U.S. DEPARTMENT OF AGRICULTURE • FOREST SERVICE • FOREST PRODUCTS LABORATORY • MADISON, WI

In Cooperation with the University of Wisconsin

U.S. FOREST SERVICE RESEARCH NOTE

FPL-059
September 1964

BENDING STRENGTH AND STIFFNESS OF PLYWOOD[1]

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Summary

Layers of a plywood beam in which the grain direction is parallel to the span have properties distinctly different from those of adjacent layers because of the 90° orientation of adjacent plies. Such differences in properties in adjacent plies complicate the stress distribution at various points in the cross section, as compared to material with the same properties at all points in the cross section. The properties of a plywood beam thus depend on the properties in the span direction of each ply and on the construction of the plywood--that is, on the thickness and number of plies.

This report presents data from tests of plywood of various ply thicknesses and numbers. Methods are given for computing the strength and elastic properties from the construction of the plywood and the properties of the individual plies.

Introduction

Wood is anisotropic in character, having three mutually perpendicular axes of symmetry--longitudinal, radial, and tangential. The properties of wood in the

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[1]This Note is a slight revision of Forest Products Laboratory Report No. 1304, originally written in 1942 by Alan D. Freas under the title, "Method of Computing the Strength and Stiffness of Plywood Strips in Bending." It was first revised in 1946 and then revised again in 1956 under the present title.

longitudinal direction are found to be distinctly different from corresponding properties in the other two directions. Bending strength in the longitudinal direction, for example, is found to be some 15 to 20 times as great as in the tangential direction. Other properties also show differences.

Plywood, consisting as it does of alternate layers with grain directions at right angles, introduces further complications. The direction of principal stress in a plywood beam is parallel to the span, Thus the principal stresses are alternately parallel to grain and perpendicular to grain from layer to layer. The differences in strength and modulus of elasticity in the parallel-to-grain and across-the-grain directions thus complicate the stress distribution at various points in the cross section of a plywood beam as compared to a beam of material with the same properties at all points in the cross section.

The objective of this report is to develop methods of calculating the elastic and strength properties of plywood beams from the properties of the component plies and the construction.

Scope of Study

The bending tests included in this investigation of plywood covered various species, thicknesses, and constructions. Specifically, the variables considered were:

Three species--Douglas-fir, Sitka spruce, and yellow-poplar.
Five veneer or ply thicknessess--1/24, 1/16, 1/12, 1/8, and 3/16 inch.
Five combinations with respect to number of plies--1, 3, 5, 7, and 9.
Five arrangements of plies--[2]
- (a) Single-ply veneer with grain parallel to span.
- (b) Laminated wood with grain of all plies parallel to span.
- (c) Laminated wood with grain of all plies perpendicular to span.
- (d) Plywood with grain of outer plies parallel to span, grain of adjacent plies at right angles.
- (e) Plywood with grain of outer plies perpendicular to span, grain of adjacent plies at right angles.

Related tests--standard specimens of solid wood with grain parallel to span.

Tests were made only on specimens in which all plies were of the same species and the same nominal thickness. Similarly, no defects were permitted in the

[2] It is desirable, for convenience, to employ a more concise, though less accurate, terminology for the various ply arrangements. The following term will, therefore, be used in later portions of the report: "All-parallel" will be used to mean ply arrangement described under (b) above: "all-perpendicular," that under (c); "outer-parallel," that under (d): and "outer-perpendicular," that under (e).

specimens tested. Defects such as knots and spiral grain that. occurred in a sheet of veneer were eliminated from the material that was to form the specimen. Deviation of the grain from the plane of the veneer (diagonal grain) is to be expected in rotary-cut veneer as a result of unavoidable eccentricity of the growth rings. No attempt was made to eliminate this defect nor to evaluate its effect, because considerable variation is possible within even a small area and because of the difficulty of measuring its magnitude. The effect of defects, therefore, has been effectively eliminated in this study.

Bending tests were made on 2- by 2- by 30-inch solid specimens cut from the cores of the peeler blocks. Ten specimens were cut from each of two cores for both Douglas-fir and Sitka spruce--a total of 20 specimens for each species. Yellow-poplar cores were not available for these tests.

The following tests were made on veneer, plywood, and laminated specimens:

Sitka Spruce

Three-ply.--Four tests were made on each of four veneers of each thickness (1/24, 1/16, 1/12, 1/8, 3/16 inch) from each of two trees and of each of the five basic constructions. The total number of tests was 800.

Five-ply.--The5-ply test series was the same as the 3-ply series, except that two tests were made on panels from each of two sheets from each of two trees for each thickness and construction. The total number of tests was 200.

Seven-ply.--The 7-ply test series was the same as the 3-ply series, except that four tests were made on panels from each of two trees for each thickness and construction. The total number of tests was 200.

Nine-ply.--The 9-ply test series was the same as the 7-ply series, with the same total of 200 tests.

In all, 1,400 tests were made on Sitka spruce panels.

Douglas-fir

The series of tests made on Sitka sprucepanels was also made on Douglas-fir panels. The total number of tests was also 1,400.

Yellow-poplar

Three-ply.--The 3-ply yellow-poplar was given the same series of tests as the 3-ply Sitka spruce. The total number of tests was 800.

Five-ply.--The 5-ply test series was the same as the 3-ply series, except that one test was made on panels from each of two sheets from one tree for each thickness and construction. The total number of tests was 50.

Seven-ply.--The 7-ply test series was the same as the 5-ply series. The total number of tests was also 50.

Nine-ply.--The 9-ply test series was the same as the 7-ply series, except that one test was made on panels from one sheet from one tree for each thickness and construction. The total number of tests was 25.

The total number of tests on yellow-poplar panels was 925.

Total

In all, 3,725 tests were made on the panels of all three species. In addition, bending tests of 2- by 2- by 30-inch specimens were made by standard methods on 20 Sitka spruce and 17 Douglas-fir specimens cut from the cores of the peeler blocks.

Material and Fabrication

Material

The exact region of growth of the material is not known. The Sitka spruce and Douglas-fir veneer were cut at Tacoma, Wash., and the yellow-poplar veneer was cut at Huntington, W. Va.

For each species, the veneer was cut by the rotary process from 8-foot bolts of 2 logs into 4-foot-wide sheets, except occasionally where defects made it necessary to cut smaller widths. Veneers of each thickness were cut from each log. The veneer sheets of each thickness were numbered successively as they were cut and were identified by log and sheet numbers.

The veneer was dried at the mills by usual methods. The cores remaining after the Sitka spruce and Douglas-fir veneer had been cut from the peeler blocks

were left intact and were shipped inthegreen condition to the Laboratory, where they were cut into 3-1/2-inch-thick planks that weresubsequently air dried. The cores from the yellow-poplar were not obtained. The core diameters were: Sitka spruce log 1, 56 inches: Sitka spruce log 2, 45-1/2 inches; Douglas-fir log 1, 32 inches; Douglas-fir log 2, 34 inches.

The veneer was specially cut for this study and was of high quality with only very minor defects.

Matching and Marking of Specimens

The specimens were made up in matched sets of five specimens. Each set consisted of one specimen of single-ply veneer and one specimen each of the all-parallel, all-perpendicular, outer-parallel, and outer-perpendicular ply arrangements,[2] all with the same number of plies and made of plies of the same thickness.

Since the chief function of the tests was to develop methods of computing the strength and stiffness of plywood, it was desirable to reduce, as far as possible, the effect of variability of material. For this reason, all material for a given set of specimens was cut from a single sheet of veneer.

Tests were made generally on not less than four sets of specimens from each tree. Usually, each set was from a different sheet of veneer, but for the smaller number of plies and the thinner veneers it was sometimes possible to get all the material for four sets of tests from a single sheet of veneer. In such cases, more than four sets of specimens were tested.

Gluing and Conditioning Specimens

The veneers were bonded with casein glue (Forest Products Laboratory formula 4b) after they had been conditioned to approximately constant weight in an atmosphere maintained at 72° F. and 52 percent, relative humidity (conditions that produce approximately 10 percent equilibrium moisture content in wood). After the specimens were glued, they were stored under the same conditions until their weight was about constant before they were tested. The gluing was done at room temperature with a spread of about 0.032 pound of glue per square foot of joint area.

The solid specimens were conditioned at 72°F. and 52 percent relative humidity until their weight was approximately constant before they were tested.

Methods of Test

All bending specimens were tested under center loading. The specimens were 2 inches wide and were made 2 inches longer than the span to provide a 1-inch overhang at each end. The span used varied with the different constructions so as to afford a uniform effect of shear deformation. The span to be used for each construction was computed from the span-depth ratios based on the nominal depth of the specimen. For the all-parallel, outer-parallel, and single-ply constructions, the span-depth ratio was 48. For the all-perpendicular and outer-perpendicular constructions, the span-depth ratio was 24.

The radius of curvature of the loading block was made 1.5 times the nominal depth of the specimen. The rate of descent of the movable head was determined by the equation (1)[3]

$$N = \frac{zL^2}{6h}$$

where N is the rate of descent of the movable head in inches per minute, z the rate of outer fiber strain (taken here to be 0.0015 inch per inch per minute), L the span in inches, and d the depth of the beam in inches.

The specimens were supported on knife edges that were adjustable laterally to compensate, where necessary, for warp. Roller supports were provided between the knife edges and the specimen to eliminate end restraint. Figure 1 shows details of the adjustable knife edges and the roller supports.

Simultaneous readings of load and deflection of the center with respect to the ends were obtained throughout each test. Deflections during the early portion of the test were measured by means of a dial gage graduated to 0.001 inch. For the longer specimens, the dial gage was attached to a metal yoke supported on nails driven into the specimen at the neutral plane immediately above the supports. The spindle of the dial gage was attached to a nail driven into the neutral plane at the center of the specimen, as illustrated in figure 1.

With the shorter specimens, it was necessary to attach the dial gage to the base of the support, with the spindle of the dial gage supported from a yoke attached to the center of the specimen (figs. 2 and 3).

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[3] Underlined numbers in parentheses refer to literature cited at the end of the text.

For tests of single-ply veneer, it was impractical to make any attachments to the specimen itself and, in such tests, the dial gage was attached to the base of the support and the spindle of the dial gage was allowed to bear against the bottom of the specimen, directly below the loading block (fig. 4).

For the longer specimens, where deflections in excess of the capacity of the dial gage were encountered, a steel scale graduated to 0.01 inch was suspended from the center of the specimen and a fine wire was stretched between nails driven into the specimen directly above the supports. The deflection was measured by observing, through a telescope, the passage of the scale past the wire. The tests were discontinued when it was certainthat the maximum load had been passed.

Where loads were small and the testing machine was not sensitive enough to give satisfactory results, a more accurate weighing system, employing a platform scale, was used. The platform scale was supported on the stationary platform of the testing machine, and motion was imparted to the loading block by means of rods passing through holes in the scale platform and connecting the movable head of the testing machine with the loading block. The testing machine was thus used only as a means of achieving the desired rate of movement of the loading block, while loads were measured with the platform scale to 0.01 pound. This device is illustrated in figure 3.

The solid 2- by 2- by 30-inch specimens were tested under center loading on a 28-inch span at a head speed of 0.10 inch per minute (2). The loading block had a radius of 3 inches. Deflection of thecenter with respect to the ends was measured with a device similar to that shown in figure 1.

All tests were made in an atmosphere maintained at 72°F. and 52 percent relative humidity.

Moisture determinations were made on pieces that were cut from each specimen immediately after it was tested.

Discussion of Results

The analyses discussed in this section are based on a comparison of theoretical values calculated from strength properties determined from tests on laminated and plywood specimens. In each case, the laminated specimen considered had the same number and thickness of plies as the plywood specimen with which comparisons were made. This procedure was adopted to eliminate any possible

effect from differences in depth of beam or from differences in the number of glue joints. The results from tests of veneer were not used in the analyses.

No corrections of data were made for the large deflections encountered during test. These corrections represent a negligible part of results, thus were not considered.

Modulus of Elasticity

Theoretical considerations show (7, 11) that the deflection of points on the central line of a centrally loaded rectangular strip of plywood is given by

$$w = \frac{Pa^3}{48E_c I}(1 - \mu_{LT}\mu_{TL})\, B\left(1 + e\frac{h^2}{a^2}\right) \tag{1}$$

where w is the deflection; P the central load; a the span; E_c the apparent modulus of elasticity in bending; I the moment of inertia, based on the full cross section of the specimen; μ_{LT} the Poisson's ratio associated with the tangential direction and stress in the longitudinal direction; μ_{TL} the Poisson's ratio associated with contraction in the longitudinal direction and stress in the tangential direction; B and e factors involving elastic constants of wood; and h the depth of the specimen,

The factor $(1 - \mu_{LT}\mu_{TL})\, B$ accounts for the difference in deflection at different points across the width of the specimenthat results from anticlassic curvature. The difference between this factor and unity was found to be relatively unimportant for the ratios of span to width used in these experiments. It was about 0.99 for all types of specimens except those with the grain of all plies perpendicular to the span, for which it was found to be 1.00.

