MODERN TIMBER DESIGN

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Second Edition

PREFACE TO THE SECOND EDITION

Shortly after the publication of the first edition, the Conservation Division of the War Production Board issued Directive 29, known as "National Emergency Specifications for the Design, Fabrication, and Erection of Stress Grade Lumber and Its Fastenings for Buildings." These specifications increased the working stresses for lumber which was graded for strength and changed the design formulas normally used to agree with this increase. In addition, the safe working loads for all types of fastenings were also increased. However, since this change in specifications applied primarily to buildings and was intended as an emergency measure, it was felt that no revision of *Modern Timber Design* was necessary.

In 1944 the National Lumber Manufacturers Association recommended the adoption of Directive 29 as a permanent design manual and published "National Design Specification for Stress Grade Lumber and Its Fastenings." In effect, this publication is similar to Directive 29 in that the working stresses were given an over-all increase of 20 per cent. This specification is now widely used and has been generally adopted by the practicing engineer. It seemed advisable, therefore, to revise the first edition of *Modern Timber Design* to conform with standard practice.

The revision is quite extensive because the change in working stresses and specifications affected almost every chapter. Since the book was undergoing an over-all revision, an excellent opportunity was provided to add information and data that were found lacking in the first edition. Many users of the book thought that more explanation was needed about the testing methods for wood and about the factors affecting the strength of wood. Because most textbooks on strength of materials do not include the latest information on the relationship between stresses and strains in wood under load, I felt that this material should also be added. Consequently, two new chapters have been added. These are entitled "Mechanical and Related Properties," and "Mechanics of Wood."

I am particularly indebted to the Forest Products Laboratory, the National Lumber Manufacturers Association, and the Timber Engineering Company for the use of data and information contained in their publications.

HOWARD J. HANSEN

GAINESVILLE, FLORIDA
January, 1948

PREFACE TO THE FIRST EDITION

Part of the material in this volume was used by the author for a course in modern timber design given as one of the engineering, science, and management defense training courses at Tulane University. Since then, the original material has been revised, new subjects have been covered, and many illustrative problems have been added. The present volume is used in a comprehensive course in timber design given to first-semester seniors at the Agricultural and Mechanical College of Texas. Since a course in indeterminate structures is offered in the last semester of the senior year, this book does not include the design of this type of wood structure. However, all the basic information needed by the designing engineer is included. The book is intended not only as a textbook but also as a guide and reference for practicing engineers.

Because wood is different from other materials and because it is nonhomogeneous, most of the design data have been derived from test results. It has been the function of the personnel at the Forest Products Laboratory at Madison, Wisconsin, which is a part of the United States Department of Agriculture, to develop the necessary data for scientific design in wood, and most of the available information is a result of their tests and interpretations. Naturally, then, no book on timber design can be written without due acknowledgment to the staff of the Forest Products Laboratory. Generous use has been made of their publications.

I gratefully acknowledge the help given by the National Lumber Manufacturers Association, the Timber Engineering Company, the West Coast Lumbermen's Association, the Southern Pine Association, the Douglas Fir Plywood Association, and the Service Bureau of the American Wood Preservers' Association.

I am also grateful for the criticisms and suggestions offered by Professor C. E. Sandstedt in his review of the contents.

HOWARD J. HANSEN

COLLEGE STATION, TEXAS
January, 1943

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CHAPTER I

CHARACTERISTICS AND PROPERTIES OF WOOD

1. General. There are more than 180 species of trees grown in the United States that may be considered commercially important. However, the number suitable for structural purposes is relatively small. Nineteen distinct groups have been assigned working stresses; these are ash, beech, birch, chestnut, cypress, elm, fir, gum, hemlock, hickory, larch, maple, oak, pecan, pine, poplar, redwood, spruce, and tupelo. Many of these comprise several species that have individual commercial names and are distinguishable because of their locality of growth and their physical and mechanical properties. Of all the groups, two are used most extensively for structural lumber. These are the southern pines, which grow in the Atlantic and Gulf states and as far north as West Virginia and Kentucky; and the Douglas firs, which grow in the coastal region of Washington, Oregon, and California and in the inland region of Montana, Idaho, Washington, and Oregon.

In using any species in the design and construction of timber structures, it is not necessary for the engineer to know a great deal about the chemical composition of wood. However, an understanding of this subject will often aid him in selecting the proper species under various conditions of use. Of more importance to the designing engineer are the mechanical properties of the different species, the factors affecting their strength, the intelligent use of their assigned working stresses, and the characteristics which make their use in design different from other structural materials.

2. Hardwoods and Softwoods. All species are divided into two general classes, namely, hardwoods and softwoods. However, no definite degree of hardness divides the two groups. Differences in structure, appearance, size, and quality keep the two groups separated. Many of the hardwoods such as oak and hickory are very hard, whereas many of the softwoods are soft; but there are many exceptions such as basswood which is classed as a hardwood but is among the softest of native woods. Longleaf pine, on the other hand, is classed as a softwood but is about as hard as any hardwood. Softwoods are also called "conifers" because most species are cone bearing. The two groups are most accurately differentiated by calling all trees with needle leaves softwoods and all broad-leaved trees hardwoods.

