
Codes and 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 is a discussion of 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 1 million new single-family homes built every year or to repair and remodel existing houses. This demand for construction material has led to better utilization of wood, which now comes from second- and third-growth forests. Compared to 50 years ago, the forest resource in the United States can generally be characterized as having a more diverse array of species available for use and is composed of

trees with smaller diameters. Efficient utilization of this “new” forest resource is a challenge to the building industry.

Modern technology has made the development of improved grading practices and improved engineered wood products possible. Solid-sawn lumber continues to provide the bulk of structural products used in construction. Although the use of mechanical grading procedures has provided precise control of property assignment, it has introduced an entire new set of “grades” to 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-diameter timbers are increasingly difficult to obtain and are often replaced by glued-laminated timbers (glulam), prefabricated wood I-joists, and larger versions of LVL and PSL products. Oriented strand-board (OSB) is being used as a substitute for structural plywood. This wide assortment of products can lead to concerns about product quality and structural reliability.

The system of codes and standards for lumber and wood products that ensures 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 is a discussion of:

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- the various types of structural wood products that are commonly available in the United States; and
- 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. These codes specify the minimum acceptable 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.

Prior to 2000, three organizations of code enforcement officials in the United States wrote model building codes: the International Conference of Building Officials (ICBO), the Building Officials and Code Administrators International, Inc. (BOCA), and the Southern Building Code Congress International (SBCCI). Each code organization was a nonprofit organization owned and operated by voting members. The voting members of each model code organization are 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 (16) has been adopted by most states west of the Mississippi River. States in the Southeast generally use the *Standard Building Code* of SBCCI (21), and states in the Northeast generally use BOCA’s (12) *Standard National Code* (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 or trade organizations. The building code describes how each referenced standard is to be used for regulation purposes. Examples of some organizations producing voluntary consensus stan-

dards for wood-based materials that are referenced by modeling codes include the following:

- American Forest & Paper Association;
- American Institute of Timber Construction;
- American Society of Civil Engineers;
- American Society for Testing and Materials;
- American Wood Preserver’s Association;
- Truss Plate Institute; and
- U.S. Department of Commerce.

In addition, each of the three model building code organizations is a member of the International Code Council (ICC). This organization was established by the three model code organizations about 5 years ago to eliminate discrepancies between the region building codes and provide a single set of comprehensive and coordinated national codes. The new International Building Codes (IBCS) are set to take effect early in 2000. The new parts of the codes set are:

- **The 2000 International Building Code (IBC).**—The IBC addresses design and installation of building systems with requirements that emphasize performance. The IBC is coordinated with all the International Codes.
- **The 2000 International Residential Code.**—This code is for one- and two-family dwellings and townhouses up to three stories. Coordinated with all codes, it includes building, plumbing, mechanical, and electrical requirements
- **The 2000 International Fire Code.**—This code is coordinated with the International Building Code, International Mechanical Code, and referenced national standards.

Updated existing codes in the 2000 International Code set include the: property maintenance code, plumbing code, mechanical code, energy conservation code, zoning code, private sewage code, fuel gas code, and electrical code.

It remains to be seen how fast the new codes will be adopted across the Nation. Beginning in 2000, the three model code agencies will no longer update their individual model building codes. However, as previously noted, adoption of a building code is a state and local responsibility. Many believe that it will be several years before the new codes are assimilated into most state and local codes (20). For example, in California, code adoption is the responsibility of the Building Standards Commission. However, in

the state of Washington the Uniform Building Code is written into law, and only the legislature can make a change in the code specified. It should be noted, however, that the IBC adopted reference the *National Design Specifications for Wood Construction* and the *Load and Resistance Factor Design Standards for Engineered Construction*. Thus both allowable stress design and load and resistance factor design may be used with the IBC.

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 in the form of utility poles, construction poles, piles, or construction logs. They represent some of the most efficient uses of forest products because minimum processing is 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 shaped to facilitate their use.

Poles and piles.—The primary use of wood poles is to support utility and transmission lines. For these types of members, the length may vary from 6.1 to 38.1 m (20 to 125ft.). Poles and piles used for building construction rarely exceed 21.3 m (70 ft.) in length. The product standard for these types of

