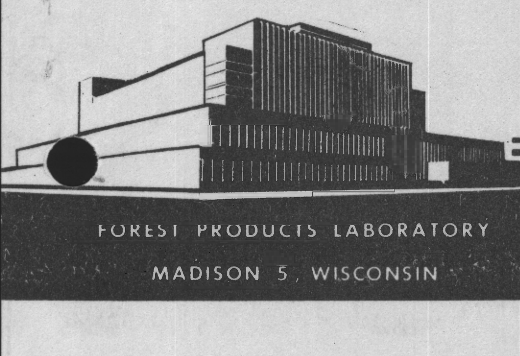
PRELIMINARY STUDY OF THE FACTORS AFFECTING TENSILE STRENGTH OF STRUCTURAL LUMBER

July 1962

No. 2251



FOREST PRODUCTS LABORATORY
MADISON 5, WISCONSIN

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

In Cooperation with the University of Wisconsin

Foreword

A major portion of the subject matter of this report was developed at the U.S. Forest Products Laboratory by the author as a thesis for the degree of Doctor of Philosophy at the University of Wisconsin.

An important purpose of a thesis is to demonstrate the author's capability to devise and use new techniques of observation and analysis of research data. Since the techniques of this thesis study are new and largely untried, they are not perfected to the point where they can be recommended for general use. Nevertheless, the information does have important implications in the grading and use of structural wood members in tension. It is therefore being offered so that others may use or improve on the techniques, and thus benefit from work already done.

PRELIMINARY STUDY OF THE FACTORS AFFECTING TENSILE STRENGTH OF STRUCTURAL LUMBER

By

W. H. ZEHRT, Engineer

Forest Products Laboratory,[1] Forest Service
U.S. Department of Agriculture

Summary

This report summarizes a preliminary study of tensile strength of structural wood in connection with a doctoral thesis and other related studies at the Forest Products Laboratory. The work included evaluation of small clear specimens and nominal 2- by 4- and 1- by 6-inch specimens with strength-reducing characteristics such as are permitted in the structural grades of lumber. The 2- by 4-inch clear specimens were of Douglas-fir and contained uniform slopes of grain, local deviations of grain, multiple slopes of grain, or slope of grain with checks. The 1- by 6-inch specimens were laminating stock of Douglas-fir or southern yellow pine with a normal distribution of characteristics for high-grade stock. A few 2- by 6-inch southern yellow pine specimens were necked down to nominal 2- by 4-inch size for evaluation.

The study of slope of grain showed that the tensile strength of wood with slope of grain can be predicted satisfactorily from an interaction equation that takes into account tension parallel, tension perpendicular, and shear parallel properties of the wood. Tensile strength of structural lumber with slopes of grain that are permissible in structural grades may be limited more by the shear-parallel properties than by the tension-parallel or tension-perpendicular properties of the wood. Stress-concentration effects were important, and unequal distribution of stress caused bending moments that were calculated into the results. Local deviations of grain were analyzed in terms of the proportion of the cross section occupied by each slope. Specimens with two slopes of grain were analyzed by a transformed area method. Slope of grain and checks were found to have a cumulative effect. The reduction of tensile strength in some of the specimens was serious.

---

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

The Douglas-fir and southern pine laminating stock showed a range of tensile strength values from 10,000 to 1,880 pounds per square inch.

Introduction

It is widely recognized that natural characteristics such as knots or slope of grain reduce the tensile strength of structural lumber. The effects from these strength-reducing characteristics, however, have had little study, due partly to the difficulty of evaluating structural lumber in tension and partly to the belief that structural connections are not adequate to utilize the full tensile strength of the member. Improved connections and increasing size and complexity of structural members, however, are combining to change this situation, and failures of structural wood in tension are becoming more common. Attention is therefore being drawn increasingly to the tensile strength values and the factors affecting the tensile strength of structural lumber.

Practice in structural design with wood has been to develop a working stress for wood from the modulus of rupture in bending and to use that same stress in tension. This is conservative for clear, straight-grained wood, because the ultimate tensile strength is higher than the modulus of rupture in bending. Recent work is showing, however, that the practice is not conservative for structural lumber containing natural strength-reducing characteristics such as knots or slope of grain. Permissible slopes of grain make the tensile strength of structural lumber a function of the strength in shear and in tension perpendicular to the grain, as well as of the strength in tension parallel to the grain of the clear wood. Location of characteristics and their proximity to each other may have more serious effects in tension than in bending because of the different stress distribution.

These circumstances led to the choice of this problem as the subject of a doctoral thesis[2] at the University of Wisconsin, for which the work was done at the Forest Products Laboratory. The thesis dealt with the effect of slope of grain on the tensile strength of structural wood members. Other recent studies of a more limited nature at the Forest Products Laboratory have been unpublished. The purpose of the present report is to make the results of all these studies available for general reference or use.

Little has been done in the evaluation of wood members of structural size and character for tensile strength. Some experiments at an aircraft company

---

[2] Zehrt, W. H. The Study of Tensile Strength of Wood Members of Structural Size and Shape. Doctoral thesis, University of Wisconsin. 1961.

about 20 years ago were unsuccessful and were discontinued. Experiments on various sizes of tension specimens were made in a thesis project at the University of Wisconsin.[3] Kollmann discussed the effect of a notch on the tensile strength (2).[4] Ylinen dealt with the distribution of tensile stress around a knot (6). Norris developed a mathematical analysis of strength under an interaction of stresses that is applicable to this problem (3). The American Society for Testing and Materials has a standard tension-parallel test method for small clear wood specimens (1).

This report is divided into six sections. The first five, which supply most of the subject matter of the report, are from the author's doctoral thesis. Section 1 involves tension studies of small clear specimens with various slopes of grain. Section 2 includes tension studies of nominal 2- by 4-inch members with uniform slopes of grain. Section 3 is the tension evaluation of nominal 2- by 4-inch specimens with large local grain deviations. Section 4 covers the effect of combining different slopes of grain by lamination into one nominal 2- by 4-inch member. Section 5 includes tension studies of specimens combining various slopes of grain with checks. Section 6 describes two tension studies made at the Forest Products Laboratory on laminating stock with scarfed end joints.

It will be seen in later sections of this report that the data are limited in scope and that some of the questions need more study. This report is to be taken as a progress report; its conclusions are to be considered as preliminary and subject to revision as more information becomes available. Nevertheless, the information is important, and its availability will permit discussion and stimulate further study of the questions involved in the tensile strength of structural lumber.

Section 1--Slope of Grain in Small Clear Specimens

Specimens and Test Methods

Small clear specimens of Douglas-fir with various slopes of grain were evaluated to check the stress interaction equation derived by Norris (3) for loading in tension at an angle to the grain. Specimens were selected from five boards, 5/4 by 12 inches and 16 feet long, and were conditioned and tested at 75° F. temperature and 64 percent relative humidity. Specimens with various slopes of grain were cut from each board as indicated in figure 1.

---

[3] Plate, G. K. and Raese, G. P. Effect of Size of Specimen on Tensile Strength of Wood Parallel to Grain. Master's thesis, University of Wisconsin. 1940.

[4] Underlined numbers in parentheses refer to Literature Cited at the end of this report.

Specimen numbers consisted of an initial digit that showed the number of the board from which the specimen was obtained and a letter that indicated the series, where A is standard tension parallel or at an angle to the grain, B is modified tension-parallel, C is static bending, D is tension perpendicular to the grain, and E is block shear parallel to the grain. The final digit in specimens A and B refers to nominal slopes of grain, as follows:

No.	Slope of grain	Angle of slope (Degrees)
1	1 in 4	14.0
2	1 in 6	9.5
3	1 in 8	7.1
4	1 in 10	5.7
5	1 in 12	4.8
6	1 in 15	3.8
7	1 in 20	1.8
8	None	0

The final digit in specimens C, D, and E is a serial number. A few extra specimens are marked with the letter X.

Specimens A were standard tension-parallel specimens (1) cut from the boards so as to have various slopes of grain. They were tested in a machine that applies the load mechanically, with load read electrically through load cells. Elongation was measured over a 2-inch length with a nonaveraging type of extensometer. Figure 2 shows a specimen in test. The rate of machine head travel was 0.05 inch per minute. Loads and deformations were read periodically. Determinations of specific gravity and moisture content were made and the true slope of grain was measured after test. Results are shown in table 1. Table 1 shows also the measurements of the true slope of grain measured at the point of failure, which differed somewhat from the nominal slope by which the specimen was cut.

Specimens B were tension specimens made with a minimum section 6 inches long (fig. 3) to accommodate flatter slopes of grain than the 2-1/2-inch minimum section in specimens A. It was necessary to have a minimum section long enough to permit the flatter slopes to run completely across it. The test methods were the same as those for specimens A except that wedge grips were used at the ends of the specimen and the rate of machine head travel was 0.035 inch per minute. Specific gravity and moisture content determinations were not made. Results are shown in table 2. Table 2 shows also the true slope of grain at the point of failure.

Specimens C were 1- by 1-inch straight-grained standard specimens (1) and were tested in static bending by standard procedures (1). Specific gravity and moisture content were determined. Results are shown in table 3.

Specimens D were designed for test in tension perpendicular to grain. They were used with wedge grips and a nonaveraging type of extensometer on a 2-inch gage length. The rate of machine head travel was 0.015 inch per minute. Specific gravity and moisture content were determined. Figure 4 shows a sketch of one of these specimens. Experimental results are shown in table 4.

Specimens E were block shear specimens differing from the standard specimen (1) in that the width was less than 2 inches. Figure 5 is a sketch of one of these specimens. The test method was the ASTM Standard (1). Specific gravity and moisture content were determined. Results of the tests are shown in table 5.

Analysis of Results

Analysis of the results in Section 1 depends mainly on the stress interaction equation developed by Norris (3). That equation is as follows:

$$\frac{1}{F_x^2} = \frac{\cos^4 \phi}{F_1^2} + \left[\frac{1}{F_{12}^2} - \frac{1}{F_1 F_2}\right] \sin^2 \phi \cos^2 \phi + \frac{\sin^4 \phi}{F_2^2}$$

in which: F_x equals tensile unit stress at an angle, ϕ, to the grain; F_1 equals tensile unit stress parallel to the grain; F_2 equals tensile unit stress perpendicular to the grain; and F_{12} equals shear unit stress parallel to the grain.

The effect of variation of properties on tensile strength from this equation was explored by calculating F_x at various angles to the grain. Values of the properties were assumed to be 20,000 pounds per square inch in tension parallel (F_1), 340 pounds per square inch in tension perpendicular (F_2), and 1,160 pounds per square inch in shear parallel (F_{12}). Calculated values of F_x are shown as curves in figures 6, 7, and 8.

With a slope of 5° (about 1 in 11.4), the tensile strength (F_x) taken from curve 1 of figures 6, 7, and 8 was about 11,300 pounds per square inch. At the same slope of grain but with F_1 decreased by 25 percent, F_x was 10,400 pounds per square inch (curve 2 of fig. 6), a reduction of about 8 percent. When $\underline{F_2}$ was decreased by 25 percent, $\underline{F_x}$ was reduced about 2 percent (curve 3 of fig. 7). When $\underline{F_{12}}$ was decreased by 25 percent, $\underline{F_x}$ was reduced about 23 percent (curve 4 of fig. 8).

This shows how the tensile strength of structural lumber with permissible slopes of grain may be limited more by the shear than by the tension-parallel or tension-perpendicular properties of the wood.

Values in tables 1 to 5 show only small variations of moisture content, indicating that this factor could be ignored in comparing these results.

Strength values in specimens A, D, and E were adjusted for differences in specific gravity to the average value within each board, and are thus shown in table 6.

The observed strength values in specimens A that were adjusted for specific gravity were plotted against slope of grain for each of the five boards, as shown in figures 9 to 11, inclusive. A curve calculated by means of the interaction equation (3) from the board average values in tension parallel, tension perpendicular, and shear is shown for comparison with the observed values. Examination of figures 9 to 11 shows that the observed values were in good agreement with the values calculated by the stress interaction equation.

Observed strength values in specimens B that were adjusted for specific gravity are plotted similarly in figures 12 to 14, inclusive. These differed from specimens A in that the minimum section was longer, permitting the flatter slopes of grain to extend fully across the minimum section in specimens B. Comparison of figures 9 to 11 with figures 12 to 14 in the regions of lower slope fails to show a clear difference between specimens A and specimens B in their positions with respect to the computed curves. There is possibly a slightly lower strength if the failure can extend fully across the minimum net cross section, but the difference is relatively small.

Section 2--Slope of Grain in 2- by 4-Inch Clear Specimens

Specimens and Test Methods

A major problem in developing the 2- by 4-inch tension specimen was the difficulty of devising end connections that would transfer the required tensile loads. Because of this limitation on transfer of loads, the flattest slope of grain used in this section of the work was 1 in 8. (The slope of grain in all specimens was in the plane of the 4-inch face.) This and steeper slopes made it difficult to find material wide enough to permit cutting specimens of sufficient length at the required angles of grain. The objective of the work in this section was to determine by comparison with Section 1 whether the size of specimen or the end conditions in the test method had an effect on the strength of tension members with slope of grain. Specimens were cut from four Douglas-fir boards and were conditioned for test at a temperature of 75° F. and 64 percent relative humidity.

Specimens F were 1-5/8 by 3-5/8 inches, 7 feet long, with hard maple cleats at the ends glued to each edge and cut away on a circular curve of an 80-inch radius to the test section to minimize stress concentration effects. The specimens were cut to have slopes of grain of 1 in 7 or 1 in 8. Figure 15 is a sketch of this specimen.

Specimens G had the same cross section, but were only 4 feet 8 inches long because of limitations in the available material. The slope of grain was 1 in 6. The maple end cleats were cut away on a radius of 16 inches to the test section. A sketch is shown in figure 16.

Specimens H were of the same cross section, but were still shorter to accommodate the steeper slopes of grain. Those with a slope of 1 in 5 were 3 feet 9 inches long, and those with a slope of 1 in 4 were 3 feet long. The maple side cleats were square-ended, some 10 inches and some 12 inches long (fig. 17).

Table 7 gives the lengths of the specimen and of the end cleats on specimens F, G, and H. The numbering of specimens is similar to that of specimens A and B (Section 1) except that the final digit refers to nominal slopes of grain as follows:

No.	Slope of grain	Angle of slope (Degrees)
1	1 in 4	14.0
2	1 in 5	11.3
3	1 in 6	9.5
4	1 in 7	8.1
5	1 in 8	7.1

Specimens F, G, and H were loaded in direct tension, with load applied through wedge grips 12 inches long. Single electrical-resistance strain gages were mounted in the middle of each of the two narrow faces of the specimens at midlength to measure strains parallel to the axis of the specimens. An electrical resistance rosette gage was mounted at the center of each wide face at midlength, each gage measuring longitudinal, transverse, and 45° strains. Rosette gages were so mounted that the pairs of gages on opposite faces were parallel. This permitted the determination of average strain on the section in any of the three directions. Figure 18 shows a specimen F mounted and with strain gages applied.

Load was first rapidly applied to 3,000 pounds to set the wedge grips and then relaxed to 200 pounds to begin the observations. The speed of head travel was selected to require about 5 minutes to complete the test to failure. Head speeds were 0.059 inch per minute for specimens 6H1, 7H1, and 8H1; 0.087 inch per minute for specimens 6H2, 7H2, and 8H2; 0.129 inch per minute for specimens 6G3, 7G3, and 8G3; and 0.171 inch per minute for specimens 6F4, 7F4, 7F5, 8F4, 9F5, and 9F5X. The experimental data are shown in table 8. This shows the actual slope of grain measured at the point of failure, which differed somewhat from the surface slope by which the specimens were cut. All specimens failed in shear and tension along the slope of grain.