The factor $\left(1 + e\frac{h^2}{a^2}\right)$ accounts for the deflections resulting from shear deformations. This factor varied in its effect with different constructions from about 1.01 to about 1.13.

The modulus of elasticity is different at different points in a cross section of a plywood strip, since the transverse plies have a modulus of elasticity parallel

to the span that is only about 3 to 5 percent of that of the longitudinal plies. The term "apparent modulus of elasticity in bending" is therefore used to mean a composite or overall modulus such as might be obtained by the use of the usual equations with tension or compression data or withstatic bending data corrected for shear deformation. The apparent modulus of elasticity in bending, E_C, has the general equation

$$E_c = \frac{1}{I} \sum_{i=1}^{i=n} E_i I_i \tag{2}$$

where E_C and I are as previously defined, E_i is the modulus of elasticity of the ith ply parallel to the span, I_i the moment of inertia of the ith ply about the central line of the full cross section, and n the number of plies. Where r is equal to E_T/E_L, E_1 is the apparent modulus for a strip with the grain of the outer plies parallel to the length of the specimen, and E_2 is the apparent modulus for a strip with the grain of the outer plies perpendicular to the length of the specimen, and it is assumed that all plies are of the same thickness, as was the case in the tests made in this study, E_c may be shown to have the following values:

Number of plies	Equation for E_c: Outer-parallel	Equation for E_c: Outer-perpendicular
3	$E_1 = \frac{r + 26}{27} E_L$	$E_2 = \frac{1 + 26r}{27} E_L$
5	$E_1 = \frac{26r + 99}{125} E_L$	$E_2 = \frac{26 + 99r}{125} E_L$
7	$E_1 = \frac{99r + 244}{343} E_L$	$E_2 = \frac{99 + 244r}{343} E_L$
9	$E_1 = \frac{244r + 485}{729} E_L$	$E_2 = \frac{244 + 485r}{729} E_L$

(3)

E_L is the modulus of elasticity of wood in the longitudinal direction, and E_T is the modulus of elasticity of wood in the tangential direction. It may be noted that,

in equation (1). $E_c = E_L$ for specimens with the grain of all plies parallel to the length of the specimens, and $E_c = E_T$ for specimens with the grain of all plies perpendicular to the length.

Values of E_L and E_T were obtained by use of equation (1) from tests on all-parallel and all-perpendicular specimens, respectively, and were used with equations (3) to calculate values of E_1 and E_2 Values of E_L and E_T and calculated values of E_1 and E_2 are shown in tables 1, 2, and 3 in columns 5, 7, 8, and 9, respectively.

Values of E_1 and E_2 were obtained by use of equation (1) from tests on outer-parallel and outer-perpendicular specimens, respectively, and are shown in tables 1, 2, and 3 in columns 11 and 13 as E_1 (obs) and E_2 (obs).

Throughout the report, the term "calculated value" is used to mean a value pertaining to plywood derived from theoretical considerations based on the construction of the plywood and from values computed from tests of all-parallel and all-perpendicular specimens. The term "observed value" is used to mean a value computed from tests on plywood. The observed values may then be compared with the calculated values to check the validity of the theoretical considerations involved in setting up the formulas for the strength and stiffness of plywood.

The ratios of observed values of E_1 and E_2 to calculated values are shown in columns 14 and 15 of tables 1, 2, and 3. The plywood specimens that gave the observed values were matched with the laminated wood specimens that gave the results used in obtaining the calculated values.

All values except specific gravity in tables 1, 2, and 3 have been adjusted to a uniform moisture content basis of 10 percent on the assumption that moisture adjustments for plywood and laminated wood maybe made in the same manner as for solid wood (12). Other work (5) has confirmed the validity of this assumption.

From a consideration of tables 1, 2, and 3, it may be seen that there is apparently no uniform variation of the ratio of observed to calculated values of E_1 and E_2, either with ply thickness for a given number of plies, with number of plies for a given thickness, or between tree 1 and tree 2. It seems proper, therefore, to consider all of these ratios together for each species. Table 4 presents statistics summarizing the comparison between observed and calculated values given in detail in tables 1, 2, and 3.

From table 4 it may be seen that, in general, the ratio between observed and calculated values is approximately unity. Considering the magnitude of the standard deviation it may be seen at once that none of the mean values of the ratio is significantly different from unity.

From this it may be concluded that equation (1) represents, within the limits of variability of the material, the relation between load and deflection of a centrally loaded rectangular strip of plywood for stresses up to the proportional limit, with the values of apparent modulus of elasticity for the plywood defined by equation (2).

Fiber Stress at Proportional Limit

Theoretically, the stress at a point z distant from the neutral axis of the cross section of a strip of plywood subjected to a bending moment M is given by

$$f = \frac{Mz}{I} \frac{E_x}{E_c} \tag{4}$$

where f is the unit stress at a point z distant from the neutral axis, M the bending moment, z the distance from the neutral axis to the point being considered, E_X the modulus of elasticity of the material in the direction of the stress at the point being considered, E_C the apparent modulus of elasticity in bending for the strip of plywood, and I the moment of inertia based on the full cross section of the specimen.

Equation (4) applies, of course, only when stresses are below the proportional limit at all points in the cross section. The analysis leading to equation (4) is based on the assumption of linear variation of strain across the cross section, and is applicable only where the shear deformations are not great enough to invalidate this assumption, as in beams of relatively large span-depth ratio or in regions of low shear, such as the centralportion of a uniformly loaded beam.

The resisting moment of a plywood beam for a stress f in the extreme fiber is given by

$$M = \frac{fE_c}{E_x} \frac{I}{c} \tag{5}$$

where c is the distance from neutral axis to extreme fiber in inches.

If $\frac{fE_C}{E_x}$ is replaced by f_a, which may be called an apparent stress, equation (5) may be replaced by

$$M = f_a \frac{I}{c} \tag{6}$$

where

$$f_a = f \frac{E_c}{E_x} \tag{7}$$

If the apparent stress at proportional limit is denoted by F_L, F_T, and F_1, for all-parallel, all-perpendicular, and outer-parallel specimens, respectively, it may be seen that, based on equation (7),

$$F_1 = F_L \frac{E_1}{E_L} \tag{8}$$

It may be noted that, for all-parallel and all-perpendicular specimens, the ratio E_c/E_x becomes unity, and equation (4) reduces to the usual equation for stress in a bent beam.

Values of F_L and F_T were obtained, by the use of equation (6), from data on all-parallel and all-perpendicular specimens, respectively, and values of F_L were used with equation (8) to calculate values of F_1. Values of F_L and F_T and F_1 (calc.) are shown in tables 5, 6, and 7 in columns 5, 10, and 7, respectively.

Values of F_1 were obtained by use of equation (6) from data on outer-parallel specimens, and are shown in tables 5, 6, and 7 in column 15 as F_1 (obs).

The observed and calculated values were then compared. The ratios of observed to calculated values are shown in column 20 of tables 5, 6, and 7 and are summarized in table 8. The calculations were made for groups of specimens as described in the discussion of modulus of elasticity.

It may be noted that the observed values were approximately 90 percent of the calculated values; ranging from 0.72 to 1.09 times the calculated values. This is

because the proportional. limit in the bending test is reached first at only one location in the beam. This location is directly under the load in the extreme compression fiber. As the test proceeds, adjacent material also reaches the proportional limit. A considerable amount of material must be affected before the load deflection curve is sufficiently influenced to indicate a proportional limit (3). Thus the proportional limits obtained from bending tests are always greater than those obtained from compression tests.

The tensile and compressive strengths of wood perpendicular to the grain are very low, Calculations indicate that the tensile strength of the outer transverse tension ply of a plywood strip that has its face grain direction perpendicular to the span is exceeded by the time the outermost longitudinal ply has reached its proportional limit. When the tensile strength of the tension transverse ply has been exceeded, it can no longer contribute to the bending strength of the plywood strip. Therefore, the proportional limit bending strength of a plywood strip is controlled by that of the outermost longitudinal ply, and the outer transverse ply may be neglected in computing the proportional limit strength of the strip.

There are indications that the proportional limit in compression perpendicular to grain is reached at a deformation about 2-1/2 to 3 times as great as that at proportional limit in compression parallel to grain. This means, then, that the outer transverse compression ply of a 3-ply plywood strip with all plies the same thickness reaches its proportional limit at about the same time as does the longitudinal ply. The same will be true of plywood with more than three plies. Therefore, the outermost longitudinal ply will be the controlling factor, and the proportional limit of the plywood strip will be reached when the stress in this ply reaches its proportional limit value.

From the above considerations, calculations of F_2 have been made on the basis that the compressive transverse ply is effective, but that the tensile transverse ply is completely ineffective. Under this assumption and neglecting the effect of change of neutral axis when the outer transverse tension ply is neglected, equation (5) becomes

$$M = \frac{F_L E_2'}{E_L} \frac{I}{c'} \tag{9}$$

where E_2' is the apparent modulus of elasticity about the centroidal axis with the outer transverse tension ply neglected and c' is the distance from the centroidal

axis to the outer longitudinal ply. If all plies are of equal thickness, then

$$c' = \frac{n-2}{n} c \tag{10}$$

where n is the number of plies. Making this substitution into equation (9), equation (5) becomes

$$M = \frac{F_L E'_2}{E_L} \frac{n}{n-2} \frac{I}{c} \tag{11}$$

Based on this equation the apparent stress at proportional limit for plywood with outer-perpendicular plies is

$$F_2 = F_L \frac{E'_2}{E_L} \frac{n}{n-2} \tag{12}$$

and for different number of plies, F_2 can be calculated from the following equations:

Number of plies	Equation for E'_2	Equation for F_2
3	$E'_2 = \frac{1 \pm 13r}{27} E_L$	$F_2 = \frac{1 \pm 13r}{9} F_L$
5	$E'_2 = \frac{26 \pm 50r}{125} E_L$	$F_2 = \frac{26 \pm 50r}{75} F_L$
7	$E'_2 = \frac{99 \pm 135r}{343} E_L$	$F_2 = \frac{99 \pm 135r}{245} F_L$
9	$E'_2 = \frac{244 \pm 292r}{729} E_L$	$F_2 = \frac{244 \pm 292r}{567} F_L$

Values of F_2 calculated on the basisofthese equations are shown in column 17 of tables 5, 6, and 7. Values of F_2 were obtained by use of equation (6) from data on outer-perpendicular specimens and are shown in column 18 of the same tables

as F_2 (obs), The ratios of observed to calculated values of F_2 are shown in column 22 of tables 5, 6, and 7 and are summarized in table 9. While considerable variability is found, the average value of the ratio is found to be about 93 percent.

From the foregoing, it may be concluded that the load-carrying capacity (for stresses at the proportional limit) of a strip of plywood may be predicted by the equation

$$M = KF_a \frac{I}{c} \tag{13}$$

where K is an empirical factor, I is the moment of inertia of the whole cross section, c is the distance from the centroidal axis to the extreme fiber, and F_a may be found from the following tabulation forplywood with all plies of the same thickness and species.

Number of plies	Equation for F_a	
	Outer-parallel	Outer-perpendicular
3	$F_1 = F_L \frac{r \pm 26}{27}$	$F_2 = F_L \frac{13r \pm 1}{9}$
5	$F_1 = F_L \frac{26 \pm 99}{125}$	$F_2 = F_L \frac{50r \pm 26}{75}$
7	$F_1 = F_L \frac{99r \pm 244}{343}$	$F_2 = F_L \frac{135r \pm 99}{245}$
9	$F_1 = F_L \frac{244r \pm 405}{729}$	$F_2 = F_L \frac{292r \pm 244}{567}$

A method is given elsewhere in this reportfor setting up similar formulas for any construction.

Modulus of Rupture

Obviously, any theories based upon assumptions of elastic behavior are invalid for application at failure. However, it is not unreasonable to assume that values

of apparent modulus of rupture for plywood, based upon the theory outlined in the preceding section, would differ from the observed values by some approximately constant factor.

Upon this premise, therefore, values of apparent modulus of rupture based upon moduli determined from tests of all-parallel and all-perpendicular specimens were calculated on the same basis as that employed in calculating values of apparent fiber stress at proportional limit. These calculated values were compared with observed values of apparent modulus of rupture from tests of outer-parallel and outer-perpendicular specimens,

Moduli of rupture from tests of all-parallel and all-perpendicular specimens are shown in tables 5, 6, and 7 in columns 6 and 11 as S_L and S_T, respectively. Values of S_1 and S_2 calculated from these moduli are shown in columns 8 and 13, respectively. Values of S_2 were calculated assuming outer tension ply ineffective as was explained for the calculation of F_2. Observed values of S_1 and S_2 as found from data of outer-parallel specimens and outer-perpendicular specimens are shown in columns 16 and 19, respectively. The ratios of observed to calculated values are shown in columns 21 and 23 of tables 5, 6, and 7.

