FOREST PRODUCTS FOR BUILDING CONSTRUCTION[1]

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ABSTRACT

Wood buildings may be of light frame-type as in residential and light industrial construction or heavy timber-type as in warehouses and other industrial/commercial buildings. In either case, the primary elements making up the structure are framing members; covering materials for roofs, walls, and floors; and connections within and between framing members and covering materials. Framing members include 2-inch dimension lumber, solid timbers, glulam beams, and various built-up beams and trusses. Covering materials may be boards, solid or laminated lumber, plywood, various other wood-base panel products, or some combination of these. Connecting systems include adhesives and such mechanical fasteners as nails, staples, screws, bolts, and metal plate connectors.

Design properties and specifying procedures for these various wood building materials and their connectors are discussed in some detail in this paper, and sources for further information are referenced.

Keywords: Wood construction, lumber, wood-base panels, fasteners, plywood.

INTRODUCTION

Much information has been published on the types, properties, specifications, and uses for wood building construction materials. This same information, however, is scattered in books, design manuals, standards, handbooks, and research reports published by a variety of industry associations, professional societies, and organizations that write standards as well as by government and university research facilities. This report brings together the basics of design properties and specifying procedures for such building materials and their connectors. The following discussions also frequently reference sources of more detailed information and thus should serve both as an introductory text and as a valuable in-depth bibliography.

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Wood buildings may be of heavy-timber construction used in warehouses and other industrial/commercial buildings, or of light-frame construction used in residential houses. The essential characteristics of heavy-timber construction are discussed by Williamson (1975), and those of light-frame construction by Percival and Suddarth (1975) and by Anderson (1970).

In all wood building construction, the primary elements making up the structure are framing members; covering materials for roofs, walls, and floors; and connections within and between framing members and skin materials. Covering materials ("skins") may be made of solid or laminated wood elements, plywood or other structural wood-base panels, or a combination of these. Wood members used as framing include dimension lumber, solid wood timbers, round poles, glulam beams, built-up plywood beams, and open-web trusses. Other possibilities include built-up beams with hardboard or particleboard shear webs and laminated veneer lumber. Skins are connected to the framing by mechanical fasteners or a combination of mechanical fasteners and adhesives. Nails are the most common mechanical fasteners. Other mechanical fasteners include staples, screws, bolts, and sheet metal plate connectors and various types of metal shear connectors. Rigid adhesives are used in the manufacture of glulam beams, laminated veneer lumber, stressed-skin panels, and some open-web wood trusses. Construction adhesives are used in conjunction with nails for on-site connecting of a skin to the framing members.

The ASCE Committee on Wood has compiled a state-of-the-art manual on wood engineering for practicing engineers and designers that was used extensively as a resource in preparing this paper. *Wood Structures—A Design Guide and Commentary* (ASCE 1975) is a comprehensive manual containing recommended basic concepts for engineering use of wood. The Commentary provides additional essential detail on wood building materials, their properties, and design considerations that could not be incorporated into this paper. It is recommended supplemental reading.

WOOD CONSTRUCTION METHODS

Customary classification of wood building systems has two broad categories: light-frame and heavy-timber construction. Applications of light-frame technology are largely limited to residential and commercial construction, while heavy timber technology most commonly is used in institutional and industrial buildings. This paper focuses on primarily light-frame construction as the technology using most of the wood and wood-base materials produced for building construction.

The expression "light-frame wood construction" is generally used in reference to structures built of sawn lumber with these maximum nominal measurements: 4-inch width and 12-inch depth. From a systems standpoint, the most common light-frame structure, a house, serves both load bearing and building enclosure or envelope functions. Light-frame structures in which load bearing and envelope functions are separated may also be classified as "post-and-beam" construction, regardless of the size of framing materials used.

The systems approach permits greater flexibility in the classification of wood construction technologies than the two broader categories of light-frame and heavy timber. It permits the physical properties of the completed structure, as well as the most significant factors of the construction method or process employed, to be recognized. Recognition of production factors is an important consideration, as gradual advancements in wood construction do not necessarily represent changes in the basic technology but, in most cases, only introduction of new production methods. In accordance with the systems approach, typical American residential and light commercial wood structures can be classified as follows:

1. Componentized construction
   a. Wall-bearing structures
   b. Post-and-beam structures
2. Panelized construction
   a. Flat structural elements
   b. Spatial core elements
3. Modular construction
   a. Sectional homes
   b. Mobile homes

Componentized construction

The conventionally site-built house is often referred to as "stick-built" construction. While such terminology may be descriptive, it is not very accurate. As the use of prefabricated components in site-built houses constantly grows, it may be more appropriate to refer to this assembly method as "componentized" construction. The term is not necessarily limited to construction with prefabricated roof and floor trusses, but may also extend to preassembled wall components or panels, as long as the siding materials are applied at the construction site rather than at the assembly plant.

Wall-bearing construction.—By definition, this category includes structures that combine load bearing and building enclosure functions, as in typical light-frame wood construction or in log construction. The most common contemporary light-frame system is platform construction (Fig. 1), developed from earlier braced (Fig. 2) and balloon framing construction methods. While modifications of these two methods may be encountered in designs with two-story high interior spaces, platform framing is more adaptable to on-site tilt-up wall construction, and also more easily integrated with other prefabricated components.

The most common prefabricated component in light-frame wood construction is the metal plate roof truss. Floor trusses are also becoming increasingly more popular (Kallio and Galligan 1978). Integration of both trusses with the connecting wall studs into a single unit (unitized frame) has resulted in the recently introduced "truss frame" assembly (Fig. 3, Tuomi et al. 1978). Improved structural performance is developed because every loaded member shares its load with other elements within the system. Advantages include reduction of framing lumber required, fast on-site erection, elimination of support beams and columns in the basement, reduction of ductwork for heating and cooling, plus the use of only one lumber size (2 by 4's) for fabrication. Estimates of materials show at least a 30% savings in structural framing lumber requirements over a conventional house with the same floor plan. The truss-frame assembly is adaptable to one- and two-story construction in a variety of stacking arrangements.

Post-and-beam construction.—The distinguishing characteristic of this framing concept is separation of load bearing and building envelope functions in exterior

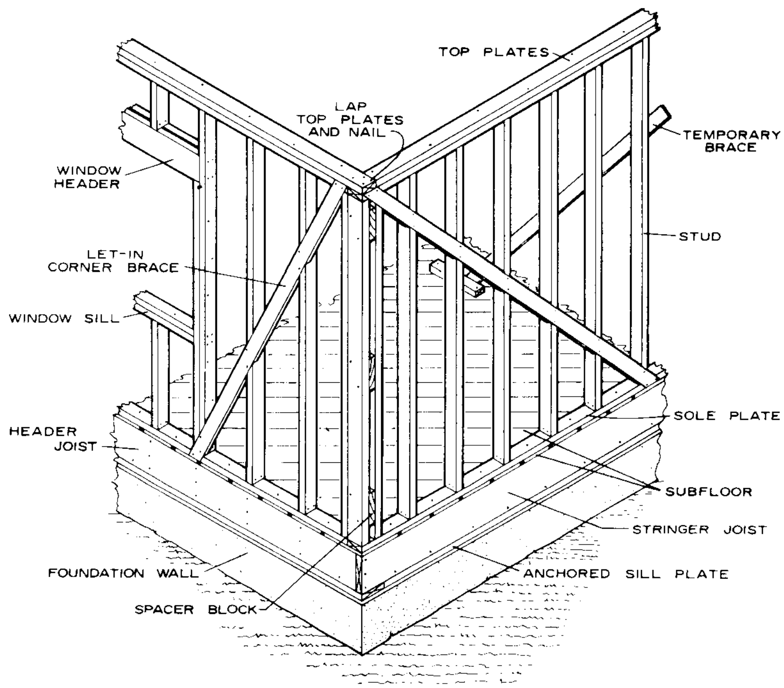

FIG. 1. Wall framing used with platform construction.

wall and roof construction (Fig. 4). Common post-and-beam construction details used in one-story houses represent adaptations from heavy timber construction practices with plank decking. For two-story houses such details are more commonly derived from colonial New England timber framing systems. The post-and-beam framing concept represents one possible avenue for increased use of hardwoods in house construction (Elliot and Wallas 1977).

In a broader sense the term "post-and-beam" often is also applied to derivatives of platform and pole construction concepts. In such construction, treated wood posts imbedded in the ground can perform not only foundation but also framing functions. For more accurate terminology, however, it may be desirable to establish a clear distinction between such building systems. In "platform" construction wood posts are used only as a foundation system that can be adapted to any conventional joist or beam floor system and any other framing system above the floor platform (Fig. 5). In "pole" construction (Fig. 6), the foundation members are extended above floor line for direct support of roof framing. Members do not need to be round poles but may also be preservative-treated rectangular timbers or assemblies. In all cases, however, the concept is distinguished by ground imbedment of primary vertical framing members (AWPI 1975).

Panelized construction

This construction concept has gained increasing attention and acceptance since the close of World War II. According to industry data (NAHM 1980), the 1978 production of single-family homes assembled by this method reached 537,000, or

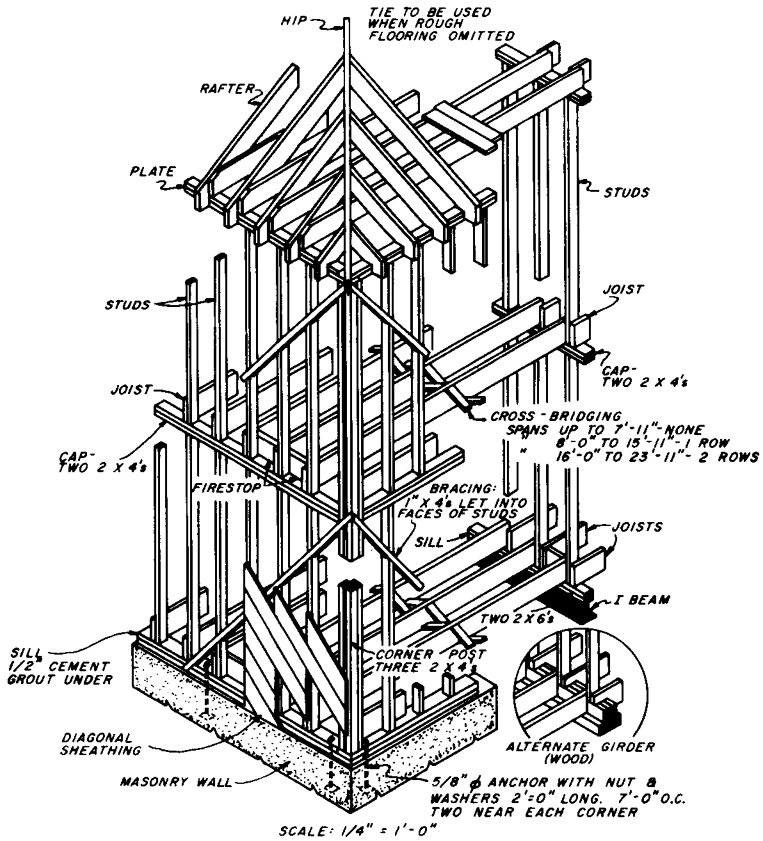

FIG. 2. Wall framing used with braced construction.

nearly 66% of the total conventional housing output of 817,000 units for that year (U.S. Department of Commerce 1979). In most panelized designs, exterior walls retain both load bearing and building envelope functions, but preassembled curtain wall panels may also be used in post-and-beam construction.