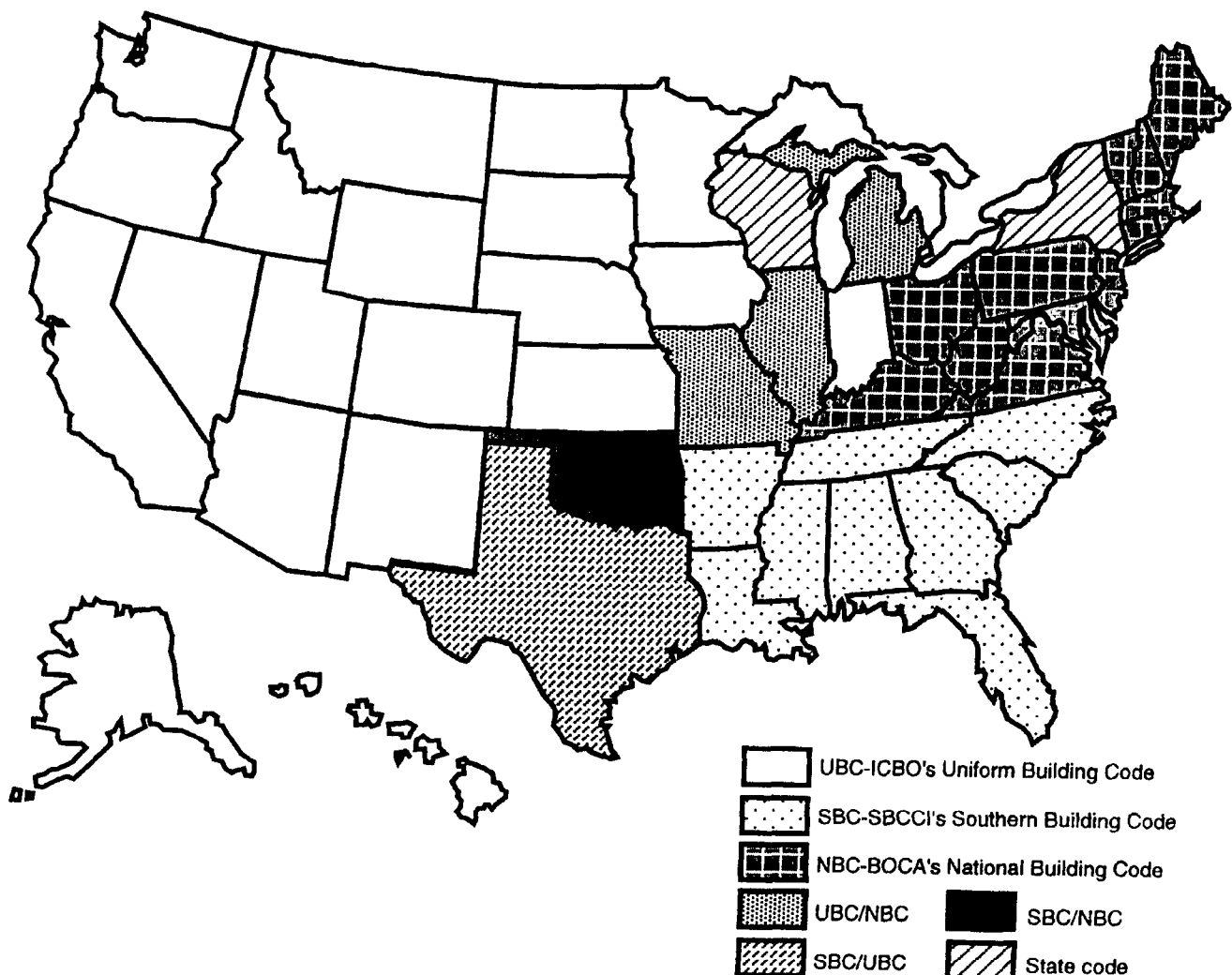


Figure 1.—Areas of model building code use in the United States (19).

round timber members includes provisions for geometry, such as diameter and taper, as well as allowable defects, such as knots, warp, and degree of spiral grain. The ANSI 05.1 standard provides these limitations for utility and construction poles (5) and ASTM D 25 for piles (10).

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, they are not compatible with the working stress design philosophy of the *National Design Specifications for Wood Construction* (NDS) (1). Reliability-based design techniques have been developed for the design of transmission line systems (6). Procedures for establishing design stresses for round timber piles are published in ASTM D 2899 (10) for various species. These procedures basically take published clear wood design stresses and adjust them to a corresponding design value for poles and piles. Design values for piles are provided in the NDS (1). For construction poles, these design stresses are adjusted so 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 D 3200 (10). The American Society of Agricultural Engineers standard EP 560 (9) publishes a complete set of calculated design values for construction poles based on ASTM D 2899 procedures.

Whether used for utility or construction, standard practice requires that the poles be pressure-treated with a preservative in accordance to an applicable AWP standard. AWP C3 establishes preservative retention and penetration values for piles; AWP C4 establishes retention and penetration values for utility poles; AWP C23 sets forth retention and penetration values for poles used in building construction; AWP C35 and other standards relate to poles requiring thermal treatments or that belong to certain species (11).

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 de-

sign stresses based on the largest rectangular cross section that fits within the machined cross section are found in ASTM D 3957 (10).

Solid-sawn structural lumber

Lumber grading.—Lumber is the product of the sawmill and planing mill and is usually not further manufactured other than by sawing, resawing, passing lengthwise through a standard planing machine, crosscutting to length, and matching (ASTM D 9). Lumber sawn from a log, regardless of species and size, is quite variable in its 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 some understanding of lumber size classifications.

During the evolution of stress grading in the United States, lumber size served as a guide to anticipating the final use of the piece. The three size classifications for structural lumber are boards, dimension lumber, and timbers. Boards are lumber less than nominal 2 inches (51 mm) thick and 2 inches or more wide. Dimension lumber is lumber that is nominal 2 to 4 inches (51 to 102 mm) thick and nominal 2 inches (51 mm) or more wide. Timbers are lumber 5 inches (127 mm) or more in the 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 design stresses are within the stresses 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 grade lumber solely on its visible characteristics. Visual grading is used with all three size classifications of lumber. Allowable design values for visually graded lumber

may be based on the results of strength tests conducted on full-size pieces of 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 that 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 softwood species that have been visually graded. However, both grading systems have also been used with hardwood species. The production of mechanically graded lumber continues to increase, particularly for 2 by 4s and in 1650f and higher grades.