Small clear specimens were cut from each of the four boards that yielded the larger specimens in this section. They were of the same types as specimens A, C, and E (Section 1) in tension parallel, static bending, and block shear. Type DA for tension-perpendicular test was similar to the ASTM Standard (1) except that the width was approximately 1-5/8 inches instead of 2 inches. Specimens were tested by the same methods as in Section 1 except that type DA followed the ASTM standard method (1) without strain readings or determination of modulus of elasticity. The experimental data are shown in table 9.

Analysis and Discussion of Results

Examination of the data showed little variation in moisture content or specific gravity, and no adjustments of the values were made for these two properties.

No end connection was devised to transmit the necessary loads without introducing bending moment. The wedge grips held the ends of the specimens quite firmly fixed, and any small misalinement either before or during load application could thus cause a bending moment. The deformation data were used to calculate the stress resulting from bending moment. This was added to the average tensile stress to give a maximum tensile stress as shown in table 10. That table shows also the strength computed by the interaction formula and the ratio of the observed strength to the calculated strength. Although table 9 shows that some slope of grain occurred in the small tension-parallel clear specimens, the maximum error this caused in the values computed by the interaction equation (column 5 of table 10) was only 0.9 percent.

Ratios of observed to calculated strength in table 10 were examined for stress concentration and size effects. While the number of evaluations was too small to prove such effects, a few trends were indicated. Average values from the last column of table 10 show a ratio of observed to calculated strength of 111 percent in specimens F, 88 percent in specimens G, 71 percent in specimens H with 12-inch cleats, and 65 percent in specimens H with 10-inch cleats. These ratios appear to represent the stress-concentration effects in specimens G and H.

Ratios exceeding 100 percent in specimens F could indicate a size effect, with the larger specimen showing the higher strength. In support of this possibility is the thought that very small and not visible weaknesses may occur at numerous places in a member, and that their effect may be relatively greater in the small than in the large specimen. On the other hand, only one specimen showed a ratio substantially exceeding 100 percent, and this cannot be considered to be enough to prove a size effect. In strength evaluations of other kinds and on other materials, a size effect is more often in the opposite direction, with the larger specimen showing the lower strength.

The bending moments and the stress concentration effects observed in these specimens point out the need for further work on an improved specimen. The specimen should be of substantially greater length (8 feet or more) to reduce bending moments and to provide a long-radius curve of transition from the end cleats. Specimens similar to F would be satisfactory, but to provide greater strength in the grip area, cover plates should be applied over the whole area of wedge grip contact. To obtain the required long specimens with steep slopes of grain, they will have to be specially cut from carefully selected logs.

Section 3--Local Grain Deviations

This section was an evaluation of tension members of nominal 2- by 4-inch cross section with substantial local deviations with steep slope of grain. The purpose was to determine if structural lumber grading rules that disregard local deviations of grain give adequate tensile strength.

Specimens and Test Methods

The nominal 2- by 4-inch specimens were fabricated from five Douglas-fir boards and in the same shape as specimens F, G, and H in Section 2. They were selected and cut to have local steep deviations of grain, but the extent of the steep slope through the cross section was difficult to estimate accurately until after the failure in test. Maple face plates one quarter inch thick were glued over the wedge grip contact area on all specimens except No. 18. Table 11 shows the dimensions of each specimen. The test procedures were the same as in Section 2, except that strain gages were not used and only initial and final failure loads were recorded. The speed of loading head travel was chosen for a 5-minute duration of test and was 0.171 inch per minute for specimens 18 and 21; 0.129 inch per minute for specimens 19 and 20; and 0.059 inch per minute for specimen 22. The data are recorded in table 11. Failures occurred in every instance in association with the local deviations of grain. Specimen 22 showed shell-out along an annual ring.

Small clear specimens were cut from the same five boards for evaluation in tension parallel to grain, static bending, tension perpendicular to grain, and shear parallel to grain. The specimens and test methods were the same as those used in Section 2. The results are shown in table 12. Although table 12 shows that there were small slopes of grain in some of the tension-parallel specimens, the maximum error these caused in the computed stresses at redistribution (columns 5 and 6, table 11) was only 1.3 percent.

Analysis and Discussion of Results

The analysis of data was based on the concept that the unit deformation would be virtually the same at all points in the cross section. That concept required the use of an interaction equation related to the elastic properties. Norris and McKinnon derived an equation for modulus of elasticity at an angle to the grain, as follows (4):

$$\frac{e_{xx}}{t_{xx}} = \frac{1}{E_x} = \frac{\cos^4 \phi}{E_a} + \left[\frac{1}{\mu_{ab}} - \frac{\sigma_{ab}}{E_a}\right] \sin^2 \phi \cos^2 \phi + \frac{\sin^4 \phi}{E_b}$$

in which: ϕ equals angle between X direction and grain direction, A; e_{xx} equals unit strain in X direction; t_{xx} equals unit stress in X direction; E_x equals modulus of elasticity in X direction; E_a equals modulus of elasticity in A direction; E_b equals modulus of elasticity in B direction, perpendicular to the grain direction, A; μ_{ab} equals modulus of rigidity; and σ_{ab} equals Poisson's ratio.

Species average values for Douglas-fir at 12 percent moisture content (5) were used with the above equation to plot a curve of slope of grain versus the ratio of the modulus of elasticity at that slope to the modulus of elasticity parallel to grain (fig. 19). Use of that curve in the analysis is illustrated in the following example.

Examination of the specimen after failure showed that the broken section could be divided into two or more areas over which the slope was nearly uniform. For example, two-thirds of the section of specimen 19 (table 11) failed at a slope angle of 25.5°. The other third failed at an angle of 7.1°. At the load level where the wood with the steeper slope of grain was about to fail but had not yet failed, it was assumed to be at its ultimate stress of 2,510 pounds per square inch, computed by the stress interaction equation from the values of small clear specimens. The ultimate stress of the portion with the flatter slope of grain was similarly computed from the small clear specimen values to be 9,360 pounds per square inch. When the stress in the portion with steeper slope was 2,510 pounds per square inch just before failure, the stress in the portion with flatter slope, assuming equal deformation, was $2,510 \times \frac{83.5}{29.5} = 7,100$ pounds per square inch (see fig. 19), less than its ultimate stress. The computed average stress was then $(2/3 \times 2,510) + (1/3 \times 7,100) = 4,040$ pounds per square inch.

After failure of the portion with steeper slope, the load was carried by the portion with flatter slope at a computed stress of $3 \times 4,040 = 12,120$ pounds per square inch. This was beyond its strength and it failed; thus, the initial failure was also the final failure, as shown in table 11. The observed stress at final failure was 2,910 pounds per square inch, 72 percent of the computed stress (table 11).

Similar computations were made for the other specimens with results shown in table 11. The average of the ratios of observed to computed stress was about 83 percent. These ratios may be below unity because of the unequal distribution of stress in the specimen causing secondary moments and stresses. The low range of some of the observed failure stress values reflects the great effect of local grain deviations on tensile strength in members of this size, and the importance of limiting local deviations where tensile strength of small members is required.

Section 4--Two Slopes of Grain

This section was an evaluation of tension members of nominal 2- by 4-inch cross section, produced by laminating two 1-by-4's with different slopes of grain.

Specimens and Test Methods

The nominal 2- by 4-inch specimens were laminated with a urea-resin glue from four clear Douglas-fir 1-inch boards. Each lamination was cut at an angle to the axis of the board to give the desired slope of grain. The slopes were all in the plane of the wide face of the specimen. Specimen designations were composed of two initial digits that represented the last digit of each of the boards used (3 to 6, inclusive, in this series); a letter M for slopes in the same direction or N for slopes in opposite directions; and two final digits representing the nominal grain slope class in each lamination. Classes of slope were as follows:

Class	Slope of grain	Angle of slope (Degrees)
1	1 in 4	14.0
2	1 in 6	9.5
3	1 in 8	7.1
4	1 in 10	5.7

All specimens were of the type of specimens H (Section 2 and fig. 17) with overall lengths of 3 or 3-1/2 feet and lengths of the square-cut end cleats 10 or 12 inches. Hard maple face cleats 1/4 inch thick were glued over the wedge grip contact areas at the ends of the specimens. Figure 20 shows several typical specimens after failure in test.

The test procedure was similar to that described for the 2- by 4-inch specimens in Section 2. The speed of loading head travel was chosen for a 5-minute duration of test and was 0.129 inch per minute for specimens 45M23, 44N22, and 45N23; and 0.087 inch per minute for the other specimens. The true slope of grain in each lamination at the point of failure was carefully measured after the failure. That information and the experimental data are given in table 13. With one exception, the specimens failed approximately along the slopes of grain in both laminations, with a shear failure close to the glue line between laminations. Specimen 35N13 failed across grain in one of the laminations (fig. 20).

Small clear specimens were cut from the same four boards for tests in tension parallel to grain, static bending, tension perpendicular to grain, and shear parallel to grain. The specimens and test methods were similar to those in Section 1 for specimens A, C, D, and E. The results are recorded in table 14. Although table 14 shows that there were small slopes of grain in two of the tension-parallel specimens, the errors these caused in the computed tensile loads (column 11, table 13) were only 2.6 percent and 1.2 percent.

Analysis and Discussion of Results

Strain readings on the two narrow faces differed, showing that bending moment was present in the plane of the wide face. A correction was computed for that bending moment effect to obtain the tensile load that would have been carried if no moment had existed. The correction and the corrected tensile load on each specimen are shown in table 13.

The computed strength of each specimen was obtained by assuming that there was no bending moment in the plane of the wide face and that a bending moment in the plane of the narrow face was the product of the tensile load and the eccentricity of the neutral axis from the center of the cross section. To obtain the location of the neutral axis, the method of transformed section was used, as is common in the analysis of composite sections. Values of the modulus of elasticity for each lamination were determined by applying percentage ratios from figure 19 to the individual values of modulus of elasticity parallel to grain obtained from the small clear specimens. The modular ratio, n, of the larger to the smaller of the two moduli provided a coefficient for transforming the areas of the two laminations in each specimen. The ultimate stress of each lamination was computed by the stress interaction equation (3) from the strength values of the small clear specimens cut from the same boards. By substituting the proper values in the following equations and solving for the maximum tensile load, P, the computed load shown in table 13 was obtained:

$$f_1 = \frac{P}{A_T} + \frac{P\,e\,(t/2 + e)}{I_T}$$

$$n\,f_2 = \frac{P}{A_T} - \frac{P\,e\,(t/2 - e)}{I_T}$$

where: P equals maximum tensile load; A_T equals transformed area; e equals distance from neutral axis to center of member; t equals total thickness of specimen; I_T equals moment of inertia of transformed section about the neutral axis, n equals ratio of larger modulus of elasticity to smaller, f_1 equals computed ultimate stress for laminate with smaller E; and f_2 equals computed ultimate stress for laminate with larger E.

Percentage ratios of the corrected observed load to the computed load for each specimen are given in the last column of table 13. All of the specimens were of type H with square-cut end cleats, and with the same stress-riser effect. The percentage based on average values in table 13 is in close agreement with the average ratio for specimens H from table 10. Differences that occur in individual specimens are attributed to imperfect matching between the laminated specimen and the small clear specimens. It appears that the transformed-area method of analysis is satisfactory for specimens of this kind. However, if a further evaluation is to be made, specimens 8 feet or more in length should be used to avoid the large stress concentration effect.

Section 5--Slope of Grain and Checks

This section was an evaluation of tension members of nominal 2- by 4-inch cross section with various slopes of grain and with artificial checks following the grain. For the steeper slopes of grain, members with no checks were used as control specimens. The purpose was to show the reduction of tensile strength where slope of grain and checks were present together.

Specimens and Test Methods

The nominal 2- by 4-inch specimens were cut from clear Douglas-fir boards, and when finally dressed were about 1-3/8 inches thick. Types F, G, and H of Section 2 were represented. Table 15 shows the lengths of the specimens and their cleats. Slopes of grain were from 1 in 4 to 1 in 20. Checks were produced to depths of 1/4, 1/2, or 11/16 inch, the latter being about half the thickness of the specimen. The length of checks was such that the checks were terminated at about 3/4 inch normal distance from each edge of the wide face of the specimen. Checks 1/4 inch deep were produced by drawing a thin-bladed knife equipped with a depth stop along the sloping grain. Deeper checks were produced in two stages, using a small thin saw to within about 3/32 inch of the required depth and the thin-bladed knife with the depth stop to the final depth.

The code used to number these specimens (table 15) consisted of two initial digits showing the number of the board from which the specimen was cut; a letter K for specimens with no check or checked on one side, or L for specimens symmetrically checked from both sides; a number 0 for no check, 1 for 1/4-inch depth of check, 2 for 1/2-inch depth of check, or 3 for 11/16-inch depth of check (summation of depths where checked on both sides); and a final number indicating the slope-of-grain class, as follows:

Code No.	Nominal slope of grain	Angle of slope (Degrees)
1	1 in 4	14.0
2	1 in 6	9.5
3	1 in 8	7.1
4	1 in 12	4.8
5	1 in 15	3.8
6	1 in 20	1.8

Final planing of the specimens resulted in some variation of slope of grain from the nominal value for its class; table 15 shows the actual slopes as they were measured after the failure in test.

Testing procedures were the same as for the 2- by 4-inch specimens in Section 3. The rate of loading head movement was chosen for a 5-minute duration of test and was 0.087 inch per minute for specimens 10K01, 10K11, 11K01, and 12K02; 0.129 inch per minute for other specimens cut from boards 10, 11, and 12, and for specimen 13K03; and 0.171 inch per minute for the remainder of the specimens. Results are shown in table 15. Figure 21 shows some of the specimens after failure in test.

Failures followed the slopes of grain and were at or away from the checks as indicated in table 15. Specimens 13K03, 13K13, 13K23, 14L13, 16L36, 17K36, and 17L24 showed a tendency for failure to follow the annual rings in a shake-like or "shell-out" separation (specimen 13K03 in fig. 21).

Small clear specimens from the same eight boards were cut for evaluation in tension parallel to grain, static bending, tension perpendicular to grain, and shear parallel to grain. The specimens and test methods followed those in Section 2 for specimens A, C, DA, and E. The results are recorded in table 16. Although table 16 shows that slopes of grain were undetected in the selection of some of the tension-parallel specimens, the errors these caused in the computed tensile loads (column 11, table 15) were not large. The errors ranged from 0.2 to 7.4 percent in 11 of the specimens and were zero in the remaining 24 specimens.

Analysis and Discussion of Results

The asymmetric section produced by checking on one side of the K specimens resulted in an eccentricity of load and some bending moment. The ratio of stress from bending moment to direct stress is a constant for a specified depth of check; it was calculated at 4.45 percent with a 1/4-inch check, 8.51 percent with a 1/2-inch check, and 9.77 percent with an 11/16-inch check. Those percentages were applied as a correction to the observed maximum tensile stress of each K specimen that contained a check, as shown in table 15.

Six checked specimens and four unchecked specimens did not fail in the checks. Their strengths were computed by the interaction equation (3) from the values of the matched small clear specimens, using the measured slope of grain at the failure. The computed values and the ratios of corrected to computed maximum tensile stress are given in the first two groups of specimens in table 15.

The remaining specimens failed in the checks. The interaction equation (3) could not be applied directly to these because there was a reduction of cross section in tension perpendicular and shear, but no reduction in tension parallel. The maximum tensile stress was computed by reducing the strengths in tension perpendicular and shear in proportion to the reduction of cross section by the check. The reduced values were used in the interaction equation to give a computed maximum tensile stress based on the full cross section, as shown in the last three groups of specimens in table 15. Ratios of corrected to computed strength were calculated for these specimens also.