Flat structural elements.—As even curtain wall panels carry wind loads, all building envelope panels can be classified as structural elements. Fully developed

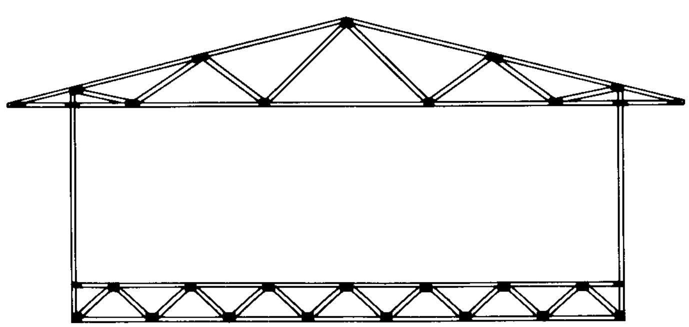

FIG. 3. Truss-frame assembly.

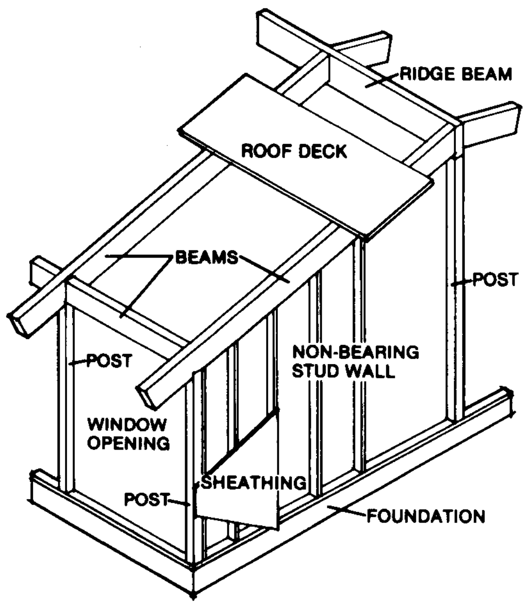

FIG. 4. Post-and-beam construction.

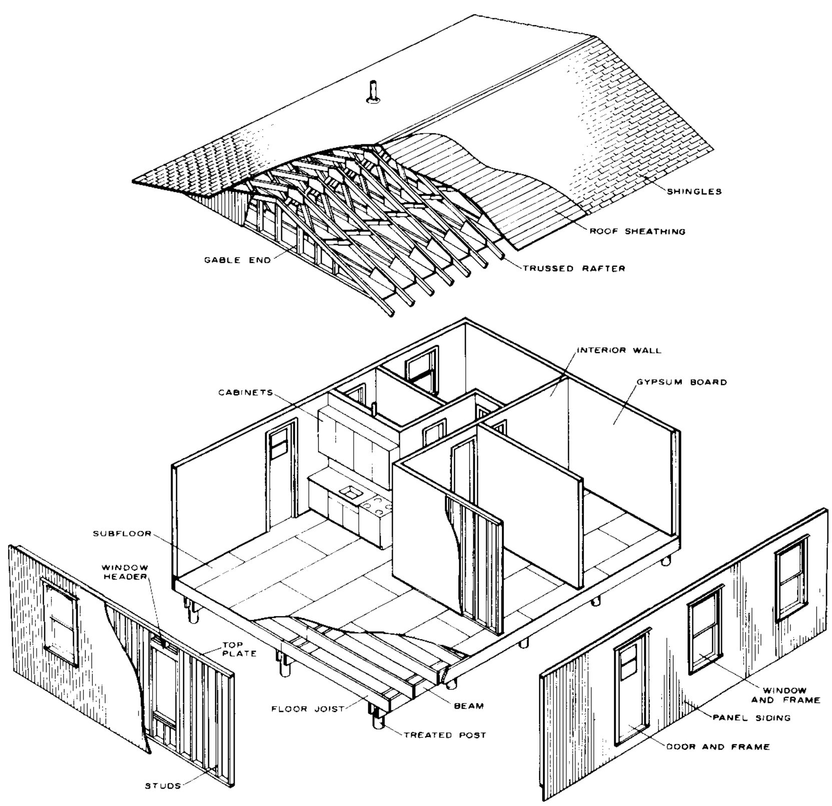

FIG. 5. Panelized house on post construction.

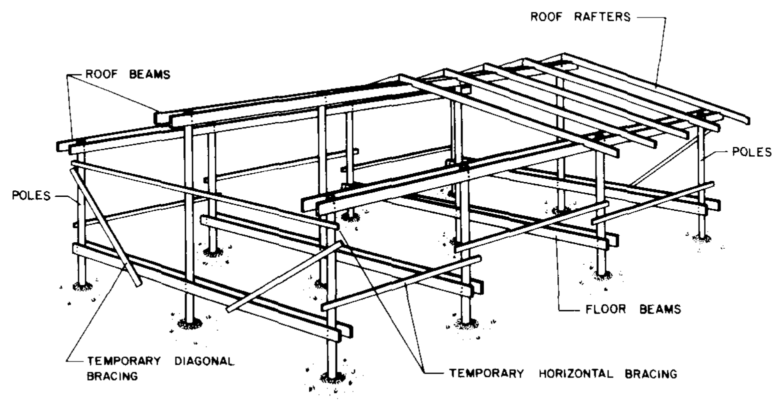

FIG. 6. Framework for a ranch house in pole construction.

panelized construction takes advantage of both diaphragm and stressed skin effects. A diaphragm is a unit in a structure such as a roof, wall, or floor that is designed and constructed to resist deformation in the plane of the unit and thereby limit the deformation of other parts of the structure. In stressed-skin construction (Fig. 7) panels are separated from one another by stringers with the whole assembly bonded so that it acts as a unit when loaded.

Two-dimensional diaphragm designs are used to resist primary loading in the plane of the panel, as in bearing wall construction, where siding (cladding) materials, skins, on both faces usually are stressed in the same mode (tension, compression, or shear). Stressed skin design allows use of relatively thin sections with primary loading perpendicular to the plane of the panel, as in floor and roof construction, resulting in opposite stresses (tension and compression) in the two facing panels. Stressed skin construction also permits use of such panels, placed on edge, to function as relatively deep and narrow box beams carrying roof loads.

In panelized construction the structural facing materials, or skins, are applied at the assembly plant and under controlled conditions. Some building systems employ "open panel" construction that allows access to the wall cavity during erection but requires installation of interior surface materials at the job site; others use "closed panel" construction where all cladding materials are applied at the assembly plant. Panelized construction often is integrated with other prefabricated components, such as roof trusses. Similarly, prefabricated floor assemblies may not constitute true panels but only sections of otherwise conventional joist

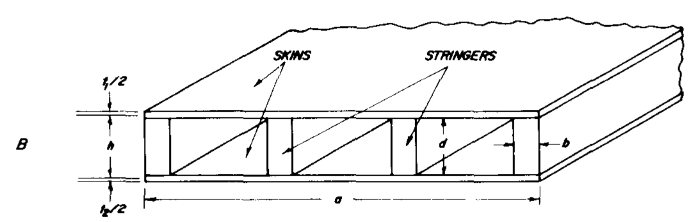

FIG. 7. Stressed-skin construction.

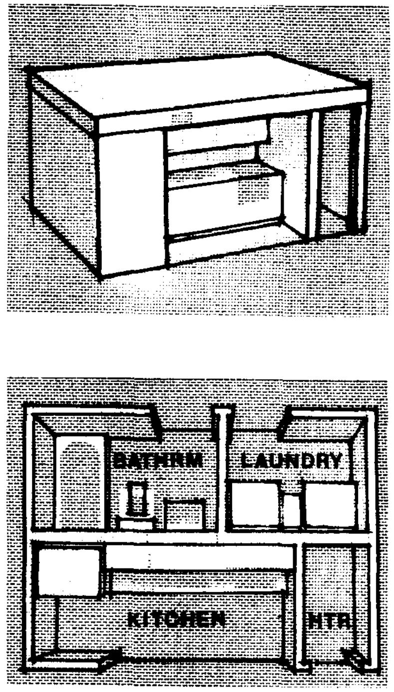

FIG. 8. Utility or "wet" core.

floors preassembled at the plant for installation in convenient widths. Such composite designs may be the result not only of specific production process requirements but also of market acceptance considerations.

Spatial core elements.—Panelized construction is often integrated with three-dimensional "core" modules containing utilities and conveniently preassembled at the plant. Such modules usually contain the "wet" kitchen and bathroom facilities and most of the mechanical and electrical equipment needed (Fig. 8). Use of core modules allows not only a reduction in construction costs but also better quality control.

As the utility functions accommodated by core modules are interior space functions, the modules generally do not perform as load-bearing components. While it may also be possible to design the core module as a windstorm-resistant shelter, present construction practices still do not show such trend. As a result, core modules usually do not represent engineered three-dimensional structures, and therefore can be classified as simple spatial elements used in panelized construction.

Modular construction

Modular structures are three-dimensional units engineered for on-site loading and also for production or transportation stresses. Although the modular construction concept offers obvious economies in the assembly process, it suffers from high transportation costs in the delivery of the finished unit to the site. Thus, applications of the concept have remained more limited than envisioned some years ago.

