

Standards for Structural Wood Products and Their Use in the United States

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Abstract

The system of model building codes and voluntary product standards used in the United States for structural lumber and engineered wood products can appear complicated and confusing to those introduced to it for the first time. This paper discusses the various types of structural wood products commonly used in U.S. residential and commercial construction, and the system of building codes and product and performance standards that help regulate the quality and use of these products.

Introduction

The United States is the leading producer and consumer of wood products in the world. The majority of this wood resource is used to construct the approximately 1 million new single-family homes built every year and to repair and remodel existing houses. The demand for construction material has led to better utilization of wood, which now comes from second- and third-growth forests. Compared with 50 years ago, the forest resource in the United States today has a more diverse array of species available for use, but is composed of trees of smaller diameter. More efficient utilization of this new forest resource is a challenge to the building industry.

Modern technology has made possible the development of improved grading practices and improved engineered wood products. Solid-sawn lumber continues to account for the bulk of structural products used in construction. Although the use of mechanical grading has provided precise control of property assignment, it has also introduced a new set of lumber grades into the marketplace. In addition, engineered wood products such as laminated veneer lumber (LVL) and parallel strand lumber (PSL) are being substituted for solid-sawn lumber. Large solid-sawn timbers are increasingly difficult to obtain and are often being replaced by glued-laminated (glulam) timbers, wood I-joists, and the

larger sizes of LVL and PSL. Oriented strandboard (OSB) is being used as a substitute for structural plywood. This widening assortment of products can lead to concerns about product quality and structural reliability among specifiers and users.

The system of model building codes and voluntary product standards for lumber and engineered wood products that ensures the quality of these products is well established and reliable. However, the system can appear complicated and confusing to those introduced to it for the first time. This paper discusses the various types of structural wood products commonly available in the United States, as well as the system of building codes and product and performance standards that help regulate the quality and use of these products.

Building Codes and Product Standards

The regulation of building construction in the United States is accomplished through a document called a building code. A building code is a collection of laws, regulations, ordinances, or other statutory requirements adopted under the legislative authority of state or local governments. The code specifies the minimum acceptable construction requirements necessary to protect public health and safety. Because of the complexity of issues faced by state and local governments in writing building codes, so-called "model" building codes began to be developed early in the 20th century. These codes are intended to be a foundation upon which a legislative body can create its own regulations.

Currently three organizations in the United States write model building codes:

- International Conference of Building Officials (ICBO);
- Building Officials & Code Administrators International, Inc. (BOCA); and
- Southern Building Code Congress International (SBCCI).

Each is a nonprofit organization owned and operated by voting members composed of representatives of city county and state governments who have adopted that organization's model code, plus representatives from the federal government. The *Uniform Building Code* of ICBO (1994) has been adopted by most states west of the Mississippi River. States in the Southeast generally use the *Standard Building Code* of SBCCI (1994), while those in the Northeast typically use BOCA'S *Standard National Code* (1996) (Fig. 1).

In establishing comprehensive regulations for all aspects of building construction, model building codes excerpt or directly reference numerous standards promulgated by a variety of nationally recognized technical and trade organizations. The text of the building code describes how each referenced standard is to be used for regulation purposes. Organizations producing voluntary consensus standards for wood-based materials referenced by model building codes include:

- American Forest & Paper Association;
- American Institute of Timber Construction;
- American Society of Civil Engineers;
- American Society for Testing and Materials;
- American Wood-Preservers' Association;
- Truss Plate Institute; and
- Department of Commerce.

In addition to belonging to the three model building code organizations, each of the above is a member of the International Code Council. ICC coordinates the efforts of the three model building code organizations.

Wood Products Used in the United States

The following describes the structural wood products commonly used in the United States and the product and performance standards applicable to each. Also discussed

is the quality control system that ensures compliance of assigned properties with model building code requirements.

Round Timbers

Round timbers are generally used as utility poles, construction poles, foundation piles, or construction logs. They represent one of the most efficient uses of wood because of the minimal processing required for their manufacture. Poles and piles are generally debarked or peeled, seasoned, graded, and treated with a preservative prior to use. Construction logs are often profiled along their length.

Poles and Piles. —The primary use of wood poles is to support utility and transmission lines. Length may vary from 20 to 125 feet. Poles used for building construction, as well as foundation piles, rarely exceed 70 feet in length. The product standards for round timbers include provisions for geometry such as diameter and taper, as well as allowable defects like knots, warp, and degree of spiral grain. *ANSI 05.1* provides the limitations for utility and construction poles (ANSI 1992a); those for piles are found in *ASTM D25* (ASTM 1997).