It may be concluded that the ultimate strength of a strip of plywood may be predicted by the equation

$$M = KS_a \frac{I}{c} \tag{14}$$

where S_a may be found from the followingtabulation for plywood with all plies of the same thickness and species, and the other terms have the meanings given in connection with equation (13)

Number of plies	Equation for S_a	
	Outer-parallel	Outer-perpendicular
3	$S_1 = S_L \frac{r + 26}{27}$	$S_2 = S_L \frac{13r + 1}{9}$
5	$S_1 = S_L \frac{26r + 99}{125}$	$S_2 = S_L \frac{50r + 26}{75}$
7	$S_1 = S_L \frac{99r + 244}{343}$	$S_2 = S_L \frac{135r + 99}{245}$
9	$S_1 = S_L \frac{244r + 485}{729}$	$S_2 = S_L \frac{292r + 244}{567}$

A later portion of this report will give a method of setting up similar equations for any construction.

Tables 8 and 9 present summaries of the comparisons between observed and calculated values given in detail in tables 5, 6, and 7. In table 8, the values of $\frac{S_1}{S_1}$ ratios for all numbers of plies are considered together. The average ratio of $\frac{S_1}{S_1}$ (obs) to $\frac{S_1}{S_1}$ (calc.) is 0.86. In table 9, however, the value of $\frac{S_2}{S_2}$ ratios for the 5–, 7–, and 9–ply constructions are considered together in one group and those for the 3–ply are considered separately, since the average ratio for 3–ply constructions is 1.15, and for the 5-, 7-, and 9–ply is approximately 1.0.

Effect of Neglecting Transverse Plies

Consideration of tables 1, 2, and 3 and 5, 6, and 7 indicates that the transverse plies may be expected to contribute, ingeneral, but little to the strength or stiffness of a plywood strip. A comparison of values of modulus of elasticity from tests of all–perpendicular specimens with those from tests of all–parallel specimens shows that $\frac{E_T}{E_T}$ is only about 3 to 5 percent of $\frac{E_L}{E_L}$. Similarly, a comparison of moduli of rupture indicates that the ultimate strength in tangential direction is only about 4 to 6 percent of that in the longitudinal direction.

From this it would appear that a good approximation could be obtained by neglecting the effect of the transverse plies and by considering that the plywood consisted only of the longitudinal plies, with the transverse plies acting only to space the longitudinal plies. Computations of modulus of elasticity, fiber stress at proportional limit, and modulus of rupture were made on this basis by considering only those plies with the grain direction parallel to the span.

Modulus of Elasticity

In the case of modulus of elasticity, neglecting the effect of the transverse plies amounts, essentially, to neglecting the terms involving r ($r = E_T/E_L$) in equations (3). The errors to be expected from this approximation may be estimated. Assuming r = 0.04 for the 3–ply outer–parallel construction, for instance, the ratio of exact to approximate value would be 26.04/26 = 1.0015. The error is only a small fraction of 1 percent. Other values of the ratio of exact to approximate values of $\frac{E_1}{E_1}$ and $\frac{E_2}{E_2}$ are tabulated below for r = 0.04.

Number of plies	Ratio of exact to approximate modulus of elasticity	
	Outer-parallel (E_1)	Outer-perpendicular (E_2)
3	1.0015	2.0400
5	1.0105	1.1523
7	1.0162	1.0986
9	1.0201	1.0795

For the outer-parallel specimens, the error is negligible in comparison with the natural variability of the material. For the outer-perpendicular specimens, on the other hand, the errors, particularly for the 3-ply, are of significant size.

Tables 10, 11, and 12 present values of E_L, F_L, and S_L calculated from the results of tests of plywood specimens by considering only the parallel plies. In columns 6 and 7 are shown ratios of the values of E_L from such calculations compared with results from tests of all-parallel specimens. The ratios are generally near unity except for those for the 3-ply outer-perpendicular specimens.

As previously pointed out, approximate values of E_c may be calculated by neglecting the terms involving r in equations (3). The ratios of values calculated from equations (3) considering the terms involving r to those calculated by neglecting such terms are shown in table 13 for various values of r. The values of r chosen are average values (table 16) for the various groups of specimens. The ratios should correspond with those given in columns 6 and 7 of tables 10, 11, and 12. The comparison, shown in table 14, indicates good agreement.

Figures 5 (left) and 6 (top) show the variation in error to be expected from neglecting the transverse plies for various values of r and for 3-, 5-, 7-, and 9-ply plywood. Figure 5 shows this relation for plywood with all plies the same thickness, and figure 6 for plywood with the face plies one-half as thick as the others.

Fiber Stress at Proportional Limit; Modulus of Rupture

Consider equation (5):

$$f = \frac{Mc}{I} \frac{E_x}{E_c} \tag{5}$$

For a 3-ply strip with the grain of outer plies parallel to the span, this equation reduces to

$$f = \frac{Mc}{I} \frac{E_L}{\frac{r + 26}{27} E_L} = \frac{Mc}{I \frac{r + 26}{27}} \tag{15}$$

for stress in the extreme fiber.

Neglecting the effect of the transverse plies here again amounts essentially to neglecting r in equation (15) and in the related equations for other constructions. The errors introduced by this approximation are indicated in figures 5 (right) and 6 (bottom) and by the ratios shown incolumns 11, 12, 16, and 17 of tables 10, 11, and 12.

For outer-parallel specimens, the error resulting from neglecting the transverse plies in computing modulus of elasticity, fiber stress at proportional limit, or modulus of rupture is so small as to be negligible, even for plywood with a large number of plies. For outer-perpendicular specimens, on the other hand, the error is considerable, especially for 3-ply and 5-ply plywood. For such constructions, the approximation may be too greatly in error to be useful.

Relation Between the Properties of Laminated Wood and Solid Wood

In the preceding sections, certain relationships between the properties of laminated wood and plywood have been developed with the tacit assumption that the properties of laminated wood and solid wood were identical. Some consideration must be given to the validity of this assumption.

In general, there appeared to be no variation in the strength properties of the laminated wood with variations in ply thickness or in number of plies, except that the results from tests of single veneers were generally somewhat lower than those from specimens withmorethanoneply. The reason for this difference is not known, but it is possible that the glue joints in the multi-ply specimens may have had some effect in increasing the strength,

Bending tests of solid wood have indicated a decrease in both fiber stress at proportional limit and modulus of rupture with increasing depth of beam (10). It might have been expected, then, that a tendency toward decreasing strength would be found for laminated material with increasing numbers of plies of a given veneer thickness, or with increasing ply thickness for specimens of a given number of plies. Such a trend was not found in either case. The variability of results was considerable, and apparently was sufficiently large to obscure a trend if any were present. The comparisonof specimens of a given veneer thickness for various numbers of plies would be expected to give the better comparison, since such specimens would have come more nearly from the same portion of the tree than would those with the same number of plies but of different veneer thicknesses.

Obviously, any exact matching of material in laminated and solid specimens is impossible. It was considered, however, that some semblance of matching might be obtained by testing solid specimens from the cores of the peeler blocks from which the veneer had been cut. The results of standard bending tests on specimens from peeler block cores are summarized in table 15. The results, adjusted to a moisture content basis of 10 percent, are also shown to facilitate comparison with the results of the tests of laminated specimens. Specific gravity values were not adjusted to the 10 percent moisture content basis.

Because of the limitations of size of available material, bending tests on specimens of solid wood with the grain perpendicular to the span could not be made.

The results from the tests of solid specimens bore no constant relation to the results from the tests of laminated specimens, although the averages were generally within the range of results from laminated specimens. It is probable that the matching was inadequate, because the solid specimens came from near the center of the tree and the laminated specimens came from varying positions near the outside. The general agreement of results, however, indicates that there is no serious difference in properties between solid and laminated specimens, and that the calculation of plywood properties using the methods discussed herein, together with strength properties from tests of solid wood, is valid.

Conclusions and Recommendations

The preceding portion of the report has presented methods of computing the strength and stiffness of plywood strips subjected to bending, with a discussion of the relationships existing between the methods. A summary of these methods will now be presented, together with the factors to be used in applying them. These factors apply to plywood having all equal thickness plies.

Deflection of Plywood Strips

Exact method.--The deflection of a plywood strip may be determined (exclusive of deflections resulting from shear deformations) by use of the usual equations, simply by replacing modulus of elasticity in bending by an apparent modulus. This apparent modulus of elasticity in bending is a function of the number and thickness of the plies in the strip, and of the longitudinal and transverse moduli of elasticity of the wood.

The apparent modulus of elasticity, E_c, may be calculated from

$$E_c = \frac{1}{I} \sum_{i=1}^{i=n} E_i I_i$$

where I is the moment of inertia of the full cross section about its central line, E_i the modulus of elasticity of the ith ply parallel to the span, I_i the moment of inertia of the ith ply about the central line of the full cross section, and n the number of plies.

For plywood with all plies of the same species, E_c may be found from

$$E_c = \frac{rI_x + I_w}{I} E_L$$

where I is the moment of inertia of the full cross section about its central line, I_x and I_w are the moments of inertial of the transverse and longitudinal plies, respectively, about the central line of the full cross section, r is the ratio of the transverse to longitudinal modulus of elasticity of the wood, and E_L is the

longitudinal modulus of elasticity of the wood (9). A table of values of E_c for plywood with all plies of the same species and the same thickness has been given, equation (3).

Approximate method. --The deflection may be computed approximately, using a moment of inertia based upon only the parallel plies; that is,

$$E_c = \frac{1}{I} \Sigma E_i I_i$$

where the summation is made only for those plies with the grain direction parallel to the span. For plywood with all plies of the same species,

$$E_c = \frac{I_w}{I} E_L$$

For plywood with the face grain parallel to the span, this approximation will, for most cases, be only slightly in error. For plywood with the face grain perpendicular to the span, however, the error may be considerable and in many cases will be so large as to render the approximation unusable. The magnitude of the errors to be expected from the approximation has been shown, for certain cases, in figures 5 (left) and 6 (top).

Values of E_T (modulus of elasticity in the tangentialdirection of the wood) and E_R (modulus of elasticity in the radial direction of the wood) for computing the ratios $r_T = E_T/E_L$ and $r_R = E_R/E_L$ are available for some species. The data are incomplete, however, in that only a few species have been tested, and little is known about the variation of these ratios with variations in specific gravity or with changes in moisture content.

The principal available data are presented in "Elastic Properties of Wood," Forest Products Laboratory Report No. 1528, and supplements thereto (4). Some data are available also in references (6) and (8). For cases in which no data are available, the use of values of $r_T = 0.05$ and $r_R = 0.10$ is suggested. Approximate values of these ratios may give results only slightly in error.

The correction for anticlastic curvature is usually so small that it may be neglected. From table II of March's paper (7), it may be seen to be less than 2 percent for 3-ply and 5-ply strips of spruce plywood, even for strips with a ratio of span to width as low as 4.

The correction for shear deformation, on the other hand, may be considerable. This correction is made (see equation (1)) by multiplying by a factor involving the constant e, which depends upon Poisson's ratios and moduli of rigidity. Data on these properties are available (4, 6) for a few species, and may be used with equations presented by March to calculate values of e. Some values of this constant have already been calculated and are presented in table 18.

These values of e may be used as a basis for estimating values of e for other species. Reasonable corrections for shear deformations may be made even with values of e considerably in error. Assume, for example, that the proper shear corrrection is (1 + 0.10) and that the value of e is 20 percent low. The computed correction would then be (1 + 0.08), which is only 2 percent in error, so that the corrected deflection would be only about 2 percent in error.

Load-Carrying Capacity of Plywood Strips

(For stresses at proportional limit)

Exact method.--The load-carrying capacity of a plywood strip for stresses at the proportional limit may be determined by

$$M = KF_a \frac{I}{c}$$

where K is an empirical factor, F_a is found as indicated below, I is the moment of inertia of the whole cross section about its central line, and c is the distance from the centrodial axis to the extreme fiber of the outermost longitudinal ply.

The term F_a for outer-parallel strips is given by

$$F_a = \frac{E_c}{E_L} F_L$$

where F_a is an apparent stress in bending, F_L is the desired stress in the outermost longitudinal ply, and the other terms are as previously defined.

For outer-parallel strips with all plies of the same species, F_a may be found from

$$F_a = \frac{rI_x + I_w}{I} F_L$$

where r, I_x, and I_w are as previously defined, and F_L is the desired stress in the outermost longitudinal ply.

For outer-perpendicular strips, F_a is given by a similar procedure, except that the outer transverse ply on the tension side will be neglected. Here, F_a will be given by

$$F_a = \frac{E_m}{E_L} F_L$$

where E_m equals E_c for a strip ofplywood with the outer plies at right angles to the span, and the outer ply on the tension side is considered ineffective. The other terms are as previously defined.

For outer-perpendicular strips with all plies of the same species, F_a will be given by

$$F_a = \frac{rI'_x + I_w}{I} F_L$$

where I'_x is the moment of inertia about the central line of the full cross section of all transverse plies except the one on the tension side, and all other symbols have the meanings previously given.