Sectional homes.—Dwellings assembled by the modular construction process and meeting the quality standards for conventionally built housing are known as "sectional homes." The three-dimensional sections are prefinished with commonly used cladding materials, but their weight has been the most critical factor limiting wider applications of this technique. Some volume builders have taken advantage of temporary on-site assembly facilities, but this technique lends itself only to large volume production.

As building modules are engineered assemblies, they also require adequate production quality control. With such control they represent a viable option for quality house construction in outlying areas where there often is a shortage of skilled workers. At the same time, engineered design also promises efficient utilization of construction materials, even if design targets may be largely determined by market acceptance rather than by structural performance factors.

Mobile homes.—The mobile home is defined as a housing unit meeting established standards for mobile homes rather than conventional houses. While such standards have been changing, at this time the mobile home is still distinguished by its integral chassis designed for transportation, while the sectional home is transported on a detachable undercarriage. The chassis allows construction of mobile homes with less stiffness in the superstructure, and in the past this feature has been exploited for maximum savings in construction costs.

Mobile homes are assembled as panelized structures. Application of simple prestressing techniques, such as banding the superstructure to the chassis, allows them to perform as tubular structures during transportation. Past development of this technology has been limited by market and cost considerations. Its full potential for combining prefabrication techniques with efficient structural design still seems to have remained unappreciated and unexplored.

The 1978 output of the mobile home industry was 274,901 units shipped (U.S. Department of Commerce 1979), or more than 33% of the number of conventional single-family homes (817,000 units).

Engineering design procedures

Prior to the introduction of shear connectors about the time of World War I, wood building construction was based largely on the concepts of established precedent and acceptable practice rather than performance analysis. Such concepts still govern most of residential and light commercial wood construction practices, except for specific engineered components such as roof and floor trusses. Regulatory standards based on acceptable practice concepts are easily enforced, and more detailed design analysis becomes economically attractive only when the material benefits of such sophistication outweigh the increased cost of design services.

The limits of acceptable practice are commonly identified by reference tables. Some references may be based on engineering analysis, such as span tables for joists and beams, but others only on conventionalized rules-of-thumb, such as required footing sizes. Gradual reorientation from specification- to performance-type standards and construction documents has allowed more detailed recognition of common load sharing and composite action effects in wood construction than was possible before. Such reorientation has been both facilitated and required by only relatively subtle changes in construction practices.

Increased use of construction adhesives has enhanced the load-sharing performance of floor and wall assemblies. Use of metal plate connectors has allowed design for greater structural continuity between framing members, as illustrated by the truss frame concept (Tuomi et al. 1978). Introduction of automated nailing and stapling equipment, widely used for prefabricated assemblies, has resulted not only in economic advantages but also in closer spacing or different distribution of fasteners.

Design references for such assemblies do not lend themselves to easy tabulation because of wide variations in configuration and load conditions, so that design must be based on careful analysis or, occasionally, on actual test data. Design services for prefabricated components, such as trusses with metal plate connectors, commonly are available from the component manufacturer. In many cases such assemblies have already been predesigned, so that the configuration of a component also allows the most efficient utilization of materials.

The concept of predesign has also been extended to material specifications. Structural plywood, for example, is no longer specified by its thickness and facing qualities, but rather by its performance-oriented use index. This index helps to simplify not only a variety of manufacturing and grading problems but also construction standards and specifications. The user is assured of comparable performance among an otherwise wide range of choices.

The building systems approach gained its initial popularity in the 1960s as a procedure for coordinating complex construction tasks. Its underlying principles have been gradually extended to considerably simpler conditions, such as those outlined above. The current trend in engineering design, emphasizing structural continuity and diaphragm action effects, rests on systems analysis concepts. As regulatory standards and material specifications are becoming increasingly more systems- and performance-oriented, all design procedures should also take advantage of such reorientation.

SKIN MATERIALS

Plywood

Construction/grading principles.—Plywood manufactured under U.S. Product Standard PS 1-74 (U.S. Department of Commerce 1974) is widely used in wood construction. The primary structural design manual for such plywood is the "Plywood Design Specification" and its supplements published by the American Plywood Association (APA), P.O. Box 11700, Tacoma, WA 98411. A list of technical publications that covers all aspects of plywood in construction is also available from APA.

Construction plywood is generally made up of an odd number of thin layers of wood (veneers) at right angles and is referred to as three-ply, five-ply, etc. Plywood is also constructed with the grain direction of adjacent plies parallel. This construction is often referred to as four-ply, six-ply, etc. Common thicknesses range from $^5/_{16}$ to $^1/_8$ inches. The standard size sheet is 4 by 8 feet, but other sizes can be manufactured. More than seventy species of wood are used in the manufacture of construction plywood. These are assigned to five groups according to similar properties, with Group I species being the strongest. Construction plywood may be interior or exterior. Exterior plywood has a fully waterproof

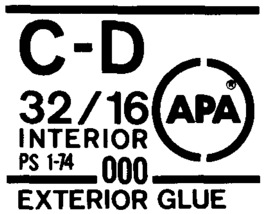

FIG. 9. Typical APA grade trademark.

glueline. It must also have no lower than C-grade veneer. Interior-grade panels may have any grade of veneers and may be made with exterior, intermediate, or interior glue that is water resistant, but not necessarily waterproof. A typical APA grade-trademark is shown in Fig. 9. Detailed descriptions of veneer grades are given in PS 1-74.

The panel depicted in Fig. 9 would have a C-grade veneer face and D-grade veneer back. The identification index, 32/16, refers to a maximum allowable roof support spacing of 32 inches when the panel is used as sheathing and a maximum floor joist spacing of 16 inches when used as subflooring. The panel would be interior type, but would be bonded with exterior glue. Numbers where the "zeros" are shown would identify the mill where the panel was manufactured.

Design properties.—Allowable plywood design stresses are based on clear wood stresses using the principles in ASTM D-2555, standard methods for establishing clear wood strength values (ASTM 1978a). There are adjustments for such factors as moisture content, conditions of loading, and veneer characteristics. Duration-of-load factors are the same as those for structural lumber. Figure 10 presents Table 3, Allowable Stresses for Plywood, as it appears in the APA "Plywood Design Specification" mentioned in the previous section for species Groups 1–4. All species within a group are assigned the same working stress. Design stresses are not assigned for Group 5. Shown on the following page is an excerpt from Table 3 that includes allowable stresses for bending, tension, compression, shear, and bearing. For stress levels S-1 and S-2, gluelines must be exterior. In addition, only veneer grades N, A, and C are allowed in the face and back for S-1 level. Veneer grades B, C-plugged, and D are allowed on the face or back for S-2 level. "WET" means plywood moisture content in service continuously or repeatedly exceeds 16%. When moisture content will be greater than 18%, exterior-type plywood should be used.

Design stresses for the particular plywood grade must be used in conjunction with the section property that applies in the specific case. Section properties in the Plywood Design Specification are given as "effective" section properties. This means they have been adjusted to account for direction of inner plies and possible mixing of veneer species. The subject is covered in more detail in APA's Plywood Design Specification and by Carney in Chapter 5 of (ASCE 1975).

Recent developments.—Composite plywood, currently being marketed by several manufacturers in the United States, is a new type of structural panel with a structural core of reconstituted wood and veneer faces. Its intended uses include roof sheathing, subflooring, and single-layer floors. The composite plywood panel cannot be interchanged with all-veneer plywood in all applications because not

Conforming to U.S. Product Standard PS-1-74 for Construction and Industrial Plywood. Normal Load Basis in PSI.

TYPE OF STRESS		SPECIES GROUP of FACE PLY	GRADE STRESS LEVEL *				
			S-1		*S-2*		*S-3*
			WET	DRY	WET	DRY	DRY ONLY
EXTREME FIBER STRESS IN BENDING (F_b)	F_b & F_t	1	1430	2000	1190	1650	1650
TENSION IN PLANE OF PLIES (F_t)		2, 3	980	1400	820	1200	1200
Face Grain Parallel or Perpendicular to Span		4	940	1330	780	1110	1110
(At 45° to Face Grain Use 1/6 F_t)							

FIG. 10. Allowable stresses for plywood.

all properties are equivalent. It is felt, however, that for many sheathing and subflooring uses it is virtually interchangeable with conventional plywood (Carney 1977). Composite plywood Sturd-I-Floor panels and roof sheathing panels were used in the construction of a demonstration house in Georgia (Koenigshof 1979).

Particleboard

Classification and properties.—Particleboard is a panel product composed of small pieces—chips, flakes, strands, shavings—of wood bonded together with an adhesive. Particleboard has some of the same uses as plywood in construction, such as sheathing and floor decking, but it is not equivalent to plywood in all properties. Factors that affect particleboard performance include panel density, adhesive content and type, as well as wood particle size and shape. Panels used in construction are generally sold as 4- by 8-foot sheets, although particleboards are available in larger sizes.

In the new American National Standard for particleboard, ANSI A208.1-1979, panels are classified according to adhesive type, density, and physical property level and in some cases by particle type (ANSI 1979). Most particleboards are made with urea formaldehyde adhesive and are intended for interior uses such as floor underlayment and corestock for furniture and cabinets. However, some particleboards are made with durable and highly moisture- and heat-resistant adhesives (generally phenolic resins) for certain exterior applications. The National Particleboard Association (NPA), 2306 Perkins Place, Silver Spring, Md. 20910, has published standards for panels manufactured specifically for such uses as single-layer mobile home and factory-built house floor decking. The NPA grade stamp for factory-built house decking is shown in Fig. 11. The term, NPA 2-72, shown in Fig. 11 is the NPA standard for this product. Tongue-and-groove panels are also manufactured for use as single-layer floors in conventional construction. Building code reports, available from NPA, give allowable shear values for specific brand-name particleboard products when used as sheathing.

Design values have not been published on an industry-wide basis for structural use of particleboard in the United States. However, work has been done on developing allowable stresses (Pearson 1977) and such values have been published in Europe. For instance, in Sweden the Svensk Byggnorm contains design stresses for structural grades of particleboard (Svensk Byggnorm 1975).