Differences in strength ratios (column 12 of table 15) between K and L specimens were not consistent and apparently not significant; this indicates comparable effects from a check or a certain depth of checks, whether on one or both sides.

The data were studied for stress concentration effects of the checks, but these could not be proved because of the presence of stress concentrations from the type of specimen as discussed in Section 2. Unchecked specimens and specimens failing away from the checks had end cleats of stress-concentrating types. The average of their strength ratios was 68 percent, about the same as those calculated for specimens H of Section 2. Specimens that failed in checks gave appreciably higher strength ratios than those not failing in checks; therefore, if there was a stress concentration effect from the checks it was probably small. The number of specimens is not enough to make this a firm conclusion. While the method of computing the strength of the specimens that failed in the checks is direct, it is possible that a more refined method would give higher computed strengths and thus lower the strength ratio to show a stress concentration effect at the checks. Kollmann (2) evaluated a stress concentration effect at notches, but there is no proof that it is additive to the stress concentration effect of a square end cleat.

It is to be expected that checks will reduce the tensile strength of a piece of structural lumber when slope of grain is present, but more research is needed to evaluate that reduction. Longer test specimens free of stress concentration at the end blocks would permit a better evaluation of check effects.

Section 6--Tensile Strength of Laminating Stock[5]

Two studies were made at the U.S. Forest Products Laboratory on the tensile strength of 1- by 6-inch and 2- by 6-inch laminating stock with scarfed end joints to determine the feasibility of a tension test on a full-size lamination for quality control purposes. More than half of the specimens failed away from the scarf joint, and results of the studies were not published. Tensile strengths of those specimens failing away from the scarf joints are reported here to indicate a range of values that may be expected in structural lumber of good grade.

Specimens and Test Methods

The A, B, and C specimens were Douglas-fir, apparently equivalent to the Select Merchantable Grade (not a stress-rated grade), 7 feet 4 inches long, 5-1/2 inches wide, and 3/4 inch thick. Each specimen was scarf-jointed near the center of the length, and the two halves of the specimen were taken from different boards. The specimens were conditioned in an atmosphere at 75° F. and 64 percent relative humidity. Short sections for determination of specific gravity and moisture content were cut from each end before test. The specimens were loaded in a mechanical testing machine with load applied through wedge grips 12 inches long and 6 inches wide. An initial load was applied to set the grips, and loading was then continued with the head of the machine moving at the rate of 0.27 inch per minute. About 3 minutes' time was required to break the specimen after the initial loading to set the grips. Figure 22 shows a specimen in the machine ready for loading. Experimental results and notes on the failures (where away from the scarf joints) are given in table 17.

The D specimens were southern yellow pine of a finish grade approximately comparable to that of the A, B, and C specimens and were also scarf-jointed near the center of the length. Specimens were 80 to 88 inches long and 5-1/2 inches wide, and the majority were 3/4 inch thick and of uniform cross section throughout their length. Some of the specimens were 1-5/8 inches

---

[5] This portion of the report is from two studies by Fred Werren and R. L. Ethington, engineers at the Forest Products Laboratory.

thick (nominal 2 inches) and were necked down on a 31-1/2-foot radius to 3-1/2 inches width at the center of length, retaining the full width at the ends (fig. 23). The moisture conditioning and the method of test were the same as in the A, B, and C specimens. Experimental data and notes on the failures (where away from the scarf joints) are given in table 18.

The wedge grips had an area of 66 square inches on each side, which was found adequate to apply loads ranging up to about 44,000 pounds without appreciable slipping and without an excessive proportion of failures in the grip area. It was thought that bending moment may have been introduced in some of the specimens by a nonuniform distribution of load across the width, but this was not evaluated. A longer specimen would reduce such a bending moment.

Discussion of Results

Because of incomplete information on the grades of lumber in these studies, it was not possible to correlate the tensile strength with the occurrence or the nature of the strength-reducing characteristics. Attempts to relate the strength or the nature of failure to the specific gravity were largely unsuccessful. The data are shown therefore only as a general indication of the range of tensile strength values to be expected in structural lumber of rather high grade.

The tensile strength values of 1- by 6-inch specimens in tables 17 and 18 are shown as frequency distributions in figure 24. A great range and some rather low values are indicated in both species. Southern pine values tended to run higher than those of Douglas-fir; on the other hand, the lowest recorded value was in southern pine. It is of interest to point out that allowable stresses in tension of glued laminated structural members fabricated of dry material of these species and a grade permitting the same size of knots may be 2,600 pounds per square inch for 10-year loading. The equivalent stress for 5-minute loading corresponding to the strength of these specimens is 8/5 x 2,600, or about 4,160 pounds per square inch. That value was not reached by 4 of the 38 Douglas-fir specimens in table 17 and 2 of the 49 southern pine specimens in table 18. There is some question, however, about the validity of the method of testing these specimens, since the stresses imposed by the method of test may be quite different from those that would be imposed in a beam. This should be studied further.

Conclusions

The most important conclusions from the research reported here are:

1. The stress interaction equation developed at the Forest Products Laboratory is satisfactory to determine the tensile strength at an angle with the grain from the values of the strengths in tension parallel, tension perpendicular, and shear parallel.

2. The tensile strength of lumber with slopes of grain that are permissible in structural grades may be limited more by the shear strength than by the tension-parallel and tension-perpendicular strengths of the wood.

3. Stress concentration effects at the end cleats used for the gripping of tension specimens can seriously affect the strength. Bending moments because of unequal distribution of stress in the cross section also may be significant.

4. Local deviations of grain can be analyzed in terms of the portion of the cross section occupied, assuming uniform strain over the section and considering the different moduli of elasticity associated with the different local slopes.

5. For members with multiple slopes of grain, a transformed-area method using the stress interaction equation will permit reliable evaluation of the strength in tension.

6. Checks reduce the tensile strength of structural lumber when slope of grain is present. In the specimens studied, it was not proved whether there is a stress concentration effect in the checks that is additive to the stress concentrations caused by the end blocks.

7. Tensile strength tests of Douglas-fir and southern pine laminating stock showed a great range and some rather low values in both species.

8. The data presented in this report are limited in scope, and some of the questions need more study. Bending moments may be typically present in tension specimens of structural size and character; those introduced at the end connections can be reduced by longer specimens, but those caused by natural characteristics such as slope of grain may have to be recognized in a standard test method. Since shear and tension-perpendicular properties are important, they should receive careful attention in species evaluations. More study is needed on stress-concentration effects, particularly those associated with checks. All these are specific parts of the far-reaching problem of improved methods for grading wood tension members for strength and establishing realistic working stresses.

LITERATURE CITED

(1) American Society for Testing and Materials
1958. Standard Methods of Testing Small Clear Specimens of Timber. ASTM Designation D143-52.

(2) Kollmann, F.
1952. The Importance of Notching in Relation to Wood Strength. Holz als Roh-und Werkstoff, June 1952.

(3) Norris, C. B.
1955. Strength of Orthotropic Materials Subjected to Combined Stresses. Forest Products Lab. Report No. 1816.

(4) Norris, C. B., and McKinnon, P. F.
1956. Compression, Tension and Shear Tests on Yellow-Poplar Plywood Panels of Sizes That Do Not Buckle With Tests Made at Various Angles to the Face Grain. Forest Products Lab. Report No. 1328.

(5) U.S. Forest Products Laboratory
1955. Wood Handbook. U.S. Department of Agriculture, Agriculture Handbook No. 72.

(6) Ylinen, A.
1942. Measurement of Elongation in the Vicinity of Knots in Pine Wood. Holz als Roh-und Werkstoff, October 1942.

Table 1.--Results of tension tests of small clear Douglas-fir specimens with various slopes of grain (Specimens A)

Specimen No.	Moisture content	Specific gravity[1]	Slope of grain at failure	Tensile stress at proportional limit	Maximum tensile stress	Tension modulus of elasticity	Type of failure
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Percent		Degrees	P.s.i.	P.s.i.	1,000 p.s.i.	
1A1	10.6	0.48	14.1	4,380	6,020	1,130	Along grain
1A1X	10.1	.50	14.1	5,580	6,690	1,120	Do.
1A2	10.3	.49	11.3	5,240	9,020	1,420	Do.
1A3	10.5	.52	7.1	8,060	12,470	1,650	Do.
1A4	10.4	.49	6.2	9,700	15,780	1,600	Do.
1A5	10.3	.49	4.0	10,850	13,840	1,520	Across the grain
1A6	10.4	.49	4.5	12,650	15,190	1,760	Along grain
1A7	10.3	.51	2.9	10,090	13,550	1,930	Across the grain
1A8	10.7	.49	0	9,490	14,890	1,790	Do.
2A1	9.9	.50	14.1	4,210	7,850	1,110	Along grain
2A1X	10.0	.50	11.3	4,940	7,130	1,170	Do.
2A2	10.0	.50	12.4	7,260	10,030	1,320	Do.
2A3	9.8	.54	6.9	8,890	13,130	1,620	Do.
2A4	10.5	.52	5.7	10,100	14,400	1,610	Do.
2A5	10.2	.50	5.7	8,320	10,390	1,570	Do.
2A6	10.6	.51	4.2	9,780	11,170	1,740	Do.
2A7	10.7	.50	2.9	7,050	13,390	1,760	Do.
2A8	10.1	.48	1.7	11,230	20,220	1,780	Across the grain
3A1	10.5	.49	14.1	3,980	6,820	1,090	Along grain
3A1X	10.2	.47	14.3	4,160	6,100	1,080	Do.
3A2	10.8	.46	9.5	6,580	8,050	1,400	Do.
3A3	10.6	.48	7.1	7,240	11,710	1,590	Do.
3A4	10.1	.51	5.4	11,440	14,160	1,580	Do.
3A5	10.3	.51	8.0	8,930	11,120	1,530	Do.
3A6	10.2	.53	5.4	8,280	13,940	1,340	Do.
3A7	10.0	.53	6.4	7,650	11,680	1,310	Across the grain
3A8	11.2	.55	3.8	9,840	17,850	1,530	Do.
4A1	10.3	.46	16.2	4,280	6,480	760	Along grain
4A1X	10.5	.43	17.8	4,120	5,770	980	Do.
4A2	10.5	.45	7.1	5,760	7,780	1,400	Do.
4A3	10.7	.46	7.1	5,520	9,320	1,450	Do.
4A5	9.8	.42	4.5	9,800	13,460	1,540	Do.
4A6	10.1	.46	2.9	12,050	15,660	1,690	Across the grain
4A7	9.9	.43	4.2	8,110	11,080	1,350	Do.
4A8	10.1	.45	3.3	12,960	17,860	1,800	Do.
4A8X	9.5	.41	1.7	10,560	14,080	1,410	Do.
5A1	10.6	.48	14.1	4,530	6,520	1,120	Along grain
5A2	10.9	.48	11.3	4,790	8,480	1,200	Do.
5A3	11.0	.48	7.1	8,420	10,300	1,380	Do.
5A4	11.4	.51	6.4	10,600	12,440	1,580	Do.
5A5	9.9	.51	6.9	13,390	14,800	1,570	Do.
5A6	9.9	.51	6.9	7,680	10,670	1,420	Do.
5A7	9.8	.51	9.5	7,570	11,280	1,560	Across the grain
5A8	10.2	.51	3.8	11,840	17,350	1,560	Do.
5A8X	10.1	.49	4.7	10,230	17,050	1,700	Do.

[1] Based on ovendry weight and volume at test.

Table 2.--Results of tension tests of small clear Douglas-fir specimens with various slopes of grain (Specimens B)

Specimen No.	Slope of grain at failure	Tensile stress at proportional limit	Maximum tensile stress	Tension modulus of elasticity	Type of failure
(1)	(2)	(3)	(4)	(5)	(6)
	Degrees	P.s.i.	P.s.i.	1,000 p.s.i.	
1B2	9.5	5,590	8,120	1,640	Along grain
1B3	10.2	4,710	6,560	1,920	Do.
1B4	6.9	6,930	11,700	1,700	Do.
1B5	8.1	8,520	13,320	2,130	Do.
1B6	2.2	10,870	14,200	1,520	Across the grain
1B7	1.2	9,780	12,420	1,780	Do.
1B8	.6	10,380	12,920	1,660	Do.
2B1	14.1	3,050	6,650	1,080	Along grain
2B1X	16.0	4,070	6,380	1,090	Do.
2B2	9.6	5,910	10,800	1,290	Do.
2B3	10.2	6,140	10,210	1,720	Do.
2B4	7.2	9,230	13,600	1,440	Do.
2B5	5.7	6,110	9,170	2,160	Do.
2B6	4.0	11,770	14,950	1,570	Do.
2B7	7.5	8,490	12,500	1,890	Across the grain
2B8	0	8,960	13,440	1,440	Do.
3B1	14.2	4,570	6,340	1,320	Along grain
3B2	8.1	3,890	7,380	1,810	Do.
3B3	7.2	6,610	9,120	1,740	Do.
3B4	6.2	5,740	9,020	2,070	Do.
3B5	6.2	8,290	8,280	1,400	Do.
3B6	4.2	8,790	11,740	1,690	Do.
3B7	6.9	8,790	11,760	1,430	Across the grain
4B1	14.1	3,440	5,390	1,000	Along grain
4B1X	14.2	3,150	6,380	1,050	Do.
4B2	9.5	6,570	8,480	1,080	Do.
4B3	7.2	7,440	10,290	1,300	Do.
4B4	11.5	6,550	13,130	1,570	Do.
4B6	4.1	10,930	10,930	1,770	Do.
4B7	3.1	11,460	14,360	1,600	Across the grain
4B8	3.8	9,010	10,330	1,450	Do.
5B1	14.1	3,860	6,950	1,150	Along grain
5B1X	14.1	3,780	7,020	1,350	Do.
5B2	11.3	3,000	7,040	1,280	Do.
5B3	7.2	7,400	11,860	1,420	Do.
5B4	5.4	8,270	11,760	1,470	Across the grain
5B5	4.4	10,000	11,410	1,650	Across the grain and along grain
5B6	4.1	11,300	14,820	1,950	Do.
5B7	8.6	7,800	9,090	2,100	Across the grain
5B8	1.2	10,740	16,260	1,590	Do.

Table 3.--Results of static-bending tests of small clear Douglas-fir specimens matched to tension specimens (Specimens C)

Specimen No.	Moisture content	Specific gravity[1]	Stress at proportional limit	Modulus of rupture	Modulus of elasticity
(1)	(2)	(3)	(4)	(5)	(6)
	Percent		P.s.i.	P.s.i.	1,000 p.s.i.
1C1	10.4	0.49	8,600	13,260	1,660
1C2	10.3	.48	7,640	13,200	1,670
1C3	11.0	.48	6,580	13,860	1,860
1CX	10.1	.48	7,540	13,650	1,610
2C1	9.5	.53	7,510	16,350	1,920
2C2	10.4	.50	8,160	14,060	1,520
2C2X	10.4	.51	7,760	14,850	2,020
2C3	10.6	.52	9,650	15,520	2,100
3C2	10.3	.51	7,170	13,440	1,430
3C3	10.6	.52	7,160	13,840	1,540
3CX	10.1	.51	6,640	14,370	1,760
4C2	9.7	.43	7,240	11,440	1,420
4C3	9.8	.46	7,700	12,680	1,730
5C1	10.4	.50	8,190	13,900	1,970
5C2	9.5	.50	8,340	14,500	1,820
5C3	9.7	.50	5,820	13,680	1,660
5CX	10.5	.52	7,740	14,450	2,180

[1]Based on ovendry weight and volume at test.

