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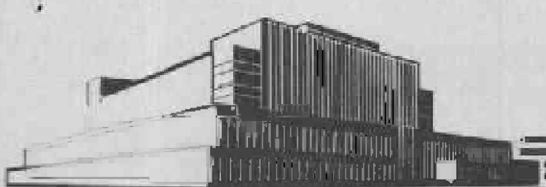

FOREST PRODUCTS LABORATORY
MADISON 5, WISCONSIN

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

FACTORS AFFECTING STRENGTH AND DESIGN PRINCIPLES OF GLUED LAMINATED CONSTRUCTION[1]

By

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Introduction

Man's use of wood for structural purposes goes back untold centuries. From the fallen-tree bridge, the rude hut, and the hollow-log canoe, we have traveled a long road to the timber structures of the present day. With this progress has come also a change in conditions. When timber supplies seemed limitless, there was little reason for concern about the species, size, or quality of the timber to be used. Consequently, much timber construction was characterized by oversize members, frequently of very high grade.

As timber supplies became more limited and prices higher, precision of use became more important. The development of structural grades, while not offering a complete solution, was an important step in the more precise, economical, and efficient use of timber. The advent of glued laminated lumber improved still further the prospects for efficient utilization, since this lumber can be made from shorter lengths, lower grades, smaller sizes, and combinations of high and low grades.

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[1] Presented at the Second Pacific Area National Meeting of the American Society for Testing Materials, Los Angeles, Calif., September 16-22, 1956. Original report dated August 1956.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Full realization of these prospects, however, depends more than ever on the greatest possible knowledge of the factors affecting strength so that sound principles of design may be developed. Since laminated lumber generally costs more than solid sawn timber, it must be used wisely and economically. To supply the basic information that would lead to the acceptance of laminated lumber, the U. S. Forest Products Laboratory began its research in this field more than 20 years ago. The first major product of this research was the bulletin "The Glued Laminated Wooden Arch."[3] Although this bulletin was first published in 1939, it is still an authoritative publication on the subject. War-time experience demonstrated some deficiencies of knowledge and this led to an extensive program of research aimed at more precise knowledge of factors affecting strength. The research on laminated lumber was reviewed at the First Pacific Area National Meeting of the American Society for Testing Materials (ASTM) in 1949.[4] Later, the available data were analyzed in the bulletin "Fabrication and Design of Glued Laminated Wood Structural Members."[5] Since this bulletin combines fabrication and design data, it is valuable to the designer, fabricator, and user alike.

It is the purpose of this paper to review the data and to describe the design principles derived from them. In view of the detailed presentation of 1949,[4] factors affecting strength will be covered in only a general way. The emphasis will be on design principles.

Factors Affecting Strength

The same characteristics, such as knots and cross grain, that affect the strength of solid sawn timbers also affect the strength of laminated timbers. There are, however, additional factors peculiar to laminated construction that must be considered.

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[3] Wilson, T. R. C., The Glued Laminated Wooden Arch, U. S. Dept. Agri. Tech. Bull. 691, 1939.

[4] Freas, Alan D., Studies of the Strength of Glued Laminated Wood Construction, ASTM Bulletin 170:48-59, December 1950.

[5] Freas, Alan D., and Selbo, M. L., Fabrication and Design of Glued Laminated Wood Structural Members, U. S. Dept. Agri. Tech. Bull. 1069, 1954.

Glue Joint Quality

Obviously, the bond between the laminations is of primary importance. Without that bond, there would be no structure, but only a group of laminations capable of serving only a limited structural purpose. For this reason, an adhesive must be chosen that will furnish such a bond, not only initially but over the period of service of the structure.

The adhesive industry has made many advances, so that, today, a wide range of adhesives is available to satisfy very nearly any service condition from mild to extreme. Furthermore, these adhesives are far beyond the laboratory stage and are in wide practical use. Perhaps the most important of the new adhesives from the standpoint of the laminating industry are the resorcinol resins and the mixtures or blends of phenol and resorcinol resins. On low-density species, resorcinol-resin adhesives may be cured adequately for many purposes at room temperatures. Phenol-resorcinol blends and resorcinol resins on high-density species require curing at elevated temperatures, if the laminated item is to withstand severe service. If properly handled, both types of adhesives are capable of withstanding adverse service conditions.

In many places, like the inside of covered buildings, service conditions are mild, and a highly resistant adhesive is not required. Under such conditions, casein adhesives are commonly used and may be expected to give long periods of satisfactory service.

Proper selection of an adhesive, however, is only one step in insuring a satisfactory glue bond. Proper techniques of use, which involve a variety of factors, are required. Among the more important factors are : uniform seasoning of the lumber, smooth and uniform surfacing of the laminations, proper mixing and spreading of the glue, adequate and uniform application of pressure, and proper curing of the glue. Proper curing includes proper temperatures and pressures as well as control of relative humidity during curing. The variety and character of these factors generally necessitate special plant equipment and special skills for the necessary control. Ordinarily, this will preclude on-site fabrication, particularly of important structural members.

Lamination Thickness

Tests of a number of defect-free beams made with laminations of varying thickness indicated that lamination thickness had no effect on properties.

Knots

A strength-reducing feature, such as a knot, will affect strength less, if it is located in a region of low stress than if it is located in a region of high stress. Thus, the effect of a knot on the strength of a laminated beam is dependent on both its size and its position. This effect is best measured by moment of inertia. Results of a considerable number of tests have provided an empirical relationship between bending properties and the ratio I_K/I_G, where I_K is the moment of inertia of the areas occupied by all knots within 6 inches of the critical cross section and I_G is the gross moment of inertia of the beam. A design curve derived from these data is shown in figure 1. The effect on modulus of elasticity (fig. 2) is considerably less than the effect on bending strength.

The relationship between bending strength and the factor I_K/I_G suggests that it should be possible to use laminations with large knots in the central part of the depth of a beam between outer laminations with smaller knots without a serious loss of strength when compared with a beam in which all laminations contain the smaller knots. Tests have confirmed this view.

In a column, there is no effect of position, since stress is uniform over the cross section. Analysis of data from tests of columns indicated that the properties are proportional to the ratio of the average size of the maximum knot in each lamination to the width of the lamination (fig. 3). A similar relationship would be expected to hold for tension members, except that the strength reduction for a given value of K/b would be somewhat greater.

Cross Grain

There has been no systematic investigation of cross grain similar to that described for knots. It is obvious, however, that steeper cross grain could be permitted in areas of low stress than in areas of high stress in a beam. In the areas of high stress, the effect of cross grain would be expected to be similar to that in solid sawn timbers.

End Joints

In laminated members of considerable size, pieces of lumber must be joined end to end to provide laminations of sufficient length. These joints are an important factor in determining the strength of laminated members.

Since stress cannot be transferred across a butt joint, such a joint represents an ineffective area, and additional cross section must be provided to compensate for it. Tests of beams have shown that for butt joints in the compression side, the strength was approximated by computing the section modulus, as if the butt-jointed lamination were not present. When the butt joints were in the tension side of the beam, particularly in the outer lamination, an even greater effect was found. Strain measurements in the vicinity of a butt joint showed a severe stress concentration in adjacent laminations. Butt joints are not commonly used in important structural members. If they are, however, both the ineffective area they represent and their stress-concentrating effects must be taken into account.

Scarf joints, on the other hand, are effective means for joining the ends of pieces to form laminations of the required length. Even so, research has shown that scarf joints are not fully effective in tension. With their sloping surfaces, scarf joints are intermediate between the side-grain glued joint, which can generally be made as strong as the wood, and the end-grain glued joint, which is characteristically weak and variable. Therefore, scarf joints are a compromise means of making an end-to-end joint with a minimum of end-grain gluing. Figure 4 illustrates the effect of scarf slope on joint strength. The steeper the slope, the greater is the proportion of end grain, and the lower the strength. In compression, scarf joint efficiency is much higher than in tension. Tests of columns containing scarf joints indicate that efficiency is on the order of 100 percent even for slopes as steep as about 1 in 5.