Recent developments.—A type of panel product that has received a lot of

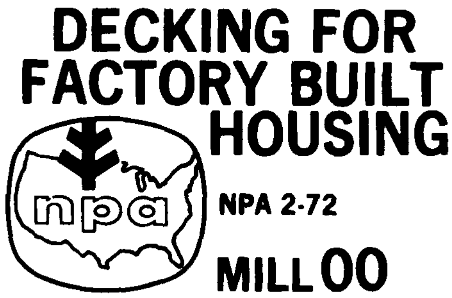

FIG. 11. NPA grade stamp for decking for factory-built housing.

attention lately, called "waferboard," is made from large, rectangular "wafers" bonded with the exterior-grade resin adhesive, phenol formaldehyde. It has approval by various code groups for use as exterior sheathing. Currently only three plants in the United States produce waferboard, although several are under construction or have been announced. Several plants in Canada produce waferboard and ship a large portion to the United States. The total North American production of waferboard in 1978 was about 600 million square feet (3⁄8-in. basis). If all the plants under construction or announced actually go into production, the total capacity for waferboard manufacture could be about 2 billion square feet. In comparison, the total U.S. production of construction and industrial plywood is almost 20 billion square feet (3⁄8-in. basis).

It is possible to mechanically or electrostatically align certain wood particle types to produce panels with increased bending strength and stiffness in one direction. The increase depends upon the degree of alignment. Panels with face flakes, or strands, aligned in the direction of the panel length and core flakes aligned in the perpendicular direction in a plywood-like construction have been made and test-marketed in the U.S. Several plants are producing such panels commercially in the U.S.

In cooperation with Purdue University, the U.S. Forest Products Laboratory (FPL) has developed an engineered thick flakeboard roof decking intended for commercial and industrial applications (Hunt et al. 1978). The panel, a three-layer design is 1⅛ inches thick and has large flakes in the face aligned in the long direction of the panel to provide adequate bending strength and stiffness; smaller randomly distributed flakes in the core resist shear. Purdue University and FPL are currently evaluating the properties of laboratory-made full-size panels 30 inches wide and 12 feet long designed to be continuous over two 6-foot spans.

Building fiberboards

Building fiberboards are divided by density into structural insulation board (less than 31 lb/ft^3) and hardboard (31 lb/ft^3, or greater).

Structural insulating board.—Structural insulating board is manufactured mainly for specific uses in construction and is produced in two general types, interior and sheathing. Interior-grade insulation boards, commonly ½ inch thick, are used as ceiling tiles and lay-in ceiling panels. Such products have a factory-applied paint finish to reduce flame spread. They may also be perforated or fissured to aid in room sound absorption. Sound-deadening board, a specially manufactured interior-grade panel, provides a reduction in sound transmission through walls in light-frame construction. It is usually applied to the wall framing with a final wall finish, such as gypsum board, applied to the outside faces of the sound-deadening board.

Insulation board sheathing is an exterior-grade product treated with asphalt or other water-resistant substance. It is used as sheathing on exterior walls in light-frame construction and is manufactured in three grades: regular-density, intermediate-density, and nailbase. Regular-density (about 18 lb/ft³) is made in ½- and 25/32-inch thicknesses. Added bracing in the wall system is sometimes required to provide adequate racking resistance when this product is used. When intermediate (about 22 lb/ft³) or nailbase (about 25 lb/ft³) sheathing is used, added bracing is not needed. Intermediate and nailbase are only made ½ inch thick. Standard specifications for structural insulation board are included in ASTM C-208, C-532 and D-2277 (1972, 1974a, 1975) and Voluntary Product Standard PS 57-73 (U.S. Department of Commerce 1973b).

Hardboard.—Hardboard is divided into two density classes: medium-density (31–50 lb/ft³) and high-density (greater than 50 lb/ft³). Quality requirements for basic hardboard are established in Voluntary Product Standard PS 58-73 (U.S. Department of Commerce 1973c). Nearly all medium-density hardboard is intended for use as house siding. Most is ⅜ or 7/16 inch thick and is fabricated for application as either lap or panel siding, usually with a factory-applied prime coat or complete finish. The Voluntary Product Standard, PS 60-73 (U.S. Department of Commerce 1973e), for hardboard siding lists lengths of 4 to 16 feet and widths of 4 to 12 inches for lap siding. Panel siding is 4 feet wide and 4 to 12 feet long.

Uses for high-density hardboard in building construction include floor underlayment, door skins, and prefinished wall paneling. Requirements for prefinished hardboard paneling are established in Voluntary Product Standard PS 59-73 (U.S. Department of Commerce 1973d). The American Hardboard Association, 887-B Wilmette Rd., Palatine, IL 60067, has published application procedures for hardboard siding, prefinished paneling, and tileboard wall paneling.

As discussed later in the section on I-beams and box-beams, hardboard is being used outside the United States as shear web material in built-up beams. Other structural uses include gusset plates for connecting members of wood trusses and facings for stressed-skin panels. Design stresses for structural uses of hardboard have been established in Europe (British Standards Institute 1971; Chow et al. 1978; and Svensk Byggnorm 1975).

Timber decking

Timber decking, solid sawn or laminated, must be at least 2 inches in nominal thickness to satisfy code requirements for heavy timber construction. Glued laminated timber decking is manufactured from three or more laminations bonded together into a single member with a tongue-and-groove pattern. It is available in different thicknesses, approximately 2¼ to 3¾ inches, which may vary between manufacturers. Detailed information on laminated decking is available from the manufacturers and suppliers. Limited stress data are also available from the American Institute of Timber Construction (AITC), 333 W. Hampden Ave., Englewood, CO 80110.

Solid-sawn timber decking may be nominal 2, 3, or 4 inches thick. Nominal

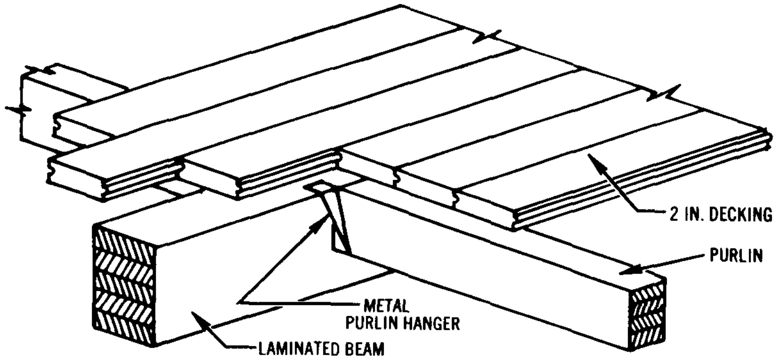

FIG. 12. Two-inch roof decking on laminated beam framing system.

width is 6 inches. Nominal 2 by 6 timber decking has a single tongue and groove. Nominal 3 by 6 and 4 by 6 decking has a double tongue and groove. Allowable stress and design information for timber decking is given in AITC 112-77, "Standard for Tongue and Groove Heavy Timber Roof Decking." Lumber used in heavy timber decking is graded according to the grading rules for the particular wood species used. Lumber grading is discussed in detail below under Structural Lumber.

On a laminated beam and purlin system (Fig. 12), nominal 2 by 6 solid-sawn decking is toe-nailed at each support with one 16d nail and face-nailed with one 16d nail. Economical span range for 2-inch decking is 6 to 12 feet. On a laminated beam system, nominal 3 by 6 and 4 by 6 solid timber decking is toe-nailed at each support with one 40d nail and face-nailed with one 6-inch spike. Adjacent deck boards are also spiked to each other with 8-inch spikes through predrilled edge holes at intervals of no more than 30 inches. Economical spans for heavy timber decking range from 8 to 20 feet, depending upon deck thickness and load conditions.

Insurance rating bureaus and all of the model building codes accept 1⅛-inch tongue-and-groove plywood with exterior glue as an alternative to 2-inch nominal tongue-and-groove lumber decking in heavy timber construction. Typical construction consists of Sturd-I-Floor 48 oc (on-center) tongue-and-groove plywood, or 1⅛-inch tongue-and-groove C-D EXT nailed to heavy timber beams which must be 4 by 6 minimum and are normally spaced 48 inches oc.

FRAMING MEMBERS

Structural lumber

Besides being used without modification in wood building construction, solid-sawn structural lumber is used to manufacture glulam beams, timber decking, stressed-skin panels, I-beams and box-beams, and open-web trusses. For this reason, structural lumber is discussed below in considerable detail under visual stress grades and machine stress grades.

Visual stress grades of lumber

Grading principles.—The majority of stress-graded lumber used structurally in the United States is graded by a traditional visual grading practice. This procedure was formally instituted through the American Society for Testing and Materials (ASTM) Standards D-245 in 1927. This grading system has been subject to continual review and modification in the years since 1927, principally through ASTM standards procedures, but also under consensus standards promulgated by the U.S. Department of Commerce (1970).

The basic premise of the visual stress-grading system is the use of the clear straight-grain wood property as a species characteristic to be further modified by strength-reducing characteristics and design adjustment factors. These are combined to provide an allowable or design property. The clear wood properties are selected by consistent procedures in accordance with ASTM Standard D-2555 "Establishing clearwood strength values" (ASTM 1978a). The properties listed in this standard by species are adjusted by procedures prescribed in the standard for the development of near minimum properties and species group combinations (Bendtsen et al. 1975; Bendtsen and Galligan 1978).

Starting with the clear wood base, the next critical step in assignment of design values is to accommodate the natural characteristics of wood. These procedures are outlined in ASTM Standard D-245 "Establishing structural grades and related allowable properties for visually graded lumber" (ASTM 1927). The basic premise is a factor called the strength ratio. This adjusts the clear wood properties for natural characteristics such as knots and slope of grain. Bending, shear, compression perpendicular and parallel to the grain, and modulus of elasticity properties can be derived directly using D-245. Allowable tension values are determined following D-245 procedures with additional reductions recently applied to accommodate observations from tests of lumber (Galligan et al. 1979). It is important to recognize that the combined D-2555/D-245 procedures allow derivation of design properties for any species-lumber characteristic combination. This two-standard combination has permitted market flexibility over the years and presently accommodates all of the softwood species and some of the hardwood species considered of commercial importance for structural use in the United States and Canada.