Table 4.--Results of tension-perpendicular tests of small clear Douglas-fir specimens (Specimens D)

Specimen No.	Moisture content	Specific gravity[1]	Stress at proportional limit	Maximum tensile stress	Modulus of elasticity
(1)	(2)	(3)	(4)	(5)	(6)
	Percent		P.s.i.	P.s.i.	P.s.i.
1D1	9.8	0.49	630	920	53,000
1D2	10.6	.49	430	950	73,000
1D3	10.2	.48	720	880	59,000
2D1	9.6	.56	1,260	1,480	285,000
2D2	10.5	.53	870	1,020	232,000
2D3	10.3	.50	700	850	258,000
3D1	9.8	.51	1,020	1,140	124,000
3D2	10.4	.52	900	1,070	76,000
3D3	10.1	.51	1,100	1,470	196,000
4D1	10.0	.42	670	870	121,000
4D2	10.2	.45	350	800	65,000
4D3	9.5	.47	480	850	41,000
5D1	9.9	.49	....	1,100	157,000
5D2	10.1	.50	1,100	1,230	143,000
5D3	10.1	.52	990	1,360	202,000

[1]Based on ovendry weight and volume at test.

Table 5.--Results of block-shear tests of small clear Douglas-fir specimens (Specimens E)

Specimen No.	Moisture content	Specific gravity[1]	Maximum shearing stress
(1)	(2)	(3)	(4)
	Percent		P.s.i.
1E1	9.9	0.48	1,630
1E2	10.7	.46	1,600
1E3	10.5	.45	1,130
2E1	10.2	.50	2,010
2E2	10.6	.50	1,940
2E2X	9.9	.51	1,750
2E3	10.2	.50	1,840
3E1	10.5	.49	1,500
3E2	10.1	.48	1,460
3E3	10.8	.50	1,820
4E1	10.4	.46	1,540
4E2	10.5	.47	1,560
4E3	10.7	.44	1,650
5E1	10.2	.52	1,610
5E2	11.0	.50	1,860
5E3	9.8	.55	2,050

[1]Based on ovendry weight and volume at test.

Table 6.--Strength values of small clear Douglas-fir specimens A, D, and E, adjusted to average specific gravities

Board 1 - Average specific gravity 0.50		Board 2 - Average specific gravity 0.50		Board 3 - Average specific gravity 0.50		Board 4 - Average specific gravity 0.44		Board 5 - Average specific gravity 0.50	
Specimen No.	Adjusted strength	Specimen No.	Adjusted strength	Specimen No.	Adjusted strength	Specimen No.	Adjusted strength	Specimen No.	Adjusted strength
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	P.s.i.		P.s.i.		P.s.i.		P.s.i.		P.s.i.
1A1	6,200	2A1	8,080	3A1	7,040	4A1	6,100	5A1	6,910
1A1X	6,630	2A1X	7,170	3A1X	6,720	4A1X	5,980	5A2	8,790
1A2	9,180	2A2	10,120	3A2	9,070	4A2	7,550	5A3	10,840
1A3	11,670	2A3	11,690	3A3	12,530	4A3	8,780	5A4	11,730
1A4	15,840	2A4	13,510	3A4	13,900	4A5	14,790	5A5	14,260
1A5	14,080	2A5	10,620	3A5	10,950	4A6	14,230	5A6	10,440
1A6	15,510	2A6	11,170	3A6	12,690	4A7	11,620	5A7	11,230
1A7	14,680	2A7	13,780	3A7	10,660	4A8	16,880	5A8	16,610
1A8	15,640	2A8	24,290	3A8	14,460	4A8X	17,580	5A8X	17,260
1D1	940	2D1	1,220	3D1	1,110	4D1	940	5D1	1,140
1D2	980	2D2	940	3D2	1,020	4D2	780	5D2	1,230
1D3	950	2D3	880	3D3	1,450	4D3	750	5D3	1,230
1E1	1,720	2E1	2,020	3E1	1,540	4E1	1,460	5E1	1,530
1E2	1,760	2E2	1,960	3E2	1,540	4E2	1,440	5E2	1,840
1E3	1,280	2E2X	1,740	3E3	1,800	4E3	1,670	5E3	1,800
		2E3	1,890						

Table 7.--Dimensions of nominal 2- by 4-inch Douglas-fir tension specimens F, G, and H

Specimen No.	Nominal slope of grain		Length of cleat	Length of specimen
	Tangent	Degrees	In.	Ft. - In.
6H1	1 in 4	14.0	10	3 - 0
6H2	1 in 5	11.3	12	3 - 9
6G3	1 in 6	9.5	17	4 - 8
7H1	1 in 4	14.0	10	3 - 0
7H2	1 in 5	11.3	12	3 - 9
7G3	1 in 6	9.5	17	4 - 8
7F4	1 in 7	8.1	28	7 - 0
8H1	1 in 4	14.0	10	3 - 0
8H2	1 in 5	11.3	12	3 - 9
8G3	1 in 6	9.5	17	4 - 8
8F4	1 in 7	8.1	28	7 - 0

Table 8.--Results of tension tests of nominal 2- by 4-inch Douglas-fir specimens F, G, and H, with various slopes of grain

Specimen No.	Moisture content	Specific gravity[1]	Slope of grain at failure	Maximum tensile stress	Tension modulus of elasticity
(1)	(2)	(3)	(4)	(5)	(6)
	Percent		Degrees	P.s.i.	1,000 p.s.i.
6H1	11.9	0.55	9.7	3,160	2,160
6H2	11.5	.55	12.2	2,690	1,920
6G3	11.7	.53	11.1	4,160	1,660
7H1	10.6	.43	11.3	2,560	1,050
7H2	10.6	.44	14.1	3,180	1,490
7G3	11.6	.42	9.9	4,380	1,350
7F4	11.4	.44	8.5	6,080	1,580
8H1	11.6	.46	14.7	2,530	1,170
8H2	11.3	.48	14.3	1,860	1,160
8G3	11.7	.48	11.3	3,630	1,350
8F4	11.4	.46	10.5	6,470	1,530

[1]Based on ovendry weight and volume at test.

Table 9.--Results of tests of small clear Douglas-fir specimens matched to structural specimens F, G, and H

Specimen No.	Moisture content	Specific gravity[1]	Stress at proportional limit	Maximum tensile stress	Modulus of rupture	Modulus of elasticity	Maximum stress in tension perpendicular	Maximum shearing stress	Slope of grain at failure	Type of failure
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Percent		P.s.i.	P.s.i.	P.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.	Degrees	
SPECIMENS A - TENSION PARALLEL										
6A8			12,670	17,880		2,850			6.4	Splintered
7A8	10.9	0.43	9,440	12,470		2,000			1.7	Across the grain
8A8	11.4	.43	10,320	15,280		1,830			2.9	Along and across the grain
SPECIMENS C - STATIC BENDING										
6C	11.3	.52	9,020		14,580	2,000				
7C	11.3	.43	6,860		10,710	1,470				
8C	10.9	.45	6,540		10,940	1,610				
SPECIMENS DA - TENSION PERPENDICULAR										
6DA	11.6						240			
7DA	10.4						360			
7DAX	9.3						290			
8DA	10.5						340			
SPECIMENS E - SHEAR PARALLEL										
6E	9.5	.56						1,360		
7E	10.9	.42						1,030		
8E	11.4	.45						1,020		

[1]Based on ovendry weight and volume at test.

Table 10.--Comparison of computed with observed tensile strengths of nominal 2- by 4-inch Douglas-fir specimens F, G, and H

Specimen No.	Maximum tensile stress direct	Stress from bending moment	Total stress, direct plus bending moment	Computed maximum tensile stress	Ratio of observed to computed stress
(1)	(2)	(3)	(4)	(5)	(6)
	P.s.i.	P.s.i.	P.s.i.	P.s.i.	Percent
6H1	3,160	350	3,510	6,240	56
6H2	2,690	280	2,970	4,490	66
6G3	4,160	800	4,960	5,130	97
7H1	2,560	260	2,820	4,710	60
7H2	3,180	70	3,250	3,620	90
7G3	4,380	270	4,650	5,400	86
7F4	6,080	380	6,460	6,350	102
8H1	2,530	180	2,710	3,440	79
8H2	1,860	200	2,060	3,640	57
8G3	3,630	300	3,930	4,820	82
8F4	6,470	100	6,570	5,450	120

Table 11.--Results of tensile evaluation of nominal 2- by 4-inch Douglas-fir specimens with local grain deviations

Specimen No.	Type of specimen	Length of specimen	Length of cleat	Computed stress at redistribution level		Observed stress at failure		Ratio of observed to computed stress at final failure
				Initial	Final	Initial	Final	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		In.	In.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	Percent
18	F	97	28	3,640	4,620	....	3,970	86
19	G	58	17	....	4,040	....	2,910	72
20	H	42	12	....	5,890	....	5,700	97
21	F	97	28	2,310	2,810	1,640	1,830	65
22	H	36	10	3,170	8,040	4,310	7,820	98

Table 12.--Results of tests of small clear Douglas-fir specimens matched to structural specimens with local grain deviations

Specimen No.	Moisture content	Specific gravity[1]	Stress at proportional limit	Maximum tensile stress	Modulus of rupture	Modulus of elasticity	Maximum stress in tension perpendicular	Maximum shearing stress	Slope of grain at failure	Type of failure
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Percent		P.s.i.	P.s.i.	P.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.	Degrees	
					SPECIMENS A - TENSION PARALLEL					
18A8	12.2	0.48	8,520	13,550		1,260			0	Across the grain
19A8	11.6	.40	11,680	13,740		1,740			1.2	Do.
20A8	11.7	.39	12,780	15,860		1,740			1.2	Across the grain and with grain
21A8	11.8	.42	7,840	10,220		1,440			2.9	Across the grain
21A8X	12.0	.39	9,180	12,880		1,550			.6	Do.
22A8	12.7	.48	6,210	14,470		2,100			0	Do.
					SPECIMENS C - STATIC BENDING					
18C	11.8	.50	6,540		12,250	1,670				
19C	11.9	.41	5,660		10,100	1,630				
20C	11.8	.41	5,820		9,480	1,500				
21C	12.7	.38	3,750		7,950	1,170				
21CX	11.7	.39	4,460		9,030	1,420				
22C	13.8	.48	5,090		10,910	1,740				
					SPECIMENS DA - TENSION PERPENDICULAR					
18DA	11.8						290			
19DA	12.6						480			
20DA	13.0						480			
21DA	12.3						340			
22DA	12.4						340			
					SPECIMENS E - SHEAR PARALLEL					
18E	11.8	.47						1,420		
19E	11.6	.40						1,280		
20E	11.9	.37						1,080		
21E	11.4	.38						910		
22E	12.9	.50						750		

[1] Based on ovendry weight and volume at test.

Table 13.--Results of tension tests of nominal 2- by 4-inch Douglas-fir specimens laminated with two slopes of grain

Specimen No.	First lamination			Second lamination			Maximum tensile load	Load correction for bending moment	Corrected maximum tensile load	Computed maximum tensile load	Ratio corrected to computed load
	Moisture content	Specific gravity[1]	Slope of grain at failure	Moisture content	Specific gravity[1]	Slope of grain at failure					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Percent		Degrees	Percent		Degrees	Lb.	Lb.	Lb.	Lb.	Percent
34M12	10.9	0.47	14.0	10.9	0.51	9.1	21,520	1,880	23,400	30,870	76
36M13	9.8	.47	14.9	9.5	.48	7.4	22,830	1,090	23,920	30,170	79
36M14	9.9	.47	13.2	10.0	.50	7.6	21,670	1,960	23,630	35,090	67
45M23	11.0	.49	10.8	11.7	.51	8.1	23,160	4,870	28,030	49,470	57
33N11	11.2	.52	15.9	10.5	.50	15.9	19,430	1,730	21,160	29,120	73
34N12	9.6	.49	13.2	9.8	.52	10.3	18,060	1,050	19,110	36,030	53
35N13	10.6	.53	15.3	11.3	.49	7.1	26,480	1,920	28,400	45,810	62
36N14	10.1	.49	14.7	9.6	.50	5.5	29,940	1,100	31,040	30,080	101
44N22	9.9	.49	10.3	10.0	.49	8.9	28,040	none	28,040	40,430	70
45N23	10.5	.47	9.6	11.0	.49	8.1	20,390	1,850	22,240	49,520	45
Average..									24,900	37,700	66

[1]Based on ovendry weight and volume at test.

Table 14.--Results of tests of small clear Douglas-fir specimens from boards used in laminating structural specimens with two slopes of grain

Specimen No.	Moisture content	Specific gravity[1]	Stress at proportional limit	Maximum tensile stress	Modulus of rupture	Modulus of elasticity	Maximum stress in tension perpendicular	Maximum shearing stress	Slope of grain at failure
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Percent		P.s.i.	P.s.i.	P.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.	Degrees
SPECIMENS A - TENSION PARALLEL[2]									
23A8	10.1	0.47	8,530	18,580		2,130			0
24A8	9.9	.50	7,940	13,050		1,820			2.9
25A8	10.9	.51	8,990	14,100		1,140			0
26A8	9.9	.50	10,440	14,700		1,790			2.9
SPECIMENS C - STATIC BENDING									
23C	10.5	.48	8,040		13,650	2,130			
24C	10.6	.50	6,920		14,250	1,720			
25C	11.2	.45	5,340		8,940	1,220			
26C	9.7	.50	7,400		13,150	1,650			
SPECIMENS D - TENSION PERPENDICULAR									
23D	9.4	.49	410			79	600		
24D	10.4	.53	620			122	1,180		
25D	10.3	.48	390			57	740		
26D	9.4	.53	....			66	990		
SPECIMENS E - SHEAR PARALLEL									
23E	10.2	.49						1,550	
24E	9.6	.49						1,380	
25E	11.1	.46						1,470	
26E	9.6	.51						1,950	

[1]Based on ovendry weight and volume at test.

[2]All specimens showed failure across the grain in test.