Many varieties of end joints involving fingers of various types have been proposed and used, mainly in nonstructural applications. Their efficiencies vary considerably depending upon the form and slope of the fingers, but they are generally somewhat low. Figure 5 illustrates a few typical joints and their efficiencies in tension. Efficiencies under compressive stress are much higher (fig. 6).

Stresses Induced by Bending Laminations to Curved Form

In fabricating curved members, such as arches, curved beams, ship frames, and the like, stresses are induced in the individual laminations, as they are bent to the curved form. The amount of stress will obviously depend upon the ratio of the radius of bend to the lamination thickness. Tests have indicated that the ratio of the strength of a curved member to that of a comparable straight member is given by the factor

$$1 - 2000\,(t/R)^2$$

where t is the lamination thickness, and R is the radius to which the lamination is bent.

The strength reduction indicated by this formula is considerably less than would be expected from a consideration of the magnitude of stresses induced by bending the laminations. For example, bending to a radius 160 times the thickness produces stresses on the order of one-half the ultimate and thus about equal to the proportional limit. Stresses at this level in individual laminations would be expected to cause severe strength reductions in the laminated member. Since severe reductions were not found in testing, it is apparent that the stresses induced in bending the laminations to form are relieved to a considerable extent. The data indicated that modulus of elasticity is not affected.

Height and Form of Bending Members

It has long been known that stresses in wood beams, as computed by conventional methods, are affected by both the height and form of the cross section. This has led to the development of empirical form and height factors to be applied to the usual bending formulas. The effect of height has heretofore been relatively unimportant, since the height that could be realized in solid timbers has been limited. In laminated construction, however, this limitation has been removed, and beams and arches of considerable height are common. Consideration of this effect thus assumes some importance in laminated structures.

Design Principles

Working Stresses

In timber design, it has been the practice to assign basic stresses to the various species and to compute working stresses for particular grades by multiplying the basic stresses by a factor called the strength ratio. The strength ratio represents the proportion of the strength of a defect-free piece remaining after taking into account the effect of strength-reducing features, such as knots and cross grain. The same principle is used for developing working stresses for laminated structural members.

Basic stresses.--The basic stress represents, essentially, the working stress applicable to a defect-free piece. It is derived from the average properties of the species by applying factors that adjust laboratory test results to actual conditions of use.

The same reduction factors that apply to solid sawn timbers will apply also to laminated timbers. Therefore, the basic stresses for laminated timbers used under service conditions involving high moisture content are the same as those for solid timbers. That is, they are based on the strength of wood in the green condition (table 1).

One of the advantages of a laminated member is that it can be made of laminations small enough in cross section to be seasoned readily before assembly. These laminations can then be assembled to form a member seasoned throughout and free from the tendency to check and distort after erection. Obviously, such a member also may be sufficiently dry throughout to justify the use of stresses based on the higher strength of dry material. This is true, however, only if the conditions of service are such as to maintain a low moisture content throughout the service life of the member.

Accordingly, a second set of basic stresses (table 2) is recommended for structures used under dry conditions. These stresses are derived by multiplying the basic stresses applicable to wet or moist conditions of service by a factor representing the effect of drying on the particular property. Since the effect of drying is not the same for all species nor for all pieces within a species, the factors were taken as approximately one-half the average increase in strength from the green to a 12-percent moisture content condition as found from tests of small clear specimens. In some instances, the increases are substantial, as comparison of tables 1 and 2 indicates.

Strength ratio.--As was indicated earlier, there are available relationships between strength and knot size and, in the case of bending members, knot position. It is impractical to preassemble a member, so that knot sizes and positions are known in order to assign a design stress. It is equally impractical to assemble members with knots of specified sizes in specified positions. Rather, laminated members will be formed from random assemblies of laminations of a specific grade or combination of grades.

It is necessary, therefore, to find some means of assigning stresses to a random assembly, and this suggests applying the principles of probability. From a survey of a typical sample of a grade, the frequency of occurrence of various knot sizes may be determined. By applying this information with the principles of probability and, for bending members, with consideration of the effects of knot position with respect to the neutral axis, the value of $\underline{I_K/I_G}$ or $\underline{K/b}$, which has any given probability of occurrence, may be predicted. Choosing a level of probability considered suitable for design, these factors may be used to obtain strength ratios from the empirical relationships described earlier.

Since knots would be expected to be more dispersed in assemblies of large numbers of laminations than in assemblies of small numbers, an increase in strength ratio with increasing numbers of laminations would be expected. This is illustrated in figure 7, which represents strength ratios computed from a probability analysis for a typical lumber grade. Combining defect-free or higher-grade outer laminations increases the strength ratio over that of a beam made wholly of the lower grade (figs. 8 and 9).

In establishing structural grades of solid sawn lumber, the limitations on knots and cross grain are set so as to give about the same strength ratio for each. Since knot dispersion results in a higher strength ratio, more restrictive limitations on cross grain must be imposed, at least in the outer groups of laminations. In this way, the higher strength ratio determined from the effect of knots may be realized.

Similarly, to assure that the end joints do not control the strength, the efficiency of the end joint chosen should not be less than that established on the basis of the occurrence of knots.

Solid, one-piece timbers of large cross section characteristically develop deep checks, as they season in service. Such checking reduces shear strength, because the area available to resist shear is reduced. Since laminated beams go into service thoroughly seasoned, they may be expected to check but little. Further, since the laminations are generally flat grained, such checks as may develop generally will lie in a vertical plane and have little effect on shear strength. For these reasons, design stresses for shear are commonly taken equal to the basic stresses. That is, there is no reduction for grade.

Design stresses proposed by lumber manufacturers associations have been developed from the principles described.

Methods of Analysis

In general, methods of structural analysis applicable to structures of other materials are applicable also to structures of laminated wood. If curved members are involved, however, two problems may arise which are not encountered in the design of solid timber structures.

When the bending moment applied to a curved member acts to straighten it, tensile stresses perpendicular to grain are generated. When the bending moment tends to shorten the radius of curvature, the stresses perpendicular to grain are compressive. These stresses are maximum at the neutral axis and may be computed approximately from the formula

$$S_R = \frac{3}{2} \frac{M}{Rbh}$$

where S_R is the radial stress, M is the bending moment, R is the radius of curvature, and b is the width and h the height of the cross section.

Compressive stresses perpendicular to grain should be limited to the value shown in tables 1 and 2. Tensile stresses should be limited to about 3/8 of the allowable shear stress for hardwoods and about 1/3 of the allowable shear stress for softwoods.

The great depth possible in curved laminated bending members creates another problem in analysis that is not ordinarily encountered in timber design. It will be recalled from the principles of mechanics that stresses computed by ordinary methods for flexure will be in error for deep, sharply curved members. The error increases with the ratio of depth to centerline radius. In the majority of cases, the error will be small. However, this factor should be considered in analysis, and a check should be made for special cases by methods of analysis for curved beams.

Fatigue

Concern is sometimes expressed over the possibility of fatigue failure of glued joints. Tests[6] have shown that well-made glued joints have fatigue characteristics similar to those for solid wood. Resistance to fatigue, therefore, is just as great in a laminated as in a solid member.

Summary

More factors affect the strength of laminated structural members than affect the strength of solid sawn timbers. In general, however, these factors have been evaluated or are capable of control, so that design is on a firm footing.