3. Structure. Wood is composed of elongated cells whose framework is cellulose. The cells are cemented together by lignin, and their arrangement in the tree greatly affects the appearance and properties of the different species. The cross section of most trees will show certain features that are common to all trees; Fig. 1 illustrates the important parts that make up the structure of any tree.

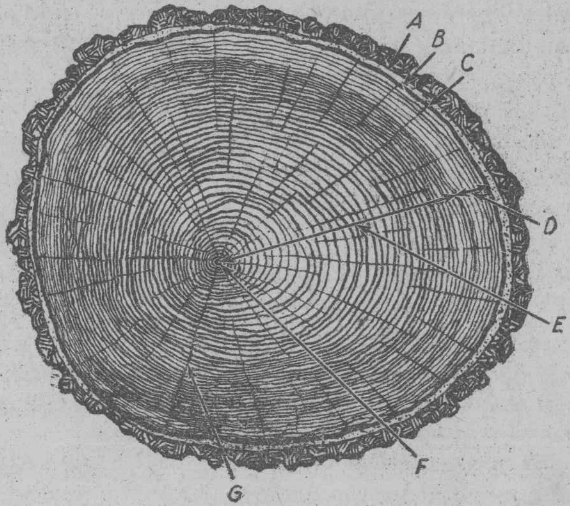

Fig. 1. Typical cross section of a tree.

A is dry, dead tissue called outer bark which serves as a protective coating.

B is the moist soft inner bark which carries food from the leaves to other parts of the tree.

C is a microscopic layer just inside the inner bark which is called the cambium. It is here that new wood and bark cells are formed.

D is the sapwood, which is light in color. Its function is to carry sap from the roots of the tree to the leaves.

E is the heartwood, which is usually dark in color. It is formed by a gradual change in sapwood and is inactive in the tree.

F is the pith. It is here that the new wood growth for twigs takes place.

G represents wood rays which connect the various parts of a tree for the storage and movement of food.

4. Heartwood and Sapwood. Heartwood is formed by a gradual change in sapwood. When wood is used under conditions conducive to decay, a large amount of heartwood in the cross section of a piece is desirable because the heartwood of all species is more durable than the sapwood. However, if the material is to be treated, sapwood is preferable because it absorbs preservatives more readily.

The heartwood of some species is considerably more durable than others. Table 1 may be used as a guide in comparing a number of species.

5. Growth Rings. As shown in Fig. 1, concentric rings start at the center or pith of the tree and continue outward toward the bark. Each ring represents the growth of the tree during one year. This growth is in the cambium, so that the new wood is added just inside this layer and tends to push the bark outward. When trees grow in a variable climate it is possible to distinguish one growth ring from another because the cells formed during a cold season are different from those formed during a warm season.

6. Springwood and Summerwood. Each annual ring is divided into two layers. The inner one, called springwood, is developed during the first part of the growing season. It is composed of large cells with thin walls and is usually lighter in color than the summerwood. The outer layer, called summerwood, consists of smaller cells with thicker walls and is the dark portion of the annual ring. It is heavier and stronger than springwood and has an important effect upon the strength properties of most species.

7. Density. Density is a definite criterion of the strength of softwoods. It is determined by the rate of tree growth and the amount of summerwood present. This means that the strength of a piece of wood is being measured by the amount and distribution of wood substance, which is the material making up the cell walls. The specific gravity of this wood substance is the same for all woods, 1.54, and all woods would be of the same specific gravity throughout were it not for the difference in the arrangement and size of cells and the thickness of the cell walls.

In grading softwood lumber for structural purposes, the number of rings per inch radially and the proportion of summerwood in the cross section of the piece are considered as part of the specifications. Material having a specified minimum number of rings per inch is termed "close-grained," and material that has in addition one-third or more of summerwood is termed "dense."

8. Grain. The wood from trees of rapid growth will have wide annual growth rings and is called coarse-grained. On the other hand wood from slow-growing trees has narrow growth rings and is often called close-grained. Straight grain and cross grain are used to describe wood in which the fibers are parallel to, or at an angle to, the sides of the piece.