Poles for transmission lines may be designed as single-member or guyed cantilevers or as structural members of a more complex structure. Values for fiber stress in bending are given in *ANSI 05.1* for most species used in transmission lines. These are near-ultimate values for poles used as cantilever beams and, as such, are not compatible with the working stress design philosophy of the *National Design Specification* (AF&PA 1997). Reliability-based design techniques have been developed for the design of transmission line systems (ANSI 1992b). Procedures for establishing design stresses for round timber piles of various species are published in *ASTM D2899* (ASTM 1997). These procedures basically take published clear wood design stresses and

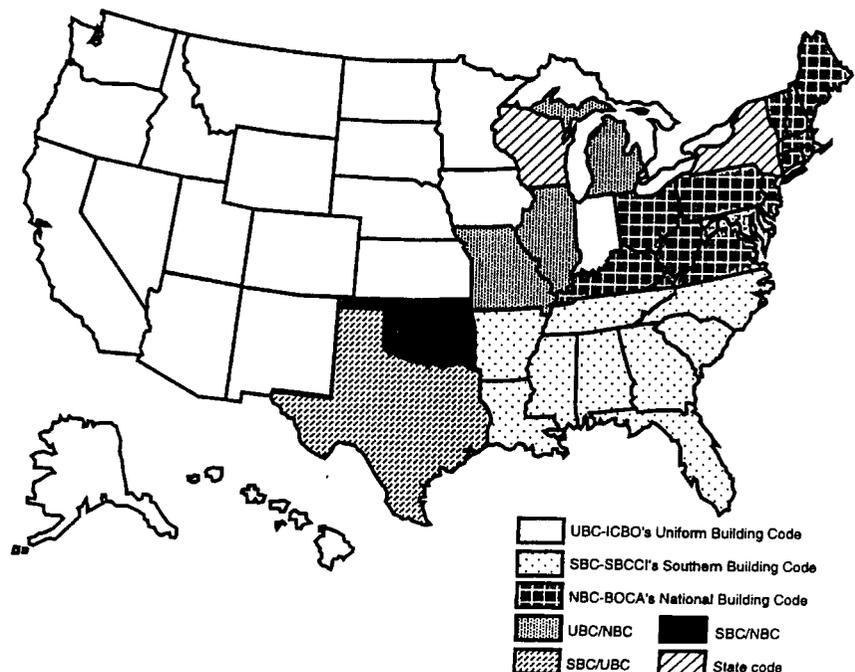


Figure 1. —Current areas of model building code use in the United States (Smulski 1997b).

adjust them to a corresponding design value for poles and piles. For construction poles, design stresses are modified such that the tip stress for piles is adjusted to a groundline design stress for poles. Methods for establishing design stresses for construction poles are set forth in *ASTM D3200* (ASTM 1997). American Society of Agricultural Engineers standard *EP 560* (ASAE 1998) includes a complete set of calculated design values for construction poles based on ASTM D2899 procedures.

Whether used for utility or construction, standard practice requires that poles be pressure-treated with a preservative in line with an applicable American Wood-Preservers' Association standard. *AWPA C4* establishes preservative retention values for utility poles; *AWPA C23* sets forth preservative retention values for poles used in building construction (AWPA 1997).

Construction Logs. —Log buildings are a popular form of construction for both recreational and residential structures. Logs are usually peeled, then machined into a variety of cross-sectional shapes. There are no standardized design properties for construction logs; however, procedures to calculate design stresses based on the largest rectangular cross section that fits within the machined cross section are found in *ASTM D3957* (ASTM 1997).

Solid-Sawn Structural Lumber

Lumber Grading. —Lumber is defined in *ASTM D9* as “the product of the sawmill and planing mill usually not further manufactured other than by sawing, resawing, passing lengthwise through a standard planing machine, cross-cutting to length, and matching” (ASTM 1997). Lumber sawn from a log, regardless of species and size, is quite variable in mechanical properties. In the same manner, its manufacture can be subject to considerable variation. Structural grading rules limit these variables by requiring conformance to a specified set of parameters. Grading rules allow users to purchase material that suits their particular purposes and allow calculation of engineering design values for use by architects and engineers. Understanding the grading system in the United States, and the standards that govern its development, requires an understanding of lumber size classifications.

During the evolution of stress grading in the United States, lumber size served as a guide to anticipating final use. The three size classifications for structural lumber are Boards, Dimension Lumber, and Timbers:

- Boards are less than 2 inches in nominal thickness.
- Dimension lumber is from 2 to 4 inches in nominal thickness and 2 or more inches wide.
- Timbers are 5 or more inches in nominal least dimension.

It is important to understand that lumber size classifications are based on the most efficient anticipated use of the member rather than on the actual use. Although grading system development has tended to parallel size classification, there are no restrictions on actual use for any size classification provided that design stresses are within those allowed for the grade.

In the United States, there are two approaches to grading structural lumber: visual grading and mechanical grading. Visual grading is the sorting of lumber into specific grades by a person trained to judge lumber solely on its visible characteristics such as knots, wane, slope of grain, and other natural and machining imperfections. Visual grading is used for all three size classifications. Allowable design values for visually graded lumber may be based on the results of strength tests conducted on full-size lumber or derived from tests of small, clear specimens of wood (Table 1).

Mechanical grading is the sorting of lumber by a machine that evaluates its mechanical or physical properties using a nondestructive test, followed by visual grading to gauge certain characteristics the machine cannot assess. Quality control procedures are used to ensure that the output of the mechanical grading process meets specified property values. At present, mechanical grading in the United States is limited to dimension lumber.

Most structural lumber sold in the United States is produced from softwoods that have been visually graded. However, both grading systems have also been used with hardwoods.