Lumber standards.—The American Softwood Lumber standard, Voluntary Product Standard PS 20 (17), establishes nationally recognized requirements for the grading of lumber. PS 20 was developed by the American Lumber Standard Committee (ALSC) in accordance with the procedures of the U.S. Department of Commerce, and it is administered by the National Institute of Standards and Technology (NIST). ALSC membership is appointed by the U.S. Secretary of Commerce to constitute an independent consensus body. The ALSC consists of the following:

- 1 representatives from each agency that participates in this program and publishes and maintains grading rules and inspection facilities covering the various species (rules-writing agencies (Appendix A));

- representatives from each lumber inspection agency participating in the program that does not publish grading rules (nonrules-writing agencies); and
- representatives from each of the following groups: architects, construction engineers, general contractors, home builders, consumers, wood-using industries, millwork manufacturers, lumber wholesalers, and lumber retailers.

The ALSC operates as an independent body with defined functions regarding the maintaining, implementing, and enforcing of the PS 20 requirement. 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- and nonrules-writing agencies from the United States and Canada, BOCA, ICBO, SBCCI, the American Society of Civil Engineers (ASCE), the American Institute of Architects (AIA), 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 establishes a Board of Review, an independent body that is 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 council of the FPL, is the final authority on the appropriateness of such standards and criteria. Figure

Table 1.—Standards and specifications to determine design values for solid-sawn structural lumber under PS 20 (17).^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 given in AWPA C2 (11).

2 is a representation of the ALSC process. When grade marks are approved, Board-recognized quality inspectors conduct periodic inspections to verify that the grading agencies are following ALSC-approved procedures. Additional sources of information on the ALSC procedure are given in Francis and Collins (14) and *Wood Design Focus* (23).

As noted, ASTM procedures are generally used to derive allowable properties for lumber sold in the United States. However, ASTM standards may not always exist for some products or procedures. In some cases, the Board may have “policy” documents that cover such omissions. For example, ASTM D 1990 (10) does not provide guidance for determining allowable properties for species growing outside of the United States. The Board’s “Foreign Lumber Policy” authorizes guidelines and criteria for agencies accredited to grademark and supervise the grademarking of lumber produced outside of the United States (18). The Board also has guidelines on how to apply the principles of D 1990 to foreign species. Another example is mechanically graded lumber. Although a standard is under development, no ASTM standard currently exists on property assignment procedures for mechanical graded lumber. Again the Board has policy documents on mechanically graded lumber. In addition, each of the rules-writing agencies that wish 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 mechanically graded lumber produced outside the United States.

Model building code approval for solid-sawn structural lumber is generally through the codes recognition of the *NDS* (1). Although the model code may recognize ALSC-approved design values directly, tying their use to the *NDS* helps keep allowable properties in sync with other *NDS* procedures. Preservative treatment requirements for lumber are given in AWPAC2, and requirements for fire-retardant treated lumber (FRT) are given in AWPAC20 (11).

Structural composite lumber

Structural composite lumber is a generic term for a family of proprietary lumber products composed of wood elements combined with exterior structural adhesives to form lumber-like members. All current composite lumber products have the grain of the

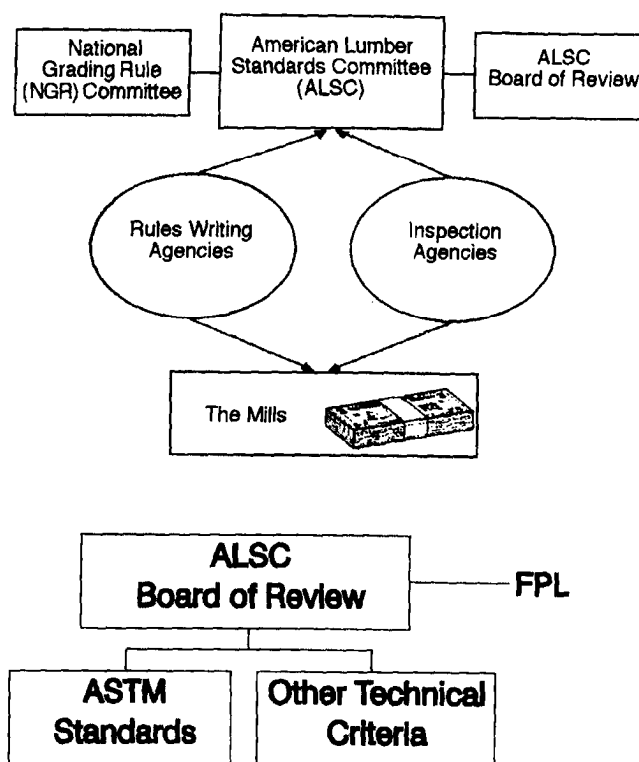


Figure 2.—American Lumber Standard Committee: (top) the process, and (bottom) the Board of Review.

wood elements oriented parallel to the length of the member. Structural composite lumber is made commercially from both softwood and hardwood species. Three types of structural composite lumber are currently commercially produced in the United States: LVL, PSL, and laminated strand lumber (LSL). There are many producers of LVL in the United States and around the world. At present, only one company makes PSL and LSL products in the United States.