Omission of the outer transverse ply on the tension side will result in a shift in the neutral axis from the center of the depth toward the compression face of the beam. The effect of this shift is generally small enough to be neglected, and the neutral axis may be assumed to be at the center of the depth of the beam.

The factor K has been determined experimentally and the following values will, in general, give results on the safe side: outer-parallel plywood, 0.85; outer-perpendicular plywood, 0.90.

Approximate method. --The load-carrying capacity may be computed approximately by

$$M = KF_L \frac{I_w}{c}$$

where the terms are as previously defined. The same values of the factor K may be used, except for the 3-ply outer-perpendicular plywood, where a value of 1.20 should be used,

For plywood with the face grain parallel to the span, this approximation, which involves neglecting the transverse plies, will, for most cases, be only slightly in error. For plywood with the face grain perpendicular to the span, however, the error may be considerable and in many cases will be so large as to render the approximation unusable, The magnitude of the errors to be expected from the approximation has been shown, for certain cases, in figures 5 (right) and 6 (bottom).

Ultimate Load-Carrying Capacity of Plywood Strips

Exact method.--The ultimate load-carrying capacity of a plywood strip may be computed by the method given for stresses at the proportional limit by substituting modulus of rupture in place of the lower stress and by using appropriate values of K, which are somewhat different for ultimate load than for the lower stresses.

Values of K are: outer-parallel plywood, 0.85; outer-perpendicular plywood, 3-ply, 1.15; outer-perpendicular plywood, 5 plies or more, 1.00.

Approximate method.--The approximate method, as given for use with stresses at the proportional limit, may be used also for computing the ultimate load-carrying capacity by substituting modulus of rupture in place of the lower stress and by using appropriate values of K. Values of K given for use with the exact method may be used with the approximate method except for 3-ply outer-perpendicular plywood, where a value of 1.50 should be used.

Literature Cited

1. American Society for Testing Materials.
   1946. Standard methods of static tests of timber in structural sizes. ASTM Designation D198-27.

2. _____ .
   1946. Standard methods of testing small clear specimens of timber. ASTM Designation D143-27.

3. Bechtel, S. C., and Norris, C. B.
1952, Strength of wood beams of rectangular cross section as affected by span-depth ratio. Forest Products Lab. Rpt. 1910.

4. Doyle, D. V,, Drow, J. T., and McBurney, R. S.
1945-46. Elastic properties of wood. Forest Products Lab. Rpt. 1528 and Supplements A, B, C, D, F, G, H.

5. Drow, J. T.
1945. Effect of moisture on the compressive, bending, and shear strengths, and on the toughness of plywood. Forest Products Lab. Rpt. 1519.

6. Jenkin, C. F.
1920. Report on materials of construction used in aircraft and aircraft engines. (Gt. Brit.) Min. Munitions, Aircraft Production Dept., Aeronautical Research Com.

7. March, H. W.
1936. Bending of a centrally-loaded rectangular strip of plywood. Physics 7(1):32-41.

8. Markwardt, L. J.
1938. Form factors and methods of calculating the strength of a wooden beam, Forest Products Lab. Rpt. 1184.

9. _____, and Wilson, T. R. C.
1935. Strength and related properties of woods grown in the United States. U.S. Dept. Agr. Tech. Bul. 479.

10. Newlin, J. A., and Trayer, G. W.
1924. The influence of the form of a wooden beam on its stiffness and strength, II. Form factors of beams subjected to transverse loading only. Natl. Advisory Comm. for Aeronautics Rpt. 181.

11. Norris, C. B.
1942. The technique of plywood. I. F. Laucks, Inc., Seattle.

12. Wilson, T. R C.
1932. Strength-moisture relations for wood. U.S. Dept. Agr. Tech. Bul. 282.

Table 1.--Comparison of observed and calculated values of E_1 and E_2 for Sitka spruce. (All values except specific gravity adjusted to 10 percent moisture content basis.)

Ply thickness	Tree No.	Number of tests[1]	All-parallel: Specific gravity[2]	All-parallel: E_L	All-perpendicular: Specific gravity[2]	All-perpendicular: E_T	E_1 (calc)	E_2 (calc)	Outer-parallel: Specific gravity[2]	Outer-parallel: E_1(obs)	Outer-perpendicular: Specific gravity[2]	Outer-perpendicular: E_2(obs)	E_1(obs)/E_1(calc)	E_2(obs)/E_2(calc)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
In.				1,000 p.s.i.		1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.		1,000 p.s.i.		1,000 p.s.i.		
							THREE-PLY							
1/24	1	16	0.356	1,542	0.367	45.1	1,487	100.5	0.344	1,383	0.343	103.4	0.930	1.029
1/24	2	16	.384	1,712	.390	46.3	1,650	108.0	.372	1,584	.372	108.9	.960	1.008
1/24	1 and 2	32	.370	1,627	.378	45.7	1,568	104.3	.358	1,483	.357	106.1	.946	1.017
1/16	1	16	.366	1,636	.371	48.8	1,577	107.6	.354	1,578	.351	106.9	1.001	.993
1/16	2	16	.398	1,739	.392	51.0	1,676	113.5	.387	1,650	.375	104.8	.984	.923
1/16	1 and 2	32	.382	1,688	.382	50.0	1,627	110.7	.371	1,614	.363	105.8	.992	.956
1/12	1	16	.364	1,672	.363	46.3	1,612	106.5	.354	1,538	.355	110.5	.954	1.038
1/12	2	16	.393	1,667	.381	52.8	1,607	112.6	.389	1,650	.374	115.3	1.038	1.024
1/12	1 and 2	32	.378	1,670	.372	49.5	1,610	109.5	.372	1,594	.364	112.9	.990	1.031
1/8	1	16	.358	1,641	.360	49.9	1,582	108.8	.360	1,526	.356	113.8	.965	1.046
1/8	2	16	.388	1,586	.388	55.2	1,529	111.9	.383	1,506	.383	101.5	.985	.907
1/8	1 and 2	32	.373	1,613	.374	52.6	1,555	110.4	.372	1,516	.370	107.6	.975	.975
3/16	1	16	.354	1,436	.352	48.8	1,385	100.2	.350	1,297	.349	102.4	.936	1.022
3/16	2	16	.378	1,730	.377	54.8	1,668	116.8	.373	1,657	.374	117.9	.993	1.009
3/16	1 and 2	32	.366	1,584	.364	51.8	1,527	108.5	.361	1,477	.362	110.1	.967	1.015
Mean	1	80											.957	1.026
Mean	2	80											.990	.974
Mean	1 and 2	160											.975	.998
							FIVE-PLY							
1/24	1	4	.366	1,633	.372	67.3	1,307	393.0	.349	1,250	.348	340.1	.956	.865
1/24	2	4	.392	1,785	.389	73.2	1,429	429.3	.368	1,394	.374	392.9	.976	.915
1/24	1 and 2	8	.380	1,709	.380	70.2	1,368	411.1	.359	1,321	.361	366.4	.966	.891
1/16	1	4	.372	1,763	.364	69.4	1,411	421.7	.360	1,340	.347	378.7	.950	.898
1/16	2	4	.404	1,768	.396	81.3	1,417	432.1	.392	1,357	.386	410.6	.958	.950
1/16	1 and 2	8	.388	1,765	.380	75.4	1,414	426.8	.376	1,348	.367	394.6	.953	.925
1/12	1	4	.368	1,704	.354	54.9	1,361	397.9	.365	1,439	.353	372.3	1.057	.936
1/12	2	4	.387	1,660	.390	69.8	1,329	400.6	.384	1,300	.378	385.1	.978	.961
1/12	1 and 2	8	.378	1,681	.372	62.3	1,344	399.0	.374	1,369	.365	378.8	1.019	.949
1/8	1	4	.360	1,670	.366	56.6	1,334	392.2	.358	1,310	.362	387.4	.982	.988
1/8	2	4	.385	1,654	.387	63.3	1,323	394.2	.384	1,311	.384	387.9	.991	.984
1/8	1 and 2	8	.372	1,663	.376	60.0	1,330	393.4	.371	1,311	.373	387.7	.986	.986
3/16	1	4	.358	1,465	.354	50.8	1,171	345.0	.356	1,159	.350	311.0	.990	.901
3/16	2	4	.372	1,806	.378	55.8	1,442	419.8	.369	1,484	.374	398.1	1.029	.948
3/16	1 and 2	8	.364	1,635	.366	53.2	1,306	382.2	.363	1,321	.362	354.6	1.011	.928
Mean	1												.987	.918
Mean	2												.986	.951
Mean	1 and 2												.987	.935

FPL-059 (Sheet 1 of 2)

Table 1.--Comparison of observed and calculated values of E_1 and E_2 for Sitka sprucde. (All values except specifice gravity adjusted to 10 percent moisture content basis.) (continued)

Ply thickness	Tree No.	Number of tests[1]	All-parallel Specific gravity[2]	All-parallel E_L	All-perpendicular Specific gravity[2]	All-perpendicular E_T	E_1 (calc)	E_2 (calc)	Outer-parallel Specific gravity[2]	Outer-parallel E_1(obs)	Outer-perpendicular Specific gravity[2]	Outer-perpendicular E_2(obs)	E_1(obs)/E_1(calc)	E_2(obs)/E_2(calc)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
In.				1,000 p.s.i.		1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.		1,000 p.s.i.		1,000 p.s.i.		
						SEVEN-PLY								
1/24	1	4	0.362	1,739	0.341	73.7	1,258	554.4	0.349	1,265	0.328	479.4	1.006	0.865
1/24	2	4	.375	1,706	.371	70.5	1,234	542.6	.370	1,262	.354	497.7	1.023	.917
1/24	1 and 2	8	.368	1,723	.356	72.1	1,247	548.6	.360	1,263	.341	488.4	1.013	.890
1/16	1	4	.355	1,647	.357	60.6	1,189	518.5	.351	1,293	.354	486.5	1.087	.938
1/16	2	4	.379	1,627	.399	79.7	1,180	526.3	.387	1,319	.374	577.7	1.118	1.098
1/16	1 and 2	8	.367	1,637	.378	70.1	1,185	522.4	.369	1,306	.364	532.1	1.102	1.019
1/12	1	4	.358	1,675	.371	65.2	1,210	529.8	.354	1,257	.358	491.5	1.039	.928
1/12	2	4	.380	1,801	.403	80.3	1,304	576.9	.370	1,299	.386	552.2	.996	.957
1/12	1 and 2	8	.369	1,737	.387	72.7	1,257	553.1	.362	1,278	.372	521.6	1.017	.943
1/8	1	4	.348	1,707	.362	55.2	1,230	532.0	.346	1,094	.356	411.4	.889	.773
1/8	2	4	.376	1,517	.384	60.9	1,097	481.2	.376	1,208	.375	533.7	1.101	1.109
1/8	1 and 2	8	.362	1,612	.373	58.0	1,163	506.5	.361	1,151	.366	472.4	.990	.933
3/16	1	4	.349	1,519	.361	58.6	1,097	480.1	.355	1,081	.355	427.5	.985	.890
3/16	2	4	.374	1,790	.394	63.6	1,292	561.9	.371	1,262	.373	524.1	.977	.933
3/16	1 and 2	8	.362	1,655	.378	61.1	1,195	521.1	.363	1,172	.364	475.7	.981	.913
Mean	1												1.001	.879
Mean	2												1.043	1.013
Mean	1 and 2												1.021	.939
						NINE-PLY								
1/24	1	4	.363	1,686	.371	90.6	1,152	624.6	.348	1,124	.368	595.9	.976	.954
1/24	2	4	.383	1,893	.390	90.4	1,290	693.7	.370	1,224	.387	672.6	.949	.970
1/24	1 and 2	8	.373	1,789	.380	90.5	1,221	659.0	.359	1,174	.378	634.0	.962	.962
1/16	1	4	.356	1,693	.369	75.2	1,152	616.7	.364	1,199	.359	585.2	1.041	.949
1/16	2	4	.395	1,689	.398	86.2	1,153	622.7	.391	1,237	.396	665.6	1.073	1.069
1/16	1 and 2	8	.376	1,691	.384	80.7	1,152	619.7	.378	1,217	.378	625.5	1.056	1.009
1/12	1	4	.359	1,713	.359	77.2	1,165	624.7	.356	1,123	.349	619.0	.964	.991
1/12	2	4	.372	1,666	.395	80.2	1,135	611.0	.374	1,163	.381	638.9	1.025	1.046
1/12	1 and 2	8	.366	1,689	.377	78.6	1,150	617.6	.365	1,143	.365	628.9	.994	1.018
1/8	1	4	.357	1,659	.369	72.9	1,128	603.8	.367	1,172	.367	601.9	1.039	.997
1/8	2	4	.388	1,653	.390	80.1	1,127	606.6	.374	1,036	.383	607.6	.919	1.002
1/8	1 and 2	8	.372	1,656	.380	76.4	1,127	605.1	.370	1,104	.375	604.8	.980	1.000
3/16	1	4	.356	1,495	.358	59.5	1,015	540.0	.354	1,023	.350	529.8	1.008	.981
3/16	2	4	.376	1,868	.377	61.9	1,263	666.4	.380	1,219	.334	614.1	.965	.922
3/16	1 and 2	8	.366	1,682	.368	60.6	1,139	603.3	.367	1,120	.342	571.3	.983	.947
Mean	1												1.005	.974
Mean	2												.986	1.002
Mean	1 and 2												.995	.987

[1]The number of tests applies to each construction. For example, for three-ply, 1/24-inch Tree 1, there were 16 all-parallel, 16 all-perpendicular, and so on.