Lumber Standards. —Voluntary *Product Standard PS 20* (NIST 1994) establishes nationally recognized requirements for the grading of lumber. *PS 20* was developed by the American Lumber Standard Committee (ALSC) in accordance with procedures of the U.S. Department of Commerce and is administered by the National Institute of

Table 1.—Standards and specifications for determining design values for solid-sawn structural lumber under *PS 20* procedure.^a

Size class	Grading	Property basis	Primary standard	Applicable to:
Boards	Visual	Clear wood	ASTM D245	All species
Dimension	Visual	Clear wood	ASTM D245	Redwood, cedars, minor western softwoods, hardwoods
		Full size	ASTM D1990	Other softwoods
	Mechanical	Full size	MSR policy rating by specific gravity policy	All species
Timbers	Visual	Clear wood	ASTM D245	All species

^a Preservative treatment of solid-sawn wood members by pressure processes is set forth in *AWPA C2* (AWPA 1996).

Standards and Technology (NIST). ALSC members are appointed by the U.S. Secretary of Commerce to constitute an independent consensus body. The ALSC consists of representatives from:

- each agency that participates in the program and publishes and maintains grading rules and inspection facilities covering the various species (rules-writing agencies);
- each lumber inspection agency participating in the program that does not publish grading rules (nonrules-writing agencies); and
- the construction community including architects, engineers, general contractors, home builders, wood-using industries, millwork manufacturers, lumber wholesalers and retailers, and consumers.

The ALSC operates as an independent body with defined functions with regard to maintaining, implementing, and enforcing *PS 20*. The ALSC established the National Grading Rules Committee (NGRC) as an autonomous body charged with establishing and maintaining nomenclature and descriptions of lumber grades. The NGRC is composed of members of rules-writing and nonrules-writing agencies from the United States and Canada, BOCA, ICBO, SBCCI, the American Society of Civil Engineers, the American Institute of Architects, consumer and distributor organizations, the Federal Highway Administration, the Defense Logistics Agency NIST, and the USDA Forest Service Forest Products Laboratory (FPL).

The ALSC also established a Board of Review as an independent body composed of three members elected by the ALSC. The function of the Board is certification and accreditation of grade rules and design values as established by the NGRC, and of agencies that wish to grade lumber under *PS 20* provisions. *PS 20* states that design values contained in grading rules shall be developed in accordance with appropriate standards of the American Society for Testing and Materials (ASTM) and other technically sound criteria. NIST, with the advice and counsel of the FPL, is the final authority as to the appropriateness of such standards and criteria (Fig. 2). Once grade marks are approved, Board-approved quality inspectors conduct periodic inspections to verify that grading agencies are following ALSC-approved procedures (Francis and Collins 1995, Smulski 1997a).

ASTM procedures are generally used to derive allowable properties for lumber sold in the United States. However, ASTM standards do not exist for some products or procedures. In some cases, the Board may have “Policy” documents that cover such omissions. For example, ASTM D 1990 does not provide guidance for determining allowable properties for species growing outside the United States. The Board’s *Foreign Lumber Policy* authorizes guidelines and criteria for agencies accredited to grademark and supervise the trademarking of lumber produced outside the United States (Shelley and Green 1994). The Board also has “Guidelines” on how to apply the principles of *ASTM D 1990*

to foreign species. No ASTM standard on property assignment procedures for mechanically graded lumber currently exists, although one is under development. Again, the Board has Policy documents on mechanically graded lumber. In addition, each of the rules-writing agencies that wishes to mechanically grade lumber must have Board-approved documents on their property assignment and quality control procedures. The Board also provides guidelines on how to adapt these procedures to the mechanical grading of lumber produced outside the United States.

Model building code approval for solid-sawn structural lumber is generally through its recognition of AF&PA’s *National Design Specification (NDS) for Wood Construction* (AF&PA 1997). While a model code may recognize ALSC-approved design values directly tying their use to the NDS helps keep allowable properties in harmony with other NDS procedures.

Structural Composite Lumber

Structural composite lumber (SCL) is a generic term for a family of proprietary lumber products composed of wood elements combined with waterproof structural adhesives to form lumber-like members. All current SCL products have the grain of the wood elements oriented parallel to the length of the member. SCL is made commercially from both softwoods and hardwoods. In the United States, three types of SCL are currently produced: LVL, PSL, and laminated strand lumber (LSL). All three have been manufactured for only about 30 years.