Laminated veneer lumber.—LVL is manufactured from layers of veneer with the grain of all veneers parallel to the length of the member. This contrasts with plywood, which traditionally has the grain angle in adjacent veneers perpendicular to each other. Most manufacturers use sheets of 2.5- to 4.2-mm-thick veneers. Typically, the rotary cut veneer is dried, then graded ultrasonically for stiffness and graded visually for defects. The veneers are laid-up with the higher grades on the face and the lower grades in the core. These veneers are stacked to achieve the desired thickness and laid end-to-end to achieve the desired length. Within the stack, the

end joints of the veneer are staggered to minimize their effect on strength. The veneer and adhesive are bonded under pressure into a billet that is typically 44 mm thick, 1.2 m wide, and up to 24.4 m long. Billets are then ripped to the desired width and cut to the desired length. The common sizes of LVL closely resemble those of solid-sawn dimension lumber.

Parallel strand lumber.—PSL is manufactured from strands or elongated flakes of wood. As with LVL, production typically starts with rotary cut and graded veneer. However, it is not necessary to start with full sheets. Because the logs are rotary peeled, veneers for PSL are mostly sapwood from the outer portions of the tree. The veneer sheets are then clipped into approximately 19-mm-wide and 2.4-m-long strips. A waterproof adhesive is applied, and the strands are fed into a continuous press. Adhesive curing is accomplished using microwave equipment. Billets, which are up to 20 m long, are then cut into smaller members. Although any species could be used to produce PSL, species currently used include Douglas-fir, southern pine, western hemlock, and yellow-poplar.

Laminated strand lumber.—LSL is made from elongated flakes using technology similar to that used to produce OSB. Strands used in LSL are significantly longer than those used to produce OSB. This

greater strand length and the orientation of the strands parallel to the length of the finished product are the key 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 currently being used for production of LSL include aspen and yellow-poplar.

Structural composite lumber standards.—Manufacturers of composite structural lumber would first obtain data and conduct analysis according to ASTM D 5456 (10) [Fig. 3]. This documentation could be submitted to building officials in every city, county, and state where the product will be marketed. This, however, would usually be impractical, so the model building code organizations created “evaluation services.” The evaluation service of each of the three model building codes is a subsidiary corporation that reviews the technical report, grants recognition if the information meets the requirements of that particular building code, and publishes Evaluation Service Reports. 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 and the IBC. For a detailed discussion of the process, see Smulski (19).

Standard design values have not been established for each type of structural composite lumber. 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). Preservative retention and penetration limits for structural composite lumber can be found in AWP C33 (11).

Structural panel products

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

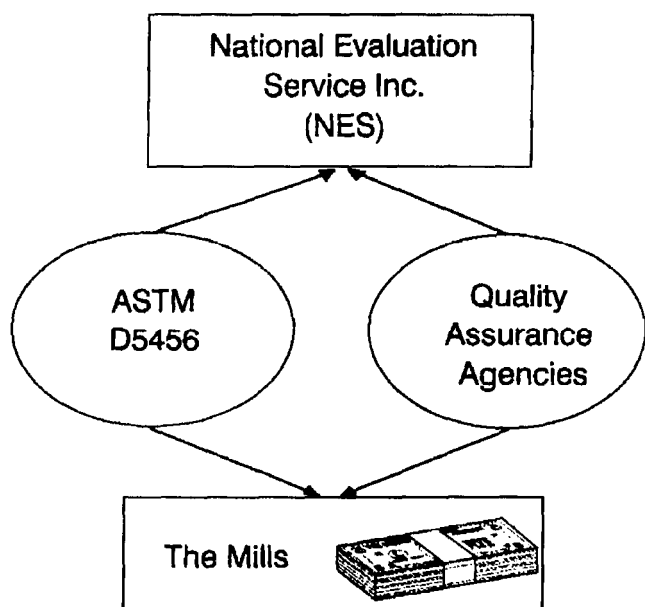


Figure 3.—Approval process for composite lumber products.

consists of products made completely or in part from bonded wood veneer) and flakeboards (made from bonded strands, wafers, or flakes). Plywood and flakeboard products make up a large percentage of the panels used in structural applications, such as roof, wall, and floor sheathing. Other panel products include particleboard made from particles and fiberboard and hardboard made from wood fibers. These other panel products are typically used in nonstructural applications and are not discussed here.

Plywood

Plywood is composed of relatively thin layers of plies or veneer with the wood grain of adjacent layers at right angles. The outside plies are called faces or face and back plies. The inner plies with grain parallel to that of the face and back are called cores or centers, and the inner plies with grain perpendicular to that of the face and back are called crossbands. Total panel thickness is typically no less than 1.6 mm (1/16 in.) nor more than 76 mm (3 in.). Veneer plies may vary in number, thickness, species, and grade. Stock plywood sheets usually measure 1.2 by 2.4 m (4 by 8 ft.), with the 2.4-m (8-ft.) dimension parallel to the grain of the face veneers.

The alternation of grain direction in adjacent plies provides plywood panels with dimensional stability across their 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 penetrate the plywood. The process of bonding wood has been known to exist since the time of the ancient Egyptians, approximately 3,500 years ago. 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 1.86 billion m² (20 billion ft.²) of plywood (3/8-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 2-92 cover the performance requirements for construction and industrial plywood. The performance requirements for hardwood and decorative plywood are covered by ANSI/HPVA HP- 1 (15). Each standard recognizes different exposure durability classifications, which are primarily based on the moisture resistance of the adhesive used, as well as the grade of veneers. The majority of U.S. structural applications involve construction and industrial plywood; therefore, the remainder of this section discusses only this product.