[2]Specific gravity based upon ovendry weight of wood (weight of specimen minus weight of glue) and volume at test. Not adjusted to 10 percent moisture content basis.

FPL-059 (Sheet 2 of 2)

Table 2.--Comparison of observed and calculated values of E1 and E2 for Douglas-fir. (All values except specific gravity adjusted to 10 percent moisture content basis.)

Ply thickness	Tree No.	Number of tests[1]	All-parallel: Specific gravity[2]	All-parallel: E_L	All-perpendicular: Specific gravity[2]	All-perpendicular: E_T	E_1 (calc)	E_2 (calc)	Outer-parallel: Specific gravity[2]	Outer-parallel: E_1(obs)	Outer-perpendicular: Specific gravity[2]	Outer-perpendicular: E_2(obs)	E_1(obs)/E_1(calc)	E_2(obs)/E_2(calc)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
In.				1,000 p.s.i.		1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.		1,000 p.s.i.		1,000 p.s.i.		
THREE-PLY														
1/24	1	16	0.497	1,931	0.511	100.5	1,863	168.3	0.494	1,892	0.499	151.8	1.016	0.902
1/24	2	16	.402	1,558	.397	62.8	1,503	118.2	.394	1,489	.385	116.1	.991	.982
1/24	1 and 2	32	.449	1,744	.454	81.7	1,682	143.3	.444	1,691	.442	134.0	1.005	.935
1/16	1	16	.479	2,016	.499	110.7	1,945	181.3	.482	1,859	.506	157.8	.956	.870
1/16	2	16	.370	1,311	.372	53.8	1,264	100.4	.376	1,371	.381	107.9	1.085	1.075
1/16	1 and 2	32	.425	1,663	.436	82.3	1,604	140.8	.429	1,615	.443	132.8	1.007	.943
1/12	1	16	.490	2,031	.485	83.8	1,959	155.9	.498	1,863	.479	131.5	.951	.843
1/12	2	16	.412	1,634	.412	64.1	1,576	122.2	.402	1,508	.402	105.6	.957	.864
1/12	1 and 2	32	.451	1,832	.448	74.0	1,767	139.1	.450	1,686	.441	118.6	.954	.853
1/8	1	16	.485	1,987	.484	80.6	1,916	151.2	.478	1,827	.475	127.4	.954	.843
1/8	2	16	.366	1,162	.358	61.4	1,121	102.2	.382	1,362	.368	108.2	1.215	1.059
1/8	1 and 2	32	.426	1,574	.421	71.0	1,518	126.7	.430	1,595	.422	117.8	1.051	.930
3/16	1	16	.490	2,190	.491	65.5	2,111	144.2	.478	2,014	.488	149.5	.954	1.037
3/16	2	16	.388	1,431	.376	71.7	1,381	122.0	.385	1,336	.386	124.9	.967	1.024
3/16	1 and 2	32	.439	1,810	.434	68.6	1,746	133.1	.432	1,675	.437	137.2	.959	1.031
Mean	1												.966	.899
Mean	2												1.043	1.001
Mean	1 and 2												.995	.938
FIVE-PLY														
1/24	1	4	.478	1,804	.492	133.5	1,457	481.0	.466	1,413	.493	580.1	.970	1.206
1/24	2	4	.368	1,287	.370	67.1	1,033	321.1	.370	1,224	.374	364.4	1.185	1.135
1/24	1 and 2	8	.423	1,546	.432	100.5	1,245	401.2	.418	1,319	.434	472.5	1.059	1.178
1/16	1	4	.469	1,875	.492	126.9	1,511	490.5	.475	1,593	.492	482.5	1.054	.984
1/16	2	4	.349	1,338	.387	70.8	1,074	334.4	.372	1,259	.367	335.7	1.172	1.004
1/16	1 and 2	8	.409	1,606	.440	98.9	1,293	412.4	.423	1,425	.430	408.9	1.102	.992
1/12	1	4	.506	2,112	.504	131.2	1,700	543.2	.502	1,647	.496	466.0	.969	.858
1/12	2	4	.401	1,568	.382	83.2	1,259	392.0	.408	1,348	.423	447.4	1.071	1.141
1/12	1 and 2	8	.454	1,839	.442	107.1	1,479	467.3	.455	1,497	.459	456.7	1.012	.977
1/8	1	4	.470	1,917	.472	97.5	1,539	476.0	.473	1,489	.470	458.9	.968	.964
1/8	2	4	.394	1,387	.374	77.7	1,115	350.0	.376	1,121	.370	320.9	1.005	.917
1/8	1 and 2	8	.432	1,653	.423	87.6	1,327	415.2	.425	1,305	.420	389.9	.983	.944
3/16	1	4	.478	2,027	.487	74.0	1,621	480.2	.480	1,706	.468	443.6	1.052	.924
3/16	2	4	.392	1,511	.386	76.7	1,213	375.0	.371	1,008	.376	319.0	.831	.851
3/16	1 and 2	8	.435	1,769	.436	75.4	1,417	427.7	.425	1,358	.422	381.5	.958	.892
Mean	1												1.003	.987
Mean	2												1.053	1.009
Mean	1 and 2												1.023	.997

FPL-059 (Sheet 1 of 2)

Table 2.--Comparison of observed and calculated values of E_1 and E_2 for Douglas-fir. (All values except specific gravity adjusted to 10 percent moisture content basis.) (continued)

Ply thickness	Tree No.	Number of tests[1]	All-parallel: Specific gravity[2]	All-parallel: E_L	All-perpendicular: Specific gravity[2]	All-perpendicular: E_T	E_1 (calc)	E_2 (calc)	Outer-parallel: Specific gravity[2]	Outer-parallel: E_1(obs)	Outer-perpendicular: Specific gravity[2]	Outer-perpendicular: E_2(obs)	E_1(obs) / E_1(calc)	E_2(obs) / E_2(calc)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
In.				1,000 p.s.i.		1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.		1,000 p.s.i.		1,000 p.s.i.		
							SEVEN-PLY							
1/24	1	4	0.495	2,094	0.509	167.9	1,538	723.8	0.482	1,422	0.490	672.5	0.925	0.929
1/24	2	4	.387	1,664	.402	96.0	1,211	548.6	.389	1,262	.397	600.1	1.042	1.094
1/24	1 and 2	8	.441	1,878	.456	132.1	1,374	636.0	.436	1,341	.444	636.5	.976	1.001
1/16	1	4	.492	1,994	.476	127.0	1,455	665.9	.501	1,537	.479	641.9	1.056	.964
1/16	2	4	.388	1,457	.379	91.1	1,063	485.3	.367	954	.368	466.8	.897	.962
1/16	1 and 2	8	.440	1,725	.428	109.1	1,259	575.5	.434	1,246	.424	554.4	.990	.963
1/12	1	4	.490	1,949	.510	105.6	1,417	637.7	.502	1,434	.510	667.8	1.012	1.047
1/12	2	4	.424	2,015	.396	92.8	1,460	647.6	.425	1,345	.401	562.4	.921	.868
1/12	1 and 2	8	.457	1,981	.453	99.2	1,438	642.3	.464	1,389	.456	614.5	.966	.957
1/8	1	4	.457	1,942	.472	99.9	1,410	631.6	.470	1,494	.465	674.5	1.060	1.068
1/8	2	4	.392	1,315	.384	82.0	959	437.9	.380	910	.377	396.5	.949	.905
1/8	1 and 2	8	.424	1,629	.428	91.0	1,185	534.9	.425	1,202	.421	535.6	1.014	1.001
3/16	1	4	.475	2,004	.477	64.0	1,444	623.9	.478	1,430	.478	625.4	.990	1.002
3/16	2	4	.387	1,487	.400	84.2	1,082	489.1	.410	1,036	.401	484.0	.957	.990
3/16	1 and 2	8	.431	1,746	.438	74.1	1,263	556.7	.444	1,234	.440	554.7	.977	.996
Mean	1												1.009	1.002
Mean	2												.953	.964
Mean	1 and 2												.985	.983
							NINE-PLY							
1/24	1	4	.483	2,063	.492	143.8	1,421	786.2	.501	1,489	.508	776.9	1.048	.988
1/24	2	4	.395	1,790	.416	116.9	1,230	676.9	.382	1,065	.395	616.0	.866	.910
1/24	1 and 2	8	.439	1,926	.454	130.3	1,325	731.3	.442	1,277	.452	696.9	.964	.953
1/16	1	4	.486	1,837	.511	132.1	1,266	702.7	.511	1,393	.489	740.5	1.100	1.054
1/16	2	4	.375	1,461	.378	87.8	1,001	547.4	.379	1,001	.374	513.2	1.000	.938
1/16	1 and 2	8	.430	1,649	.444	109.9	1,134	625.0	.445	1,196	.432	625.8	1.055	1.001
1/12	1	4	.507	1,957	.503	93.3	1,333	717.1	.510	1,408	.515	713.4	1.056	.995
1/12	2	4	.425	1,919	.402	86.9	1,306	700.1	.421	1,251	.414	653.1	.958	.933
1/12	1 and 2	8	.466	1,937	.452	90.1	1,319	708.3	.466	1,329	.464	682.8	1.008	.964
1/8	1	4	.466	1,922	.479	97.8	1,311	708.4	.471	1,408	.471	739.0	1.074	1.043
1/8	2	4	.394	1,411	.417	85.0	967	528.8	.405	1,096	.411	526.4	1.133	.995
1/8	1 and 2	8	.430	1,667	.448	91.5	1,140	618.8	.438	1,251	.441	632.7	1.097	1.022
3/16	1	4	.468	2,062	.487	64.4	1,393	733.0	.482	1,348	.486	706.2	.968	.963
3/16	2	4	.369	1,562	.432	73.3	931	504.6	.386	899	.406	523.5	.966	1.037
3/16	1 and 2	8	.418	1,713	.460	68.9	1,163	619.2	.434	1,123	.446	614.9	.966	.993
Mean	1												1.049	1.008
Mean	2												.985	.963
Mean	1 and 2												1.018	.987

[1] The number of tests applies to each construction. For example, for three-ply 1/24-inch Tree 1, there were 16 all-parallel, 16 all-perpendicular, and so on.

[2] Specific gravity based upon ovendry weight of wood (weight of specimen minus weight of glue) and volume at test. Not adjusted to 10 percent moisture content basis.

Table 3.--Comparison of observed and calculated values of E_1 and E_2 for yellow-poplar. (All values except specific gravity adjusted to 10 percent moisture content basis.)