Table 15.--Results of tension tests of nominal 2- by 4-inch Douglas-fir specimens with slope of grain and checks

Specimen No.	Length of specimen: Over-all	Length of specimen: Length of cleat	Transition radius of end block	Observed slope of grain: Check at front face	Observed slope of grain: Check at rear face	Observed slope of grain: Unchecked portion at failure	Maximum load at failure	Maximum tensile stress: Observed	Maximum tensile stress: Corrected for eccentricity	Maximum tensile stress: Computed	Ratio corrected to computed strength
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	In.	In.	In.	Degrees	Degrees	Degrees	Lb.	P.s.i.	P.s.i.	P.s.i.	Percent
UNCHECKED SPECIMENS											
10K01	36	10	None	......	......	15.9	10,950	2,220	2,220	4,160	53
11K01	36	10	None	......	......	16.9	11,610	2,370	2,370	3,120	76
12K02	42	10	None	......	......	12.8	18,920	3,830	3,830	5,200	74
13K03	67	19	16	......	......	7.4	19,300	3,780	3,780	7,450	51
CHECKED SPECIMENS WHICH FAILED AWAY FROM CHECKS											
11K11	36	10	None	16.9	......	16.4	11,470	2,260	2,360	3,250	73
13K13	67	19	16	6.0	......	6.6	20,720	4,060	4,240	7,990	53
10L11	36	10	None	15.9	15.9	17.9	9,800	1,920	1,920	3,560	54
10L21	36	10	None	15.5	15.5	16.9	17,140	3,370	3,370	3,870	87
11L11	36	10	None	14.7	15.1	14.9	10,740	2,150	2,150	3,580	60
14L13	67	19	16	10.0	9.0	11.3	28,100	5,530	5,530	5,420	102
CHECKED SPECIMENS WHICH FAILED AT CHECKS 1/4 INCH DEEP											
10K11	36	10	None	17.1	......	15.9	15,700	3,100	3,240	3,490	93
12K12	42	10	None	11.8	......	13.7	25,420	5,080	5,310	5,130	104
12L12	42	10	None	11.3	10.3	....	33,430	6,560	6,560	6,560	100
CHECKED SPECIMENS WHICH FAILED AT CHECKS 1/2 INCH DEEP											
10K21	36	10	None	14.0	......	15.9	12,950	2,600	2,820	3,350	84
11K21	36	10	None	15.9	......	14.7	15,270	3,060	3,320	2,960	112
12K22	42	10	None	11.3	......	12.5	18,960	3,800	4,130	5,080	81
13K23	67	19	16	5.6	......	2.9	23,870	4,680	5,080	7,070	72
17K24	85	28	80	5.7	......	....	25,570	5,020	5,450	7,380	74
11L21	36	10	None	14.7	15.1	....	14,580	2,870	2,870	2,880	100
12L22	42	10	None	11.9	10.8	....	23,420	4,700	4,700	5,520	85
17L24	85	28	80	6.2	5.5	....	23,470	4,610	4,610	7,200	64
CHECKED SPECIMENS WHICH FAILED AT CHECKS 11/16 INCH DEEP											
10K31	36	10	None	14.0	......	20.3	13,520	2,680	3,140	2,500	126
11K31	36	10	None	14.7	......	15.9	11,330	2,240	2,460	2,490	99
12K32	42	10	None	11.3	......	....	13,930	2,760	3,030	5,090	60
14K33	67	19	16	9.5	......	8.7	15,760	3,100	3,410	5,650	60
15K34	85	28	80	7.1	......	4.8	27,840	5,480	6,020	6,500	93
15K35	85	28	80	5.4	......	6.0	26,300	5,170	5,680	7,690	74
17K36	85	28	80	3.9	......	....	34,440	6,740	7,400	8,960	83
10L31	36	10	None	17.9	15.9	....	9,080	1,810	1,810	3,000	60
11L31	36	10	None	13.1	13.7	....	15,820	3,130	3,130	3,140	100
12L32	42	10	None	11.9	11.1	....	22,460	4,480	4,480	4,990	90
14L33	67	19	16	10.9	10.1	9.8	22,020	4,330	4,330	4,500	96
15L34	85	28	80	5.3	5.3	....	37,230	7,320	7,320	8,160	90
15L35	85	28	80	4.8	4.3	....	43,950	8,640	8,640	8,720	99
16L36	85	28	80	6.7	8.7	....	29,430	5,800	5,800	7,510	77

Table 16.--Results of tests of small clear Douglas-fir specimens matched to structural specimens with slope of grain and checks

Specimen No.	Moisture content	Specific gravity[1]	Stress at proportional limit	Maximum tensile stress	Modulus of rupture	Modulus of elasticity	Maximum stress in tension perpendicular	Maximum shearing stress	Slope of grain at failure	Type of failure
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Percent		P.s.i.	P.s.i.	P.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.	Degrees	
SPECIMENS A - TENSION PARALLEL										
10A8	12.4	0.55	6,230	12,810		1,260			0	Across the grain
11A8	12.5	.47	10,170	16,400		1,660			6.4	Do.
12A8	12.6	.56	14,580	21,500		2,120			0	Do.
13A8	11.2	.42	9,860	12,750		1,410			0	Do.
14A8	12.2	.54	12,260	16,650		1,950			2.4	Do.
15A8	....	....	6,400	8,000		1,200			3.8	Along grain
16A8	12.9	.65	9,120	11,550		1,510			3.8	Across the grain
17A8	10.9	.41	8,700	10,150		1,450			2.9	Splintered
SPECIMENS C - STATIC BENDING										
10C	13.1	.53	4,530		12,100	1,160				
11C	12.5	.46	5,770		10,650	1,540				
12C	12.3	.55	6,240		15,050	1,960				
13C	11.5	.41	5,590		9,180	1,280				
14C	11.6	.54	5,840		13,350	1,780				
15C	12.2	.47	5,040		10,840	1,610				
16C	13.3	.57	5,300		13,150	1,500				
17C	11.6	.41	5,920		10,100	1,120				
SPECIMENS DA - TENSION PERPENDICULAR										
10DA	12.8						450			
10DAX	13.0						380			
11DA	11.6						390			
12DA	12.3						360			
13DA	11.3						350			
14DA	11.7						290			
15DA	11.5						380			
16DA	12.9						370			
17DA	11.0						340			
17DAX	10.7						280			
SPECIMENS E - SHEAR PARALLEL										
10E	12.7	.50						1,470		
11E	12.5	.45						1,090		
12E	12.1	.58						1,710		
13E	11.6	.41						1,090		
14E	12.2	.55						1,340		
15E	11.6	.49						1,370		
16E	12.8	.59						1,530		
17E	11.2	.42						1,030		

[1] Based on ovendry weight and volume at test.

Table 17.--Tensile strength of nominal 1- by 6-inch Douglas-fir laminating stock

Specimen No.	Specific gravity[1] "a" end	Specific gravity[1] "b" end	Moisture content "a" end	Moisture content "b" end	Tensile stress At initial failure	Tensile stress At maximum load	Initial failure End	Initial failure Type or apparent cause
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
			Percent	Percent	P.s.i.	P.s.i.		
A-1	0.42	0.51	10.1	10.2	3,780	4,310	b	1-inch knot near edge
A-2	.54	.41	9.5	10.0	5,040	5,540	a	Steep local cross grain
A-4	.43	.44	9.5	11.4	5,700	7,390	a	Brash tension
A-5	.49	.34	10.5	9.7	....	5,510	b	Brash tension
A-6	.52	.34	10.1	9.8	....	4,490	b	Brash tension across width
A-8	.44	.46	9.3	9.5	4,520	5,140	a	Brash tension 2/3 of width
A-9	.37	.53	9.0	9.2	....	5,840	a	Brash tension 1/3 of width
A-11	.46	.44	10.4	9.5	3,240	3,910	b	Cross grain at 7/8-inch knot
A-12	.46	.45	10.2	9.8	3,980	4,370	b	Cross grain at 3/4-inch knot
A-16	.54	.46	9.6	11.0	....	5,880	a	Tension and grip failure
A-17	.42	.50	9.5	9.3	4,800	5,600	a	Tension at burls
A-18	.50	.44	9.1	9.4	....	7,160	b	Brash tension
A-19	.54	.38	10.8	9.2	5,380	5,660	b	Brash tension
A-20	.56	.36	10.4	9.1	2,850	3,220	b	3/4-inch knot near edge
B-4	.47	.51	10.8	10.5	5,180	10,600	b	Damage by grips
B-5	.45	.48	13.4	11.2	....	4,690	a	Local cross grain 1:2
B-6	.51	.51	10.1	13.2	....	7,310	a	Splintering tension
B-7	.45	.45	12.6	13.6	2,940	3,810	b	Brash tension and spiral grain, 1:10
B-8	.54	.44	14.2	13.1	....	4,880	b	3 knots in same cross section
B-10	.59	.46	12.7	11.3	5,060	6,050	b	1/2-inch knot
B-11	.48	.45	10.9	10.2	....	5,630	a	7/8-inch knot
B-12	.38	.44	12.5	11.0	....	6,770	a-b	Brash tension
B-13	.43	.33	9.2	12.6	....	6,660	a	Tension and possible decay
B-15	.51	.49	12.1	9.5	....	6,130	a	Brash tension and diagonal grain, 1:10
B-16	.42	.52	14.0	12.7	....	5,240	b	Cross grain
B-17	.61	.46	12.8	13.2	4,140	4,780	b	Cross grain, 1:15 and 1:9
B-18	.42	.43	13.3	13.8	5,500	6,290	a	Two 7/8-inch knots
B-19	.41	.60	13.0	12.6	2,850	4,840	a	5/8-inch knot
C-1	.57	.40	10.2	10.2	2,880	6,270	b	1-inch knot near grips
C-8	.48	.47	11.8	11.7	....	7,550	a-b	Pin knots and split
C-11	.50	.48	11.4	13.0	....	6,380	b	1/2-inch knot near edge
C-12	.50	.58	12.5	9.9	5,610	7,600	a	Local cross grain
C-13	.46	.46	10.5	11.7	5,920	6,490	a	3/4-inch knot
C-16	.58	.56	12.0	12.0	....	5,570	b	Knot in grips
C-17	.53	.44	11.2	10.9	....	3,360	b	Steep local cross grain
C-18	.49	.49	11.1	11.1	5,540	5,640	a	3/4-inch knot
C-19	.53	.47	11.5	11.2	2,230	5,180	b	Local cross grain
C-20	.46	.41	11.4	11.2	....	4,650	b	Brash tension

[1]Based on ovendry weight and volume at test.

Table 18.--Tensile strength of nominal 1- by 6-inch and 2- by 4-inch southern yellow pine laminating stock

Specimen No.	Specific gravity[1] "a" end	Specific gravity[1] "b" end	Moisture content "a" end	Moisture content "b" end	Tensile stress At initial failure	Tensile stress At maximum load	Initial failure End	Initial failure Type or apparent cause
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
			Percent	Percent	P.s.i.	P.s.i.		
SPECIMENS 3/4 BY 5-1/2 INCHES								
D-2	0.52	0.55	10.7	10.9	....	7,810	a	Grip
D-3	.59	.58	12.3	10.4	....	6,900	b	Local cross grain
D-4	.52	.51	11.9	10.6	....	7,460	b	Brash tension
D-5	.58	.47	10.4	11.8	....	8,440	b	Grip
D-6	.50	.48	12.1	10.7	....	6,640	b	Brash tension
D-7	.50	.51	12.2	10.8	....	5,330	a	Pin knot
D-9	.46	.57	11.0	10.7	....	7,000	a	Local cross grain
D-10	.49	.50	10.4	11.0	....	7,430	b	Brash tension
D-11	.48	.52	11.0	12.4	....	7,120	a	Slivered off
D-12	.53	.56	12.3	10.8	....	9,020	a	Local cross grain
D-26	.43	.48	10.7	12.4	....	4,240	a	Knot
D-27	.55	.44	10.7	10.8	....	6,840	b	Knot
D-29	.44	.53	12.6	12.9	....	6,550	b	Pitch pocket
D-30	.40	.57	10.3	10.9	....	1,880	b	Knot
D-34	.48	.51	10.7	10.1	5,240	6,040	a	Local cross grain
D-35	.47	.54	13.2	12.9	....	10,000	b	Brash tension
D-36	.48	.53	12.4	12.3	....	6,560	a	Local cross grain
D-38	.45	.49	10.5	12.9	....	7,760	b	Brash tension
D-39	.52	.54	13.4	14.1	....	9,440	b	Grip
D-40	.56	.45	13.5	10.6	....	9,220	b	Grip
D-41	.52	.48	11.4	14.0	....	7,230	a	Grip
D-42	.66	.53	12.6	12.3	....	5,160	b	Knots
D-43	.49	.52	13.0	11.1	....	4,860	b	Knots
D-44	.64	.53	12.7	11.2	....	7,720	b	Local cross grain
D-45	.54	.49	10.4	12.0	5,700	6,330	b	Local cross grain
D-46	.51	.57	13.1	10.5	....	8,010	a	Knot
D-48	.53	.51	10.3	11.0	....	5,690	b	Spiral grain 1:7
D-49	.55	.52	10.5	10.2	....	5,660	a	Brash tension
D-50	.54	.47	10.8	10.4	....	7,210	b	Brash tension
D-51	.48	.54	12.1	10.3	....	7,440	a	Local cross grain
D-53	.47	.48	10.2	10.7	....	7,400	a	Grip
D-54	.43	.56	10.5	10.7	....	4,620	a	Knot
D-55	.47	.56	11.5	13.3	....	8,080	a	Grip
D-56	.53	.54	12.7	12.2	....	6,440	a	Brash tension
D-57	.49	.42	12.0	13.4	....	7,150	b	Knot
D-58	.51	.48	10.3	13.1	....	8,490	b	Grip
D-59	.52	.50	12.4	11.6	....	7,670	b	Diagonal grain
D-60	.51	.52	12.8	13.0	....	5,680	a-b	Brash tension
D-61	.60	.53	12.6	11.9	7,520	8,740	b	Local cross grain
D-62	.54	.49	13.7	11.3	....	7,380	b	Brash tension
D-64	.54	.61	13.5	13.6	....	8,000	b	Brash tension
SPECIMENS 1-5/8 INCHES NECKED TO 3-1/2 INCHES								
D-13	.49	.50	13.2	12.2	....	7,050	a	Local cross grain
D-14	.58	.64	....	12.8	....	9,300	b	Grip, cross grain, 1:7
D-16	.52	.49	10.6	11.1	....	7,420	b	Grip
D-18	.51	.55	10.4	12.7	....	5,260	a	Knot
D-19	.50	.51	12.3	13.4	....	7,440	a	Knot
[2]D-20	.49	.50	11.3	12.7	....	3,580	b	Grip
D-21	.48	.46	10.5	10.7	....	6,540	a	Knot
D-22	.50	.52	10.9	10.7	6,900	7,060	b	Spiral grain 1:7

[1]Based on ovendry weight and volume at test.

[2]Specimen was tested in 5-1/2-inch width without necking down, and had excessive crushing in the grips.

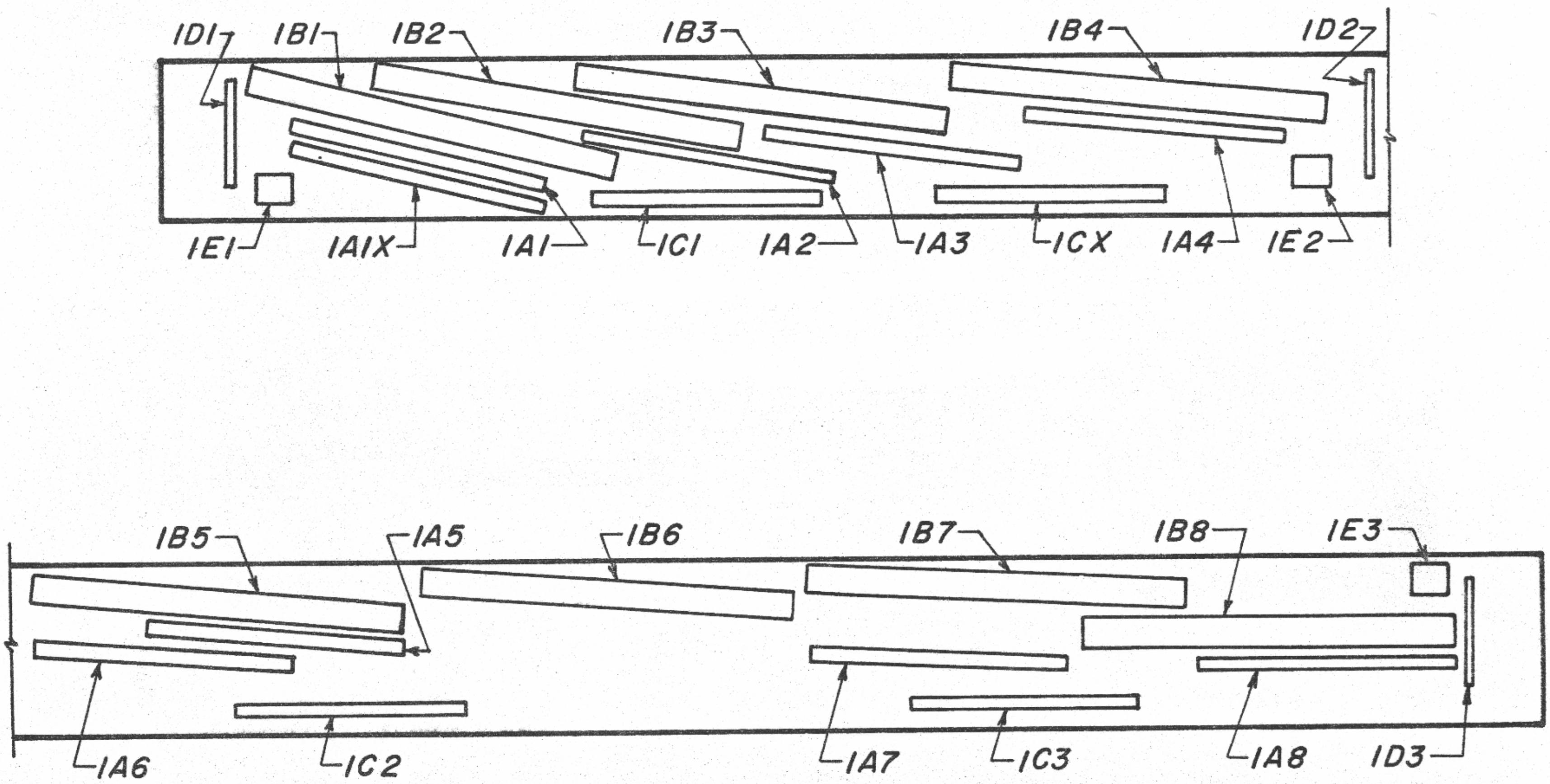


Figure 1. --Typical layout for cutting small clear specimens from the two halves of a board. A are standard tension-parallel specimens, B are modified tension-parallel, C are static bending, D are tension perpendicular to grain, and E are block shear parallel to grain.