Table 1. Durability of Heartwood of Various Species

[Wood Handbook, U. S. Dept. Agr., 1935]

Heartwood durable even when used under conditions that favor decay.	Cedar, Alaska. Cedar, eastern red. Cedar, northern white. Cedar, Port Orford. Cedar, southern white. Cedar, western red. Chestnut. Cypress, southern. Locust, black. Osage-orange. Redwood. Walnut, black. Yew, Pacific.
Heartwood of intermediate durability but nearly as durable as some of the species named in the high-durability group.	Douglas fir (dense). Honey locust. Oak, white. Pine, southern yellow (dense).
Heartwood of intermediate durability.	Douglas fir (unselected). Gum, red. Larch, western. Pine, southern yellow (unselected). Tamarack.
Heartwood between the intermediate and the nondurable group.	Ash, commercial white. Beech. Birch, sweet. Birch, yellow. Hemlock, eastern. Hemlock, western. Hickory. Maple, sugar. Oak, red. Spruce, black. Spruce, Engelmann. Spruce, red. Spruce, Sitka. Spruce, white.
Heartwood low in durability when used under conditions that favor decay.	Aspen. Basswood. Cottonwood. Fir, commercial white. Willow, black.

The slope of grain, expressed as a ratio between a one-inch deviation of the grain from the side of the piece and the distance within which this deviation occurs, is taken into consideration in the specifications for structural timbers because it has a marked effect on the strength of the piece.

Grain, however, usually refers to the appearance of the piece. Lumber sawed in such a manner that the annual rings form an angle of 45° or

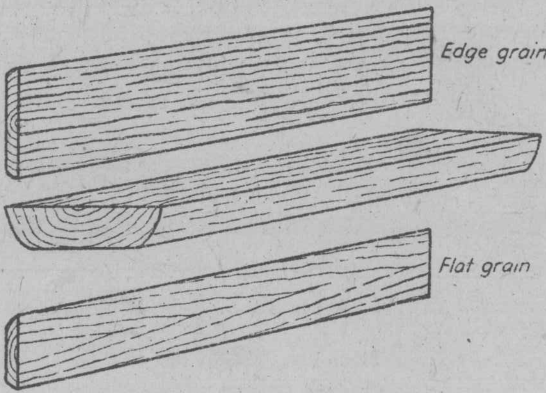

FIG. 2. Flat- and edge-grain lumber.

more with the surface of the piece is called edge grain, vertical grain, or rift sawn in softwoods and quarter sawn in hardwoods. Flat grain or plain sawn refers to lumber that has been sawed approximately tangent to the growth rings, that is, the rings form an angle of less than 45° with the surface of the piece.

9. Knots. The many types and classifications of knots depend upon the appearance of the knot on a sawed surface and on whether the knot is the result of a limb that was alive or dead when the tree was cut. The engineer should be concerned with the influence of the knot on the strength of a piece of wood rather than with the type of knot. Knots affect the strength because it is necessary for the grain to deviate from its regular direction in passing around them, and because checking often results in and around them as the piece loses moisture. The influence on strength is determined by the location of the knot and the area that it occupies in the cross section of a piece.

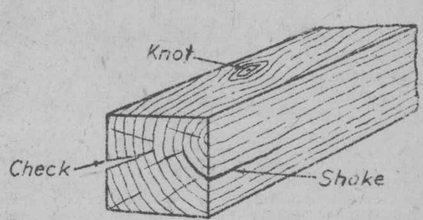

FIG. 3. Knots, checks, and shakes.

The rules for grading structural lumber, which depend upon the working stress assigned to the individual grade and whether or not the piece is to be used as a beam or column, limit the size of knots.

10. Checks and Shakes. A check is a lengthwise separation of the wood across the annual growth rings, and a shake is a separation along the grain between the annual growth rings. A number of checks and shakes in a piece will reduce its working value in shear. The amount and location of checks and shakes are limited in structural timber grades. In some grading rules the unit working stress in horizontal shear is the same for all structural grades, but higher or lower horizontal shear stresses may be secured within certain limits by specifying the working stress that is desired.

11. Moisture Content. Wood contains a considerable amount of free water within its cell walls. After a tree is cut it begins to lose moisture, and the moisture content continues to drop throughout the entire

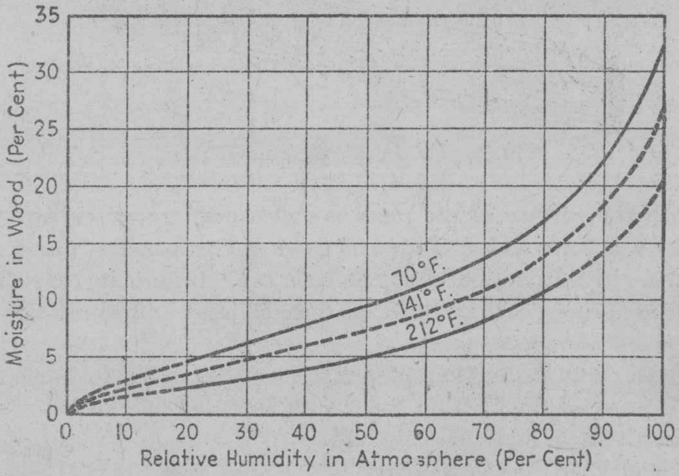

CHART 1. Humidity-moisture-content relationship at three temperatures. (*Wood Handbook, U. S. Dept. Agr., 1935.*)

manufacturing process. This moisture content is defined as the weight of water contained in wood expressed as a percentage of the weight of the oven-dry wood. When put into use, wood will continue to dry until it is in equilibrium with the surrounding atmosphere. By equilibrium moisture content is meant the ultimate moisture content depending upon the temperature and the relative humidity in the atmosphere, that wood will attain. Chart 1 shows the average relationship between the moisture content of wood and the relative humidity of the surrounding atmosphere at three temperatures.