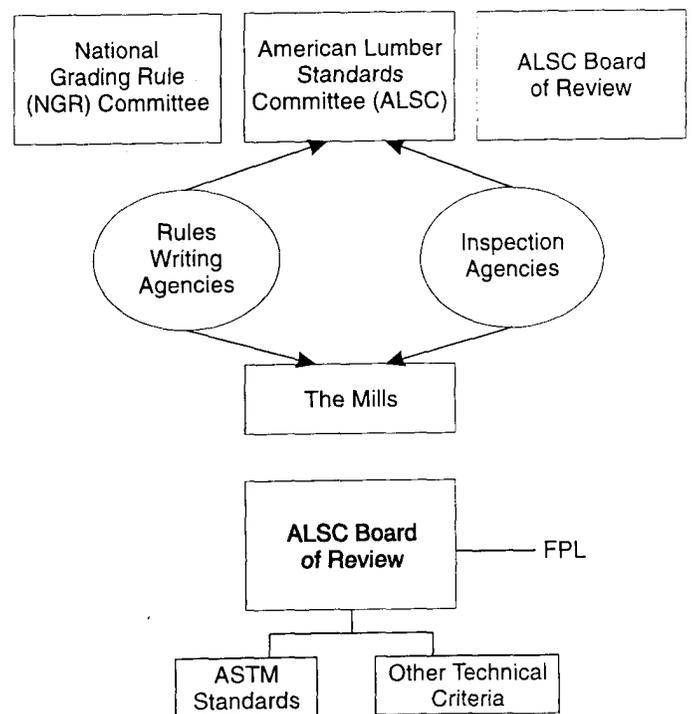


Figure 2.—American Lumber Standard Committee process (top) and the Board of Review (bottom).

Laminated Veneer Lumber. —LVL is manufactured from layers of veneer, with the grain of all veneers oriented parallel to the length of the member. This contrasts with plywood, which traditionally has the grain of adjacent veneers perpendicular to each other. Most manufacturers use sheets of veneer 0.10 to 0.165 inch thick. Typically the rotary cut veneer is dried, then graded ultrasonically for stiffness and visually for defects. The veneers are laid-up with higher grades on the face and lower grades in the core. The veneers are stacked to achieve the desired thickness and laid end to end to achieve the desired length. Within the stack, veneer ends are staggered to minimize their effect on strength. The veneers are bonded with a waterproof structural adhesive under heat and pressure into a billet typically 1.75 inches thick, 48 inches wide, and up to 80 feet long. Billets are ripped to the desired width and cross-cut to the desired length. Presently most LVL is made from Douglas-fir southern pine, and yellow-poplar; common sizes closely resemble those of solid-sawn dimension lumber.

Parallel Strand Lumber. —PSL is manufactured from long strands of wood. As with LVL, production typically starts with rotary cut and graded veneer. The veneer is then clipped into strips about 0.75 inch wide and up to 8 feet long. A waterproof adhesive is applied, and the strands are fed into a continuous press. Adhesive is cured using microwave equipment. Billets, which are up to 66 feet long, are cut into smaller members. Although any species could be used to produce PSL, those currently used include Douglas-fir, southern pine, western hemlock, and yellow-poplar.

Laminated Strand Lumber. —LSL is made from strands of wood using technology similar to that used to produce OSB. Strands for LSL are significantly longer than those for OSB, but shorter than those for PSL. This greater length, and orienting the strands parallel to the length of the finished product, are the keys to the longitudinal strength of LSL. Unlike LVL and PSL, logs for the production of LSL need not be peelable. Thus, smaller logs and crooked logs

of many species could be used in LSL production. Species presently being used include aspen and yellow-poplar.

Structural Composite Lumber Standards. -Manufacturers of composite structural lumber obtain and analyze product property data according to *ASTM D5456* (*ASTM 1997*) (Fig. 3). This documentation could be submitted to building officials in every city county and state where the product will be marketed, however, this would usually be impractical. To avoid duplication of effort, the model building code organizations have created "evaluation services." The evaluation service of each of the three model building code agencies is a subsidiary corporation that reviews the technical report, grants recognition if the information meets the requirements of that particular building code, and publishes "National Evaluation Service Reports" (Fig. 4). These reports verify the product's compliance with the model code. The process may also include periodic inspection and testing by a quality control inspection service approved by the model building code agency. For manufacturers who plan to distribute their products nationally application can be made to the National Evaluation Service (NES). Although more cumbersome and expensive, issuance of an NES report carries the seal of all three model code agencies (Smulski 1997b).

Because SCL products are proprietary standardized design values have not been established. Rather, each manufacturer submits data for approval by the model building code agencies as discussed previously. Thus, design information varies among manufacturers and is given in their product literature. In general, the products are manufactured so that allowable properties compare favorably with those of solid-sawn dimension lumber (Table 2).

Structural Panel Products

Structural panel products is a family of wood products made by bonding veneer or flakes into flat sheets to form large structural elements. The primary members of this

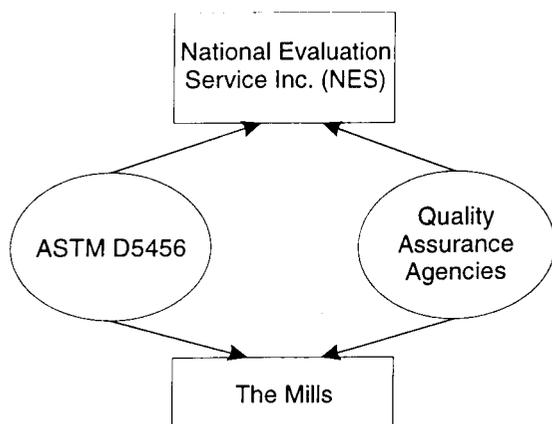


Figure 3.—Approval process for structural composite lumber products.