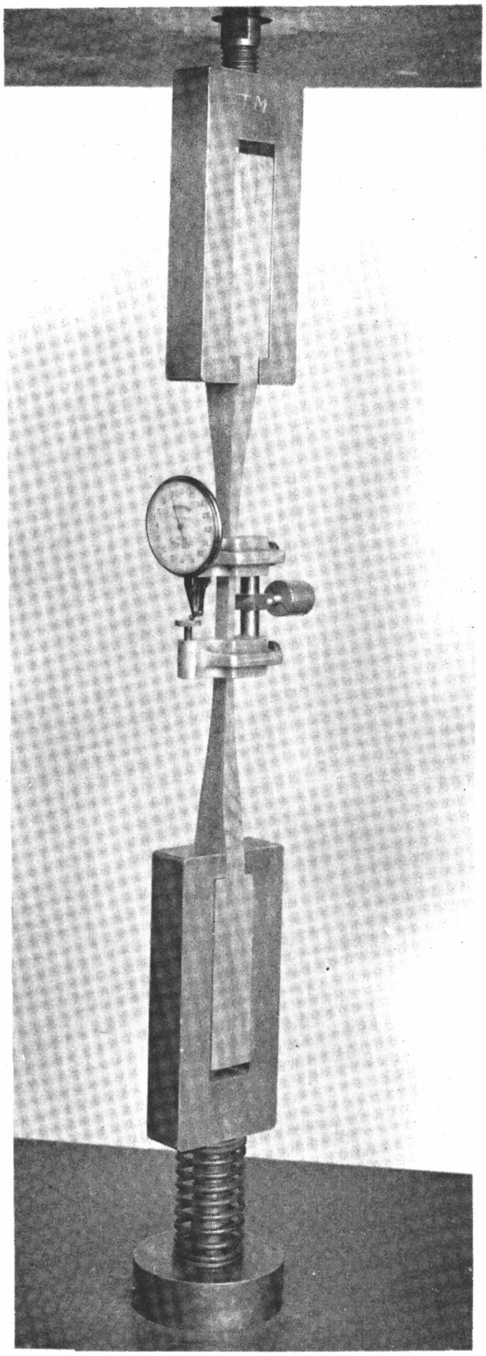


Figure 2. --Tension-parallel specimen (A) in test.

ZM 89843 F

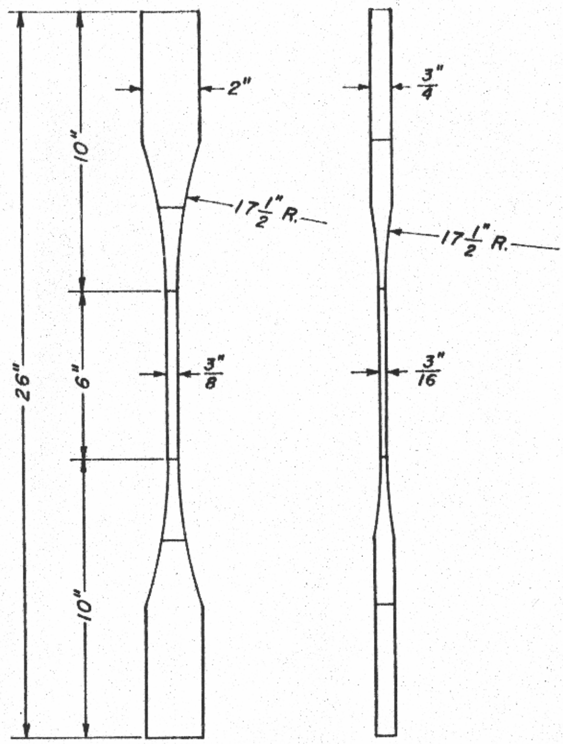


Figure 3.--Sketch of modified tension-parallel (B) specimen.

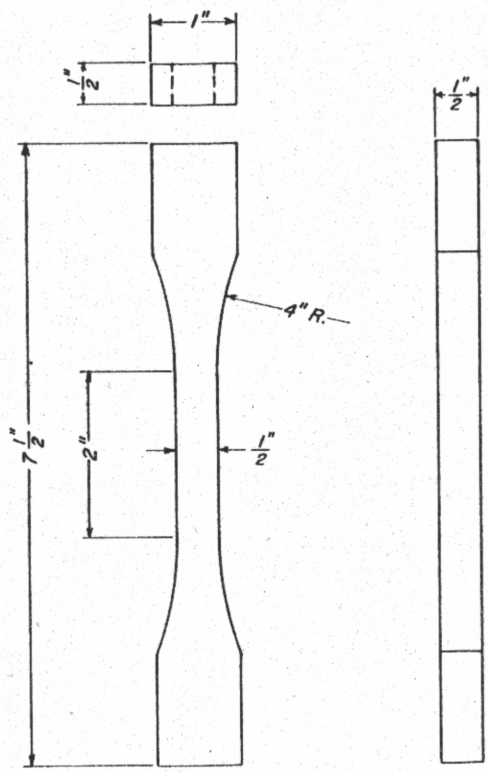


Figure 4.--Sketch of tension-perpendicular (D) specimen.

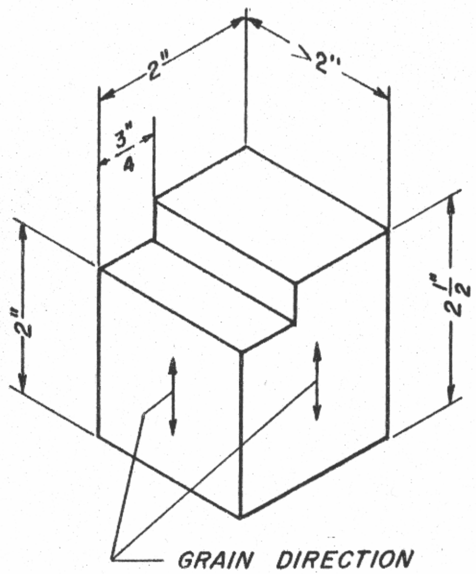


Figure 5. --Sketch of block shear (E) specimen.

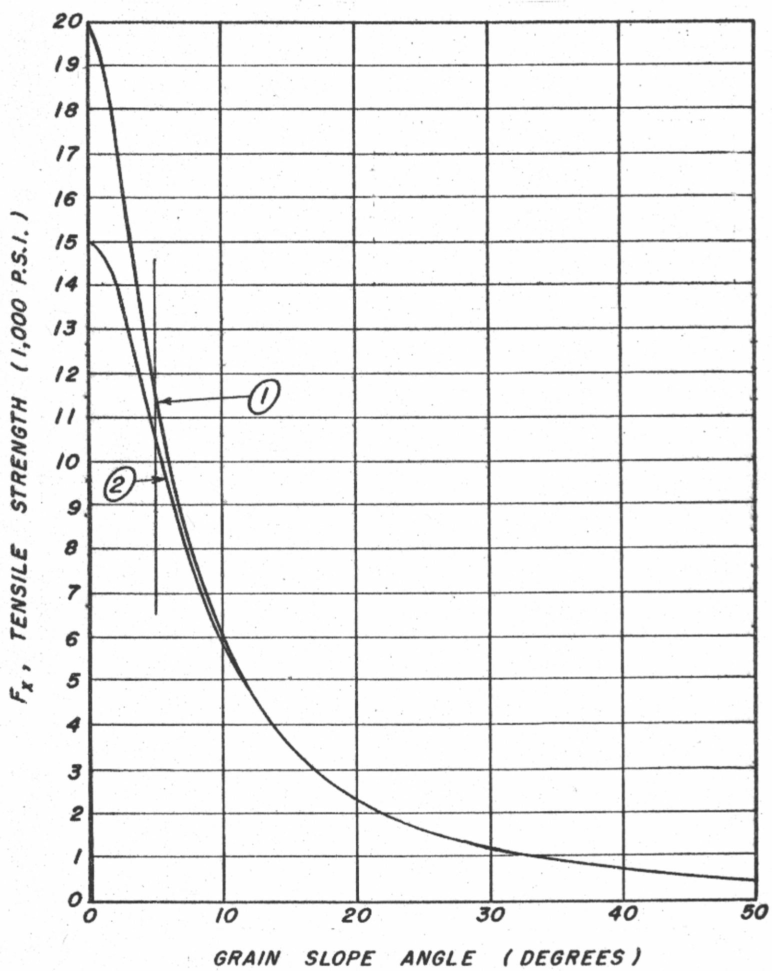


Figure 6. --Calculated values of tensile strength F_x when the tension parallel value was 20,000 pounds per square inch (curve 1) or 15,000 pounds per square inch (curve 2).

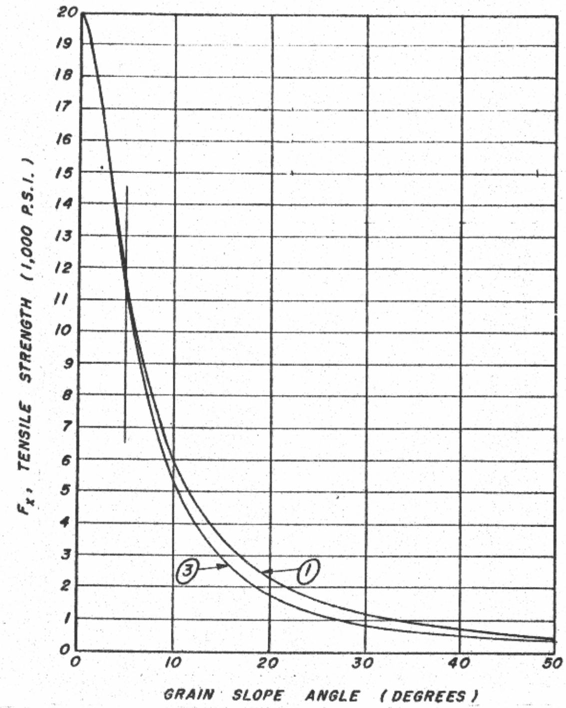


Figure 7.--Calculated values of tensile strength F_x when the tension perpendicular value was 340 pounds per square inch (curve 1) or 255 pounds per square inch (curve 3).

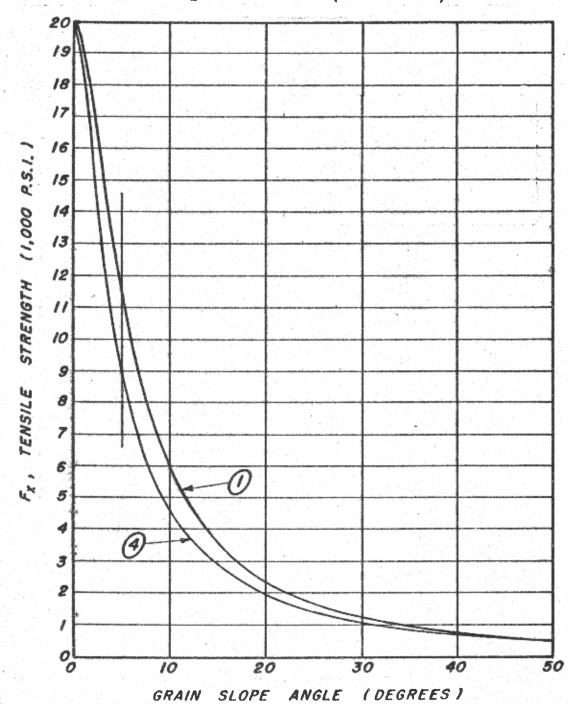


Figure 8.--Calculated values of tensile strength F_x when the shear strength was 1,160 pounds per square inch (curve 1) or 870 pounds per square inch (curve 4).

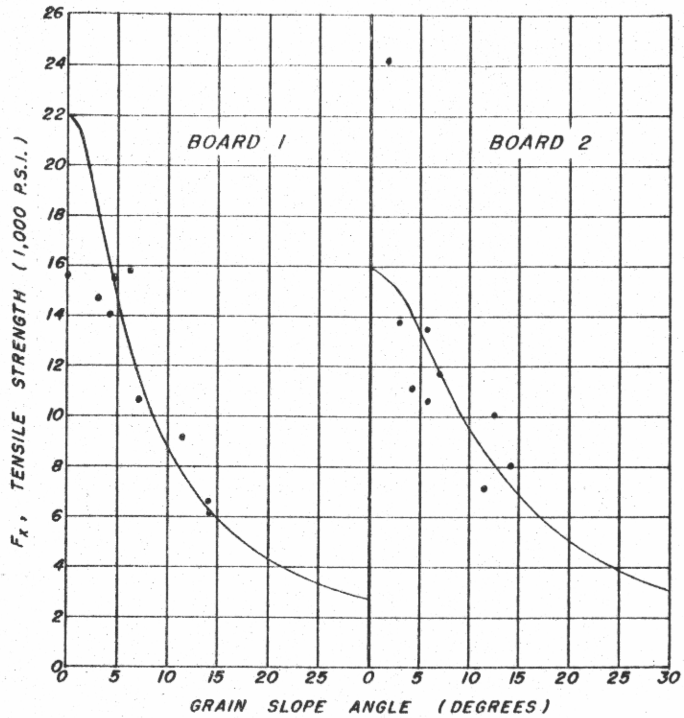


Figure 9. --Observed strength values of tension-parallel (A) specimens at various angles to the grain in board 1 and board 2, plotted against the curve calculated by the interaction formula.