Ply-thickness	Tree No.	Number of tests[1]	All-parallel Specific gravity[2]	All-parallel E_L	All-perpendicular Specific gravity[2]	All-perpendicular E_T	E_1 (calc)	E_2 (calc)	Outer-parallel Specific gravity[2]	Outer-parallel E_1(obs)	Outer-perpendicular Specific gravity[2]	Outer-perpendicular E_2(obs)	E_1(obs)/E_1(calc)	E_2(obs)/E_2(calc)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
In.				1,000 p.s.i.		1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.		1,000 p.s.i.		1,000 p.s.i.		
THREE-PLY														
1/24	1	16	0.406	1,396	0.394	44.2	1,346	94.3	0.391	1,351	0.382	107.5	1.004	1.140
1/24	2	16	.440	1,647	.442	51.9	1,588	111.0	.438	1,637	.437	119.3	1.031	1.075
1/24	1 and 2	32	.423	1,522	.418	48.0	1,467	102.6	.414	1,494	.409	113.4	1.018	1.105
1/16	1	16	.412	1,415	.451	53.9	1,365	104.3	.419	1,468	.433	113.9	1.075	1.092
1/16	2	16	.314	958	.330	32.4	924	66.7	.320	1,023	.323	88.6	1.107	1.328
1/16	1 and 2	32	.363	1,186	.391	43.2	1,144	85.5	.369	1,246	.378	101.2	1.089	1.184
1/12	1	16	.375	1,282	.357	46.9	1,256	92.6	.355	1,255	.362	102.1	1.015	1.103
1/12	2	16	.382	1,374	.377	51.0	1,325	100.0	.364	1,246	.373	103.8	.940	1.038
1/12	1 and 2	32	.378	1,328	.367	48.9	1,281	96.3	.359	1,250	.368	103.0	.976	1.070
1/8	1	16	.402	1,655	.405	51.1	1,596	110.5	.419	1,845	.414	122.3	1.156	1.107
1/8	2	16	.359	1,265	.365	48.5	1,220	93.6	.362	1,359	.366	96.8	1.114	1.034
1/8	1 and 2	32	.380	1,460	.385	49.9	1,408	102.1	.390	1,602	.390	109.6	1.138	1.073
3/16	1	16	.373	1,286	.367	45.4	1,240	91.3	.357	1,173	.369	97.7	.946	1.070
3/16	2	16	.411	1,547	.396	53.3	1,492	108.6	.400	1,526	.398	112.7	1.023	1.038
3/16	1 and 2	32	.392	1,416	.382	49.3	1,365	99.9	.378	1,350	.384	105.2	.989	1.053
Mean	1												1.045	1.102
Mean	2												1.037	1.085
Mean	1 and 2												1.041	1.095
FIVE-PLY														
1/24	1	2	.395	1,245	.409	62.8	999	308.7	.400	1,205	.403	347.9	1.206	1.127
1/16	1	2	.440	1,556	.412	56.9	1,244	368.7	.407	1,152	.438	343.7	.926	.932
1/12	1	2	.379	1,295	.393	51.0	1,036	309.8	.382	1,171	.382	320.3	1.130	1.034
1/8	1	2	.417	1,806	.411	59.3	1,443	422.6	.422	1,340	.410	388.9	.929	.920
3/16	1	2	.358	1,528	.400	47.7	1,220	355.6	.377	1,290	.345	293.4	1.057	.825
Mean													1.037	.960
SEVEN-PLY														
1/24	1	2	.407	1,448	.400	77.9	1,053	473.4	.371	1,063	.380	370.0	1.009	.782
1/16	1	2	.408	1,424	.457	70.6	1,033	461.2	.410	1,190	.432	523.7	1.152	1.136
1/12	1	2	.357	1,284	.363	47.2	927	404.2	.350	900	.359	400.1	.971	.990
1/8	1	2	.397	1,723	.399	57.2	1,242	538.0	.405	1,314	.401	626.4	1.058	1.164
3/16	1	2	.321	1,082	.336	55.2	786	351.6	.312	717	.330	411.6	.912	1.171
Mean													1.029	1.046
NINE-PLY														
1/24	1	2	.401	1,431	.380	74.6	977	528.6	.383	962	.376	509.6	.985	.964
1/16	1	2	.452	1,763	.423	65.2	1,195	633.5	.443	1,163	.410	617.8	.973	.975
1/12	1	2	.367	1,326	.354	50.3	899	477.3	.361	1,029	.345	426.6	1.145	.894
1/8	1	2	.401	1,824	.412	65.3	1,235	653.9	.424	1,373	.409	624.5	1.112	.955
3/16	1	2	.341	876	.329	38.6	596	318.9	.340	760	.322	343.5	1.275	1.077
Mean													1.079	.966

[1] The number of tests applies to each construction. For example, for three-ply, 1/24-inch Tree 1, there were 16 all-parallel, 16 all-perpendicular, and so on.

[2] Specific gravity based upon ovendry weight of wood (weight of specimen minus weight of glue) and volume at test. Not adjusted to 10 percent moisture content basis.

Table 4,--Summary of ratios of observed to calculated values from table 1

Number of plies	Item	Ratio $\frac{E_1(obs)}{E_1(calc)}$						Ratio $\frac{E_2(obs)}{E_2(calc)}$					
		Sitka spruce		Douglas-fir		Yellow-poplar		Sitka spruce		Douglas-fir		Yellow-poplar	
		Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2
3	Mean	0.957	0.990	0.966	1.043	1.045	1.037	1.026	0.974	0.899	1.001	1.102	1.085
5	Mean	.987	.986	1.003	1.053	1.037	.....	.918	.951	.987	1.009	.960	.....
7	Mean	1.001	1.043	1.009	.953	1.029	.....	.879	1.013	1.002	.964	1.046	.....
9	Mean	1.005	.986	1.049	.985	1.079	.....	.974	1.002	1.008	.963	.966	.....
3, 5, 7, 9	Mean	.975	.996	.989	1.023	1.046	.....	.982	.979	.942	.991	1.077	.....

Table 5.--Comparison of observed and calculated values of F_1, S_1, F_2, and S_2 for Sitka spruce.

(All values except specific gravity adjusted to 10 percent moisture content basis.)

Ply thickness	Tree No.	Number of tests[1]	All-parallel: Specific gravity[2]	All-parallel: F_L	All-parallel: S_L	F_T (calc)	S_1 (calc)	All-perpendicular: Specific gravity[2]	All-perpendicular: F_T	All-perpendicular: S_T	F_2 (calc)	S_2 (calc)	Outer-parallel: Specific gravity[2]	Outer-parallel: F_1 (obs)	Outer-parallel: S_1 (obs)	Outer-perpendicular: Specific gravity[2]	Outer-perpendicular: F_2 (obs)	Outer-perpendicular: S_2 (obs)	F_1(obs)/F_1(calc)	S_1(obs)/S_1(calc)	F_2(obs)/F_2(calc)	S_2(obs)/S_2(calc)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
In.				P.s.i.	P.s.i.	P.s.i.	P.s.i.		P.s.i.	P.s.i.	P.s.i.	P.s.i.		P.s.i.	P.s.i.		P.s.i.	P.s.i.				
THREE-PLY																						
1/24	1	16	0.356	6,287	10,284	5,639	9,224	0.367	444	656	964	1,577	0.344	5,273	7,930	0.343	1,047	2,177	0.935	0.860	1.086	1.380
1/24	2	16	.384	7,080	12,254	7,013	11,337	.390	412	648	1,138	1,839	.372	6,399	9,349	.372	1,250	2,389	.912	.825	1.098	1.299
1/24	1 and 2	32	.370	6,934	11,269	6,320	10,272	.378	428	652	1,052	1,710	.358	5,836	8,640	.357	1,148	2,283	.923	.841	1.091	1.335
1/16	1	16	.366	6,670	10,963	6,433	10,574	.371	411	725	1,029	1,690	.354	5,913	8,769	.352	962	2,052	.919	.829	.935	1.214
1/16	2	16	.398	6,555	11,960	6,219	11,348	.392	385	677	1,006	1,835	.387	5,667	9,192	.375	1,024	1,990	.911	.810	1.018	1.084
1/16	1 and 2	32	.382	6,612	11,462	6,322	10,960	.382	398	701	1,018	1,764	.371	5,790	8,380	.363	993	2,021	.916	.819	.975	1.146
1/12	1	16	.364	6,891	10,839	6,339	9,971	.363	342	641	1,041	1,638	.354	5,638	8,293	.355	991	1,870	.889	.832	.952	1.142
1/12	2	16	.393	7,230	11,624	7,156	11,505	.381	283	621	1,134	1,824	.389	6,435	9,210	.374	1,026	2,124	.899	.801	.905	1.164
1/12	1 and 2	32	.378	7,060	11,232	6,739	10,721	.372	312	631	1,087	1,729	.372	6,036	8,752	.364	1,008	1,997	.896	.816	.927	1.155
1/8	1	16	.358	6,286	9,996	5,845	9,295	.360	309	514	974	1,549	.360	5,325	7,981	.356	878	1,751	.911	.859	.901	1.130
1/8	2	16	.388	6,607	11,073	6,274	10,517	.388	283	534	1,066	1,788	.383	5,767	8,603	.383	828	1,830	.919	.818	.777	1.023
1/8	1 and 2	32	.373	6,446	10,536	6,059	9,903	.374	264	524	1,020	1,667	.372	5,546	8,292	.370	853	1,790	.915	.837	.836	1.074
3/16	1	16	.354	6,352	9,073	5,737	8,197	.352	219	484	1,018	1,454	.350	5,365	7,290	.349	782	1,667	.935	.889	.768	1.146
3/16	2	16	.378	6,738	11,256	6,454	10,781	.377	261	506	1,057	1,766	.373	5,951	8,911	.374	869	1,891	.922	.827	.822	1.071
3/16	1 and 2	32	.366	6,545	10,166	6,103	9,479	.364	240	495	1,036	1,609	.361	5,658	8,100	.362	826	1,779	.927	.855	.797	1.106
Mean	1																		.918	.854	.928	1.202
Mean	2																		.913	.816	.924	1.128
Mean	1 and 2																		.915	.834	.925	1.163
FIVE-PLY																						
1/24	1	4	.366	7,383	11,114	5,652	8,508	.372	458	751	2,762	4,158	.349	4,551	7,930	.348	1,985	3,980	.805	.931	.719	.957
1/24	2	4	.392	8,175	12,482	6,385	9,748	.389	453	750	3,057	4,668	.368	5,303	8,414	.374	2,344	4,258	.831	.863	.767	.912
1/24	1 and 2	8	.380	7,779	11,798	6,013	9,120	.380	456	750	2,910	4,414	.359	4,927	8,167	.361	2,164	4,119	.819	.896	.744	.933
1/16	1	4	.372	6,310	11,273	4,796	8,569	.364	405	688	2,353	4,204	.360	4,507	7,967	.347	2,223	3,838	.940	.930	.945	.913
1/16	2	4	.404	7,175	11,863	5,507	9,105	.396	457	819	2,707	4,476	.392	4,899	8,039	.386	2,722	4,466	.890	.883	1.006	.998
1/16	1 and 2	8	.388	6,742	11,568	5,149	8,834	.380	431	754	2,529	4,339	.376	4,703	8,003	.367	2,472	4,152	.913	.906	.977	.957
1/12	1	4	.368	6,257	10,721	5,284	9,054	.354	237	492	2,303	3,946	.365	4,351	8,346	.353	1,978	3,734	.823	.922	.859	.946
1/12	2	4	.387	5,991	10,854	4,692	8,500	.390	331	710	2,245	4,067	.384	4,128	7,450	.378	2,140	4,006	.880	.876	.953	.985
1/12	1 and 2	8	.378	6,124	10,788	4,987	8,786	.372	284	601	2,274	4,007	.374	4,240	7,898	.365	2,059	3,870	.850	.899	.905	.966
1/8	1	4	.360	6,871	10,469	5,390	8,212	.366	239	477	2,337	3,866	.358	4,176	7,166	.362	2,382	3,862	.775	.873	.939	.999
1/8	2	4	.385	7,261	11,468	5,755	9,090	.387	209	561	2,703	4,268	.384	4,740	8,198	.384	2,413	4,008	.824	.902	.893	.939
1/8	1 and 2	8	.372	7,066	10,968	5,570	8,646	.376	224	519	2,619	4,066	.371	4,458	7,682	.373	2,398	3,935	.800	.889	.916	.968
3/16	1	4	.358	4,550	9,150	3,600	7,239	.354	196	367	1,683	3,384	.356	3,771	6,209	.350	1,591	3,120	1.048	.858	.945	.922
3/16	2	4	.372	6,790	10,738	5,379	8,823	.378	242	470	2,494	3,944	.369	4,840	8,067	.374	2,024	3,818	.868	.914	.812	.968
3/15	1 and 2	8	.364	5,670	9,944	4,581	8,035	.366	219	418	2,088	3,662	.363	4,306	7,138	.362	1,808	3,469	.940	.888	.866	.947
Mean	1																		.878	.903	.881	.947
Mean	2																		.859	.888	.886	.960
Mean	1 and 2																		.864	.896	.882	.954

(Sheet 1 of 2)

Table 5.--Comparison of observed and calculated values of F_1, S_1, F_2, and S_2 for Sitka spruce. (All values except specific gravity adjusted to 10 percent moisture content basis.) (continued)