The higher design stresses possible with laminated timbers offer substantial advantages over solid timbers. However, this is only one of the factors that are bringing laminated construction into a prominent place in the building of churches, gymnasiums, bridges, farm structures, and in many other fields. The almost unlimited size possibilities, the possibility of fabricating curved members, and the freedom from excessive checking and distortion all play a prominent role.

Another important factor is the possibility this type of construction offers for the structural utilization of small sizes and low grades. As pointed out earlier, low grades can be effectively utilized in the lower-stressed portions of beams and arches. There should be equal opportunity to combine the lighter, lower-strength species with high-strength species, and research to develop design principles for this type of construction is under way.

In summary, it may be said that laminated construction, in spite of its phenomenal growth over about the last two decades, has not yet demonstrated all of its possibilities. Imagination in design, coupled with advances in fabrication procedures and research, can be expected to broaden the horizons of laminated construction utilization.

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[6] Lewis, Wayne C., "Fatigue of Wood and Glued Joints Used in Laminated Construction," Forest Products Research Society Proceedings, Vol. 5, 1951.

Table 1.--Basic stresses for structural members, laminated from clear material and under long-time service at maximum design load and under wet conditions, for use in determining working stresses according to grade of laminations and other applicable factors

Species[1]	Extreme fiber in bending or tension parallel to grain	Maximum horizontal shear	Compression perpendicular to grain	Compression parallel to grain L/d = 11 or less	Modulus of elasticity in bending
(1)	(2)	(3)	(4)	(5)	(6)
	P.s.i.	P.s.i.	P.s.i.	P.s.i.	1,000 p.s.i.
SOFTWOODS					
Baldcypress (southern cypress)	1,900	150	220	1,450	1,200
Cedars					
Redcedar, western	1,300	120	145	950	1,000
White-cedar, Atlantic (southern white cedar) and northern	1,100	100	130	750	800
White-cedar, Port Orford	1,600	130	185	1,200	1,500
Yellow-cedar, Alaska (Alaska cedar)	1,600	130	185	1,050	1,200
Douglas-fir, coast type	2,200	130	235	1,450	1,600
Douglas-fir, coast type, close-grained	2,350	130	250	1,550	1,600
Douglas-fir, Rocky Mountain type	1,600	120	265	1,050	1,200
Douglas-fir, all regions, dense	2,550	130	275	1,700	1,600
Fir, California red, grand, noble, and white	1,600	100	220	950	1,100
Fir, balsam	1,300	100	110	950	1,000
Hemlock, eastern	1,600	100	220	950	1,100
Hemlock, western (West Coast hemlock)	1,900	110	220	1,200	1,400
Larch, western	2,200	130	235	1,450	1,600
Pine, eastern white (Northern white), ponderosa, sugar, and western white (Idaho white)	1,300	120	185	1,000	1,000
Pine, jack	1,600	120	160	1,050	1,100
Pine, lodgepole	1,300	90	160	950	1,000
Pine, red (Norway pine)	1,600	120	160	1,050	1,200
Pine, southern yellow	2,200	160	235	1,450	1,600
Pine, southern yellow, dense	2,550	160	275	1,700	1,600
Redwood	1,750	100	185	1,350	1,200
Redwood, close-grained	1,900	100	195	1,450	1,200
Spruce, Engelmann	1,100	100	130	800	800
Spruce, red, white, and Sitka	1,600	120	185	1,050	1,200
Tamarack	1,750	140	220	1,350	1,300
HARDWOODS					
Ash, black	1,450	130	220	850	1,100
Ash, commercial white	2,050	185	365	1,450	1,500
Beech, American	2,200	185	365	1,600	1,600
Birch, sweet and yellow	2,200	185	365	1,600	1,600
Cottonwood, eastern	1,100	90	110	800	1,000
Elm, American and slippery (white or soft elm)	1,600	150	185	1,050	1,200
Elm, rock	2,200	185	365	1,600	1,300
Hickory, true and pecan	2,800	205	440	2,000	1,800
Maple, black and sugar (hard maple)	2,200	185	365	1,600	1,600
Oak, commercial red and white	2,050	185	365	1,350	1,500
Sweetgum (red or sap gum)	1,600	150	220	1,050	1,200
Tupelo, black (blackgum)	1,600	150	220	1,050	1,200
Tupelo, water	1,600	150	220	1,050	1,200
Yellow-poplar	1,300	120	160	950	1,100

[1] Species names from approved check list, U. S. Forest Service, 1944. Commercial designations are shown in parentheses.

Table 2.--Basic stresses for structural members laminated from clear material and under long-time service at maximum design load and under dry conditions, as in most covered structures, for use in determining working stresses according to grade of laminations and other applicable factors

Species[1]	Extreme fiber in bending or tension parallel to grain	Maximum longitudinal shear	Compression perpendicular to grain	Compression parallel to grain	Modulus of elasticity in bending
(1)	(2)	(3)	(4)	(5)	(6)
	P.s.i.	P.s.i.	P.s.i.	P.s.i.	1,000 p.s.i.
SOFTWOODS					
Baldcypress (southern cypress)	2,400	170	330	2,000	1,300
Cedars					
Redcedar, western	1,600	135	220	1,300	1,100
White-cedar, Atlantic (southern white cedar) and northern	1,400	115	195	1,050	900
White-cedar, Port Orford	2,000	150	275	1,650	1,600
Yellow-cedar, Alaska (Alaska cedar)	2,000	150	275	1,450	1,300
Douglas-fir, coast type	2,750	150	350	2,000	1,800
Douglas-fir, coast type, close-grained	2,950	150	375	2,150	1,800
Douglas-fir, Rocky Mountain type	2,000	135	310	1,450	1,300
Douglas-fir, all regions, dense	3,200	150	410	2,350	1,800
Fir, California red, grand, noble, and white	2,000	115	330	1,300	1,200
Fir, balsam	1,600	115	165	1,300	1,100
Hemlock, eastern	2,000	115	330	1,300	1,200
Hemlock, western (West Coast hemlock)	2,400	125	330	1,650	1,500
Larch, western	2,750	150	350	2,000	1,800
Pine, eastern white (Northern white), ponderosa, sugar, and western white (Idaho white)	1,600	135	275	1,400	1,100
Pine, jack	2,000	135	240	1,450	1,200
Pine, lodgepole	1,600	100	240	1,300	1,100
Pine, red (Norway pine)	2,000	135	240	1,450	1,300
Pine, southern yellow	2,750	180	350	2,000	1,800
Pine, southern yellow, dense	3,200	180	410	2,350	1,800
Redwood	2,200	115	275	1,850	1,300
Redwood, close-grained	2,400	115	295	2,000	1,300
Spruce, Engelmann	1,400	115	195	1,100	900
Spruce, red, white, and Sitka	2,000	135	275	1,450	1,300
Tamarack	2,200	160	330	1,850	1,400
HARDWOODS					
Ash, black	1,800	150	330	1,150	1,200
Ash, commercial white	2,550	210	550	2,000	1,600
Beech, American	2,750	210	550	2,200	1,800
Birch, sweet and yellow	2,750	210	550	2,200	1,800
Cottonwood, eastern	1,400	100	165	1,100	1,100
Elm, American and slippery (white or soft elm)	2,000	170	275	1,450	1,300
Elm, rock	2,750	210	550	2,200	1,400
Hickory, true and pecan	3,500	235	660	2,750	2,000
Maple, black and sugar (hard maple)	2,750	210	550	2,200	1,800
Oak, commercial red and white	2,550	210	550	1,850	1,600
Sweetgum (red or sap gum)	2,000	170	330	1,450	1,300
Tupelo, black (blackgum)	2,000	170	330	1,450	1,300
Tupelo, water	2,000	170	330	1,450	1,300
Yellow-poplar	1,600	135	240	1,300	1,200

[1]Species names from approved check list, U. S. Forest Service, 1944. Commercial designations are shown in parentheses.