Wood is said to have reached the fiber saturation point when all the free water in the cells is evaporated and the cell walls are still saturated. This point is generally reached when the moisture content is between 24 and 30 per cent. As wood dries beyond the fiber saturation point it increases in strength. However, such properties as toughness or shock resistance decrease because wood in a dry condition will not bend as much as wood in a green condition. In commercial structural grades the increase in strength due to drying is to a large extent offset by the influence of defects that develop during seasoning.

12. Shrinkage. Shrinkage takes place after the fiber saturation point has been reached. Accompanied by a reduction in moisture content is

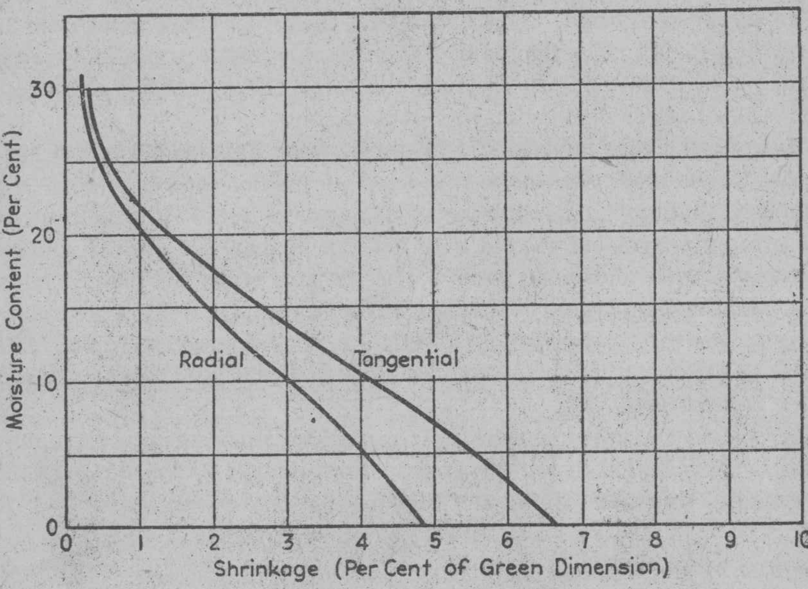

CHART 2. Average moisture-shrinkage curves for southern pine and Douglas fir. (*Wood Handbook, U. S. Dept. Agr., 1935.*)

a reduction in the size of a piece, for as wood dries it also shrinks. Wood shrinks most tangentially or in the direction of the annual growth rings and about one-half to two-thirds as much radially or across the annual rings. The longitudinal shrinkage in most woods is negligible. Tests at the Forest Products Laboratory have established average shrinkage values for all species. Chart 2, which shows typical moisture-shrinkage curves for Douglas fir and southern pine, may be used for estimating the amount of change in dimension that will take place with a change in moisture content.

Naturally, the engineer should attempt to secure lumber that is seasoned to its ultimate moisture content. However, it is seldom possible to obtain large timbers fully seasoned, and therefore a certain amount of shrinkage is to be expected and provided for in the design. Methods of design and construction that provide vertical bearings across the grain should be avoided. For instance, the use of joists placed directly on top of a girder increases the vertical height of wood used and results in increased shrinkage. If the joists bear on ledger strips fastened to the sides of a girder, there is a reduction in vertical height and less shrinkage. In the construction of mill buildings and similar structures this same idea can be carried out to eliminate part of the shrinkage by using metal post caps to separate the upper column from the lower column. This means that the girder is not being used as a bearing for the upper column. The use of a cast-iron pintle, bearing on a metal post cap, will produce the same effect and will also allow the girder to bear directly on the lower column.

Structural joints fabricated with green wood and loaded before seasoning takes place should be inspected at regular intervals while the timber is undergoing a reduction in moisture content. If nails become loose, simply resetting the old nails is not sufficient; the joint should be reinforced with additional nails. The design details for bolted joints and for joints employing connectors, given in Chapter V, provide reductions in the safe design loads for different conditions of seasoning, but these joints should be inspected for serious checks that might weaken them and for loose bolts.

13. Sizes. A table of sizes for the various items of lumber manufactured is included in the Appendix. For material 2, 2½, 3, and 4 in. in nominal thickness, the actual thickness or dressed size becomes 1⅝, 2⅛, 2⅝, and 3⅝ in. respectively; the actual width is ⅜ in. off the nominal width through 7 in. and ½ in. off the nominal width above that dimension. For material 5 in. thick and thicker by 5 in. wide and wider, the actual thickness and width are ½ in. off the nominal. Calculations for areas and moments of inertia are based on actual sizes. However, lumber is sold on the basis of the contents of the nominal size expressed in terms of board feet. A board foot is the contents of a volume 12 by 12 by 1 in.

