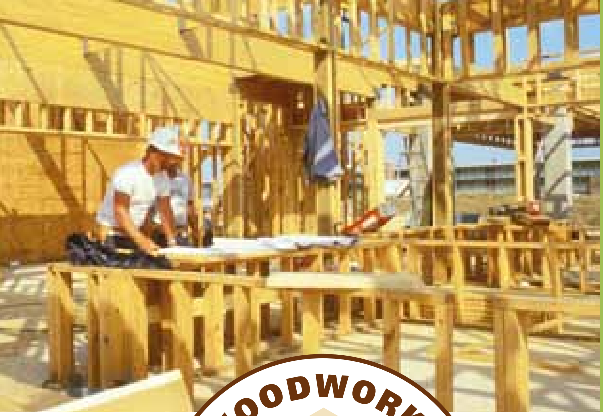


Structural Properties and Performance

WOOD DESIGN & BUILDING SERIES

Wood's unique natural properties offer a number of benefits, including design flexibility, ease of installation and durability. As a result, design and building professionals are increasingly using wood products, not only for homes, but for a wide range of commercial, institutional and other non-residential applications.

Earn one AIA/CES LU (HSW) by reading this document and taking a short online quiz. For details and learning objectives, visit the Online Training Library at *woodworks.org*. WoodWorks is an approved AIA provider.

Wood is a renewable building material whose structural properties vary by species, natural growth characteristics and manufacturing practices.

Design values for most species and grades of visually graded structural lumber products are determined in accordance with ASTM standards—including D 1990 – *Establishing Allowable Properties for Visually Graded Dimension Lumber from In-Grade Tests of Full-Size Specimens,* D 245 – *Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber,* and D 2555 – *Establishing Clear Wood Strength Values*—which consider the effects of strength reducing characteristics, size, load duration, safety and other influencing factors. The applicable standards are based on results of tests conducted in cooperation with the USDA Forest Products Laboratory.

Design Values for Wood Construction, a supplement to the *ANSI/AF&PA National Design Specification® for Wood Construction (NDS®)* provides these lumber design values, which are recognized by the model building codes.

THERE ARE SIX PUBLISHED LUMBER DESIGN VALUES:

Bending (F_b) – When loads are applied, structural members bend, producing tension in the fibers along the face farthest from the applied load, and compression in the fibers along the face nearest to the applied load. These induced stresses are designated as "extreme fiber stress in bending" (F_b). Single member F_b design values are used in design where the strength of an individual piece, such as a beam, may be solely responsible for carrying a specific design load. Repetitive member F_b design values are used in design when three or more load sharing members, such as joists, rafters, or studs, are spaced no more than 24 inches apart and are joined by flooring, sheathing or other load-distributing elements. Repetitive member stresses are also used where three or more pieces are adjacent, such as decking and built-up beams.

Shear Parallel to Grain (Fv) – Shear parallel to grain, or horizontal shear stresses, tend to slide wood fibers over each other horizontally. High applied shear stresses most often limit design in short, heavily-loaded, deep beams. Increasing a beam's cross-section decreases its applied shear stresses.

Compression Perpendicular to Grain (Fc-perp) – Where a joist, beam or similar wood member bears on supports, the load tends to compress the fibers. The bearing area must be sufficient in size to prevent crushing perpendicular to the grain (e.g., a sill plate with studs bearing down on it).

Compression Parallel to Grain (Fc) – In many parts of a structure, members transfer loads from end to end compressing the fibers. Examples include studs, posts, columns and struts. Applied stresses from this type of loading are generally considered consistent across the entire cross-section of the member, and the fibers are uniformly stressed parallel to the grain along the full length of the member.

Tension Parallel to Grain (Ft) – Tensile stresses are similar to compression parallel to grain in that they act across the full cross-section and tend to stretch the member.

Modulus of Elasticity (E and Emin) – Modulus of elasticity (also known as Young's Modulus) measures the ratio of the amount a wood member will deflect in proportion to an applied load. E is a measurement of stiffness and not a strength property. E represents average properties, and Emin is the fifth percentile property. Emin is the modulus of elasticity for beam and column stability calculations.

Published design values assume "normal" conditions of use—which include a dry environment and the absence of special and/or environmental loading conditions such as wind, seismic and snow and represent a cumulative load duration of 10 years. As with all design values, where other conditions exist, the values must be adjusted.