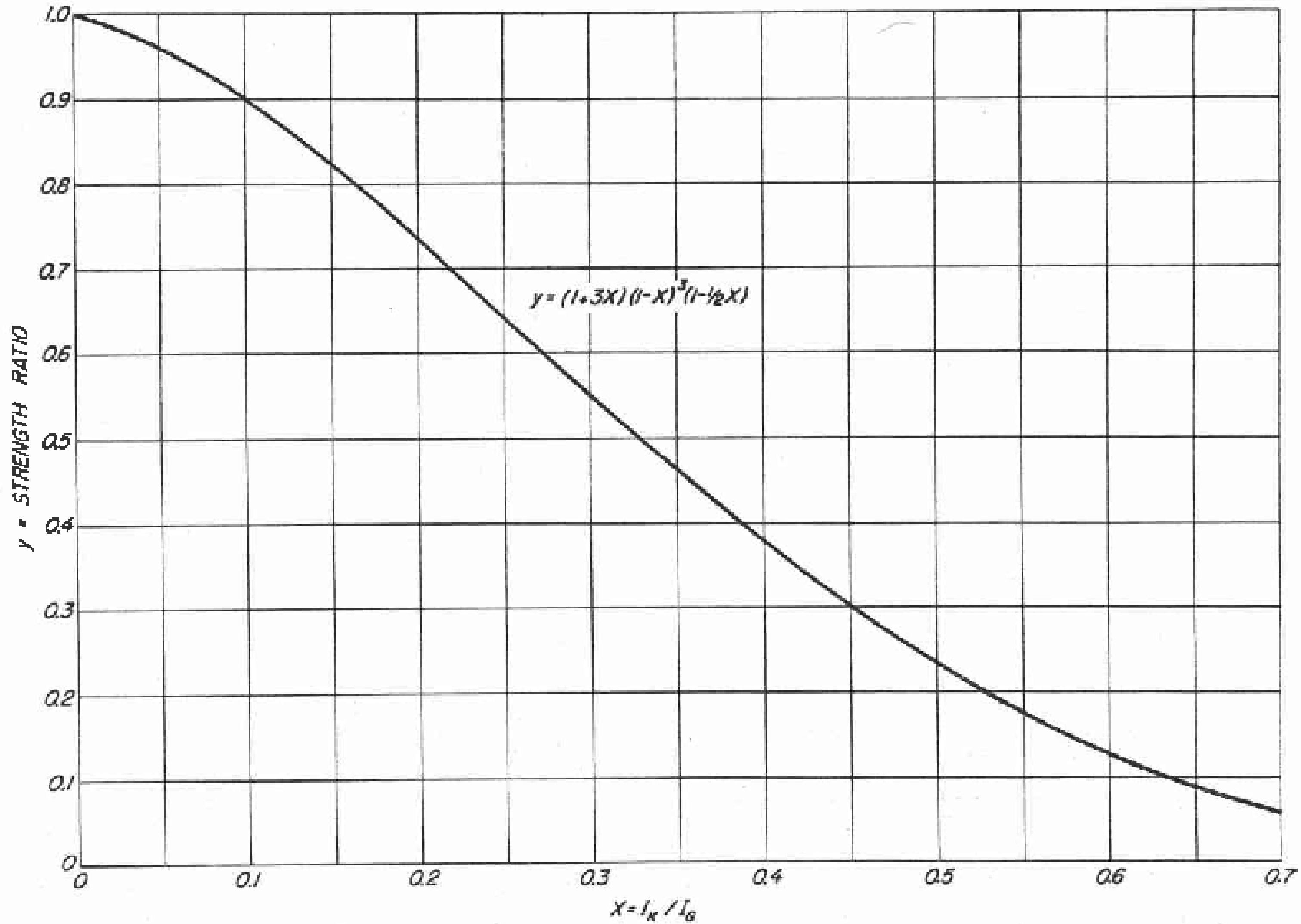

Figure 1. --This design curve relates allowable flexural stress to moment of inertia of areas occupied by knots in the laminations of laminated beams.

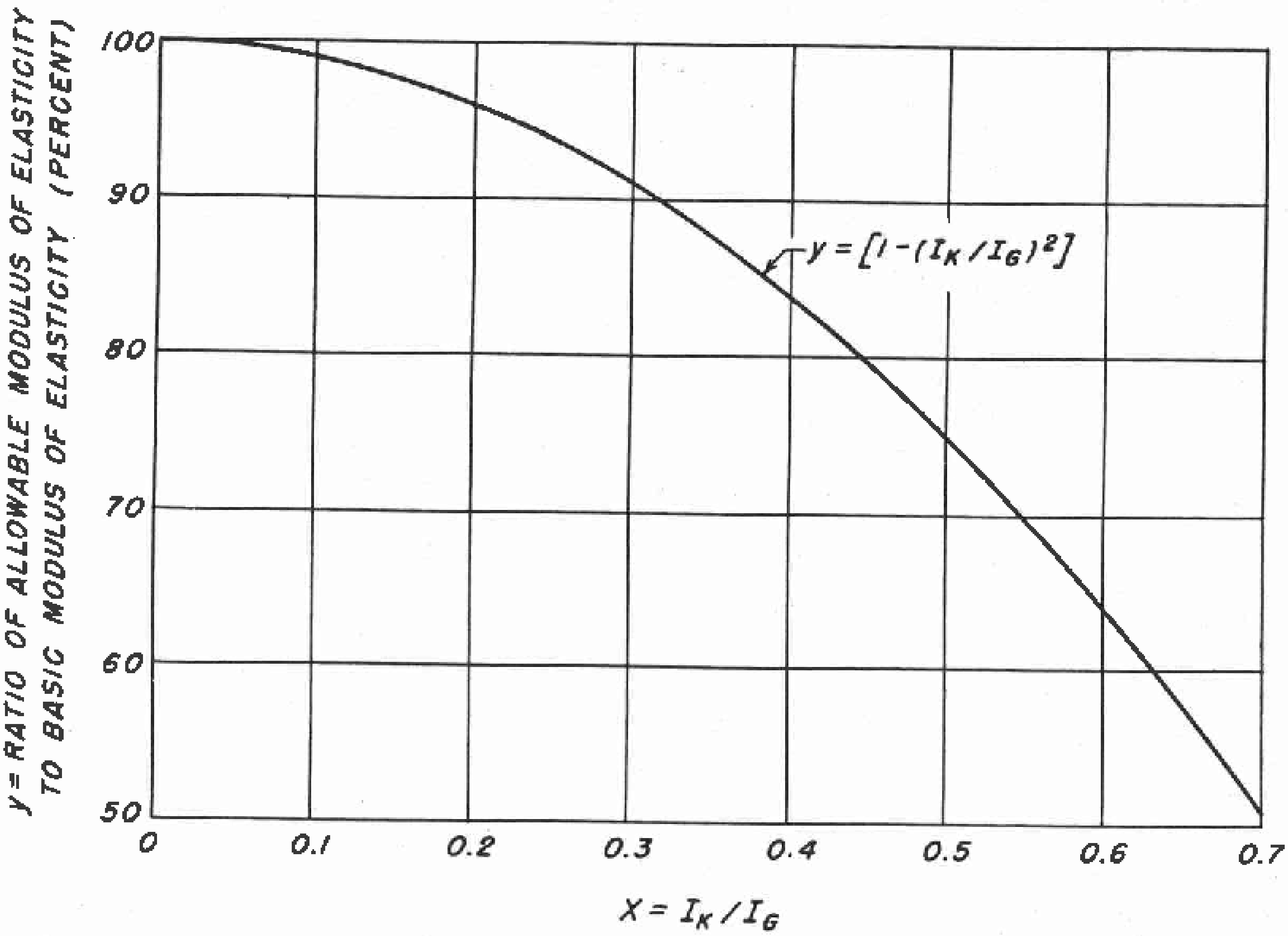

Figure 2. --This design curve for laminated beams with knots in the laminations relates allowable modulus of elasticity to moment of inertia of areas occupied by knots.