Ply thickness	Tree No.	Number of tests[1]	All-parallel: Specific gravity[2]	All-parallel: F_L	All-parallel: S_L	F_1 (calc)	S_1 (calc)	All-perpendicular: Specific gravity[2]	All-perpendicular: F_T	All-perpendicular: S_T	F_2 (calc)	S_2 (calc)	Outer-parallel: Specific gravity[2]	Outer-parallel: F_1 (obs)	Outer-parallel: S_1 (obs)	Outer-perpendicular: Specific gravity[2]	Outer-perpendicular: F_2 (obs)	Outer-perpendicular: S_2 (obs)	F_1(obs)/F_1(calc)	S_1(obs)/S_1(calc)	F_2(obs)/F_2(calc)	S_2(obs)/S_2(calc)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
In.				P.s.i.	P.s.i.	P.s.i.	P.s.i.		P.s.i.	P.s.i.	P.s.i.	P.s.i.		P.s.i.	P.s.i.		P.s.i.	P.s.i.				
SEVEN-PLY																						
1/24	1	4	0.362	6,056	11,877	4,405	8,639	0.341	468	768	2,588	4,996	0.349	3,727	7,313	0.328	2,513	4,841	0.846	0.847	0.971	0.954
1/24	2	4	.375	6,251	12,512	4,624	9,255	.371	436	751	2,668	5,302	.370	4,243	7,997	.354	2,919	4,981	.918	.864	1.094	.933
1/24	1 and 2	8	.368	6,154	12,194	4,511	8,938	.356	452	760	2,628	5,148	.360	3,985	7,655	.341	2,716	4,911	.883	.856	1.033	.943
1/16	1	4	.355	5,568	10,636	4,371	8,350	.357	301	615	2,363	4,937	.351	3,348	7,075	.354	2,273	4,209	.766	.847	.962	.932
1/16	2	4	.379	5,507	11,396	4,465	9,239	.399	394	793	2,374	5,748	.387	4,391	8,096	.374	2,621	5,001	.983	.876	1.104	1.018
1/16	1 and 2	8	.367	5,538	11,016	4,418	8,789	.378	348	704	2,369	5,344	.369	3,870	7,586	.364	2,447	4,605	.876	.863	1.033	.977
1/12	1	4	.358	7,083	10,939	5,325	8,209	.371	240	616	3,014	4,643	.354	4,457	6,962	.358	2,542	4,350	.839	.848	.843	.934
1/12	2	4	.380	8,074	11,850	5,824	8,547	.403	342	719	3,461	4,945	.370	4,549	7,882	.386	2,877	5,194	.781	.922	.831	1.022
1/12	1 and 2	8	.369	7,578	11,394	5,576	8,384	.387	291	668	3,237	4,795	.362	4,503	7,422	.372	2,710	4,772	.808	.885	.837	.980
1/8	1	4	.348	6,613	10,047	4,238	6,439	.362	195	576	2,796	4,293	.346	4,190	6,301	.356	2,373	3,821	.989	.979	.851	.901
1/8	2	4	.376	6,791	10,772	5,408	8,578	.384	213	582	2,894	5,101	.376	4,765	7,913	.375	2,925	4,781	.881	.922	1.011	1.041
1/8	1 and 2	8	.362	6,702	10,410	4,785	7,433	.373	204	579	2,841	4,716	.361	4,478	7,107	.366	2,649	4,301	.936	.956	.932	.975
3/16	1	4	.349	6,552	9,310	4,663	6,626	.361	273	398	2,787	2,903	.355	5,029	6,298	.355	2,043	3,659	1.078	.950	.733	.924
3/16	2	4	.374	7,553	10,764	5,325	7,589	.394	234	487	3,199	4,013	.371	4,885	6,946	.373	2,729	4,327	.917	.915	.853	.949
3/16	1 and 2	8	.362	7,052	10,037	4,994	7,108	.378	254	442	2,993	3,441	.363	4,957	6,622	.364	2,386	3,993	.993	.932	.797	.937
Mean	1																		.904	.394	.872	.929
Mean	2																		.896	.900	.979	.993
Mean	1 and 2																		.899	.898	.926	.962
NINE-PLY																						
1/24	1	4	.363	6,329	11,109	4,220	7,406	.371	491	738	2,899	4,854	.348	3,788	7,036	.368	2,886	5,103	.898	.950	.996	1.003
1/24	2	4	.383	7,722	13,155	4,993	8,506	.390	446	710	3,514	5,282	.370	4,425	7,994	.387	3,146	5,595	.886	.940	.895	.935
1/24	1 and 2	8	.373	7,026	12,132	4,610	7,961	.380	468	724	3,207	5,072	.359	4,106	7,515	.378	3,016	5,349	.891	.944	.940	.966
1/16	1	4	.356	6,071	10,225	4,299	7,241	.369	298	609	2,757	4,739	.364	3,982	7,089	.359	2,666	4,555	.926	.979	.969	.983
1/16	2	4	.395	6,299	11,765	4,613	8,617	.398	313	702	2,876	5,421	.391	4,054	7,076	.396	3,304	5,518	.879	.821	1.149	1.027
1/16	1 and 2	8	.376	6,185	10,995	4,451	7,913	.384	306	656	2,814	5,085	.378	4,018	7,082	.378	2,985	5,036	.903	.895	1.061	1.007
1/12	1	4	.359	6,377	10,369	4,181	6,798	.359	292	616	2,893	4,939	.356	3,234	6,156	.349	2,380	4,884	.773	.906	.823	1.036
1/12	2	4	.372	6,659	11,006	4,649	7,683	.395	312	698	3,031	5,560	.374	3,703	6,848	.381	2,804	5,360	.797	.891	.925	1.070
1/12	1 and 2	8	.366	6,518	10,688	4,411	7,233	.377	302	657	2,961	5,257	.365	3,468	6,502	.365	2,592	5,122	.786	.899	.875	1.055
1/8	1	4	.357	7,723	10,579	5,456	7,473	.369	229	528	3,498	4,360	.367	3,931	6,508	.367	2,622	4,701	.720	.871	.750	.981
1/8	2	4	.388	7,512	11,225	4,708	7,035	.390	229	561	3,420	4,256	.374	3,869	6,155	.383	2,617	4,819	.822	.875	.765	.943
1/8	1 and 2	8	.372	7,618	10,902	5,079	7,268	.380	229	544	3,459	4,306	.370	3,900	6,332	.375	2,620	4,760	.768	.871	.757	.961
3/16	1	4	.356	6,297	9,188	4,309	6,287	.358	247	479	2,839	4,265	.354	3,726	5,592	.350	2,655	4,100	.865	.889	.935	.990
3/16	2	4	.376	6,831	10,884	4,458	7,103	.377	257	440	3,056	4,365	.380	4,559	6,795	.334	2,719	4,677	1.023	.957	.890	.960
3/16	1 and 2	8	.366	6,564	10,036	4,371	6,683	.368	242	460	2,947	4,336	.367	4,142	6,194	.342	2,687	4,388	.948	.927	.912	.974
Mean	1																		.836	.919	.895	.999
Mean	2																		.881	.897	.925	.987
Mean	1 and 2																		.859	.907	.909	.993

[1] The number of tests applies to each construction. For example, for three-ply, 1/24-inch Tree 1, there were 16 all-parallel, 16 all-perpendicular, and so on.

[2] Specific gravity based upon ovendry weight of wood (weight of specimen minus weight of glue) and volume at test. Not adjusted to 10 percent moisture content basis.

(Sheet 2 Of 2)

Table 6.--Comparison of observed and calculated values of F_1, S_1, F_2 and S_2 for Douglas-fir.

(All values except specific gravity adjusted to 10 percent moisture content basis.)

Ply thickness	Tree No.	Number of tests[1]	All-parallel: Specific gravity[2]	All-parallel: F_L	All-parallel: S_L	F_1 (calc)	S_1 (calc)	All-perpendicular: Specific gravity[2]	All-perpendicular: F_T	All-perpendicular: S_T	F_2 (calc)	S_2 (calc)	Outer-parallel: Specific gravity[2]	Outer-parallel: F_1 (obs)	Outer-parallel: S_1 (obs)	Outer-perpendicular: Specific gravity[2]	Outer-perpendicular: F_2 (obs)	Outer-perpendicular: S_2 (obs)	F_1(obs)/F_1(calc)	S_1(obs)/S_1(calc)	F_2(obs)/F_2(calc)	S_2(obs)/S_2(calc)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
In.				P.s.i.	P.s.i.	P.s.i.	P.s.i.		P.s.i.	P.s.i.	P.s.i.	P.s.i.		P.s.i.	P.s.i.		P.s.i.	P.s.i.				
THREE-PLY																						
1/24	1	16	0.497	9,271	14,143	9,084	13,857	0.511	545	911	1,726	2,633	0.494	8,027	12,181	0.499	1,433	2,992	0.884	0.879	0.830	1.136
1/24	2	16	.402	7,288	11,838	6,965	11,314	.397	419	644	1,234	2,004	.394	6,337	9,211	.385	1,017	2,175	.910	.814	.824	1.085
1/24	1 and 2	32	.449	8,280	12,990	8,028	12,595	.454	482	778	1,480	2,321	.444	7,182	10,696	.442	1,225	2,584	.895	.849	.828	1.113
1/16	1	16	.479	9,395	14,466	8,663	13,339	.499	505	915	1,789	2,754	.482	7,680	11,797	.506	1,392	3,141	.887	.884	.778	1.141
1/16	2	16	.370	6,339	10,124	6,629	10,588	.372	254	532	1,080	1,724	.376	6,380	9,007	.381	848	2,085	.962	.851	.785	1.208
1/16	1 and 2	32	.425	7,867	12,295	7,640	11,940	.436	380	724	1,437	2,245	.429	7,030	10,402	.443	1,120	2,612	.920	.871	.779	1.163
1/12	1	16	.490	9,077	14,200	8,326	13,026	.485	330	651	1,550	2,425	.498	7,306	11,586	.479	990	2,438	.877	.889	.639	1.005
1/12	2	16	.412	6,880	10,184	6,350	9,399	.412	278	514	1,154	1,708	.402	5,829	8,213	.402	849	1,864	.918	.874	.736	1.091
1/12	1 and 2	32	.451	7,978	12,192	7,342	11,220	.448	304	582	1,352	2,067	.450	6,568	9,900	.441	920	2,151	.895	.882	.680	1.041
1/8	1	16	.485	8,091	12,275	7,440	11,287	.484	227	451	1,374	2,084	.478	7,217	10,999	.475	912	2,445	.970	.974	.664	1.173
1/8	2	16	.366	4,837	8,805	5,669	10,320	.358	317	605	906	1,650	.382	5,224	8,771	.368	943	1,839	.922	.850	1.041	1.115
1/8	1 and 2	32	.426	6,464	10,540	6,550	10,680	.421	272	527	1,140	1,858	.430	6,220	9,885	.422	928	2,142	.950	.926	.814	1.153
3/16	1	16	.490	7,961	12,591	7,321	11,579	.491	202	368	1,228	1,943	.478	7,342	10,561	.488	997	2,467	1.003	.912	.812	1.270
3/16	2	16	.388	5,540	8,882	5,172	8,292	.376	231	509	1,017	1,630	.385	5,409	8,142	.386	822	1,738	1.046	.982	.808	1.066
3/16	1 and 2	32	.439	6,750	10,736	6,246	9,935	.434	216	438	1,120	1,781	.432	6,376	9,352	.437	910	2,102	1.021	.941	.812	1.180
Mean	1																		.924	.908	.745	1.145
Mean	2																		.952	.874	.839	1.113
Mean	1 and 2																		.936	.894	.783	1.130
FIVE-PLY																						
1/24	1	4	.478	8,384	12,766	6,567	10,000	.492	654	985	3,320	5,055	.466	6,041	8,736	.493	3,831	6,579	.920	.874	1.154	1.301
1/24	2	4	.368	6,733	10,857	6,403	10,325	.3[illegible]0	369	794	2,568	4,141	.370	4,629	8,118	.374	2,569	4,294	.723	.786	1.000	1.037
1/24	1 and 2	8	.423	7,558	11,812	6,448	10,078	.432	512	888	2,948	4,607	.418	5,335	8,427	.434	3,200	5,436	.827	.856	1.085	1.180
1/16	1	4	.469	8,596	14,424	7,303	12,255	.492	440	810	3,368	5,651	.475	6,782	9,832	.492	3,394	6,033	.929	.802	1.008	1.068
1/16	2	4	.349	5,528	10,483	5,202	9,865	.387	313	587	2,111	4,003	.372	4,828	8,411	.367	2,128	4,070	.928	.853	1.008	1.017
1/16	1 and 2	8	.409	7,062	12,454	6,266	11,050	.440	376	698	2,738	4,828	.423	5,805	9,122	.430	2,761	5,052	.926	.826	1.008	1.046
1/12	1	4	.506	7,957	13,499	6,205	10,527	.504	379	784	3,088	5,239	.502	6,430	10,863	.496	2,619	5,739	1.036	1.032	.848	1.095
1/12	2	4	.401	6,424	10,683	5,523	9,184	.382	338	610	2,455	4,082	.408	4,552	8,072	.423	2,494	4,582	.824	.879	1.016	1.122
1/12	1 and 2	8	.454	7,190	12,091	5,853	9,842	.442	358	697	2,772	4,661	.455	5,491	9,468	.459	2,556	5,160	.938	.962	.922	1.107
1/8	1	4	.470	8,901	12,987	6,913	10,087	.472	218	454	3,368	4,943	.473	6,249	9,095	.470	2,942	5,239	.904	.902	.868	1.060
1/8	2	4	.394	5,961	9,891	4,818	7,994	.374	232	613	2,289	3,798	.376	4,423	6,902	.370	1,962	3,741	.918	.863	.857	.985
1/8	1 and 2	8	.432	7,431	11,439	5,867	9,031	.423	225	534	2,839	4,370	.425	5,336	7,998	.420	2,452	4,490	.909	.886	.864	1.027
3/16	1	4	.478	6,443	10,670	5,422	8,980	.487	243	394	2,390	3,959	.480	5,419	8,047	.468	2,434	4,687	.999	.896	1.018	1.184
3/16	2	4	.392	6,157	9,561	4,107	6,378	.386	268	462	2,343	3,638	.371	4,144	6,205	.376	1,580	3,572	1.009	.973	.674	.982
3/16	1 and 2	8	.435	6,300	10,116	4,837	7,766	.436	256	428	2,363	3,795	.425	4,782	7,125	.422	2,007	4,130	.989	.917	.849	1.088
Mean	1																		.958	.901	.979	1.142
Mean	2																		.880	.871	.911	1.029
Mean	1 and 2																		.918	.885	.946	1.090