A significant portion of the market for construction and industrial plywood is in residential con-

Table 2.—Example of design values for structural lumber products. ^a

Product	Modulus of elasticity ($\times 10^6$ lb./in. ²)	Bending strength (F_b)	Tensile strength parallel to grain (F_t)	Compression strength parallel to grain (F_c)	Horizontal shear strength (F_v)	Shear strength perpendicular to grain (F_{cp})
----- (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
Machine stress rated	2.0	2,400	1,925	1,975	90	565
Machine stress rated	1.5	1,650	1,020	1,700	90	565

^a Values are for dry 2 by 4s. Solid-sawn lumber is southern pine. Approximate design values can be obtained by multiplying lb./in.² values by 6,894 to obtain millions of pascals (GPa).

struction. This market reality has resulted in the development of performance standards for sheathing and single-layer subfloor or underlayment for residential construction. Plywood panels conforming to these performance standards for sheathing 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 specifications of plywood without resorting to specific structural engineering design. This system indicates performance without the need to refer to species group or panel thickness. It gives allowable span when the face grain is placed across supports. If design calculations are desired, APA-The Engineered Wood Association provides a design guide titled *Plywood Design Specifications* (7). This design guide contains tables of grade stamp references, section properties, and allowable stresses for plywood used in construction. Preservative treatment requirements for plywood are listed in AWPAC9 and C22, and FRT requirements in C27 (11).

Flakeboard products.—Structural flakeboards are wood panels made from specially produced flakes typically from relatively low-density species, such as aspen or pine, and bonded with an exterior-type water-resistant adhesive. Two major types of flakeboards are recognized: OSB and waferboard. OSB is a flakeboard product made from wood strands (long and narrow flakes) that are formed into a mat of three to five layers. The outer layers are aligned in the long panel direction, and the inner layers are aligned at right angles to the outer layers, or are randomly aligned. In waferboard, products are made almost exclusively from aspen wafers (wide flakes), the flakes are not usually oriented in any direction, and they are bonded with an exterior-type resin. 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 commonly range from 6- to 19-mm (0.25 to 0.75-in.) thick and 1.2- by 2.4-m (4- by 8-ft.) surface dimension. However,

thicknesses up to 28.58 mm (1.125 in.) and surface dimensions up to 2.4 by 7.3 m (8 by 24 ft.) are available by special order.

Waferboard originated in the 1950s as a product that utilized species such as aspen that were not considered suitable as sources of lumber, veneer, and pulp. OSB evolved from the original waferboard product, and it was not until 1982 that the first true OSB mill was constructed. Today, approximately 1.15 billion m² (12.4 billion ft.²) (3/8-in.-thick basis) of OSB is produced annually in the United States.

A substantial portion of the market for structural flakeboard is in residential construction. For this reason, structural flakeboards are usually marketed as conforming to a product standard for sheathing or single-layer subfloor or underlayment and are graded as a performance-rated product similar to that for construction and industrial plywood. The Voluntary Product Standard PS 2-92 (17) is the performance standard for wood-based structural-use panels, which governs such products as OSB, waferboard, composite panels, and includes plywood. The PS 2-92 is not a replacement for PS 1-95, 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 is also applied for structural flakeboard products. The only difference is that the grade stamp used for structural flakeboard references the PS 2-92 standard (17).

Design capacities of structural flakeboards can be determined by using procedures outlined in the APA (8). In this reference, allowable design strength and stiffness properties, as well as nominal thicknesses and section properties, are specified based on the span rating of the panel. Additional adjustment factors based on panel grade and constructions 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 currently available. No preservative standards exist for structural flakeboards because serviceability after pressure preservative treatment is quite variable.

Glued-laminated timber

Glulam is an engineered product made by end jointing solid-sawn structural lumber end-to-end to make continuous laminations. These laminations

are then face bonded to produce structural members that can have a wide range of lengths, sizes, or structural shapes. Laminations are typically made of specially selected and prepared sawn lumber. Standard 38-mm-thick (nominal 2-in.-thick) lumber is used for straight or slightly curved members, and standard 19-mm-thick (nominal 1-in.-thick) lumber is used for members with significant curvature. Glulam members 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 that will be subjected to higher stresses. These members are used as main, load-carrying structural members in residential as well as commercial applications. Recent advancements in this technology have also included the use of high-strength fiber-reinforced plastics as a tension reinforcement layer to the glulam members. The high strength and stiffness properties of these advanced materials enable the design of these reinforced glulam members to utilize a larger percentage of low-quality laminating lumber in the beam cross section.

Glulam, as it is known today, was first used in 1893 to construct an auditorium in Basel, Switzerland. Patented as the "Hetzer System," it used adhesives that were not waterproof, thereby limiting its applications to dry-use conditions. Today, approximately 30 laminating plants in the United States and Canada produce approximately 708,000 m³ (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 the bending stresses caused by loads applied perpendicular to the wide faces of the laminations. Typically, lower grades of laminating lumber are used for the center portion (core) of the combination where bending stress is low, and higher grades are placed on 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 members designed to resist the axial tension and compression stresses. They are also used as members having flex-

ural loads applied parallel to the wide faces of the laminations, called vertically laminated members.