 Council of American Building Officials		
<small>INTERNATIONAL CONFERENCE OF BUILDING OFFICIALS</small>	<small>SECRETARIAL SOUTHERN BUILDING CODE CONGRESS INTERNATIONAL, INC.</small>	<small>BUILDING OFFICIALS AND CODE ADMINISTRATORS INTERNATIONAL, INC.</small>
<small>5360 South Workman Mill Road Whittier, California 90601</small>	<small>900 Moreclair Road Birmingham, Alabama 35213</small>	<small>4051 West Florence Road Country Club Hills, Illinois 60478</small>
NATIONAL EVALUATION SERVICE COMMITTEE		
<small>REPORT NO. NES-293 Revised August 1, 1991 This report is subject to re-issuance in 1 year.</small>		
<small>MACMILLAN BLOEDEL LIMITED 1273 DERWENT WAY ANNACIS ISLAND, B.C., CANADA V3M 5R1</small>		
<small>I. SUBJECT Paralam® Parallel Strand Lumber (PSL)</small>		
<small>Based on test data, Paralam PSL's lateral nail resistance and nail withdrawal are equivalent to that of Douglas Fir sawn lumber.</small>		
<small>Nails installed perpendicular to the wide face of strands shall be installed in accordance with the adopted code. Nails installed parallel to the wide face of strands must be spaced a minimum of 3 inches on center for 8d nails, 4 inches on center for 10d and 12d nails, and 5 inches on center for 16d nails. See Figure No. 1 for details on strand orientation. Bolt design values are as provided in the adopted code for Douglas Fir. Specific approval is required for nail and bolt connections not herein prescribed.</small>		

Figure 4.—National Evaluation Service Report.

family are plywood, which consists of products made completely or in part from veneer, and flakeboards made from strands, wafers, or flakes. Plywood and flakeboard products make up the largest percentage of panels used in structural applications such as roof, wall, and floor sheathing. Other panel products include particleboard, which is made from irregular particles of wood, and fiberboard and hardboard, which are made from wood fibers. These panel products are typically used in nonstructural applications.

Plywood.—Plywood is composed of thin layers or plies of veneer, with the grain of adjacent layers at right angles. The outside plies are called faces or face and back plies. Inner plies whose grain parallels the face and back are called cores or centers; those whose grain is perpendicular to the face and back are crossbands. Veneer plies vary in number, thickness, species, and grade. Panel thickness ranges from about 0.125 to 3 inches. Stock sheets usually measure 4 by 8 feet, with the 8-foot dimension parallel to the grain of the face veneers.

The alternation of grain direction in adjacent plies provides plywood substantial dimensional stability across its width. It also results in fairly similar axial strength and stiffness properties in perpendicular directions within the panel plane. The laminated construction results in a distribution of defects and markedly reduces splitting (compared with solid wood) when fasteners are placed close to edges. Plywood as we know it today has existed since about 1905, when it was introduced at the Lewis and Clark Centennial Exposition in Portland, Oregon. Today more than 20 billion ft.² of plywood (0.375 -in. -thick basis) is produced annually in the United States.

Two general classes of plywood, covered by separate standards, are available: construction and industrial plywood, and hardwood and decorative plywood. *Voluntary Product Standards PS 1-95* and *PS 2-92* cover the performance requirements for construction and industrial plywood

(NIST 1992, 1995). The performance requirements for hardwood and decorative plywood are outlined in *ANSI/HPVA HP-1* (HPVA 1994). Each standard recognizes different exposure durability classifications which are based primarily on the moisture resistance of the adhesive used, as well as the grade of veneers. The majority of structural applications in the United States involve construction and industrial plywood.

A significant portion of the market for construction and industrial plywood is residential construction. This has resulted in the development of performance standards for plywood used as roof and wall sheathing and single-layer subfloor or underpayment in residential construction. Panels are marked with grade stamps indicating conformance to a particular product standard, exposure durability classification, span rating, thickness, and the logo of the third-party inspection agency overseeing the panel's manufacture. Nonmandatory information, such as the manufacturer's name or mill number, is often included.

The span rating system for construction and industrial plywood was established to simplify the specification of plywood by eliminating the need to resort to specific structural engineering design data. This system indicates plywood performance without referring to species group or panel thickness. The two-number code (32/16, for instance) gives the maximum allowable on-center spacing between supports when used on roofs (32 in.) and floors (16 in.), respectively as long as the face grain is placed across two or more supports. If design calculations are desired, APA-The Engineered Wood Association's *Plywood Design Specification* can be consulted (APA 1995a). The guide contains tables of grade stamp references, section properties, and allowable stresses for plywood used in construction.

If calculations for the actual physical and mechanical properties of plywood are desired, formulas relating the properties of the wood species in the component plies to the laminated panel are provided in the *Wood Handbook* (FPL 1987). The formulas can be applied to plywood of any species, provided the basic mechanical properties of the species are known. These formulas yield predictions of the ultimate properties of plywood made with defect-free veneers, however, not allowable design values.

Flakeboard Products.—Structural flakeboards are wood panels made from specially produced flakes of relatively low-density species such as aspen or pine bonded with a waterproof adhesive. Two types are recognized: OSB and waferboard. OSB is made from wood strands (long, narrow flakes) felted into a mat of three to five layers. The outer layers of strands are aligned with the panel's long dimension. Inner layers are most often aligned at right angles to the outer layers, but may be unoriented. Waferboard products are made almost exclusively from aspen wafers (wide, squarish flakes). The flakes are not usually oriented in any direction and are bonded with a waterproof adhesive.