CHAPTER II

MECHANICAL AND RELATED PROPERTIES

14. Strength Properties. The structure of wood makes it unlike any other structural material, and no two pieces of wood have exactly the same strength properties. Consequently, the development of the mechanical properties for important species required thousands of tests in order to obtain true average values. Several hundred thousand tests have been performed at the Forest Products Laboratory on small clear specimens from 164 species. Table 2 gives the strength properties of the commercially important species; information on additional species appears in Technical Bulletin 479, published by the United States Department of Agriculture.

The values in Table 2 are primarily for the comparison of species in the form of clear wood and should not be used in design.

TESTING METHODS

The mechanical properties given in Table 2 are the results of tests on specimens 2 by 2 in. in cross section and of various lengths, depending on the type of test. Only clear specimens free from knots, cross grain, shakes, and checks were tested.

15. Static Bending. In the static bending test the specimen is 2 by 2 in. in cross section and 30 in. long, supported on roller bearings which rest on knife edges 28 in. apart. The load is applied at the center of the span through a hard maple block $3\frac{13}{16}$ in. wide with a curvature of 3 in. radius over the central $2\frac{1}{8}$ in. of arc and a curvature of 2-in. radius on each side (Fig. 4). The beam is placed with the annual rings horizontal and a constant rate of deflection (0.1 in. per minute) is maintained until the beam fails.

The fiber stress at the proportional limit is the stress at which the load ceases to increase in direct proportion to the deflection.

The modulus of rupture is the stress obtained by using the maximum load, instead of the load at the proportional limit, in the formula $f = Mc/I$.

Table 2. Strength Properties of Commercially Important Species

[Compiled from *Tech. Bull.* 479, U. S. Dept. Agr., 1935]

Commercial and Botanical Name of Species	Moisture Content	Specific Gravity	Static Bending: Fiber Stress at Proportional Limit	Static Bending: Modulus of Rupture	Static Bending: Modulus of Elasticity	Static Bending: Work to Proportional Limit	Static Bending: Work to Maximum Load	Impact Bending: Fiber Stress at Proportional Limit	Impact Bending: Height of Drop Causing Complete Failure (50-Lb. Hammer)	Compression Parallel to Grain: Fiber Stress at Proportional Limit	Compression Parallel to Grain: Maximum Crushing Strength	Compression Perpendicular to Grain—Fiber Stress at Proportional Limit	Shear Parallel to Grain—Maximum Shearing Strength	Hardness: Load Required to Embed a 0.444-In. Ball to One-Half Its Diameter: End	Hardness: Side
	per cent		*lb. per sq. in.*	*lb. per sq. in.*	*1,000 lb. per sq. in.*	*in.-lb. per cu. in.*	*in.-lb. per cu. in.*	*lb. per sq. in.*	*in.*	*lb. per sq. in.*	*lb. per sq. in.*	*lb. per sq. in.*	*lb. per sq. in.*	*lb.*	*lb.*
Alder, red (*Alnus rubra*)	98	0.37	3,800	6,500	1,170	0.70	8.0	8,000	22	2,620	2,960	310	770	550	440
	12	0.41	6,900	9.800	1,380	1.85	8.4	11,600	20	4,530	5,820	540	1,080	980	590
Ash, black (*Fraxinus nigra*)	85	0.45	2,600	6,000	1,040	0.41	12.1	.....	33	1,690	2,300	430	860	590	....
	12	0.49	7,200	12,600	1,600	1.57	14.9	.....	35	4,520	5,970	940	1,150	1,150	....
Ash, commercial white (*Fraxinus* sp.)	43	0.54	5,300	9,500	1,400	1.14	14.7	12,800	37	3,360	4,060	860	1,350	1,010	940
	12	0.58	8,900	14,600	1,680	2.68	15.6	17,000	40	5,580	7,280	1,510	1,920	1,680	1,260
Ash, Oregon (*Fraxinus oregona*)	48	0.50	4,200	7,600	1,130	0.92	12.2	8,900	39	2,760	3,510	650	1,190	850	790
	12	0.55	7,000	12,700	1,360	2.08	14.4	13,300	33	4,100	6,040	1,540	1,790	1,430	1,160
Aspen (*Populus tremuloides*)	94	0.35	3,200	5,100	860	0.69	6.4	7,000	22	1,670	2,140	220	660	280	300
	12	0.38	5,600	8,400	1,180	1.53	7.6	9,000	21	3,040	4,250	460	850	510	350
Basswood (*Tilia glabra*)	105	0.32	2,700	5,000	1,040	0.40	5.3	6,300	16	1,690	2,220	210	600	290	250
	12	0.37	5,900	8,700	1,460	1.37	7.2	9,800	16	3,800	4,730	450	990	520	410
Beech (*Fagus grandifolia*)	54	0.56	4,300	8,600	1,380	0.85	11.9	11,500	43	2,550	3,550	670	1,290	970	850
	12	0.64	8,700	14,900	1,720	2.63	15.1	16,000	41	4,880	7,300	1,250	2,010	1,590	1,300
Birch (*Betula* sp.)	62	0.57	4,400	8,700	1,560	0.79	15.9	11,100	48	2,640	3,510	550	1,160	910	850
	12	0.63	10,100	16,700	2,070	2.83	19.8	20,000	52	6,200	8,310	1,250	2,020	1,660	1,340
Birch, paper (*Betula papyrifera*)	65	0.48	3,000	6,400	1,170	0.45	16.2	8,000	49	1,640	2,360	340	840	470	560
	12	0.55	6,900	12,300	1,590	1.80	16.0	12,400	34	3,610	5,690	740	1,210	890	910
Butternut (*Juglans cinerea*)	104	0.36	2,900	5,400	970	0.52	8.2	7,300	24	2,020	2,420	270	760	410	390
	12	0.38	5,700	8,100	1,180	1.59	8.2	11,200	24	4,200	5,110	570	1,170	570	490
Cedar, Alaska (*Chamaecyparis nootkatensis*)	38	0.42	3,800	6,400	1,140	0.77	9.2	9,100	27	2,500	3,050	430	840	540	440
	12	0.44	7,100	11,100	1,420	2.06	10.4	12,200	29	5,210	6,310	770	1,130	790	580
Cedar, eastern red (*Juniperus virginiana*)	35	0.44	3,400	7,000	650	1.08	15.0	7,000	35	2,540	3,570	860	1,010	760	650
	12	0.47	3,800	8,800	880	1.01	8.3	8,500	22	....	6,020	1,140	....	900	....
Cedar, incense (*Libocedrus decurrens*)	108	0.35	3,900	6,200	840	0.94	6.4	7,300	17	2,940	3,150	460	830	570	390
	12	...	5,900	8,000	1,040	1.67	5.4	9,600	17	4,760	5,200	730	880	830	470