Equilibrium Moisture Content of Solid Wood and Structural Panels at 70°F (21°C)

	Equilibrium Moisture Content (%)		
Relative Humidity	**Solid Wood**	**Plywood**	**OSB**
10	2.5	1.2	0.8
20	4.5	2.8	1.0
30	6.2	4.6	2.0
40	7.7	5.8	3.6
50	9.2	7.0	5.2
60	11.0	8.4	6.3
70	13.1	11.1	8.9
80	16.0	15.3	13.1
90	20.5	19.4	17.2

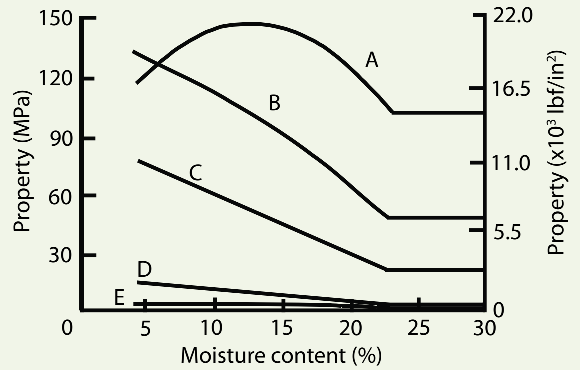
Source: APA – The Engineered Wood Association, Form TT-028A, December 2006

Load Duration

Load duration measures wood's ability to resist stresses when those loads apply over time. The duration of load, or the time during which a load acts continuously or intermittently on a wood member, is an important factor in determining the total load that the member can safely carry.

Wood can carry substantially greater loads for short durations than for long periods. In other words, wood is able to resist higher stresses when the load applies for a shorter time—a feature that enhances its performance in seismic and high wind zones. This also becomes a factor when building designers must calculate stresses such as snow or construction loads.

Effect of Moisture Content on Wood Strength Properties.



A, tension parallel to grain; B, bending; C, compression parallel to grain; D, compression perpendicular to grain; and E, tension perpendicular to grain.

Source: USDA Forest Products Laboratory

LOAD DURATION UNDER VARIOUS LOADING CONDITIONS

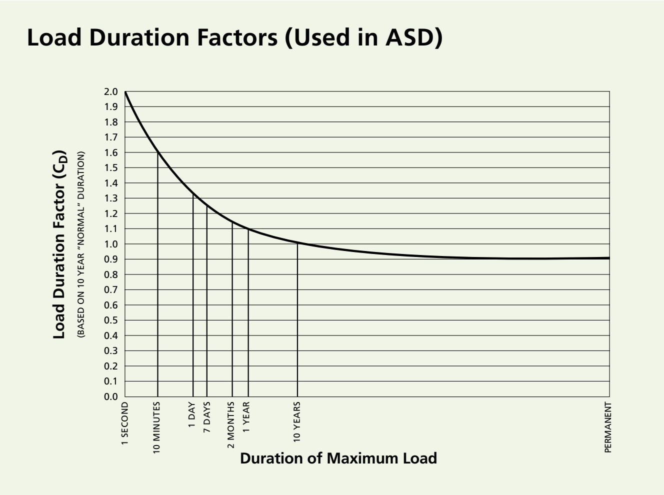
Design engineers customarily set working stresses for structural materials at levels below the yield point, or elastic limit, to ensure safe and satisfactory performance under service loading. They recognize that materials loaded beyond the elastic limit may lose elasticity and take on characteristics of brittleness or plasticity. Materials differ widely in this respect and, in some, such as wood products, the strength properties are greatly affected by the duration of loading.

Wood has a property that is valuable to the structural designer in that both its elastic limit and its ultimate strength are higher under short periods than under long-time loading. This permits higher working stresses when considering live loads of comparatively short duration, such as construction, heavy wind or seismic loads. The "normal" duration of load for wood members is considered to be equal to the cumulative permissible design load for 10 years.

The long record of satisfactory performance with wood structures designed using load duration adjustment factors, and the results of load duration tests on full-size members, substantiate the general applicability of the standard strength-load duration relationship.

CREEP

Creep is the time-dependent deformation of loaded members undergoing elastic deformation. The NDS addresses creep in Section 3.5.2, *Long-Term Loading*. Under long-term loading, the expected (average) deflection will be 1.5 times the immediate deflection due to the long-term component of the design load for seasoned (dried) lumber and 2.0 times the immediate deflection for unseasoned (green) lumber. Long-term loading



Source: National Design Specification for Wood Construction (NDS)

deflection. Creep deflection varies anywhere from zero to twice the initial deflection. This means that the total long term deflection can vary from the initial deflection by as much as two times.

Other Considerations

Many factors influence how a system responds to loading. It is important to realize that the way building professionals select and use materials will influence performance as well as cost.

- **Section properties** – These properties relate to the geometry of section. For example, a 2x4 flat-wise is not nearly as stiff or strong as a 2x4 on edge, even though it has the same material properties. The difference is the geometry or orientation of the member. This is the same reason a 2x6 is stiffer and stronger than a 2x4, given the same orientation.
- **E (modulus of elasticity) of individual elements** – E relates to the stiffness of a material, which is a measure of deformation caused by a given load. A material with a higher E value is stiffer. For example, No. 2 grade Eastern white pine has an E value of 1,100,000 psi and No. 2 Hem-Fir has an E value of 1,300,000 psi. Hem-Fir is a stiffer material.
- **F_b (bending design value)** – As indicated above under Properties and Performance, loads cause beams, joists and rafters to bend. An F_b value indicates design strength for the outmost (or extreme) wood fibers. The higher the F_b, the stronger the wood member in bending.
- **Lumber grade** – Lumber grades are assigned based on visual inspection and/or mechanical testing. Physical strength and stiffness characteristics are the primary considerations for structural lumber and appearance is secondary. Some manufacturers sort Machine Stress-Rated (MSR) lumber nondestructively using mechanical stress-rating equipment to measure the lumber's stiffness and other physical working properties before they do a visual inspection. The grade stamp will include the phrase "Machine Rated" along with the E and F_b ratings.