Table 2.—Typical design values for structural lumber products.

Product	MOE	F_b	F_t	F_{cpar}	F_v	F_{cper}
	($\times 10^6$ lb./in. ²)	----- (lb./in. ²) -----				
Composite						
LVL	2.0	3,452	1,805	2,725	285	750
PSL	2.0	3,335	2,400	2,900	210	525
LSL	1.5	2,520	1,580	1,950	400	775
Solid-sawn						
Select Structural	1.8	2,850	1,600	2,100	100	565
No. 2	1.6	1,500	825	1,650	90	565
MSR	2.0	2,400	1,925	1,975	90	565
MSR	1.5	1,650	1,020	1,700	90	565

^a Values are for dry 2 by 4s. Solid-sawn lumber is southern pine. MOE = modulus of elasticity; F_b = bending strength; F_t = tensile strength parallel to grain; F_{cpar} = compression strength parallel to grain; F_v = horizontal shear strength; F_{cper} = compression strength perpendicular to grain (or to wide face of strand).

Because flakes are aligned in OSB, the bending properties (in the aligned direction) of this type of flakeboard are generally superior to those of waferboard. For this reason, OSB is the predominant form of structural flakeboard. Panels range from 0.25 to 0.75 inch thick and 4 by 8 feet in surface dimension. Thicknesses up to 1.125 inches and surface dimensions up to 8 by 24 feet are available by special order.

Waferboard originated in the 1950s as a means of utilizing wood species not considered suitable for lumber, veneer, or pulp. OSB evolved from the original waferboard product, but it was not until 1982 that the first true OSB mill was constructed. Today approximately 12 billion ft.² (0.375 -in.-thick basis) of OSB is produced annually in the United States.

A substantial portion of the market for structural flakeboard is residential construction. For this reason, structural flakeboards are usually marketed as conforming to a product standard for sheathing or single-layer subfloor or underpayment and are graded as a performance-rated product just as construction and industrial plywood are. *Voluntary Product Standard PS 2-92* (NIST 1992) is the performance standard that governs wood-based structural-use products such as OSB, waferboard, composite panels, and plywood. *PS 2-92* is not a replacement for *PS 1-95* (NIST 1995) which contains necessary veneer grade and adhesive bond requirements as well as prescriptive lay-up provisions and includes many plywood grades not covered under *PS 2-92*. The same span rating system used for structural plywood applies to structural flakeboard products. The grade stamp on structural flakeboard references *PS 2-92* rather than *PS 1-95*.

Design capacities of structural flakeboards can be determined by using procedures outlined in *Design Capabilities of ARA Performance-Rated Structural-Use Panels* (APA 1995b). Allowable design strength and stiffness properties, as well as nominal thickness and section properties, are specified based on span rating. Additional adjustment factors based on panel grade and construction are also provided. Because of the complex nature of structural flakeboards, formulas for determining actual strength and stiffness properties as a function of the component material are not yet available.

Glued-Laminated Timber

Glued-laminated (glulam) timber is an engineered wood product made by joining solid-sawn structural lumber end-to-end to make continuous laminations. The laminations are then face-bonded with a waterproof structural adhesive to produce structural members in a wide range of lengths, widths, and depths in various structural shapes. Laminations are typically made of specially selected and prepared sawn lumber. Nominal 2-inch-thick dimension lumber is used for straight or slightly curved members, while nominal 1-inch-thick lumber is used for members of greater curvature. Glulam timbers are specially designed to resist stresses based on their intended use as bending, axial, curved, or tapered members by strategically placing higher grade

laminations in areas subject to higher stresses. These members are used as main, load-carrying structural members in residential and commercial applications. Recent advancements include the use of high-strength fiber-reinforced plastics as a tension layer reinforcement in glulam members. The high strength and stiffness of these advanced materials enables the design of reinforced glulam members that utilize a larger percentage of low-quality lumber in their cross section.

Glulam timber, as it is known today was first used in 1893 to construct an auditorium in Basel, Switzerland. Today approximately 30 laminating plants in the United States and Canada produce about 300 million board feet of glulam timber per year.

Bending Members. —Glulam members intended to carry flexural loads are designed using bending combinations. Referred to as horizontally laminated members, they are based on combinations that provide the most efficient and economical cross section for resisting bending stresses caused by loads applied perpendicular to the wide face of the laminations. Typically lower grades of lumber are used for the center portion of the combination, or core, where bending stress is low, and higher grades for the outside faces where bending stress is relatively high.

Axial Members and those Loaded Parallel to the Wide Face. —Axial combinations were developed to optimize the cross section of glulam member designed to resist axial tension and compression stresses. They are also used where flexural loads are applied parallel to the wide faces of the laminations in so-called vertically laminated members.