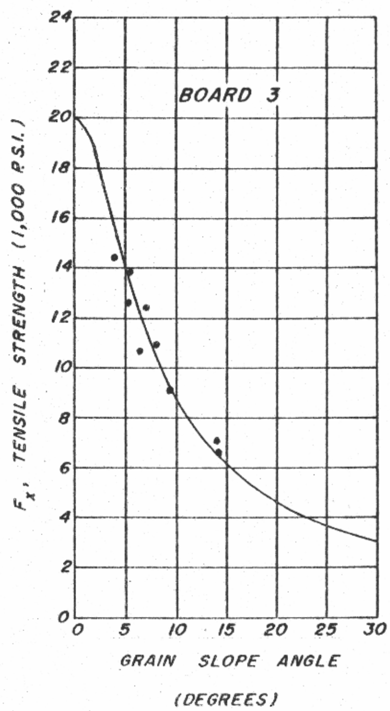


Figure 10. --Observed strength values of tension specimens (A) at various angles to the grain in board 3, plotted against the curve calculated by the interaction formula.

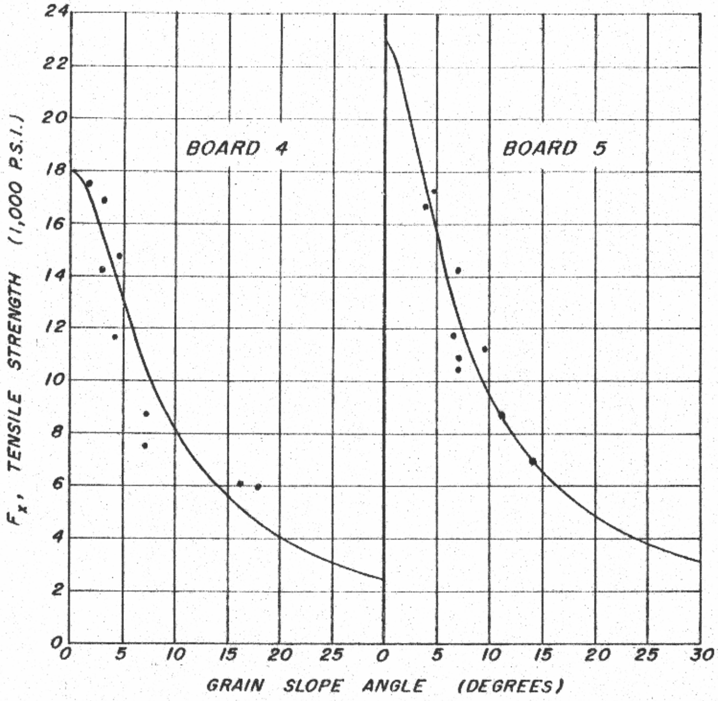


Figure 11. --Observed strength values of tension specimens (A) at various angles to the grain in boards 4 and 5, plotted against the curve calculated by the interaction formula.

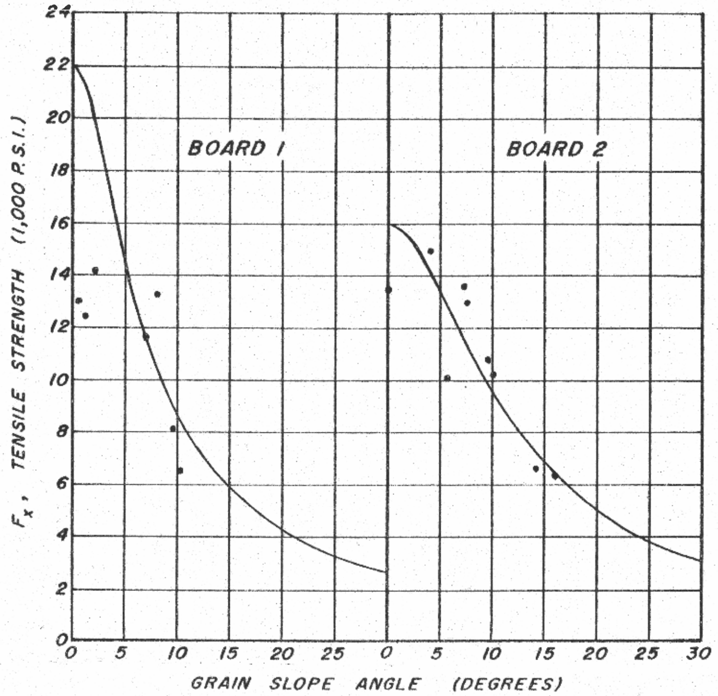


Figure 12. --Observed values of tension specimens (B) at various angles to the grain in boards 1 and 2, plotted against the curve calculated by the interaction formula.

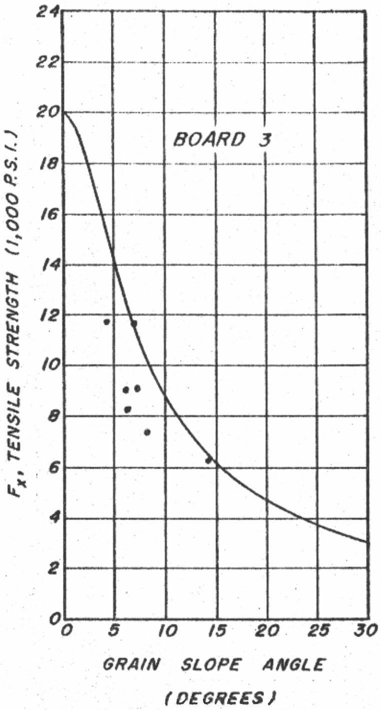


Figure 13. --Observed values of tension specimens (B) at various angles to the grain in board 3, plotted against the curve calculated by the interaction formula.

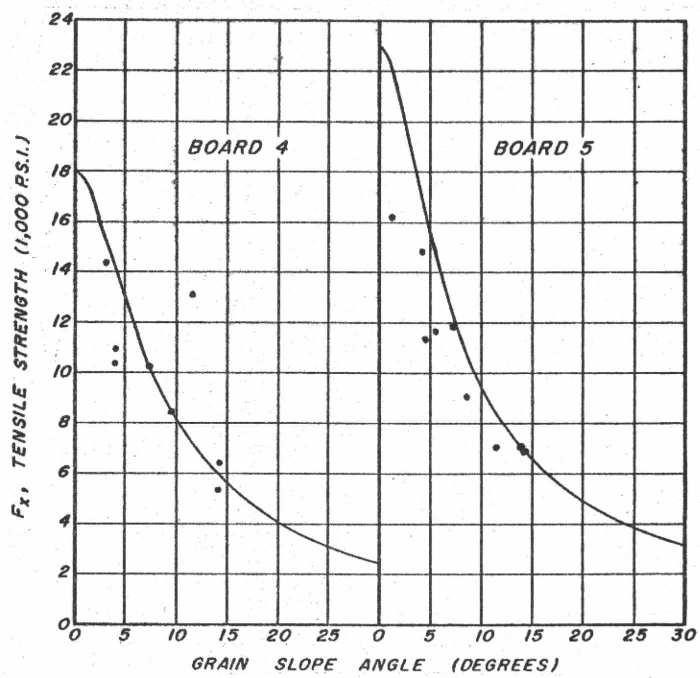


Figure 14. --Observed values of tension specimens (B) at various angles to the grain in boards 4 and 5, plotted against the curve calculated by the interaction formula.

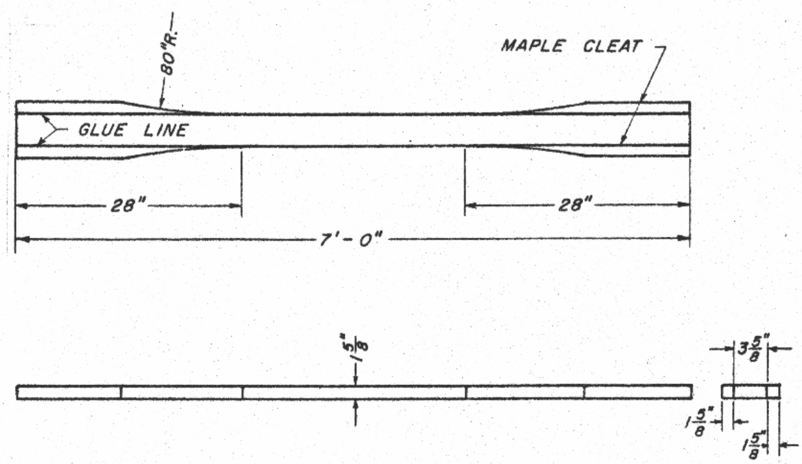


Figure 15.--Sketch of nominal 2- by 4-inch tension (F) specimen.

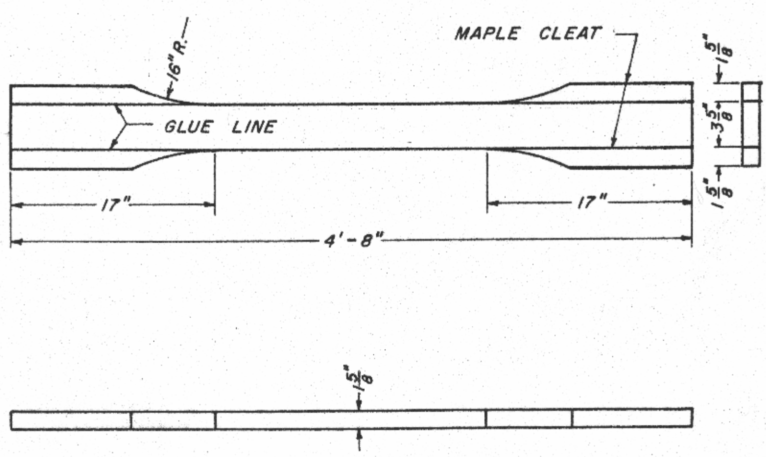


Figure 16.--Sketch of nominal 2- by 4-inch tension (G) specimen.

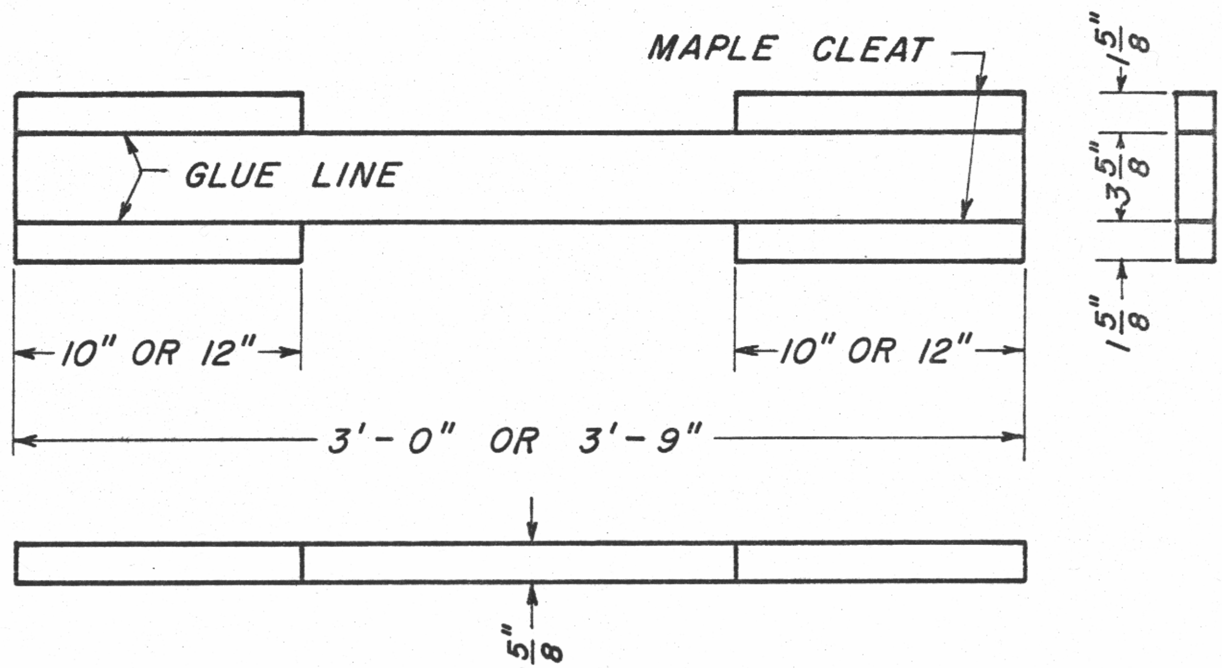


Figure 17.--Sketch of nominal 2- by 4-inch tension (H) specimen. The 10-inch cleat was used with the 3-foot specimen; the 12-inch cleat with the 3-foot 9-inch specimen.

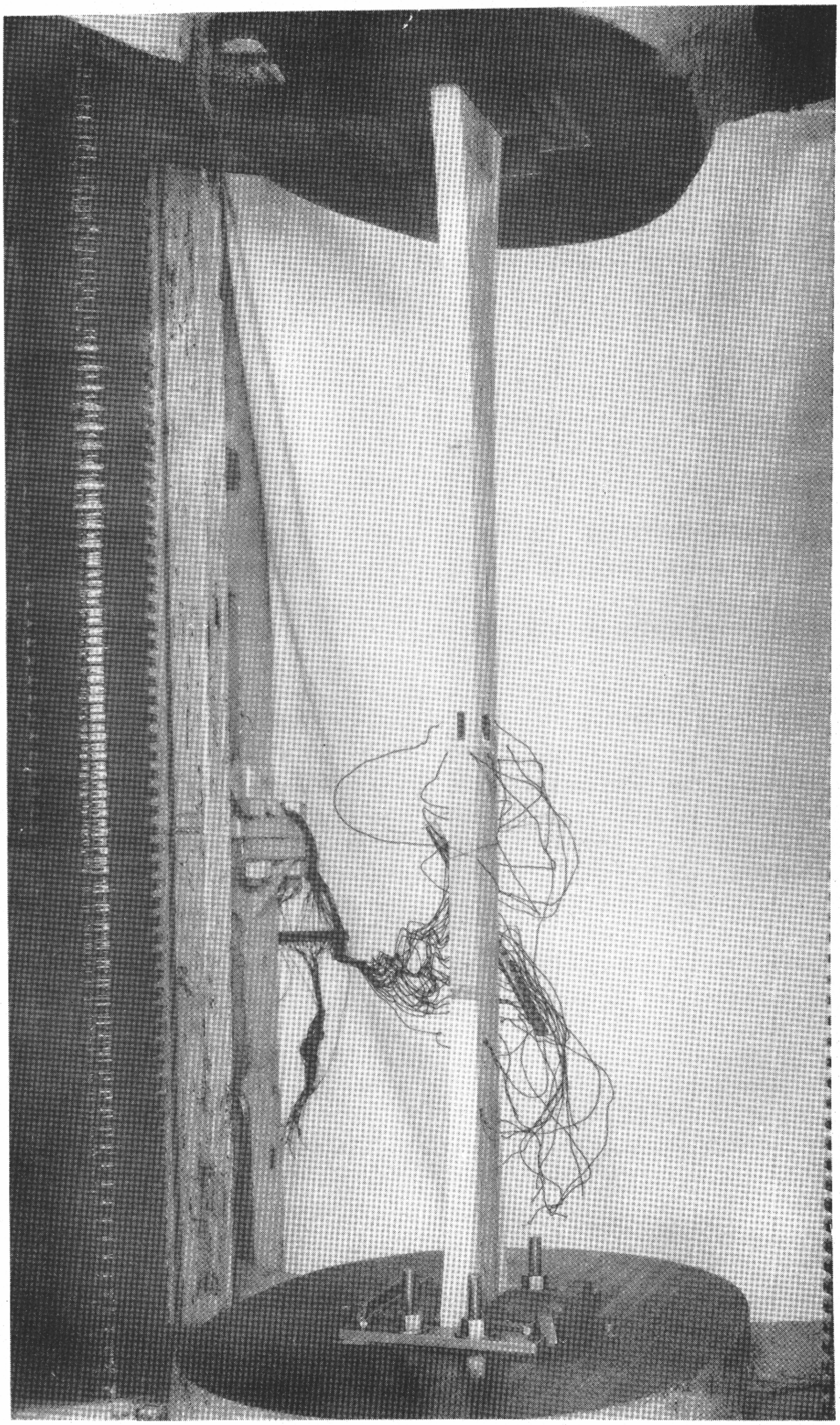


Figure 18.--Tension specimen (F) mounted and with electrical strain gages attached for test.