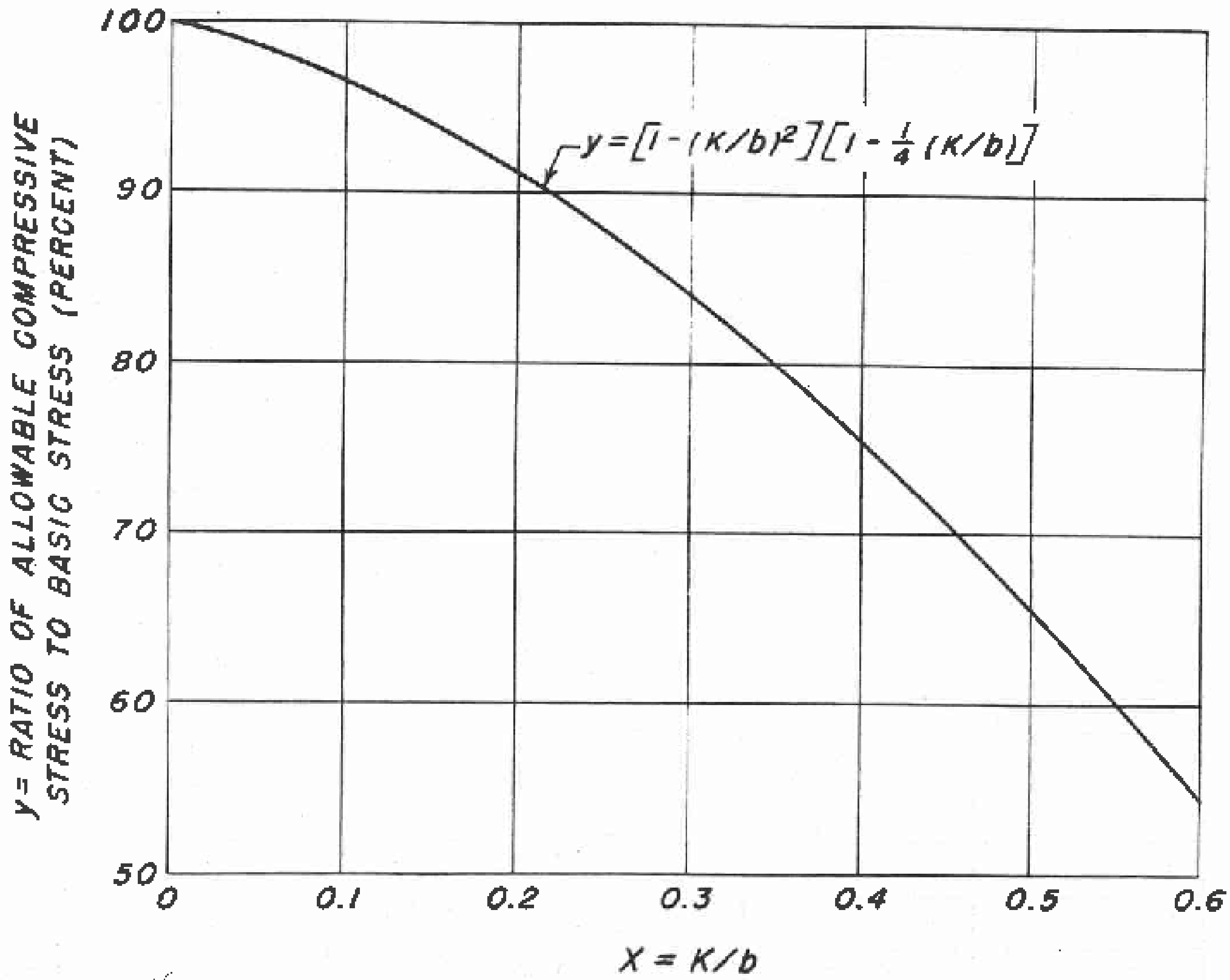

Figure 3. --This design curve for laminated columns with knots in the laminations relates allowable compressive stress to knot size.

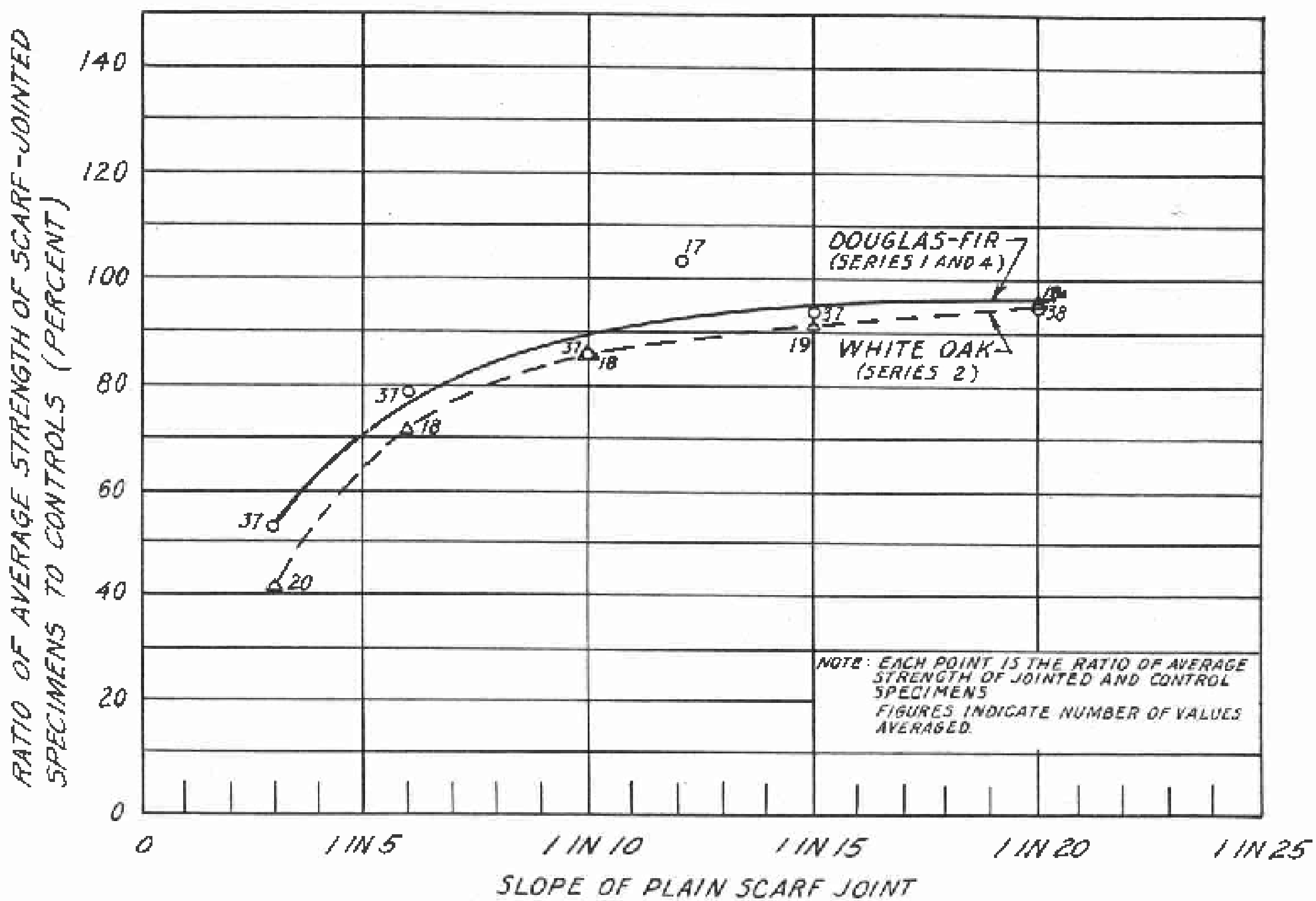

Figure 4. --Maximum strength in tension parallel to grain as related to the slope of a plain scarf joint in Douglas-fir and white oak.