To provide uniformity in the marketplace for lumber size, grades, and species combinations, the current American Softwood Lumber Standard (ALS), Product Standard 20-70 (U.S. Department of Commerce 1970) was promulgated under the U.S. Department of Commerce. A feature is the National Grading Rule, a provision of this standard that was enacted to create particular uniformity in the critical dimension lumber grades (i.e. lumber 2–4-in. thick).[3]

Under the ALS, authority is vested in rules-writing agencies to describe the nature and size of characteristics such as knots permitted in all grade/size combinations and to specify permitted manufacturing characteristics such as skip and wane. These agencies also calculate and publish the corresponding design values and have responsibility for inspection procedures. The following agencies are granted rules-writing status under the ALS. Specific inquiries regarding content of grades, grading practices, and allowable properties corresponding to these grades, should be directed to these agencies.

[3] Specifically, the National Grading Rule provides that the same grade description shall accompany all stress grades with common grade names for dimension lumber—the subsequent design values varying in accordance with clear wood properties. Consequently, commonality of grading procedures exist for all lumber 2 to 4 inches thick, graded under the American Lumber Standards procedures.

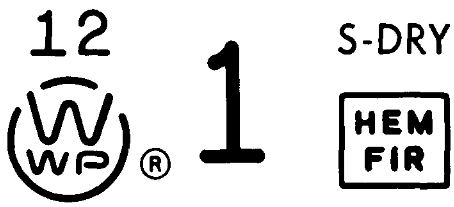

FIG. 13. Typical grade stamp for visually-graded lumber.

Organization	Mailing Address
Northeastern Lumber Manufacturers Association, Inc. (NELMA)	4 Fundy Road, Falmouth, ME 04105
Northern Hardwood and Pine Manufacturers Association, Inc. (NH & PMA)	Suite 501, Northern Building, Green Bay, WI 54301
Redwood Inspection Service (RIS)	617 Montgomery Street, San Francisco, CA 94111
Southern Pine Inspection Bureau (SPIB)	Box 846, Pensacola, FL 32594
West Coast Lumber Inspection Bureau (WCLIB)	Box 23145, 6980 Southwest Varnes Road, Portland, OR 97223
Western Wood Products Association (WWPA)	1500 Yeon Building, Portland, OR 97204
National Lumber Grades Authority (NLGA) (Canada)	1055 West Hastings Street, Vancouver, BC Canada V6E 2H1

In addition to agencies vested with the responsibility of preparing grading rules for species, other agencies are certified under the ALS to grade, using the rules prepared by the rules-writing agencies. At the time this report was prepared, fourteen agencies, in addition to the above rules-writing agencies, had grading status for lumber marketed in the United States. A typical visual grade stamp is shown in Fig. 13. The stamp shows species group (HEM FIR), grade (1), dryness at manufacture (S-DRY),[4] grading agency, (Western Wood Products Association), and mill number (ASTM 1978a).

The result of the above procedures is a concise grading rule for each grade of lumber, an accompanying list of properties, and a uniform labeling procedure. As an example of a typical grade, No. 2 Douglas-fir 2 by 4 lumber is limited in characteristics that affect strength and stiffness values to provide a fiber stress in bending value of 45% of that allowed for clear, straight-grained wood and to provide a recommended design value for modulus of elasticity of 90% of that allowed for the clear wood average. This grade is recommended for many construction uses. Characteristics limited include checks, knots, rate of growth, shake, skips, slope of grain, splits, stain, unsoundwood, wane, warp, and white speck. Each limitation is explained in the official grade description (WCLIB 1975; WWPA 1979).

[4] S-DRY means surfaced at a maximum moisture content of 19%. S-GRN, also used, means surfaced at a moisture content above 19% (i.e., "green"). Southern Pine Inspection Bureau often uses the "KD" designation to mean kiln-dried to not over 15% moisture content.

TABLE 1. *Common grade and size categories of visually stress-graded lumber.**

2 to 4 inches thick		
2 to 4 inches wide	2 to 6 inches wide	5 inches and wider
Structural Light Framing	*Studs*	*Structural Joists and Planks*
Select Structural	Stud	Select Structural
No. 1		No. 1
No. 2		No. 2
No. 3		No. 3
Appearance Framing		*Appearance Framing*
Appearance		Appearance
Light Framing		
Construction		
Standard		
Utility		
other thicknesses		
Beams and Stringers		*Posts and Timbers*
5 inches and thicker, 8 inches and wider		5 by 5 inches and greater, approximately square
Structural Boards		*Decking*
less than 2 inches thick		several sizes and patterns

* All grades described in all United States rules in accordance with the American Lumber Standard. Allowable stresses assigned to Structural Light Framing are not the same as those assigned to Structural Joists and Planks of the same grade name. Allowable stresses also vary with species. All sizes are nominal.

Properties.—The procedures outlined above are applied to approximately forty-five species or species groups in the domestic United States lumber market. Major species groupings that accommodate the majority of the market are Douglas-fir-larch, hem fir, lodgepole pine-Engelmann spruce, southern pine, and spruce-pine-fir. Other species and species combinations may be equally or more important in certain geographical markets. All are graded, and the properties developed, using the same ALS- and ASTM-based procedures.

Grade names assigned to lumber under ALS standard procedures vary by size, category, and end-use. Table 1 lists categories and corresponding names. Note that certain names, e.g., Construction, apply only in the narrow widths and thus are not officially used for joist-type lumber.

The universal reference for sizes, grades, and species in the United States is the National Design Specification (NDS) supplement entitled "Design Values for Wood Construction" (National Forest Products Association 1977). The excerpt on the following page from the NDS Table 4A illustrates the display of data accompanying one species marketing group (Douglas fir-larch) for lumber 2 to 4 inches thick (Fig. 14). Additionally, individual rules-writing agencies publish selection guides containing allowable properties for the species/grade/size combinations under their jurisdiction. A comprehensive list of commercial species groups and the corresponding official names is in ASTM D-1165 "Standard Nomenclature of Domestic Hardwoods and Softwoods" (ASTM 1976).

Marketing/availability.—Grades and sizes available in the market vary by geo-

(Design values listed are for normal loading conditions. See other provisions in the footnotes and in the National Design Specification for adjustments of tabulated values.)

Species and commercial grade	Size classification	Design values in pounds per square inch							Grading rules agency
		Extreme fiber in bending "F_b"		Tension parallel to grain "F_t"	Horizontal shear "F_v"	Compression perpendicular to grain "$F_{c\perp}$"	Compression parallel to grain "F_c"	Modulus of elasticity "E"	
		Single-member uses	Repetitive member uses						
DOUGLAS FIR-LARCH (Surfaced dry or surfaced green. Used at 19% max. m.c.)									
Dense Select Structural		2450	2800	1400	95	455	1850	1,900,000	
Select Structural		2100	2400	1200	95	385	1600	1,800,000	
Dense No. 1		2050	2400	1200	95	455	1450	1,900,000	
No. 1	2" to 4"	1750	2050	1050	95	385	1250	1,800,000	
Dense No. 2	thick	1700	1950	1000	95	455	1150	1,700,000	
No. 2	2" to 4"	1450	1650	850	95	385	1000	1,700,000	
No. 3	wide	800	925	475	95	385	600	1,500,000	
Appearance		1750	2050	1050	95	385	1500	1,800,000	
[illegible]		800	925	475	95	385	600	1,500,000	
	2" to 4"	1050	1200	625	95	385	1150	1,500,000	WCLIB
	thick	600	675	350	95	385	925	1,500,000	WWPA
	4" wide	275	325	175	95	385	600	1,500,000	
		2100	2400	1400	[illegible]	455	1650	1,900,000	
		1800	2050	[illegible]		385	1400	[illegible]	(see footnotes
			[illegible]			[illegible]	[illegible]	[illegible]	1 through 12)

FIG. 14. Design values for visually graded structural lumber (NFPA 1977).

graphical region. For example, southern pine often is sold as separate grades such as No. 1, No. 1 Dense, No. 2, and No. 2 Dense. The "Dense" connotes an additional growth requirement. It is common to sell western species in combinations such as No. 2 and Better (2 & Btr), for example. In such a mix there may be grades stamped No. 2, No. 1, and Select Structural.

In dimension sizes the effect of the National Grading Rule is to have the same grade characteristics associated with a common grade name across all species. Therefore the availability of certain stress levels is a function of the clear wood strength. Accordingly, high design values will not be found in some of the dimension grades for species of lower clear wood strength species. For example, a Douglas-fir Select Structural 2 by 4 has an allowable bending strength of 2,100 lb/in.^{2} while the corresponding Select Structural western cedar 2 by 4 has an allowable bending strength of 1,300 lb/in.^{2}. As a result, users should consider purchasing by desired property level rather than only by species or grade. Such a procedure permits the market to seek the most economical species/grade combination having the proper design value.

Size categories such as posts and timbers are not covered by the National Grading Rule. Consequently there are slightly different grade descriptions (permitted characteristics) between agencies for grades with the same name. Purchasing such grade/size categories by desired property level therefore is perhaps even more important than for dimension sizes.

In any specific market location, certain combinations of species, grades, and sizes may have greater regional market acceptance, have greater production feasibility, or may be influenced by shipping costs. Consequently, not all possible combinations of size, grade, or species are available in all locations. Specifiers and purchasers concerned with the availability of stress levels, species, or sizes are advised to use the services of the lumber distribution system and particularly sales organizations specializing in industrial lumber in order to minimize confusion regarding the availability of the most optimum combinations of lumber properties.

Trends.—An assessment of the allowable properties of certain grades and sizes of lumber is underway. This is a cooperative project of universities, the Forest

Products Laboratory, and three of the lumber grading rules-writing agencies of the United States. Cooperation also is being maintained with a similar study in Canada. The magnitude of this assessment is great; results will not be available for several years.

One possible outcome of the lumber grade assessment is some consolidation of the existing visual grades. Presently the large number of individual species/grade/size combinations causes some marketing concern as being confusing and perhaps inefficient. Careful consideration of the actual structural needs by users could be a positive contribution to the lumber marketing experts as they assess possible changes in market combinations.

Machine stress grading

Grading principles.—A second grading system was initiated 15 years ago. This procedure is termed "machine stress grading" and carries the abbreviation MSR. This system is currently being used in the United States and Canada to a limited degree and is coordinated with the visual grading system. The MSR system is based on measuring the stiffness of each piece of lumber using a mechanical device. This measurement is related to strength through established correlative relationships (Hoyle 1968). The MSR system includes edge-knot and other visual requirements, often termed visual quality levels, as a part of the National Grading Rule requirements (Galligan et al. 1977).