Curved members.—The same combinations that are used for straight, horizontally laminated bending members are also 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 faces of the laminations. As the radius of curvature of a glulam member 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, these radial stresses can become a critical factor in designing curved glulam combinations.

Tapered members.—Straight or curved beams of glulam can be tapered to achieve architectural effects, provide pitch roofs, facilitate drainage, and lower wall height requirements at the 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 glulam member, because interrupting the continuity of the tension-side lamination would decrease strength capacity. 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).

Glued timber standards.—The product standard for glulam members is the ANSI/AITC A190.1, *The American National Standard for Wood Products—Structural Glued Laminated Timber* (2). 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. The manufacturing process involves:

- 1 drying and grading the lumber;
- 1 end jointing the lumber into longer laminations;
- 1 face gluing the laminations;
- 1 finishing and fabrication; and

- preservative treatment, when necessary.

Specific combinations for softwood glulam are published in the AITC 117—Manufacturing. Design values assigned to these various glulam combinations are published in AITC 117—Design (3). Provisions for hardwood glulam combinations are provided in AITC 119 (4). Design values published in these standards are based on procedures of ASTM D 3737 (10). Preservative treatment requirements for glulam are published in AWPAC28 and C32 (11).

Mechanically laminated members

Mechanically laminated members refer to a family of structural members in which the individual layers of lumber are mechanically fastened together. Typical mechanical fasteners include nails, screws, bolts, and/or shear transfer plates. Additional discussion of mechanically laminated member design is given in Chapter 15 of the NDS (1). These types of members are commonly used in agricultural structures to house equipment and/or farm animals.

Performance of these members is based primarily on the grade of the laminating lumber and the adequacy of the mechanical fasteners to transfer the shear loads between plies. **Thus**, grade requirements of the laminating lumber are governed by the same Voluntary Product Standard (PS 20) used for solid-sawn lumber; lumber design values are those published in the NDS. The American Society of Agricultural Engineers standard EP 559 (9) publishes 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 the lumber design values. These materials should be preservative-treated before construction only as required in AWPAC15 or C16 (11).

Prefabricated structural I-joists

Prefabricated structural I-joists are a second-generation engineered wood product that evolved from the marriage of structural panel products to form the web and lumber-type products to form the 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 wood aircraft construction. A structural wood I-joist, as we know it today, first appeared in

1968 when Trus Joist Corporation began marketing this as a proprietary product. Today, the United States has over a dozen wood I-joist manufacturing plants producing more than 12.2 million lineal meters (300 million lineal feet) annually (19). Wood I-joists manufactured today can vary in depth from 23.5 cm (9.25 in.) to 97 cm (38 in.) and are available in lengths up to 24 m (80 ft.). Flanges range from 3.8 by 3.8 cm (1.5 by 1.5 in.) to 11.7 by 6.7 cm (4.625 by 2.625 in.) in cross section, and webs range from 0.95 cm (0.375 in.) to 2.2 cm (0.875 in.) thick.

Wood I-joists are proprietary products; the manufacturing procedures used by each producer vary. There are no standards that provide guidelines on required flange and web properties; each manufacturer produces a product that is unique to that facility. 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 D 5055 outlines the empirical/rational procedures (10). Treatment of wood I-joists is currently not recommended.

Metal-plate-connected wood trusses

Metal-plate-connected (MPC) wood trusses are an efficient framework of lumber-type products held together by toothed metal plates that are 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 has existed for hundreds of years in Europe. The first light-frame MPC 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 9 m (30 ft.) are easily achieved in residential structures and up to 30 m (100 ft.) 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 MPC wood trusses.

Similar to all other engineered wood products, the individual components and the manufacture of MPC wood trusses must meet certain established requirements. The majority of manufacturers in the United States use web and chord members consisting of standard 5- by 10-cm (nominal 2- by 4-in.)

Table 3.—Standards and specifications for various structural wood products.

Product	Product standard	Preservative treatment ^a	Engineering design values	
			Calculation procedure	Published design value
Round timbers				
Piles	ASTM D25	AWPA C3	ASTM D2899	NDS
Utility poles	ANSI 05.1	AWPA C4, C35	- -	ANSI 05.1
Construction poles	ANSI 05.1 _b	AWPA C23	ASTM D3200	ASAE EP 560
Construction logs	- - _b	- -	ASTM D3957	- - _b
Structural composite lumber	- - _b	C33	ASTM D5456	- - _b
Structural panel products				
Construction plywood	PS 1, PS 2	AWPA C9, C22, C27	APA-PDS	APA-PDS
Hardwood plywood	HPVA HP-1	NR	- -	***
Flakeboard products	PS 2	NR	APA-N375B	APA-N375B
Glulam	ANSI 05.1	AWPA C28, C32	ASTM D3737	AITC 117, AITC 119, NDS
Mechanically laminated members	EP 559 _b	AWPA C2	ASAE EP 559	- - _b
Wood I-joists	- - _b	NR	ASTM D5055	- - _b
Wood trusses	ANSI/TPI 1	AWPA C2, C20	ANSI/TPI 1	- - _b

^a Standards listed are specific to the product; all timber products are also covered by AWPAC1 (1998); NR is not recommended.