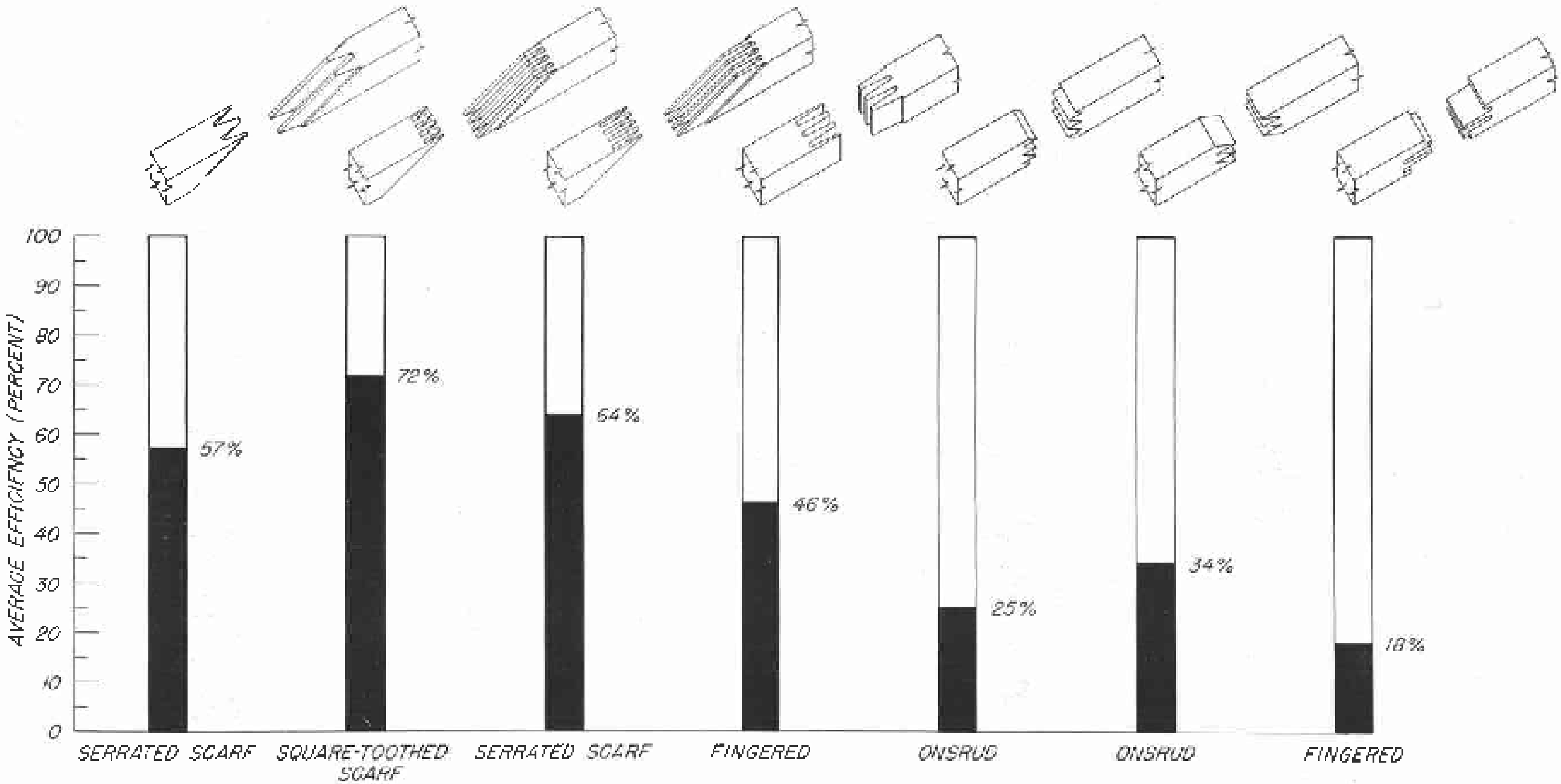

Figure 5. --Comparison of the strength in tension parallel to the grain of Douglas-fir specimens with various end joints and corresponding control specimens.

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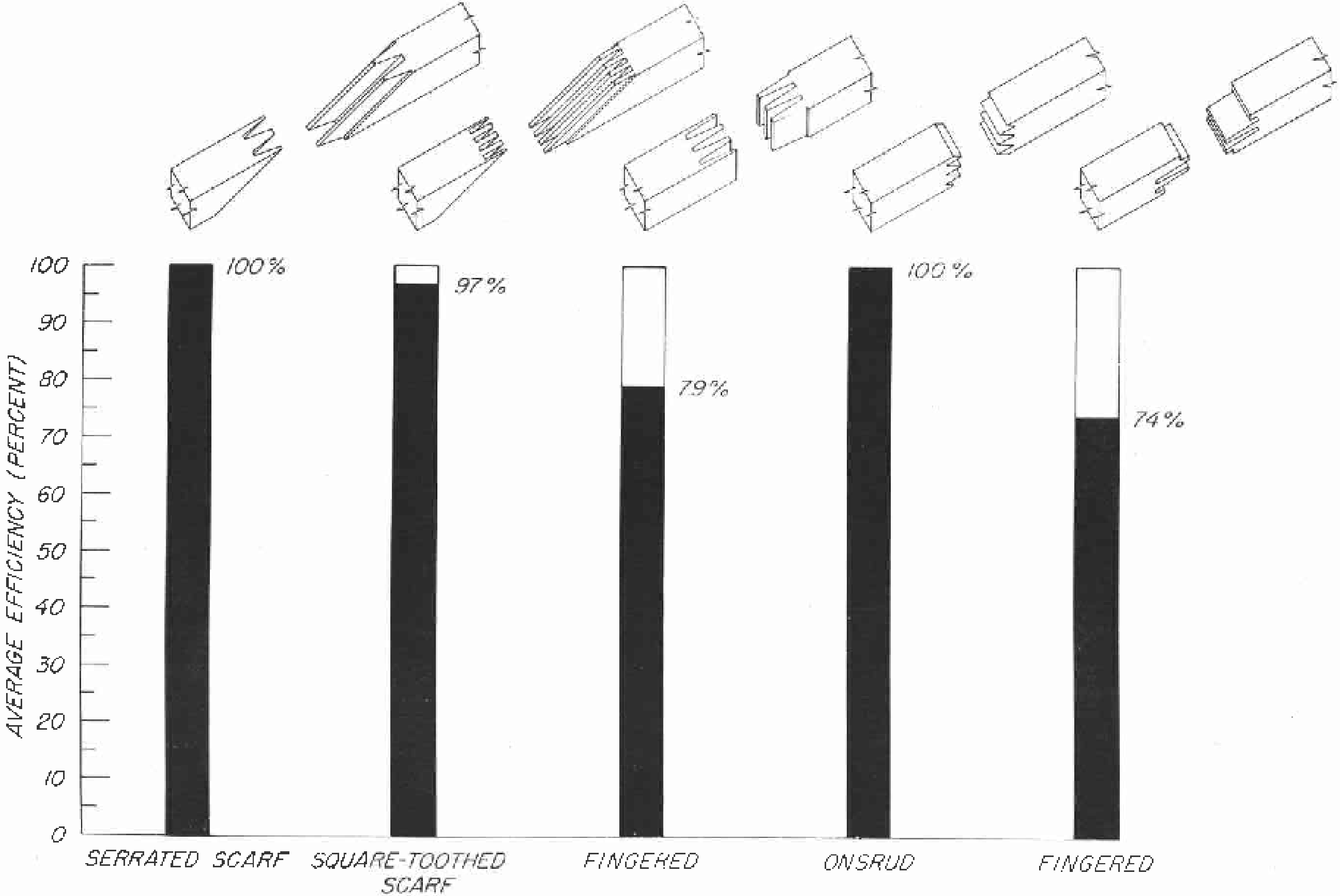

Figure 6. --Comparison of the strength in compression parallel to the grain of Douglas-fir specimens with various end joints and corresponding control specimens.