Curved Members. —The same combinations used for straight, horizontally laminated bending members are used for curved members. However, an important consideration with these members is the development of radial stresses in the curved portion, commonly referred to as radial tension. Loads that cause a change in the curvature of a curved member induce radial tension stresses perpendicular to the wide face of the laminations. As the radius of curvature decreases, the radial stress in the curved portion increases. Because of the relatively low strength of lumber in tension perpendicular to grain compared with tension parallel to grain, radial stresses can become a critical factor in designing curved glulam combinations.

Tapered Members. —Straight or curved glulam beams can be tapered to achieve architectural effects, provide pitched roofs, facilitate drainage, and lower wall heights at end supports. The taper is created by sawing across one or more laminations at the desired slope. The cut is made only on the compression side of a member because interrupting the continuity of the tension side laminations would decrease strength. Common forms of tapered combinations include single tapered (a constant slope from end to end), double tapered (two slopes that form a peak), tapered both ends (slope at each end of a flat middle), and tapered one end (slope only at one end).

Glulam Timber Standards.—The product standard for glulam members is *ANSI/AITC A190.1* (AITC 1992). This standard has a two-step approach to all phases of the manufacturing process. The first is a qualification step in which all equipment and personnel critical to the production of a quality product are thoroughly examined by a third-party agency. Next, daily quality assurance procedures and criteria are established that are targeted to keep each of the critical phases of the manufacturing process under control: drying and grading of lumber; end jointing lumber into longer laminations; face-gluing laminations; finishing and fabrication; and preservative treatment.

Specific combinations for softwood glulam are published in *AITC 117-Manufacturing* (AITC 1993a). Design values assigned to these various glulam combinations are published in *AITC 117-Design* (AITC 1993 b). Provisions for hardwood glulam are provided in *AITC 119* (AITC 1996). Design values published in these standards are based on the procedures of *ASTM D3737* (ASTM 1997).

Mechanically Laminated Members

Mechanically laminated members refers to a family of structural products in which the individual layers of lumber are fastened together with nails, screws, bolts, and/or shear transfer plates. Design of mechanically laminated members is outlined in Chapter 15 of the *NDS*. These members are commonly used as posts, beams, headers, and other structural framing in agricultural structures housing equipment and animals.

Performance of mechanically laminated members is based primarily on the grade of the lumber and the adequacy of the fasteners for transferring shear loads between plies. Thus, grade requirements for the lumber are governed by the same standard—*PS 20*—used for solid-sawn lumber; lumber design values are those published in the *NDS*. American Society of Agricultural Engineers standard *EP 559* (ASAE 1998) provides recommendations on the proper pattern and density of mechanical fasteners, as well as procedures for determining design values for these members. Basically design values for mechanically laminated members are determined by applying repetitive-member adjustment factors to lumber design values.

Wood I-Joists

Wood I-joists are a second generation engineered wood product that evolved from the marriage of a structural panel product web and lumber-type product flanges. The concept of using a wood panel product web and sawn lumber flanges was not fully developed until the 1940s, when it was driven by war-related research on wooden aircraft. The wood I-joist we know today appeared in 1968 and is a proprietary product. Today the United States has about 12 wood I-joist manufacturing plants that produce in toto more than 300 million lineal feet of product annually (Smulski 1997b). Wood I-joists vary in depth from 9.25 to 38 inches and are available in lengths up to 80 feet. Flanges may be

solid-sawn lumber or LVL and may range from 1.5 by 1.5 inches to 4.625 by 2.625 inches in cross section. Plywood and OSB are used for webs which may be from 0.375 to 0.875 inch thick.

Wood I-joists are proprietary products; the manufacturing procedures used by each producer vary. Since there are no standards that provide guidelines on required flange and web properties, each manufacturer produces a unique product. Therefore, each wood I-joist manufacturer must individually gain building code acceptance for its product. Manufacturers use either empirical (testing-based), rational (engineering theory-based), or combined empirical/rational analysis procedures to establish wood I-joist allowable design properties. *ASTM D5055* outlines the empirical/rational procedures (ASTM 1997).

Metal Plate Connected Wood Trusses

Metal plate connected wood trusses are an efficient framework of lumber-type products held together by toothed metal plates, and designed to support loads over large spans. Truss construction has existed in the United States for more than 200 years, when heavy timber structures were commonplace, and for hundreds of years in Europe. The first light-frame wood trusses were designed and constructed in the mid-1950s and have since become a standard structural element in residential and commercial construction. Clear spans of 30 feet are easily achieved in residential structures; spans up to 100 feet are not uncommon in light commercial and agricultural applications. The Wood Truss Council of America estimates that more than 75 percent of all new residential roofs constructed in the United States today use wood trusses.

As with all other engineered wood products, the individual components and the manufacture of wood trusses must meet certain established requirements. The majority of manufacturers in the United States use web and chord members consisting of nominal 2 by 4 lumber; however, members as large as nominal 2 by 12 are not uncommon. The same product standards and design values used for visually graded lumber and mechanically graded lumber—machine stress rated (MSR) and machine-evaluated lumber (MEL)—are applied to these members. The primary concern with the performance of webs and chords is the variability of material properties. For this reason, manufacturers of light-frame wood trusses are the largest users of MSR and MEL lumber in the United States. This is also why glulam timber, LYL, and PSL are gaining acceptance as webs and chords.