^b Due to the proprietary nature of the product, this information is normally supplied by the manufacturer.

lumber; however, members as large as standard 5-by 30-cm (nominal 2 by 12 in.) lumber are not uncommon. The same product standards and design values used for the visually graded, machine stress rated, and machine evaluated lumber are applied to these members. The primary concern with the performance of the web and chord material is the variability of material properties. For this reason, manufacturers of light-frame wood trusses are the largest users of MSR lumber in the wood industry. This is also the reason that glued-laminated timber, LVL, and PSL are gaining acceptance as alternative web and chord material.

The connector plates consist of 20- to 14-gauge sheet metal having teeth that are punched out of one side. Two metal plate connectors are pressed into the wood joints, one on each side, to provide the load transfer between elements. These connector plates must meet the requirements published in ANSI/TPI 1-95, *National Design Standard for Metal Plate Connected Wood Truss Construction* (22). This standard also provides the procedures for designing MPC wood trusses in the United States. The design process involves determining internal

truss member forces through a structural analysis, computing combined stress indices for each member from the forces determined, selecting wood member sizes and grades, and sizing plates for connections. The number of structural analysis models and methods can be many; therefore, the ANSI/TPI 1-95 standard provides some guidance for choosing a mathematical model for typical design situations. The structural analysis model can then be used to ensure that stresses in the individual members do not exceed design values and that overall truss deflection does not exceed specified design criteria.

Concluding remarks

The system of model building codes and voluntary product standards in the United States has been refined over many years (Table 3). 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 for structural wood products is contained in Appendix B.

Literature cited

1. American Forest & Paper Association. 1997. National design specifications for wood construction. AF&PA, Washington, D.C.
2. American Institute of Timber Construction. 1992. ANSI/AITC. A 190.1 AITC, Englewood, Colo.
3. _____. 1993. AITC 117. Standard specification for structural glued laminated timber of softwood species. AITC, Englewood, Colo.
4. _____. 1996. AITC 119. Standard specification for structural glued laminated timber of hardwood species, AITC, Englewood, Colo.
5. American National Standards Institute, Inc. 1992. ANSI 05.1. American National Standard for Wood Poles—Specifications and Dimensions. ANSI, New York, N.Y.
6. _____. 1992. ANSI C2. National Electrical Safety Code. ANSI, New York, N.Y.
7. APA-The Engineered Wood Association. 1995. Plywood design specifications. APA, Tacoma, Wash.
8. _____. 1995. Design capabilities of American Plywood Association performance-rated structural-use panels. Tech. Note N375 B. APA, Tacoma, Wash.
9. American Society of Agricultural Engineers. 1998. EP 559: Design Requirements and Bending Properties for Mechanically Laminated Columns. EP 560: Design Values for Round Construction Poles. ASAE, St. Joseph, Mo.
10. American Society for Testing and Materials. 1998. Volume 04.10, Wood. Annual Book of Standards. ASTM, West Conshohocken, Pa.
 D 9 Standard terminology relating to wood.
 D 25 Standard specification for round timber piles.
 D 245 Standard practice for establishing structural grades and related allowable properties for visually graded lumber.
 D 1990 Standard practice for establishing allowable properties for visually graded dimension lumber from in-grade tests of full-size specimens.
 D 2899 Standard practice for establishing design stresses for round timber piles.
 D 3200 Standard specification and test method for establishing recommended design stresses for round timber construction poles.
 D 3737 Standard practice for establishing stresses for structural glued laminated timber (glulam).
 D 3957 Standard practice for establishing stress grades for structural members used in log buildings.
 D 5055 Standard specification for establishing and monitoring structural capacities of prefabricated wood I-joists.
 D 5456 Standard specification for evaluation of structural composite lumber products.
11. American Wood-Preservers' Association. 1997. Book of Standards. AWP, Woodstock, Md.
 C1 All timber products-preservative treatment by pressure processes,
 C2 Lumber, timbers, bridge ties and mine ties- preservative treatment by pressure processes.
 C3 Piles—preservative treatment by pressure processes.
 C4 Poles—preservative treatment by pressure processes.
 C9 Plywood—pressure treatment.
 C15 Wood for commercial-residential construction—preservative treatment.
 C16 Wood used on farms-pressure treatment.
 C20 Structural lumber-fire-retardant treatment by pressure processes.
 C22 Lumber and plywood for permanent wood foundations-preservative treatment by pressure processes.
 C23 Round poles and posts used in building construction-preservative treatment by pressure processes.
 C27 Plywood-fire-retardant treatment by pressure processes.
 C28 Standard for preservative treatment of structural glued laminated members and laminations before gluing of southern pine, Pacific Coast Douglas fir, hem-fir, and western hemlock by pressure processes.
 C32 Glue laminated poles of southern yellow pine or Coastal Douglas-fir-preservative treatment by pressure processes.
 C33 Preservative treatment of structural composite lumber.
 C35 Western red cedar, Alaska yellow cedar, northern white cedar, western larch poles-thermal treatment.
12. Building Officials and Code Administrators International, Inc. 1996. National Building Code. BOCA, Country Club Hills, Ill.
13. Forest Products Laboratory. 1999. Wood Handbook: Wood as an Engineering Material. GTR 113. USDA Forest Serv., Forest Prod. Lab., Madison, Wis. 466 pp.
14. Francis, S.M. and D.S. Collins. 1995. Wood in construction: a reliable system of standards and quality control. Building Official and Code Administrator. (March/April.) pp. 24-31.
15. Hardwood Plywood and Veneer Association. 1994. American National Standard for Hardwood and Decorative Plywood. HP-1. ANSI/HPVA, Reston, Va.
16. International Conference of Building Officials. 1994. Uniform Building Code. ICBO, Whittier, Calif.
17. National Institute of Standards and Technology. Voluntary product standards. U.S. Dept. of Commerce, Gaithersburg, Md.
 PS 2-92. Performance standard for wood-base structural-use panels, 1992.
 PS 20-94. National Institute of Standards and Technology, 1994.
 PS 1-95. Construction and industrial plywood, 1995.
18. Shelley, B.E. and D.W. Green. 1994. Establishing allowable design values for structural lumber of foreign species for use in the United States. In: Proc. Globalization of wood: supply, processes, and markets. Forest Prod. Soc., Madison, Wis. pp. 215-228.