Cedar, northern white (*Thuja occidentalis*)	55	0.29	2,600	4,200	640	0.60	5.7	5,300	15	1,490	1,990	290	620	320	230
	12	0.31	4,909	6,500	800	1.72	4.8	7,100	12	2,630	3,960	380	850	450	320
Cedar, Port Orford (*Chamaecyparis lawsoniana*)	43	0.40	4,000	6,200	1,420	0.65	7.4	9,200	22	2,770	3,130	350	830	460	400
	12	0.42	7,700	11,300	1,730	1.97	9.1	13,500	28	5,890	6,470	760	1,089	730	560
Cedar, southern white (*Chamaecyparis thyoides*)	35	0.31	2,500	4,700	750	0.51	5.9	6,000	18	1,660	2,390	300	690	400	290
	12	0.32	4,800	6,800	930	1.46	4.1	7,600	13	2,740	4,700	500	800	520	350
Cedar, western red (*Thuja plicata*)	37	0.31	3,200	5,100	920	0.63	5.0	6,900	17	2,470	2,750	340	710	430	270
	12	0.33	5,300	7,700	1,120	1.44	5.8	8,600	17	4,360	5,020	610	860	660	350
Cherry, black (*Prunus serotina*)	55	0.47	4,200	8,000	1,310	0.80	12.8	10,200	33	2,940	3,540	440	1,130	750	660
	12	0.50	9,000	12,300	1,490	3.11	11.4	13,600	29	5,960	7,110	850	1,700	1,470	950
Chestnut (*Castanea dentata*)	122	0.40	3,100	5,600	930	0.59	7.0	7,900	24	2,080	2,470	380	800	530	420
	12	0.43	6,100	8,600	1,230	1.78	6.5	10,700	19	3,780	5,320	760	1,080	720	540
Cottonwood, eastern (*Populus deltoides*)	111	0.37	2,900	5,300	1,010	0.49	7.3	7,200	21	1,740	2,280	240	680	380	340
	12	0.40	5,700	8,500	1,370	1.39	7.4	7,300	20	3,490	4,910	470	930	580	430
Cottonwood, northern black (*Populus trichocarpa hastata*)	132	0.32	2,900	4,800	1,070	0.44	5.0	6,800	20	1,760	2,160	200	600	280	250
	12	0.35	5,300	8,300	1,260	1.25	6.7	9,800	22	3,270	4,420	370	1,020	540	350
Cypress, southern (*Taxodium distichum*)	91	0.42	4,200	6,600	1,180	0.91	6.6	8,800	25	3,100	3,580	500	810	440	390
	12	0.46	7,200	10,600	1,440	2.15	8.2	10,400	24	4,740	6,360	900	1,000	660	510
Douglas fir (coast region) (*Pseudotsuga taxifolia*)	36	0.45	4,800	7,600	1,550	0.85	6.8	9,800	24	3,410	3,890	510	930	510	480
	12	0.48	8,100	11,700	1,920	1.96	8.6	12,700	30	6,450	7,420	910	1,140	760	670
Douglas fir ("Inland Empire" region) (*Pseudotsuga taxifolia*)	42	0.41	3,600	6,800	1,340	0.55	6.9	8,700	22	2,460	3,240	500	870	530	470
	12	0.44	7,400	11,300	1,610	1.91	8.6	11,800	27	5,520	6,700	950	1,190	720	630
Douglas fir (Rocky Mountain region) (*Pseudotsuga taxifolia*)	38	0.40	3,600	6,400	1,180	0.65	6.8	9,100	20	2,540	3,000	450	880	450	400