The result is a grading system that is a combination of predicting variables—a stiffness measurement plus the visual criteria. The system functions by adjusting grading machines to adequately measure stiffness from which bending strength is directly inferred from tests. Allowable tension and compression parallel design values are based on a percentage of the allowable bending value (Galligan et al. 1979; WCLIB 1975; WWPA 1979). Compression perpendicular and shear values are determined as in the visual stress grading procedures (ASTM D-2555, 1978a; Bendtsen and Galligan 1978).

An essential element of the MSR system is the certification and quality control requirement that accompanies performance of this system in a production sawmill. A supervisory grading agency uses the certification procedure to establish the grade-size combinations permitted for that individual installation. The grading agency and the production mill utilize an ongoing quality control procedure to verify that the strength and stiffness characteristics of the grade are being met. A grade stamp on Machine Stress Rated lumber indicates that the stress rating system used meets requirements of the grading agency's certification and quality control procedures. MSR lumber is visually graded to limit such characteristics as checks, knots, shake, skip, splits, wane, and warp. Shown in Fig. 15 is an example of a grade stamp for MSR lumber (WWPA). The "f" rating is extreme fiber stress in bending in lb/in.^{2}, and the "E" rating is the rated modulus of elasticity in millions of lb/in.^{2}.

Properties.—Commercial species groups machine stress graded at this time (1979) are limited primarily to Douglas-fir, hem fir, southern pine, and spruce-pine-fir. The reasons for this species orientation rests in the yields obtainable, the presently attractive market grades, and the existence of production operations with sufficient sophistication and marketing capability.

Properties for these grades are commonly displayed as shown in Fig. 16, which

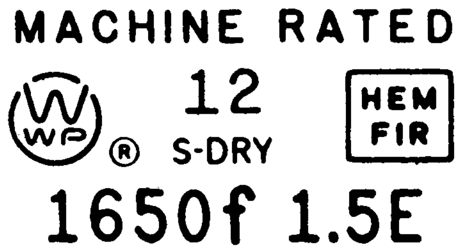

FIG. 15. Example of a grade stamp for machine stress rated (MSR) lumber.

presents an excerpt from the NDS Table 4B (National Forest Products Association 1977), Supplement on Design Values for Wood Construction.

Marketing/availability.—The MSR grade most prominent at this time is 1.5E-1650f, primarily in support of the metal plate wood truss industry. Other grades available include 1.6E-1800f, 1.8E-2100f, and 2.0E-2400f. The latter two grades have often been sold for proprietary long-span trusses and are of interest also for flat metal plate trusses. At this time production is limited to dimension lumber. The most common size available is 2 by 4. Two by 3 and 2 by 6, as well as wider widths, are available in smaller quantities.

Potentially any species can be machine graded but the production of specific grades may be emphasized or diminished depending upon characteristics of the species. In 1979 approximately 1% of the softwood lumber market, i.e., 300 million board feet, was graded by MSR procedures. Because the quantity of MSR is small relative to visually stress graded material, and because the quantity of specific size-grade combinations may vary by producer and species, MSR lumber should be specified with a clear view of availability and specific need for stress level.

Trends.—The conventional MSR tradition has permitted a variety of grade combinations that have been relatively stable for the last 10 years. Recent rule changes under the ALS have made different E-f combinations possible to better suit the production potential of geographical areas and markets. A few new combinations are now reaching the marketplace.

(Design values listed are for normal loading conditions.[8] See footnotes, and other provisions in the National Design Specification, for adjustments of tabulated values.[10])

Grade designation	Grading rules agency (see footnotes 1,2,3)	Size classification	Design values in pounds per square inch[5]				
			Extreme fiber in bending "F_b"[9]		Tension parallel to grain "F_t"	Compression parallel to grain "F_c"	Modulus of elasticity "E"
			Single-member uses	Repetitive-member uses			
900f-1.0E	1	Machine rated lumber 2" thick or less All widths	900	1050	350	725	1,000,000
1200f-1.2E	3		1200	1400	600	960	1,200,000
1450f-1.3E	1		1450	1650	800	1150	1,300,000
1500f-1.4E	3		1500	1750	900	1200	1,400,000
1650f-1.5E	3		1650	1900	1020	1320	1,500,000
1800f-1.6E	3		1800	2050	1175	1450	1,600,000
2100f-1.8E	3		2100	2400	1575	1700	1,800,000
2400f-2.0E	3		2400	2750	1925	1925	2,000,000
2700f-2.2E	3		2700	3100	2150	2150	2,200,000
3000f-2.4E	2		3000	3450	2400	2400	2,400,000
3300f-2.[illegible]	2		3300	3800	2650	2650	2,600,000
	3		900	1050	350	725	1,000,000
	[illegible]		[illegible]			[illegible]	1,200,[illegible]

FIG. 16. Design values for machine stress rated structural lumber (NFPA 1977).

Design values for normal load duration and wet conditions of use, pounds per square inch

Species	Compression parallel to grain F_c	Extreme fiber in bending F_b	Horizontal shear F_v	Compression perpendicular to grain $F_{c\perp}$	Modulus of elasticity E
Pacific Coast Douglas Fir[1]	1250	2450	115	230	1,500,000
Southern Pine[2]	1200	2400	110	250	1,500,000
Red Oak[3]	1100	2450	135	350	1,250,000
Red Pine[4]	900	1900	85	155	1,280,000

1. Pacific Coast Douglas Fir values apply to this species as defined in ASTM Designation D1760-76, Standard Specification for Pressure Treatment of Timber Products. For fastener design, use Douglas Fir-Larch design values.

2. Southern Pine values apply to Longleaf, Slash, Loblolly and Shortleaf Pines.

3. Red Oak values apply to Northern and Southern Red Oak.

4. Red Pine values apply to Red Pine grown in the United States. For fastener design, use Northern Pine design values.

FIG. 17. Design values for treated round timber piles (NFPA 1977).

Increased interest in MSR is evident by both producers and users. There have been recent additions of MSR facilities in both the United States and Canada. Most growth is in production for the engineering areas such as trusses and laminated beams because of the appeal of the certification and quality control procedures as well as desirable combinations of properties. The changes in MSR rules and a better understanding of the sawmill and lumber sales implementation of MSR (Galligan et al. 1977) suggest that this grading system will be expanded in the future.

Round poles

Properties.—Round construction poles can serve both foundation and aboveground load-carrying functions in wood construction. The circular cross section of the tree bole results in efficient structural use of the wood. Design properties for poles are obtained through ASTM standard D-3200 (ASTM 1974c), which, with the use of ASTM D-25 (ASTM 1973), specifies sizes and physical characteristics.

In construction poles, uniformity of the pole may be more critical than in piles or power poles. Consequently, AWPA Standard C23 (American Wood Preservers Association, current editions) specifies that construction poles for building construction should be machine-peeled and requires control on short crook that is more restrictive than as defined in ASTM D-25.

By reference to ASTM D-2899 (ASTM 1974b), D-3200 provides the mechanical property derivation procedures (ASTM 1974c). This latter procedure is based on clear wood properties from ASTM D-2555 plus variability, size, and end use adjustments relevant to piles and poles. Background information on properties of poles can be found in American National Standard ANSI 05.1; "Specification and Dimensions of Wood Poles"; in the ASTM publication "Strength and Related Properties of Wood Poles" (Wood et al. 1960); and in Wilkinson (1968).

Design values for the more common pole species are listed in Table 6A of the NDS (National Forest Products Association 1977), reproduced on the following page (Fig. 17), and would be used, as specified by ASTM D-3200, for construction poles; other species values can be developed using ASTM D-2899.

Design considerations

The properties derived for poles assume wet service conditions; therefore, reduction for exterior exposure is unnecessary. Normal load duration is assumed. Adjustments for other end-use conditions can be obtained through use of the recommendations of NDS, part VI. Wood poles should be treated with preservatives for long service life. However, preservatives often do not penetrate to the center of the pole. Consequently it is essential that care be taken to treat on site those untreated parts of the pole exposed by field cutting. Recommendations on treatment specifications and on proper treatment for cuts made on the job are found in American Wood Preservers Association references (AWPA, 1980). Federal Interim Specification TT-W-00571J has somewhat higher retention requirements for building poles for certain treatments (U.S. Department of Agriculture 1974). For foundation considerations, readers are referred to the American Wood Preservers Institute, 2600 Virginia Ave., Washington, D.C. 20037 for publications and recommendations.

Glued laminated timber

Manufacturing principles.—Structural glued laminated timber, or glulam, is an engineered, stress-rated member made up of three or more wood laminations bonded with adhesives. Glulam has been used in building construction in the United States since 1935. Grain direction of all laminations is approximately parallel to the length of the member, and individual laminations do not exceed 2 inches in thickness. Material, manufacture, and quality control requirements are given in Product Standard PS 56-73, "Structural Glued Laminated Timber" (U.S. Department of Commerce 1973a). Glue joint quality is a critical consideration in manufacturing glulam members. Adhesives must comply with the specifications contained in PS 56. Wet-use (waterproof) adhesives may be used for all moisture conditions, but are required when the moisture content exceeds 16% for repeated or prolonged periods of time.

Glulam beams are classified as either vertically or horizontally laminated beams according to the orientation of the glueline within the beam cross section. Vertically laminated beams are usually limited in depth to the width of lumber available. Horizontally laminated beams may be 7 feet or more in depth. They are usually limited by the widths of laminating stock available; however, when wide members are needed, the laminations may consist of multiple pieces laid side by side and need not be edge-glued if the edge joints are lapped in adjacent laminations. Widths up to 24 inches have been achieved in this manner. Horizontally laminated beams lend themselves to more efficient design because lumber grades can be selectively placed throughout the cross section in accordance with stress requirements (Moody et al. 1975)

Most glulam timbers are manufactured using visually graded lumber. Research has indicated that stiffer glulam beams of equal or higher strength can be made using machine-stress-rated (MSR) laminations (Moody et al. 1975). Supplemental requirements for lumber used in laminating are included in the laminating specifications.