19. Smulski, S., ed. 1997. Engineered wood products: A guide for specifiers, designers, and users. PFS Res. Foundation, Madison, Wis.
20. Southerland, R. 2000. The international building code: meeting the needs of this millennium. Structural Engineer. 1(1):30-33.
21. Southern Building Code Congress International. 1994. Standard Building Code. SBCCI, Birmingham, Ala.
22. Truss Plate Institute. 1995. ANSI/TPI 1-95. National design standard for metal plate connected wood truss construction. TPI, Madison, Wis.
23. Wood Design Focus. 1997. Machine-stress rated lumber. Forest Prod. Soc., Madison, Wis. 8(2):1-24.

Appendix A: Rules writing grading agencies for solid-sawn lumber

- Northeastern Lumber Manufacturers
272 Tuttle Road
PO. Box 87A
Cumberland Center, ME 04021
www.nelma.org
- Northern Softwood Lumber Bureau
272 Tuttle Road
PO. Box 87A
Cumberland Center, ME 04021
www.nelma.org
- Southern Pine Inspection Bureau
4709 Scenic Highway
Pensacola, FL 32504
(850) 434-2611, fax (850) 433-5594
www.spib.org
- Western Wood Products Association
Yeon Building
522 SW Fifth Ave.
Portland, OR 97204-2122
(503) 224-3930, fax (503) 224-3934
www.wwpa.org
- West Coast Lumber Inspection Bureau
Box 23145
6980 SW Varns Road
Portland, OR 97223
(503) 639-0651, fax (503) 684-8928
www.wclib.org
- Redwood Inspection Service
405 Enfrente Drive
Suite 200
Novato, CA 94949
(415) 382-0662, fax (415) 382-8531
www.calredwood.org
- American Wood Preservers' Association
P.O. Box 5690

Granbury, TX 76049
(817) 326-6300, fax (817) 326-6306
www.awpa.com

Appendix B: Selected Spanish language publications

Anonymous. 1994. Manual de construcción de estructuras ligeras de madera: Manual of light-frame timber construction. Nat'l. Council of Wood Construction, Mexico City, Mexico. 472 pp.

PFS Research Foundation, 2402 Daniels St., Madison, WI 53718. Phone: 608-221-3361, Fax: 608-221-0180, e-mail: pfsrf@pfs-teco.com.

PS 2-92. Norma de realización para entrepaños de uso estructural basados en madera.

PS 1-95. Madera contrachapada industrial y de construcción

Southern Pine Council, Kenner, La. Available in Mexico from Dr. Ramon Echenique-Manrique, Western Wood Prod. Assoc., Mecma S.A. de C.V., Apartado Postal 459, Xalapa, Veracruz 91000. Phone: 522-816-3275, Fax: 522-816-3275.

Answers to Often-Asked Questions About Treated Wood. Publ. No. 516.

International Buyer's Guide. Publ. No. 501.

Pressure-Treated Southern Pine—Int'l. Ed. Publ. No. 509.

Southern Pine Lumber: An Importer's Reference Guide. Publ. No. 505.

Southern Pine Inspection Bureau, Inc., Pensacola, Fla. Available from SPIB, 4709 Scenic Highway, Pensacola, FL 32504-9094. Phone: 850-434-2611, Fax 850-433-5594.

Spanish Graders Manual for Boards and 2-Inch Dimension. Publ. No. 9000.

Spanish Pocket Guide for 2-Inch Dimension. Publ. No. 9001.

Spanish Pocket Guide for Finish and Boards. Publ. No. 9003.

Spanish Pocket Guide for Timbers. Publ. 9004.

Spanish Pocket Guide for Radius Edge Decking. Publ. No. 9005.

Western Wood Products Association, Portland, Oreg. Available in Mexico from Dr. Ramon Echenique-Manrique, Western Wood Prod. Assoc., Mecma S.A. de C.V., Apartado Postal 459, Xalapa, Veracruz 91000. Phone: 522-816-3275, Fax: 522-816-3275.

Ponderosa Pine Species Facts. Publ. No. FS-2S.

Softwoods of the Western USA. Publ. No. WW-S.

Western Wood Species Book, Vol. 1: Dimension. Publ. No. EX-10S.

Western Wood Species Book, Vol. 2: Common Boards. Publ. No. EX-11S.

Western Wood Species Book, Vol., 3: Factory Lumber. Publ. No. EX-12S.

North American Forestry Commission

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June 23, 1998, Mérida, Yucatán, México