	12	0.43	6,300	9,600	1,400	1.60	6.4	12,100	26	4,660	6,060	820	1,070	740	630
Elm, American (*Ulmus americana*)	89	0.46	3,900	7,200	1,110	0.81	11.8	.....	38	1,920	2,910	440	1,000	680	....
	12	0.50	7,000	11,800	1,340	2.53	13.0	.....	39	4,030	5,520	850	1,510	1,110	....
Elm, rock (*Ulmus racemosa*)	48	0.57	4,600	9,500	1,190	1.05	19.8	.....	54	2,970	3,780	750	1,270	980	....
	12	0.63	8,000	14,800	1,540	2.45	19.2	.....	56	4,700	7,050	1,520	1,920	1,510	....
Elm, slippery (*Ulmus fulva*)	85	0.48	4,000	8,000	1,230	0.82	15.4	9,200	47	2,790	3,320	510	1,110	750	660
	12	0.53	7,700	13,000	1,490	2.35	16.9	15,300	45	4,760	6,360	1,010	1,630	1,120	860
Fir, balsam (*Abies balsamea*)	117	0.34	3,000	4,900	960	0.52	4.7	6,900	16	2,080	2,400	210	610	290	290
	12	0.36	5,200	7,600	1,230	1.23	5.1	7,800	20	3,970	4,530	380	710	510	400
Fir, commercial white (*Abies* sp.)	108	0.36	3,800	5,800	1,120	0.75	5.3	8,300	22	2,470	2,810	360	750	390	340
	12	0.38	6,300	9,300	1,470	1.55	7.0	11,200	20	3,870	5,380	610	930	710	460
Gum, black (*Nyssa sylvatica*)	55	0.46	4,000	7,000	1,030	0.91	8.0	9,800	30	2,490	3,040	600	1,100	790	640
	12	0.50	7,300	9,600	1,200	2.54	6.2	14,500	22	3,470	5,520	1,150	1,340	1,240	810
Gum, red (*Liquidambar styraciflua*)	81	0.44	3,700	6,800	1,150	0.81	9.4	10,000	33	2,230	2,840	460	1,070	630	520
	12	0.49	8,100	11,900	1,490	2.57	11.3	16,800	32	4,700	5,800	860	1,610	950	690
Gum, tupelo (*Nyssa aquatica*)	97	0.46	4,200	7,300	1,050	0.98	8.3	9,000	30	2,690	3,370	590	1,190	800	710
	12	0.50	7,200	9,600	1,260	2.41	6.9	12,500	23	4,280	5,920	1,070	1,590	1,200	880
Hackberry (*Celtis occidentalis*)	65	0.49	2,900	6,500	950	0.58	14.5	7,900	48	2,070	2,650	490	1,070	760	700
	12	0.53	5,900	11,000	1,190	1.72	12.8	13,700	43	3,710	5,440	1,100	1,590	1,110	880
Hemlock, eastern (*Tsuga canadensis*)	111	0.38	3,800	6,400	1,070	0.76	6.7	7,900	21	2,600	3,080	440	850	500	400
	12	0.40	6,100	8,900	1,200	1.79	6.8	10,700	21	4,020	5,410	800	1,060	810	500
Hemlock, western (*Tsuga heterophylla*)	74	0.38	3,400	6,100	1,220	0.57	6.8	8,100	22	2,480	2,990	390	810	520	430
	12	0.42	6,800	10,100	1,490	1.82	7.5	12,400	26	5,340	6,210	680	1,170	940	580
Hickory, pecan (*Hicoria* sp.)	68	0.59	5,300	9,900	1,380	1.18	19.3	14,200	60	3,810	4,320	980	1,260	1,274	1,308
	12	0.65	9,100	16,300	1,780	2.61	18.8	20,900	57	6,360	8,280	2,040	1,770	1,930	1,820