Design considerations.—Procedures for establishing allowable design stresses for glulam made from visually graded lumber are covered in ASTM D-3737 (ASTM

ALLOWABLE UNIT STRESSES (psi) FOR STRUCTURAL GLUED LAMINATED TIMBER FOR NORMAL CONDITIONS OF LOADING, MEMBERS STRESSED PRINCIPALLY IN BENDING, LOADED PERPENDICULAR TO THE WIDE FACE OF THE LAMINATIONS[a,b,c]

Part A Dry Condition of Use

Combination Symbol	Number of Laminations	Allowable Unit Stresses: Extreme Fiber In Bending F_b	Tension Parallel to Grain F_t	Compression Parallel To Grain F_c	Compression ⊥ to Grain: Tension Face $F_{c\perp}$	Compression Face $F_{c\perp}$	Horizontal Shear F_v	Modulus of Elasticity E
Douglas fir and larch								
16*F*	4 or more	1,600	1,600	1,500	385	385	165	1,600,000
18*F*	4 or more	1,800	1,600	1,500	385	385	165	1,700,000
20*F*	4–8[c]	2,000	1,600	1,500	410	410	165	1,700,000
	9–12[d]	2,000	1,600	1,500	450	450	165	1,700,000
	13 or more	2,000	1,600	1,500	385	385	165	1,700,000
22*F*	4–10[e]	2,200	1,600	1,500	410	410	165	1,800,000
	4 or more	2,200	1,600	1,500		385	165	1,800,000
24*F*	4 or more		1,600	1,500		385		

Note [illegible]

[illegible]

FIG. 18. Example of allowable unit stresses for glulam (AITC 1974).

1978c). Discussions are underway in ASTM Subcommittee D 07.02 on Laminated Timber to include "E"-rated lumber in this ASTM standard. Bending proof loaders are becoming available for use by glulam manufacturers for testing tension laminations.

Two of the principal species used for laminations are Douglas fir and southern pine, although specifications cover a number of other softwood species and hardwoods. Specifications for glulam timbers from these and other species used are available from the American Institute of Timber Construction (AITC), which is the national technical trade association for the glulam industry. An overall discussion of glulam design and applications is given in the AITC publication "Glulam Systems." Information on glulam beams for residential and light construction is also available from AITC. More complete design information is given in the *Timber Construction Manual* published by AITC. An example of allowable unit stresses for glulam is shown in the excerpt on the following page from Table 2.9 of the *Timber Construction Manual* (Fig. 18). Part B of Table 2.9 gives allowable stresses for wet-use conditions. Allowable stresses published in the United States for glulam bending members are applicable to members 12 inches or less in thickness. When the depth of a rectangular beam exceeds 12 inches, the allowable unit stress in bending (F_b) must be reduced by using a size factor discussed in Chapter 2 of the *Timber Construction Manual.* Method of loading and span-depth ratio are also design considerations in adjusting bending stresses.

A quality control and inspection system for glulam is provided by AITC based on PS 56 and the AITC Inspection Manual. Figure 19 shows an example of a custom product quality inspection mark. Each qualified plant has an individual designation. The designation "P-143," in Fig. 18 is used for illustration only and is not assigned to any plant.

Laminated-veneer lumber

Parallel-laminated-veneer lumber (LVL), as the name implies, is made by laminating veneers together with all plies parallel to make 2-inch dimension lumber or larger structural members. Interest in laminating veneers was generated by the need for high-strength lumber from lower quality raw material. Research on lam-

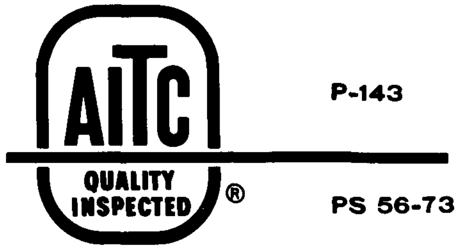

FIG. 19. Example of AITC custom product quality inspection mark.

inating veneer ranging from 0.1 to 0.5 inch thick indicates that a product more homogeneous than conventional lumber is possible (Moody 1972). Lumber produced from laminating veneers allows randomization of defects, which results in a higher-quality, more uniform product. Laminated veneer lumber has been produced with veneer 0.10 to 0.25 inch thick (Kantor 1972). One manufacturer uses C- and D-grade veneers laminated with a phenolic resin adhesive. The continuous "billet," 24 inches wide and up to 2½ inches thick, emerges from the press and is cut to lengths up to 80 feet and to desired widths. A major use for this material is for top and bottom flanges of plywood-web I-beams and open-web wood-steel trusses (Kunesh 1972). Other potential markets include tension laminations for glulam beams (Braun and Moody 1977) and roof deck support systems.

The Forest Products Laboratory has investigated a process for quickly producing structural members from parallel-laminated veneers, using rotary cut veneers up to ½ inch thick (U.S. Forest Products Laboratory Press-Lam Research Team 1972). Producers can go from log to ready-to-use product in less than an hour. In this process, called Press-Lam, logs are first peeled on a lathe into veneer. This veneer is then clipped into sheets and press-dried in a rapid new process producing a flatter and more stable product than that obtained through conventional drying. These veneer sheets are coated with adhesive while still hot and then laminated in an overlapping fashion so that the butt joints in the different layers do not occur close to one another. A wide, thick panel of continuous length can be built up from these sheets. After pressing, where residual heat from drying helps cure the adhesive, the resultant panel can then be crosscut and ripped into timbers of desired dimension. As a demonstration project, a 6- by 12-inch Press-Lam beam, 47 feet long, was installed as the basement beam for a factory-built house (Youngquist et al. 1978).

Composite lumber

The Southeastern Forest Experiment Station of the Forest Service, U.S. Department of Agriculture, in cooperation with HUD and with assistance from forest products manufacturers, has developed a composite veneer-particleboard floor joist for light-frame construction (Duff et al. 1978). It is a structural sandwich construction with a particleboard core bonded between layers of parallel-laminated veneers. The particleboard core makes up 70 to 80% of the composite. Although not commercially available, 2 by 8 and 2 by 10 members designed to be used interchangeably with conventional floor joists in house construction were used, 24 inches on center, in the construction of a demonstration house (Koenigshof 1979).

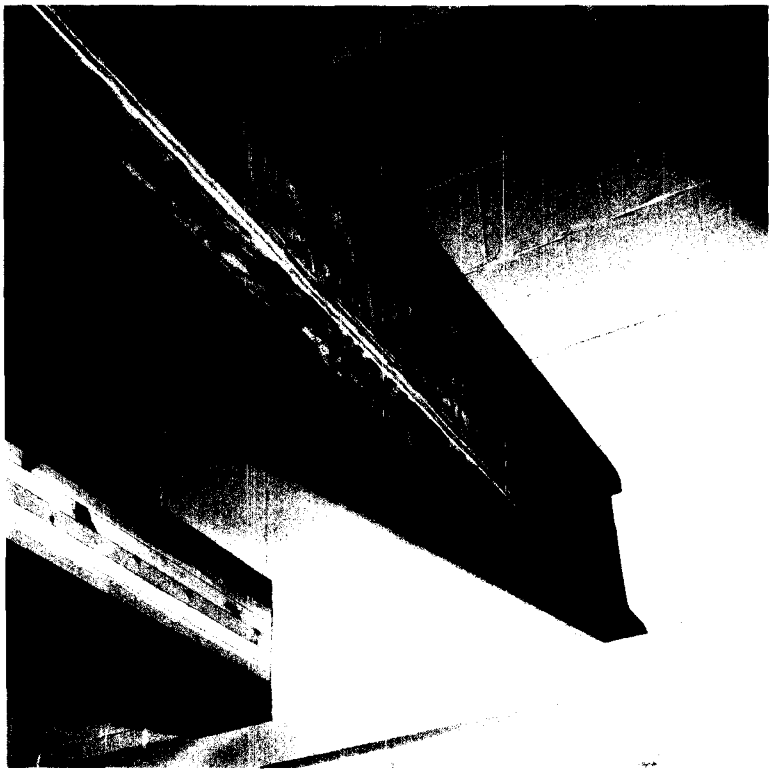

FIG. 20. Plywood-webbed I-beam with laminated veneer lumber flanges (display beam at U.S. FPL).

I-beams and box-beams

Glued plywood beams are generally fabricated with solid or LVL lumber flanges and Structural I or C-D EXT, plywood webs. Webs are commonly ⅜- or ⅝-inch plywood. The construction may be either I- or box-beam design, but the I-beam configuration is most popular. Design procedures for plywood beams are available from APA.

Prefabricated glued plywood I-beams with the plywood web face grain oriented vertically (Fig. 20) are available from different manufacturers who also supply load tables for different beam sizes and technical assistance in selection and use. Manufacturers' literature lists beams available in depths up to 24 inches and in lengths up to 80 feet. Within certain size and spacing limitations as specified in the manufacturers' literature, holes can be cut in the plywood web for installation of ductwork, plumbing, and wiring.

Because of the availability of material, hardboard as well as plywood has been used in Europe as the shear web in built-up wood beams (McNatt 1980). Hardboard-web I-beams were used in Sweden more than 40 years ago (Lundgren 1957). Twelve-meter-long hardboard-web I-beams were installed in a building recently constructed in London (FPRS 1976). FPL has published several technical reports on the use of hardboard in I-beams (Ramaker and Davister 1972; Superfesky and

FIG. 21. Open-web floor truss with metal plate connectors (display beam at U.S. FPL).

Ramaker 1978; and Superfesky and Ramaker 1976) and has developed background information necessary for assigning design stresses to hardboard (McNatt 1970). However, there are currently no published design values in the U.S. for hardboard. Structural particleboard has also been proposed as a shear web material (Hunt 1975).

Open-web trusses

Open-web trusses are available that have wood flanges (chords) and either wood or steel web members. One all-wood truss design has finger-joint connections between web and flange members. Another design uses metal truss plate connectors (Fig. 21). One wood-steel truss design uses steel tubes as web members and 2-inch dimension lumber, either solid sawn or laminated veneer, as flange members. Steel pin connections are used between web and flange members. Parallel chord trusses with double 2 by 6 flange members may be up to 63 inches deep and designed to span close to 80 feet. These are proprietary products that have specific regulatory approvals.

Custom designs for specified loads and dimensions are usually provided by the manufacturer (Nelson 1975). Technical assistance is also available for proper sizing and selection of truss design. The open-web design can easily accommodate ductwork, plumbing, and wiring.