The toothed connector plates consist of 20 to 14 gauge metal, the teeth having been punched from one side. Two plates are pressed into the wood at each joint, one on each side, to transfer loads between webs and chords. Connector plates must meet the requirements of *ANSI/TPI 1-95* (TPI 1995). This standard also provides the procedures for designing wood trusses in the United States. The design process involves determining internal truss member forces

through structural analysis; computing combined stress indices for each member; selecting lumber sizes, species, and grades; and sizing plates for connections. Since there are many structural analysis models and methods, *ANSI/TPI 1-95* provides guidance for choosing a model for typical design situations. The model is then used to ensure that stresses in individual members do not exceed design values and that overall truss deflection does not exceed specified design criteria.

Summary

The system of model building codes and voluntary product standards in the United States has been refined over many years. These codes and standards provide the public with assurance of product quality for structural wood products within a legal framework that is responsive to both public needs and technological developments. Understanding this system, and equivalent systems in Canada and Mexico, is essential in promoting free exchange of wood products within North America. To foster this exchange, a list of selected Spanish language publications related to standards and uses of structural wood products is found in the Appendix.

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- APA-The Engineered Wood Association. 1995a. Plywood Design Specification. APA. Tacoma, Washington.
- APA-The Engineered Wood Association. 1995b. Design Capabilities of APA Performance-Rated Structural-Use Panels. Technical Note N375 B. APA. Tacoma, Washington.
- American Society of Agricultural Engineers. 1998. Standards. St. Joseph, Missouri.
- EP 559 Design requirements and bending properties for mechanically laminated columns.
- EP 560 Design values for round construction poles.
- American Society for Testing and Materials. 1997. Annual Book of Standards. ASTM. West Conshohocken, Pennsylvania.
- D9 Standard terminology relating to wood.
- D25 Standard specification for round timber piles.
- D245 Standard practice for establishing structural grades and related allowable properties for visually graded lumber.
- D1990 Standard practice for establishing allowable properties for visually graded dimension lumber from in-grade tests of full-size specimens.
- D2899 Standard practice for establishing design stresses for round timber piles.
- D3200 Standard specification and methods for establishing recommended design stresses for round timber construction poles.
- D3737 Test methods for establishing stresses for structural glued-laminated timber (glulam).
- D3957 Standard practices for establishing stress grades for structural members used in log buildings.
- D5055 Standard specification for establishing and monitoring structural capacities of prefabricated wood I-joists.
- D5456 Standard specification for evaluation of structural composite lumber products.
- American Wood-Preservers' Association. 1997. Book of Standards. AWWA. Granbury, Texas.
- C2 Lumber, timber, bridge ties and mine ties—preservative treatment by pressure processes.
- C4 Poles—preservative treatment by pressure processes.
- C23 Round poles and posts used in building construction—preservative treatment by pressure processes.
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- Truss Plate Institute. 1995. ANSI/TPI 1-95 National Design Standard for Metal Plate Connected Wood Truss Construction. TPI. Madison, Wisconsin.

Appendix: Selected Spanish Language Publications

- Anon. 1994. Manual de construcción de estructuras ligeras de madera. (Manual of light-frame timber construction.) National Council of Wood Construction. Mexico City, Mexico.
- Southern Pine Inspection Bureau. Pensacola, Florida. (850) 434-2611, (850) 433-5594 fax.
- Spanish Graders Manual for Boards & 2-inch Dimension, Publication No. 9000.
- Spanish Pocket Guide for 2-inch Dimension, Publication No. 9001.
- Spanish Pocket Guide for Finish and Boards. Publication No. 9003.
- Spanish Pocket Guide for Timbers. Publication No. 9004.
- Spanish Pocket Guide for Radius Edge Decking. Publication No. 9005.
- Southern Pine Marketing Council. Kenner, Louisiana. (504) 443-4464, (504) 443-6612 fax.
- Answers to Often-Asked Questions About Treated Wood. Publication No. 516.
- International Buyer's Guide. Publication No. 501.
- Pressure-Treated Southern Pine—International Edition, Publication No. 509.
- Southern Pine Lumber: An Importer's Reference Guide. Publication No. 505.
- Western Wood Products Association. Portland, Oregon. (503) 224-3930, (503) 224-3934 fax.
- Ponderosa Pine Species Facts, Publication No. FS-2S.
- Softwoods of the Western USA, Publication No. WW-S.
- Western Wood Species Book, Vol.1: Dimension., Publication No. EX-10S.
- Western Wood Species Book, Vol.2: Common-Boards, Publication No. EX-11S.
- Western Wood Species Book, Vol.3: Factory Lumber, Publication No. EX-12S.
- NIST publications PS 2-92 and PS 1-95 are available from PFS/TECO, 2402 Daniels St., Madison, Wisconsin, 53704. (608) 221-3361, (608) 221-0180 fax.
- Publications of the SPIB and the WWPA are available in México from Dr. Ramon Echenique-Manrique, Mecma S. A. de C. V., Apartado Postal 459, Xalapa, Veracruz, México 91000. (522) 816-3275, (522) 816-3275 fax.

***Focus: North American Standards
for Structural Wood Products***

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