Table 2. Strength Properties of Commercially Important Species—*Continued*

[Compiled from *Tech. Bull.* 479, U. S. Dept. Agr., 1935]

Commercial and Botanical Name of Species	Moisture Content	Specific Gravity	Static Bending					Impact Bending		Compression Parallel to Grain		Compression Perpendicular to Grain—Fiber Stress at Proportional Limit	Shear Parallel to Grain—Maximum Shearing Strength	Hardness: Load Required to Embed a 0.444-In. Ball to One-Half Its Diameter	
			Fiber Stress at Proportional Limit	Modulus of		Work to		Fiber Stress at Proportional Limit	Height of Drop Causing Complete Failure (50-Lb. Hammer)	Fiber Stress at Proportional Limit	Maximum Crushing Strength			End	Side
				Rupture	Elasticity	Proportional Limit	Maximum Load								
	per cent		*lb. per sq. in.*	*lb. per sq. in.*	*1,000 lb. per sq. in.*	*in.-lb. per cu. in.*	*in.-lb. per cu. in.*	*lb per sq. in.*	*in.*	*lb. per sq. in.*	*lb. per sq. in.*	*lb. per sq. in.*	*lb. per sq. in.*	*lb.*	*lb.*
Hickory, true (*Hicoria* sp.)	57	0.65	6,100	11,300	1,570	1.34	28.9	15,700	88	3,650	4,570	1,080	1,360	....	....
	12	0.73	10,900	19,700	2,180	3.07	27.2	22,900	75	....	8,970	2,310	2,140	....	....
Honey locust (*Gleditsia triacanthos*)	63	0.60	5,600	10,200	1,290	1.40	12.6	11,800	47	3,320	4,420	1,420	1,660	1,440	1,390
	12	....	8,800	14,700	1,630	2.74	13.3	15,400	47	5,250	7,500	2,280	2,250	1,860	1,580
Larch, western (*Larix occidentalis*)	58	0.48	4,600	7,500	1,350	1.01	7.1	9,400	24	3,250	3,800	560	920	470	450
	12	0.52	7,900	11,900	1,710	2.46	8.0	15,100	32	5,950	7,490	1,080	1,360	1,110	760
Locust, black (*Robinia pseudoacacia*)	40	0.66	8,800	13,800	1,850	2.36	15.4	18,300	44	6,120	6,800	1,430	1,760	1,640	1,570
	12	0.69	12,800	19,400	2,050	4.62	18.4	21,100	57	6,800	10,180	2,260	2,480	1,580	1,700
Magnolia, cucumber (*Magnolia acuminata*)	80	0.44	4,200	7,400	1,560	0.66	10.0	9,300	30	2,810	3,140	410	990	600	520
	12	0.48	8,000	12,300	1,820	1.98	12.2	14,700	35	4,840	6,310	710	1,340	950	700
Magnolia, evergreen (*Magnolia grandiflora*)	105	0.46	3,600	6,800	1,110	0.67	15.4	8,800	54	2,160	2,700	570	1,040	780	740
	12	0.50	6,800	11,200	1,400	1.90	12.8	13,600	29	3,420	5,460	1,060	1,530	1,280	1,020
Maple, bigleaf (*Acer macrophyllum*)	72	0.44	4,400	7,400	1,100	1.02	8.7	8,500	23	2,510	3,240	550	1,110	760	620
	12	0.48	6,600	10,700	1,450	1.66	7.8	.....	28	4,790	5,950	930	1,730	1,330	850
Maple, black (*Acer nigrum*)	65	0.52	4,100	7,900	1,330	0.70	12.8	10,200	48	2,800	3,270	740	1,130	940	840
	12	0.57	8,300	13,300	1,620	2.39	12.5	13,500	40	4,600	6,680	1,250	1,820	1,700	1,180
Maple, red (*Acer rubrum*)	63	0.49	3,800	7,700	1,390	0.71	11.4	.....	32	2,360	3,280	500	1,150	780	....
	12	0.54	8,700	13,400	1,640	2.84	12.5	.....	32	4,650	6,540	1,240	1,850	1,430	....
Maple, silver (*Acer saccharinum*)	66	0.44	3,100	5,800	940	0.61	11.0	6,800	29	1,930	2,490	460	1,050	670	590
	12	0.47	6,200	8,900	1,140	1.90	8.3	12,400	25	4,360	5,220	910	1,480	1,140	700
Maple, sugar (*Acer saccharum*)	58	0.56	5,100	9,400	1,550	1.03	13.3	12,200	40	2,850	4,020	800	1,460	1,070	970
	12	0.63	9,500	15,800	1,830	2.76	16.5	20,600	39	5,390	7,830	1,810	2,330	1,840	1,450
Oak, red (*Quercus* sp.)	80	0.57	4,400	8,500	1,360	0.85	12.6	10,800	43	2,590	3,520	800	1,220	1,050	1,030
	12	0.63	8,400	14,400	1,810	2.30	15.0	17,000	43	4,610	6,920	1,260	1,830	1,490	1,300
Oak, white (*Quercus* sp.)	70	0.59	4,700	8,100	1,200	1.08	11.3	10,900	42	2,940	3,520	850	1,270	1,110	1,070
	12	0.67	7,900	13,900	1,620	2.31	13.3	17,400	39	4,350	7,040	1,410	1,890	1,420	1,330