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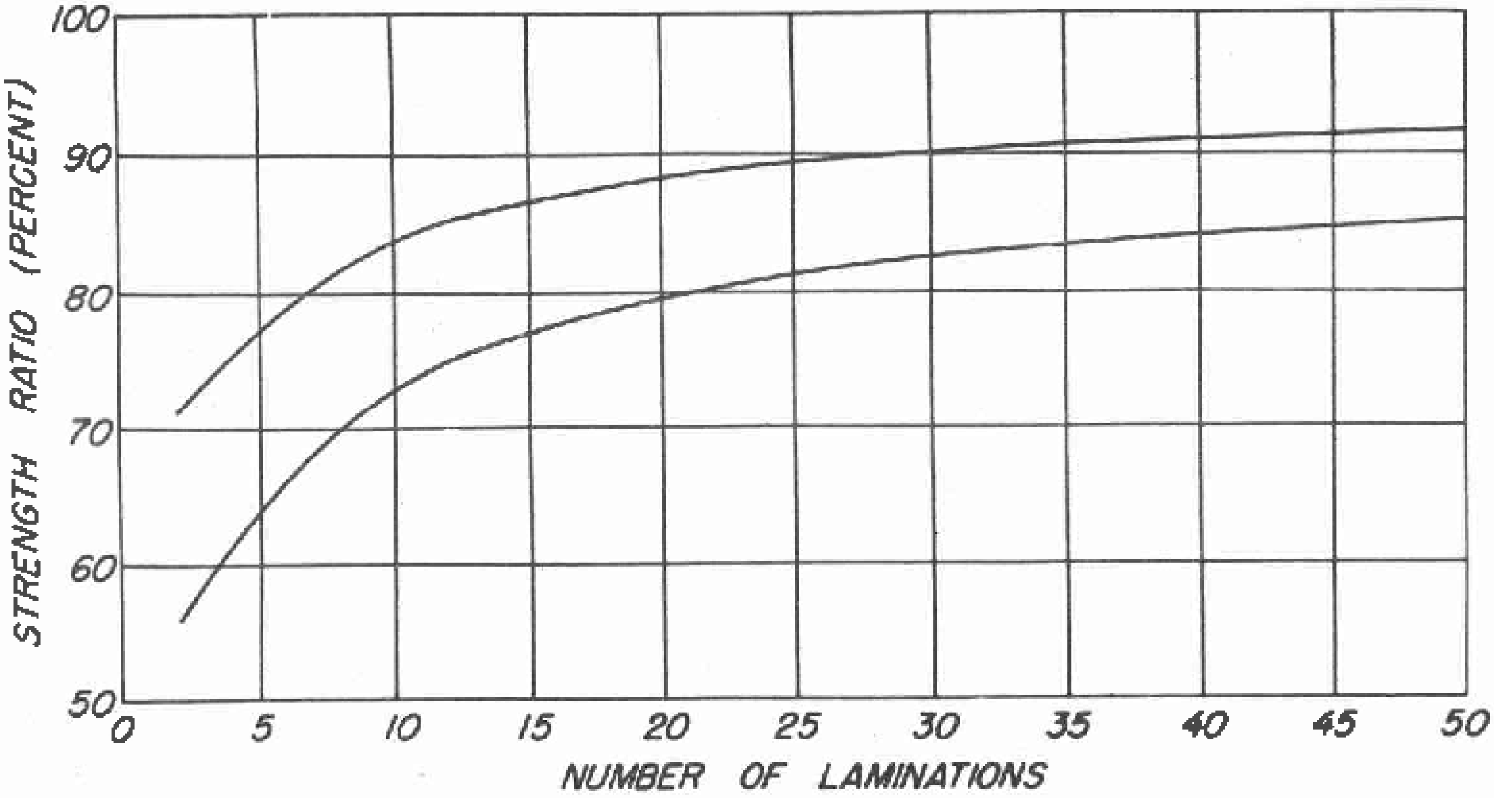


Figure 7. --Sample plot of strength ratios for laminated bending members containing various numbers of laminations as based on a survey of knot size and location. Each curve represents a typical lumber grade.