INFLUENCE OF END-USE ENVIRONMENT

Design properties for wood, as generally published in the United States, are based on normal (10-year) loading assumptions and a moderate temperature and moisture content environment. Where the end use varies from these conditions, e.g., high temperature or high moisture contents, the NDS provides advice on property modifications (National Forest Products Association 1977). Some end uses may anticipate a load duration other than conventional 10-year loading. Also, many designs must be checked for adherence to several loading conditions, i.e., snow, wind, earthquake, etc. National Design Specification provides both a load-duration curve and a commentary to assist in carrying out this analysis (National Forest Products Association 1977 Appendix B).

In addition to NDS, other wood design references are available to assist in application and modification of published design values to specific end uses (Gurfinkel 1973; Hoyle 1973; Southern Forest Products Association 1975; USDA Forest Products Laboratory 1974; and Western Wood Products Association 1979). It is important to note that some wood products such as particleboard, glulam, and LVL originate by manufacturing processes that result in design property/end-use relationships different from lumber. Consequently, end-use property adjustments for some of these products may vary from those of solid wood. The design advice of the appropriate industrial association should be sought.

For applications involving chemicals, or combinations of severe environmental conditions, such as high temperature and moisture, caution is recommended. General principles of wood performance under these conditions are outlined in the *Wood Handbook* (USDA Forest Products Laboratory 1974); however, current industrial experience is often a necessary input to such design applications. Where decay and fire are hazards, specification of appropriate pressure-impregnation treatment should be considered.

CONNECTING SKINS TO FRAMING MEMBERS

Strength and stiffness of wood construction depend primarily on the fasteners used to connect the skin to the framing members. The connections may be mechanical fasteners or adhesives or a combination of both. Adhesives provide stress transfer from the skin to the framing members with the load distributed over the entire bonded area. Forces are transferred from surface to surface. In contrast, mechanical fasteners, such as nails, develop localized load transfer from within the thickness of the skin and framing members. The use of both adhesives and mechanical fasteners combine the advantages of both systems, but in many applications this is not economical.

Mechanical fasteners

Nails are the mechanical fasteners used most often in wood diaphragm construction. There are many types, sizes, and forms of nails. The most frequently used nail is the bright, smooth, common steel wire nail, which is available in sizes from four- to sixtypenny. Six-, eight-, and tenpenny (6d, 8d, and 10d) common nails are used extensively in wood diaphragm construction.

Table 2 in (Anderson 1970) gives recommended nailing schedule for framing and sheathing in light-frame construction. Application instructions for heavy timber decking refer to spikes, which are nothing more than large nails. Common

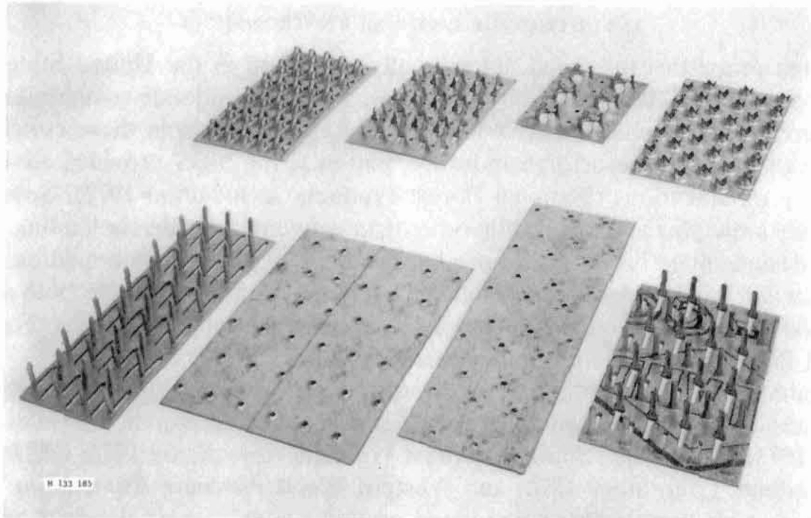

FIG. 22. Various configurations of galvanized sheet metal connector plates.

wire spikes come in lengths from 3 to 12 inches. They are larger in diameter than common wire nails of the same length, and beyond the 60d size they are usually designated by inches of length.

Various deformed-shank nails such as annularly threaded and helically threaded nails can provide higher withdrawal resistance than plain-shank nails of the same size. Deformed-shank nails are recommended for certain floor constructions such as the APA Sturd-I-Floor.

Staples have been tested as fasteners in diaphragm construction (Tissell 1966) and are accepted for attaching roof sheathing and subflooring. Typical staple size for these uses are 14- or 16-gage galvanized steel wire. Because of the reduced diameter of staple legs as compared to nail shank diameter, staples are spaced closer together than nails.

Manual No. 19-71, "Pneumatic and Mechanically Driven Building Construction Fasteners" published by the Industrial Stapling and Nailing Technical Association, contains descriptions, installation details, and spacings for staples, T-nails, modified and conventional roundhead nails, and deformed-shank nails used with pneumatic or mechanical nailers. A footnote to Table III in that manual states that plywood not exceeding 1⅛ inches in thickness may be connected with T-nails, roundhead nails, modified roundhead nails, or staples provided that the fastener penetration into the main member meets the specified requirements. Manual No. 19-71 is included in its entirety as an integral part of FHA's "Application and Fastening Schedule: Power-Driven, Mechanically-Driven, and Manually-Driven Fasteners" (U.S. Department of Housing and Urban Development 1971).

Self-drilling, self-tapping screws have also been used to attach plywood directly to all-steel open-web joists (Tissell 1966).

Galvanized sheet metal connector plates are used to transfer loads between framing members, particularly in wood trusses. Some types are fastened with nails; others have barbs, prongs, or teeth embedded into the wood. Various configurations are shown in Fig. 22. Design information for metal plate connected

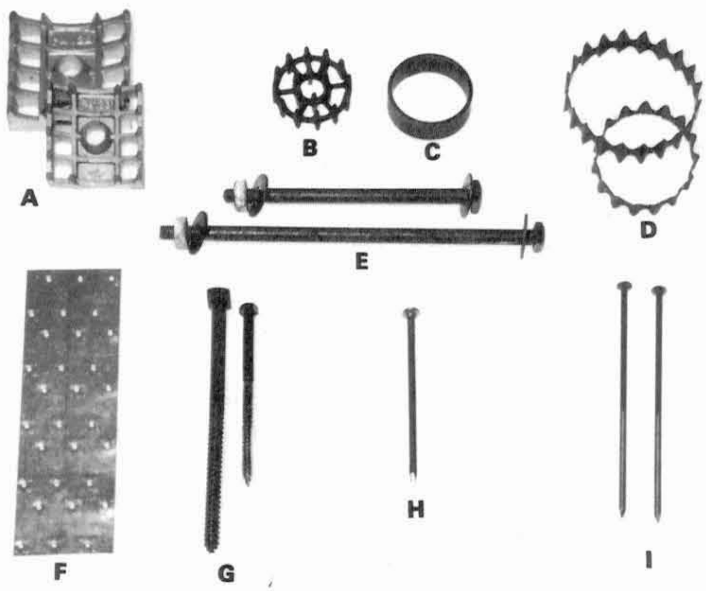

FIG. 23. Connectors used in heavy timber and pole construction: A. Spiked grids; B–D. Spiked, split ring, and toothed connectors; E and G. Through bolts and log screws used with A–D; F. Connector plate; H. Spikes; I. Pole-barn nails.

trusses is available from the Truss Plate Institute, Glenview, IL. Some additional metal connecting devices used in wood construction include joist hangers, frame anchors, metal straps, and plywood clips. Connectors such as split rings, shear plates, and spiked grids are used in conjunction with bolts in heavy timber and pole construction (Fig. 23).

Mechanical fasteners of all types are discussed in the Design Guide and Commentary (ASCE 1975), and design information is included in NDS (National Forest Products Association 1977).

Adhesives

Adhesives used in wood construction include both rigid and elastomeric. The use of rigid adhesives is limited to factory-type operations because they require carefully controlled conditions that are not typical of on-site construction. Rigid adhesives are used in the manufacture of such components as plywood, glulam, laminated-timber decking, built-up plywood beams, laminated-veneer lumber, and stressed-skin panels.

Until synthetic resin adhesives were introduced in the 1930s, casein was the dominant structural adhesive for wood where greater water resistance was required than could be provided by animal and vegetable adhesives. It is still extensively used in structural components intended for interior application (Blomquist and Virk 1977).

For the most durable joints subjected to severe conditions, such as direct exposure to the weather, the adhesives of choice are the phenol and resorcinol resins or blends of the two. Phenolic-resin adhesives are widely used to produce construction plywood by hot-pressing to yield exterior-type gluelines. Resorcinol and phenol-resorcinol-resin adhesives can be cold-pressed and find use for gluing laminated timbers that will withstand exposure to the weather (Gillespie 1975). Details on composition, properties, and durability of rigid and elastomeric adhesives can be found in Adhesives in Building Construction (Gillespie et al. 1978).

On-site or field gluing became practical, even under adverse conditions, with the introduction of elastomeric adhesives in the 1960s. These adhesives contain a material such as natural or synthetic rubber, which at room temperature is capable of recovering substantially in size and shape after removal of a deforming force. Consequently, elastomeric adhesives give a nonrigid and somewhat flexible bond. In diaphragm construction, elastomeric adhesives are used together with nails to connect the skin to the framing members. In the APA Glued Floor System the adhesive is applied in the joint between plywood panels and to the top edge of the joists before each panel is fastened down. By gluing the plywood to the joists, nail popping and squeaking floors are practically eliminated. The added stiffness as a result of composite T-beam action permits wider spacing of joists or longer spans for some joist sizes. In some floors, joist sizes may be reduced. Fewer nails also are required (Rose 1970). Construction adhesives for field gluing plywood to wood framing must meet minimum performance standards specified in ASTM D-3498 (ASTM 1978b).

Application of elastomeric adhesives to the tongue-and-groove joints between solid or laminated-timber decking can greatly increase the strength and stiffness of roof diaphragms (Johnson 1974; Zahn 1972).

Elastomeric adhesives are ready-mixed and can be applied with hand caulking guns. They are also available in large containers for use with portable pneumatic systems. For reliable performance, elastomeric adhesives must have adequate shear strength, should form reliable bonds under a wide range of temperature and moisture conditions, and need good gap-filling qualities to bond members within ordinary tolerances of fit typical of on-site construction. The adhesive should also maintain adequate strength after exposure to wetting and drying and should not become brittle or deteriorate with age (Rose 1970).

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