ZM 119 892

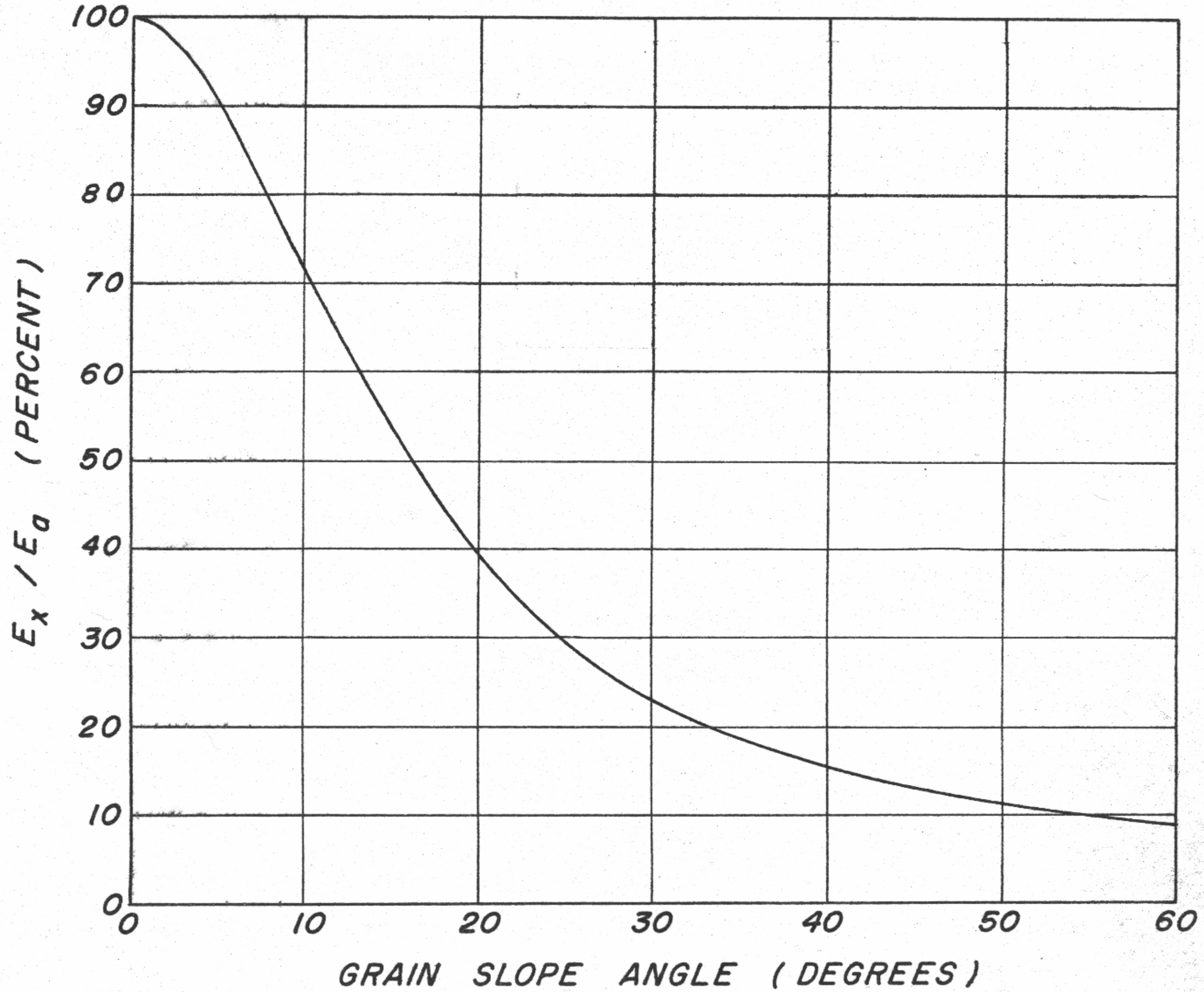


Figure 19.--Ratio of modulus of elasticity E_x to modulus of elasticity parallel to grain E_a in relation to the slope of grain. Here, the modulus of elasticity perpendicular to the grain, E_b, equals 0.068 E_a; the modulus of rigidity, μ_{ab}, equals 0.064 E_a; and Poisson's ratio, σ_{ab}, equals 0.292.

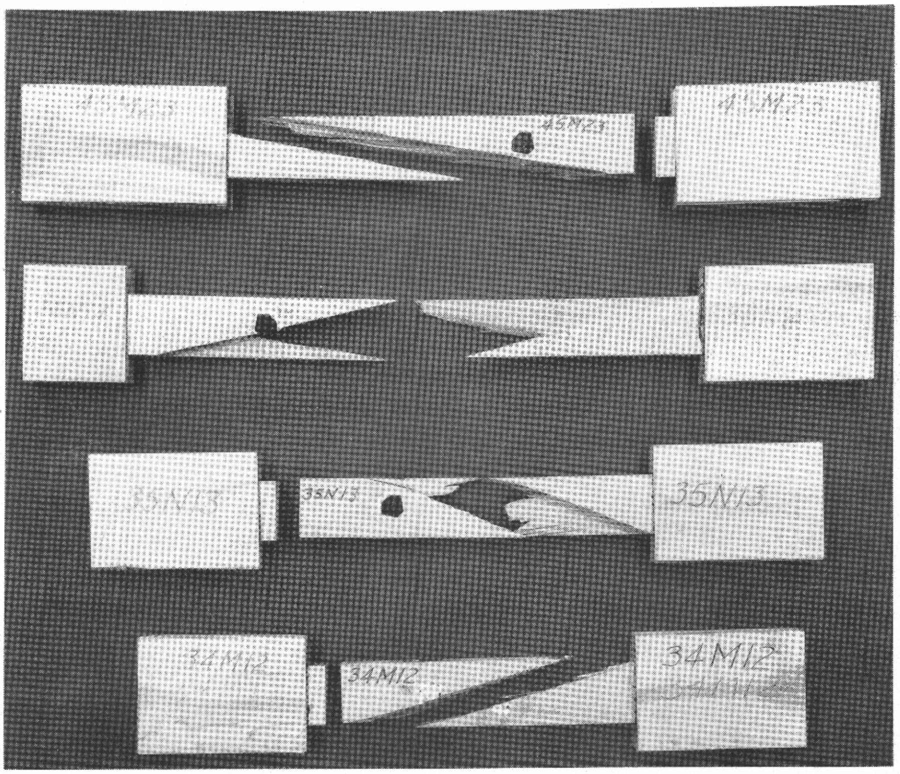


Figure 20.--Typical test failures in nominal 2- by 4-inch specimens laminated with different slopes of grain. Top and bottom specimens had slopes in the same direction; the middle pair in opposite directions. Only 35N13 failed across the grain in one of the laminations.

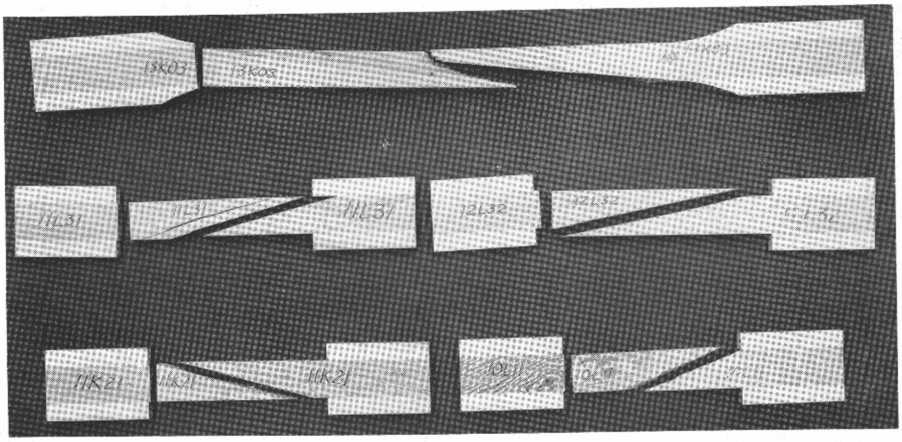


Figure 21.--Typical test failures in nominal 2- by 4-inch specimens with slope of grain and checks.

Z M 121 718

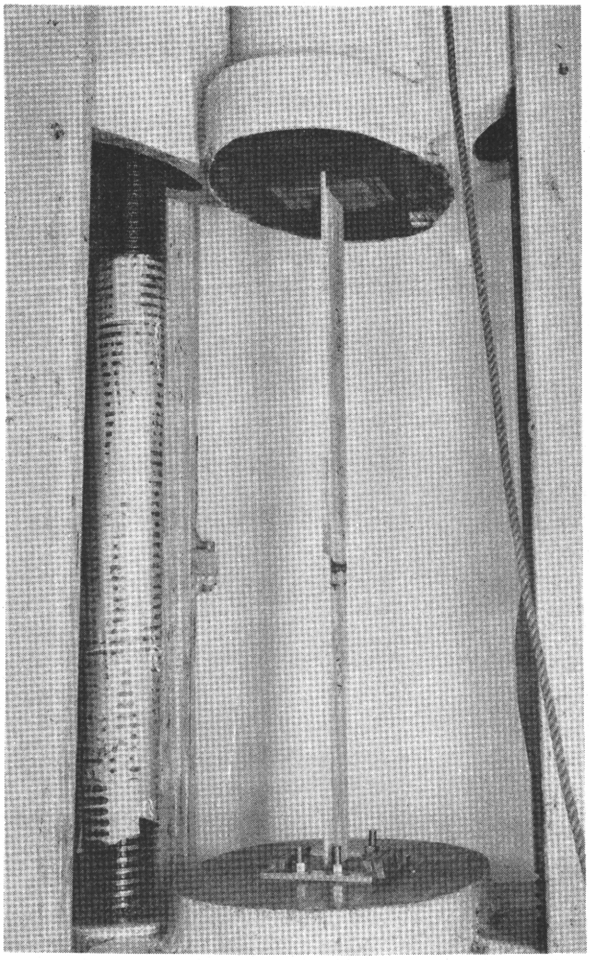


Figure 22.--Nominal 1- by 6-inch scarf-jointed specimen mounted for tension test.

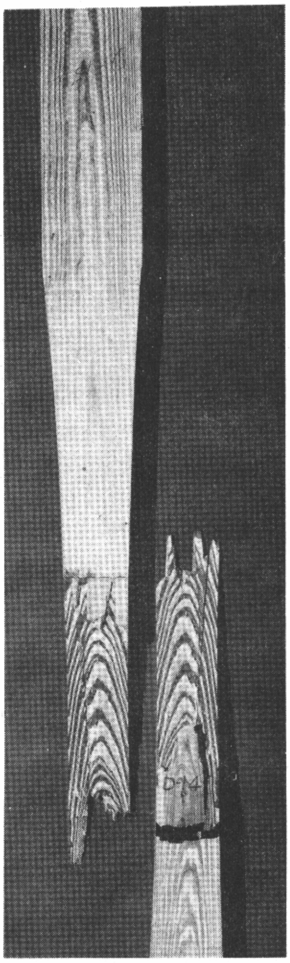


Figure 23.--Test failure of nominal 2-by 6-inch scarf-jointed specimen necked down to 3-1/2-inch width.

Z M 121 719

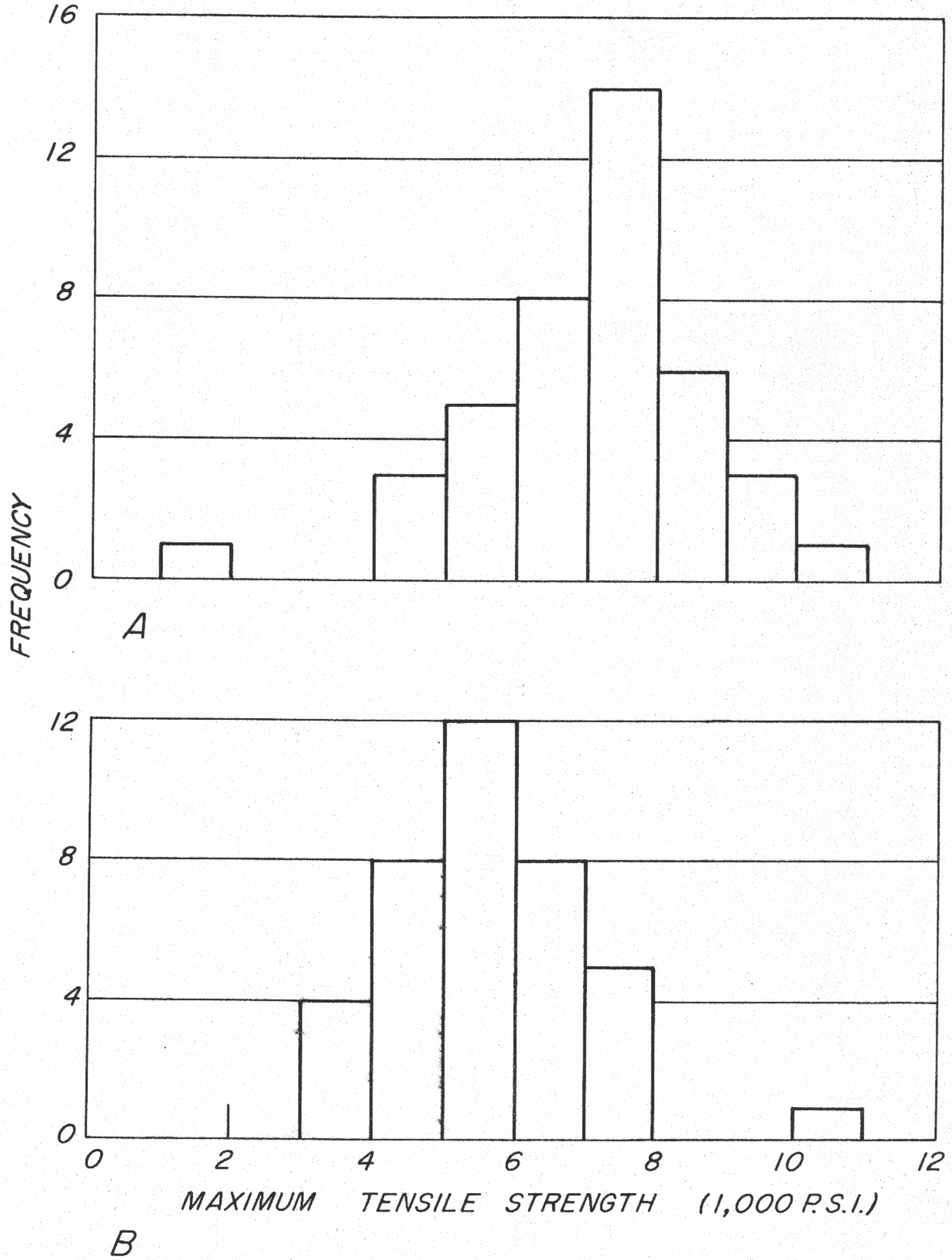


Figure 24.--Frequency distributions of tensile strength values in 1- by 6-inch laminating stock. A is based on 41 tests of southern pine and B on 38 tests of Douglas-fir.

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.