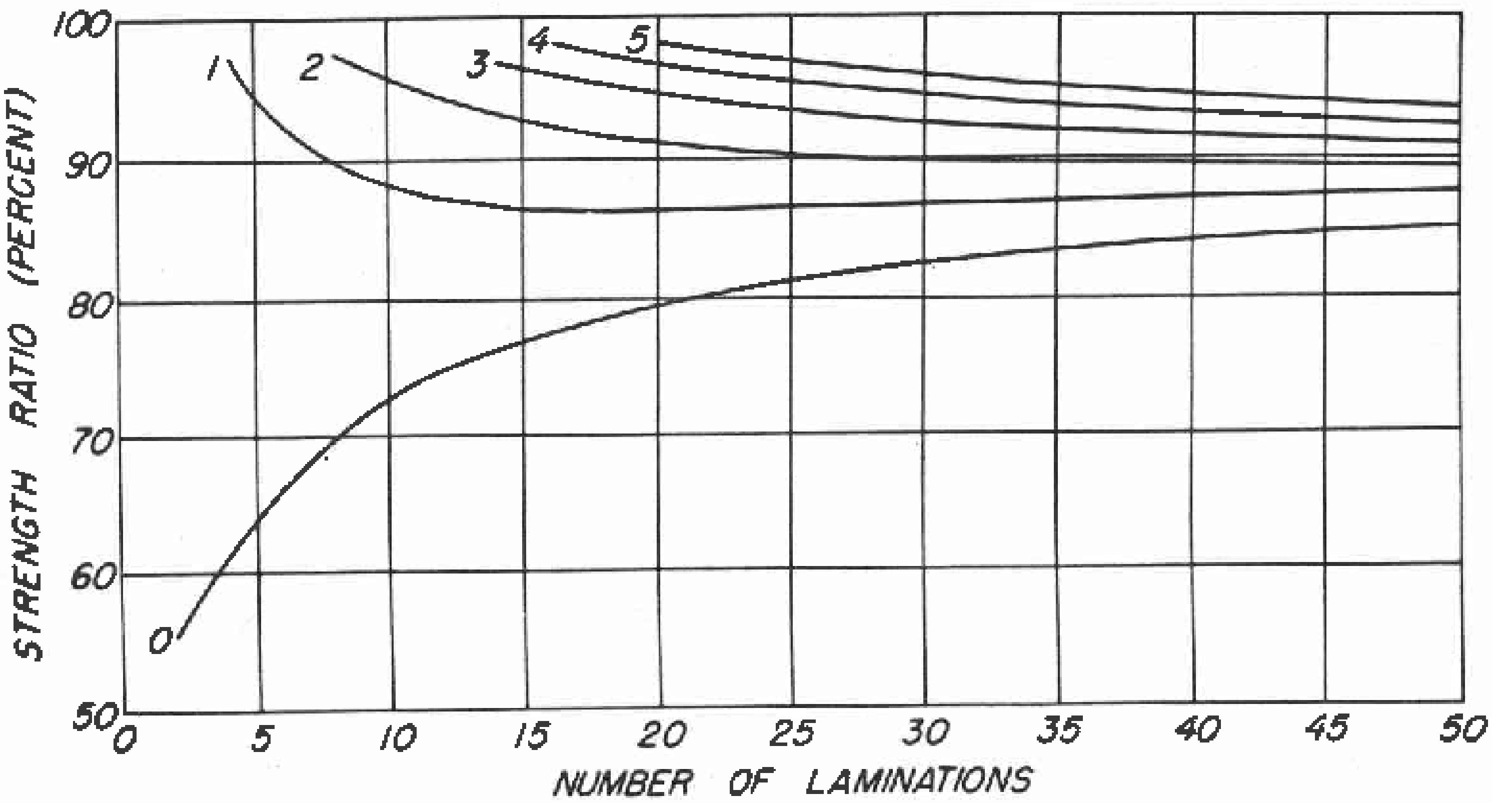
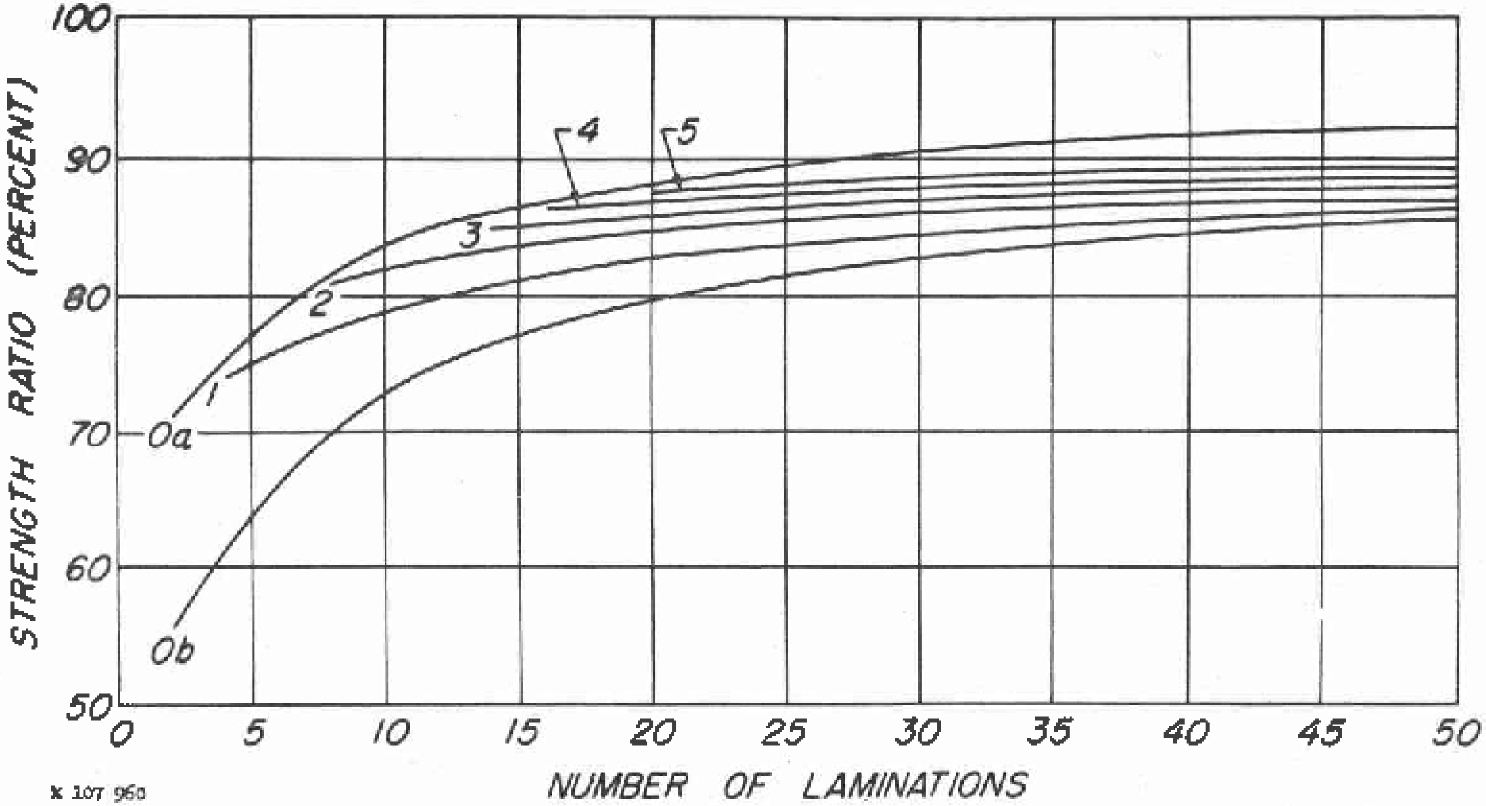


Figure 8. --Sample plot of strength ratios for laminated bending members containing various numbers of laminations as based on a survey of knot size and location. A typical grade was used for the inner laminations and was combined with defect-free outer laminations. The curve numbers indicate the number of clear laminations on each side.



x 107 960

Figure 9. --Sample plot of strength ratios for laminated bending members containing various numbers of laminations based on a survey of knot size and location. Two typical grades of lumber were used in various combinations, and the curve numbers indicate the number of laminations on each side that are of higher grade, except curve Oa representing beams in which all laminations are of higher grade, and curve Ob in which all are of lower grade.

SUBJECT LISTS OF PUBLICATIONS ISSUED BY THE FOREST PRODUCTS LABORATORY

The following are obtainable free on request from the Director, Forest Products Laboratory, Madison 5, Wisconsin.

List of publications on Box and Crate Construction and Packaging Data

List of publications on Chemistry of Wood and Derived Products

List of publications on Fungus Defects in Forest Products and Decay in Trees

List of publications on Glue, Glued Products, and Veneer

List of publications on Growth, Structure, and Identification of Wood

List of publications on Mechanical Properties and Structural Uses of Wood and Wood Products

Partial list of publications for Architects, Builders, Engineers, and Retail Lumbermen

List of publications on Fire Protection

List of publications on Logging, Milling, and Utilization of Timber Products

List of publications on Pulp and Paper

List of publications on Seasoning of Wood

List of publications on Structural Sandwich, Plastic Laminates, and Wood-Base Aircraft Components

List of publications on Wood Finishing

List of publications on Wood Preservation

Partial list of publications for Furniture Manufacturers, Woodworkers and Teachers of Woodshop Practice

Note: Since Forest Products Laboratory publications are so varied in subject, no single list is issued. Instead a list is made up for each Laboratory division. Twice a year, December 31 and June 30, a list is made up showing new reports for the previous 6 months. This is the only item sent regularly to the Laboratory's mailing list. Anyone who has asked for and received the proper subject lists and who has had his name placed on the mailing list can keep up to date on Forest Products Laboratory publications. Each subject list carries descriptions of all other subject lists.

FPL FILING SYSTEM DESIGNATION--L

Freas, Alan D'Yarmett
Factors affecting strength and design principles of glued laminated construction. 2d ed. Madison, Wis., U. S. Forest Products Laboratory, 1962.
10 p., illus. (F.P.L. rpt. no. 2061)

Combines fabrication and design data on glued laminated wood structural members. Emphasis is on design principles although general coverage of factors affecting strength is given.

Freas, Alan D'Yarmett
Factors affecting strength and design principles of glued laminated construction. 2d ed. Madison, Wis., U. S. Forest Products Laboratory, 1962.
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