ASD versus LRFD

When designing with wood, commercial building designers may use either an Allowable Stress Design (ASD) format or a Load and Resistance Factor Design (LRFD) approach.

LRFD and ASD are two separate methods for selecting structural members and components, and differ in terms of both their applicable load combinations and resistance values. While ASD is the most common method in use today, the American Forest & Paper Association (AF&PA) developed the 2005 NDS as a dual format specification, incorporating design provisions for both ASD and LRFD for structural design of wood members and their connections. Adopted by the International Code Council in the *International Building Code (IBC)*, the National Fire Protection Association (NFPA) in the *NFPA 5000: Building Construction and Safety Code,* and all model building codes in the U.S., building professionals use the NDS to design wood structures.

Also published by AF&PA, the *ASD/LRFD Manual for Engineered Wood Construction* brings together all required elements for the design of wood structures in one comprehensive package. It includes design information and examples for wind and seismic, structural lumber, glued laminated timber, structural-use panels, shear walls and diaphragms, poles and piles, I-joists, structural composite lumber, structural connections (nails, bolts, screws), metal plate connected wood trusses, and pre-engineered metal connectors. It also includes over 40 details on connections as well as a chapter on fire design, which includes fire rated wall and floor assemblies for solid sawn lumber, I-joists and trusses.

Standards and Codes

Although building codes themselves define criteria for structural analysis, they also rely on consensus standards written by industry groups that have a material interest in how their products are used. These standards may in turn cite other consensus standards or material specifications to ensure a minimum level of performance for the desired material property. Codes typically only recognize consensus standards. Non-consensus standards, and specifications and standards written by manufacturers for their own proprietary products, are recognized and given credibility through organizations like the International Code Council – Evaluation Service, Factory Mutual, Underwriters Laboratories Inc. and others. Together, these codes, standards and specifications provide the basis for design confidence.

MANUFACTURING STANDARDS

Manufacturing standards detail the specific steps that a company must take to manufacture a particular product while meeting certain standards. Examples include the *Voluntary Product Standard PS 1-07, Structural Plywood* and the *American Softwood Lumber Standard PS 20.*

PERFORMANCE STANDARDS

In contrast, a performance standard allows a product to meet certain end-use criteria without prescribing the manufacturing technology required to achieve this performance. An example is the *Voluntary Product Standard PS 2-04, Performance Standard for Wood-Based Structural-Use Panels.* Most OSB and composite panels, as well as many grades of plywood panels, are performance-rated.

A number of organizations work to provide comprehensive performance standards for the wood-frame construction industry. In the U.S., for example, the Truss Plate Institute (TPI) maintains a truss design standard while structural glued laminated timber products are manufactured in conformance with *ANSI/AITC Standard A190.1-92, American National Standard for Structural Glued Laminated Timber.*

Like all building materials, wood has unique design properties. By understanding the nature of these properties and the manner in which their performance is measured, designers are able to optimize the numerous advantages wood brings to non-residential construction.

SOURCES AND OTHER MATERIALS

American Forest & Paper Association / American Wood Council, www.awc.org

- *ANSI/AF&PA NDS-2005 National Design Specification for Wood Construction (NDS)*
- *ASD/LRFD Manual for Engineered Wood Construction*
- *Details for Conventional Wood Frame Construction*
- *Lumber Substitution Based on Modulus of Elasticity*
- *Structural Wood Design Using ASD and LRFD*
- *The International Building Code and Its Impact on Wood-Frame Design and Construction*

APA – The Engineered Wood Association, www.apawood.org

- *Moisture-Related Dimensional Stability*
- *Voluntary Product Standard PS 1-07, Structural Plywood*
- *Voluntary Product Standard PS 2, Performance Standard for Wood-Based Structural-Use Panels*

Other

- *ANSI/AITC A190.1, Structural Glued Laminated Timber,* American National Standards Institute / American Institute of Timber Construction
- *Relation of Strength of Wood to Duration of Load,* USDA Forest Service, Forest Products Laboratory
- *Understanding Loads and Using Span Tables,* Paul Fisette, Department of Building Materials and Wood Technology, University of Massachusetts Amherst
- *Voluntary Product Standard PS-20, Lumber,* American Lumber Standard Committee, Inc.
- *Wood Handbook; Wood as an Engineering Material,* USDA Forest Service, Forest Products Laboratory
- Washington State University, Department of Civil and Environmental Engineering, http://timber.ce.wsu.edu

Materials are also available via the WoodWorks Web site, in the section on *Key Issues/Structural Design,* www.woodworks.org

WoodWorks is an initiative of the Wood Products Council, which includes all of the major North American wood associations.

Photo credits: Southern Forest Products Association (p. 1), Duke Integrative Medicine, Duke University Medical Center, Duda/Paine Architects (p. 3)