(Sheet 1 of 2)

Table 6.--Comparison of observed and calculated values of F1, S1, F2, and S2 for Douglas-fir. (All values except specific gravity adjusted to 10 percent moisture content basis.) (continued)

Ply thickness	Tree No.	Number of tests[1]	All-parallel: Specific gravity[2]	All-parallel: F_L	All-parallel: S_L	F_1 (calc)	S_1 (calc)	All-perpendicular: Specific gravity[2]	All-perpendicular: F_T	All-perpendicular: S_T	F_2 (calc)	S_2 (calc)	Outer-parallel: Specific gravity[2]	Outer-parallel: F_1 (obs)	Outer-parallel: S_1 (obs)	Outer-perpendicular: Specific gravity[2]	Outer-perpendicular: F_2 (obs)	Outer-perpendicular: S_2 (obs)	F_1(obs)/F_1(calc)	S_1(obs)/S_1(calc)	F_2(obs)/F_2(calc)	S_2(obs)/S_2(calc)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
In.				P.s.i.	P.s.i.	P.s.i.	P.s.i.		P.s.i.	P.s.i.	P.s.i.	P.s.i.		P.s.i.	P.s.i.		P.s.i.	P.s.i.				
SEVEN-PLY																						
1/24	1	4	0.495	9,699	13,219	6,587	10,335	0.509	725	1,144	4,348	6,823	0.482	5,660	8,972	0.490	4,337	6,775	0.859	0.868	0.997	0.993
1/24	2	4	.387	8,049	11,209	6,104	8,501	.402	462	829	3,509	4,886	.389	4,666	8,403	.397	3,444	6,152	.764	.988	.981	1.259
1/24	1 and 2	8	.441	8,874	13,214	6,337	9,436	.456	594	986	3,929	5,851	.436	5,163	8,688	.444	3,890	6,464	.815	.921	.990	1.105
1/16	1	4	.492	9,387	14,412	7,235	11,109	.476	437	813	4,123	6,330	.501	5,529	9,286	.479	3,714	6,437	.764	.836	.901	1.017
1/16	2	4	.388	6,882	10,592	4,506	6,936	.379	416	686	3,018	4,645	.367	3,967	6,712	.368	2,549	4,872	.880	.968	.845	1.049
1/16	1 and 2	8	.440	8,134	12,502	5,875	9,030	.428	426	750	3,570	5,487	.434	4,748	7,999	.424	3,132	5,654	.808	.886	.877	1.030
1/12	1	4	.490	9,148	13,435	6,731	9,885	.510	366	721	3,969	5,829	.502	5,837	8,568	.510	3,684	6,704	.867	.867	.928	1.150
1/12	2	4	.424	7,740	12,194	5,166	8,139	.396	358	666	3,324	5,237	.425	4,600	6,794	.401	2,995	5,041	.890	.835	.900	.963
1/12	1 and 2	8	.457	8,444	12,814	5,921	8,985	.453	362	694	3,645	5,532	.464	5,218	7,681	.456	3,338	5,872	.881	.855	.916	1.061
1/8	1	4	.457	8,620	13,456	6,631	10,352	.472	251	462	3,727	5,818	.470	5,942	8,424	.465	3,370	5,916	.896	.814	.904	1.017
1/8	2	4	.392	6,321	8,908	4,374	6,164	.384	298	651	2,772	3,906	.380	4,269	6,533	.377	1,796	4,137	.976	1.060	.648	1.059
1/8	1 and 2	8	.424	7,470	11,182	5,512	8,251	.428	274	556	3,250	4,863	.425	5,106	7,478	.421	2,583	5,026	.926	.906	.795	1.034
3/16	1	4	.475	9,109	10,864	6,500	7,753	.477	211	309	3,841	4,581	.478	5,845	7,321	.478	3,571	5,202	.899	.944	.930	1.136
3/16	2	4	.387	6,722	9,228	4,683	6,429	.400	311	468	2,926	4,017	.410	4,350	5,850	.401	2,919	4,492	.929	.910	.998	1.118
3/16	1 and 2	8	.431	7,916	10,046	5,595	7,101	.438	261	388	3,383	4,294	.444	5,098	6,586	.440	3,245	4,847	.911	.927	.959	1.129
Mean	1																		.857	.866	.932	1.063
Mean	2																		.888	.952	.874	1.090
Mean	1 and 2																		.868	.899	.907	1.072
NINE-PLY																						
1/24	1	4	.483	9,417	14,753	6,797	10,649	.492	629	921	4,390	6,878	.501	6,133	8,630	.508	3,981	6,515	.902	.810	.907	.947
1/24	2	4	.395	8,011	12,351	4,767	7,349	.416	536	858	3,717	5,731	.382	4,159	7,059	.395	3,483	5,790	.872	.961	.937	1.010
1/24	1 and 2	8	.439	8,714	13,552	5,777	8,985	.454	582	890	4,053	6,303	.442	5,146	7,844	.452	3,732	6,152	.891	.873	.921	.976
1/16	1	4	.486	8,606	13,789	6,526	10,456	.511	469	743	4,022	6,445	.511	6,123	8,979	.489	3,830	6,433	.938	.859	.952	.998
1/16	2	4	.375	7,102	10,291	4,866	7,050	.378	354	750	3,276	4,747	.379	4,620	6,870	.374	2,929	4,922	.949	.974	.894	1.037
1/16	1 and 2	8	.430	7,854	12,040	5,697	8,733	.444	412	746	3,649	5,594	.445	5,372	7,924	.432	3,380	5,678	.943	.907	.926	1.015
1/12	1	4	.507	8,707	11,741	6,265	8,448	.503	330	545	3,961	5,341	.510	6,537	8,471	.515	3,585	6,796	1.043	1.003	.905	1.272
1/12	2	4	.425	8,213	12,299	5,354	8,018	.402	327	579	3,726	5,580	.421	4,793	6,585	.414	3,208	5,642	.895	.821	.861	1.011
1/12	1 and 2	8	.466	8,460	12,020	5,804	8,247	.452	328	562	3,843	5,461	.466	5,665	7,528	.464	3,396	6,219	.976	.913	.884	1.139
1/8	1	4	.466	9,051	11,596	6,631	8,495	.479	245	441	4,132	5,294	.471	5,501	7,031	.471	3,676	6,064	.830	.828	.890	1.145
1/8	2	4	.394	5,714	9,590	4,439	7,450	.417	259	579	2,636	4,424	.405	4,574	6,183	.411	2,486	4,454	1.030	.830	.943	1.007
1/8	1 and 2	8	.430	7,382	10,593	5,539	7,949	.448	252	510	3,385	4,858	.438	5,038	6,607	.441	3,081	5,259	.910	.851	.910	1.083
3/16	1	4	.468	7,027	9,758	4,594	6,379	.487	194	280	3,137	4,356	.482	4,995	5,809	.486	3,882	5,178	1.087	.911	1.237	1.189
3/16	2	4	.369	6,149	9,367	4,059	6,183	.432	235	396	2,816	4,290	.386	3,971	5,360	.406	3,003	4,378	.978	.867	1.066	1.021
3/16	1 and 2	8	.418	6,588	9,562	4,319	6,269	.460	214	338	2,971	4,312	.434	4,483	5,584	.446	3,442	4,778	1.038	.891	1.159	1.108
Mean	1																		.960	.882	.978	1.110
Mean	2																		.945	.891	.940	1.017
Mean	1 and 2																		.952	.883	.960	1.064

[1] The number of tests applies to each construction. For example, for three-ply, 1/24-inch Tree 1, there were 16 all-parallel, 16 all-perpendicular, and so on.

[2] Specific gravity based upon ovendry weight of wood (weight of specimen minus weight of glue) and volume at test. Not adjusted to 10 percent moisture content basis.

(Sheet 2 of 2)

GPO 812-915-4

Table 7.--Comparison of observed and calculated values of F1, S1, F2, and S2 forf yellow-poplar.

(All value except specific gravity adjusted to 10 percent moisture content basis.)

Ply thickness	Tree No.	Number of tests[1]	All-parallel: Specific gravity[2]	All-parallel: F_L	All-parallel: S_L	All-parallel: F_1 (calc)	All-parallel: S_1 (calc)	All-perpendicular: Specific gravity[2]	All-perpendicular: F_T	All-perpendicular: S_T	All-perpendicular: F_2 (calc)	All-perpendicular: S_2 (calc)	Outer-parallel: Specific gravity[2]	Outer-parallel: F_1 (obs)	Outer-parallel: S_1 (obs)	Outer-perpendicular: Specific gravity[2]	Outer-perpendicular: F_2 (obs)	Outer-perpendicular: S_2 (obs)	F_1 (obs) / F_1 (calc)	S_1 (obs) / S_1 (calc)	F_2 (obs) / F_2 (calc)	S_2 (obs) / S_2 (calc)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
In.				P.s.i.	P.s.i.	P.s.i.	P.s.i.		P.s.i.	P.s.i.	P.s.i.	P.s.i.		P.s.i.	P.s.i.		P.s.i.	P.s.i.				
THREE-PLY																						
1/24	1	16	0.406	6,368	10,600	6,165	10,259	0.394	473	868	999	1,663	0.393	5,231	8,052	0.382	1,225	2,057	0.849	0.785	1.226	1.257
1/24	2	16	.440	6,969	12,109	6,919	12,055	.442	550	1,015	1,090	1,896	.458	5,557	9,344	.457	1,176	2,210	.803	.776	1.079	1.197
1/24	1 and 2	32	.425	6,664	11,354	6,541	11,145	.418	512	942	1,044	1,778	.414	5,394	8,698	.409	1,200	2,164	.825	.780	1.117	1.217
1/16	1	16	.412	6,557	10,655	6,595	11,055	.451	496	912	1,056	1,770	.419	6,009	8,961	.455	1,145	2,140	.911	.811	1.082	1.209
1/16	2	16	.314	3,913	7,007	4,178	7,482	.330	352	680	626	1,120	.320	3,451	5,755	.325	782	1,512	.826	.769	1.249	1.350
1/16	1 and 2	32	.365	5,155	8,831	5,395	9,278	.391	414	796	841	1,446	.369	4,730	7,357	.370	962	1,826	.877	.795	1.144	1.263
1/12	1	16	.375	4,894	8,824	4,791	8,638	.357	340	817	803	1,447	.355	4,255	6,460	.362	826	1,524	.888	.748	1.029	1.102
1/12	2	16	.382	5,055	9,371	4,164	8,498	.377	329	843	829	1,543	.364	4,427	6,955	.373	867	1,683	.970	.818	1.046	1.091
1/12	1 and 2	32	.378	4,964	9,098	4,675	8,564	.367	344	830	816	1,495	.359	4,341	6,708	.368	846	1,638	.929	.783	1.037	1.096
1/8	1	16	.402	5,904	10,439	6,582	11,637	.405	309	688	919	1,625	.419	5,473	8,426	.414	950	1,834	.852	.724	1.034	1.129
1/8	2	16	.359	4,485	8,205	4,818	8,812	.365	296	734	746	1,365	.362	4,396	7,003	.366	820	1,483	.912	.795	1.099	1.086
1/8	1 and 2	32	.380	5,194	9,321	5,699	10,228	.385	302	711	834	1,496	.390	4,934	7,714	.390	885	1,658	.866	.754	1.061	1.108
3/16	1	16	.375	4,916	8,410	4,484	7,672	.367	264	694	797	1,363	.357	4,571	6,557	.369	689	1,498	1.019	.852	.864	1.099
3/16	2	16	.411	5,355	9,818	5,479	9,684	.396	296	744	894	1,580	.400	5,380	7,801	.398	787	1,666	.982	.806	.820	1.054
3/16	1 and 2	32	.392	5,236	9,114	4,932	8,609	.382	280	719	845	1,471	.378	4,976	7,169	.384	738	1,582	.997	.825	.875	1.075
Mean	1																		.892	.780	1.047	1.155
Mean	2																		.894	.792	1.071	1.156
Mean	1 and 2																		.895	.786	1.055	1.152
FIVE-PLY																						
1/24	1	2	.395	5,038	9,412	4,876	9,110	.409	325	975	1,916	3,579	.400	4,019	8,028	.403	2,255	3,837	.824	.881	1.177	1.072
1/16	1	2	.440	6,744	11,948	4,995	8,846	.412	388	771	2,503	4,434	.407	5,726	7,187	.438	1,918	3,639	.746	.812	.766	.821
1/12	1	2	.379	5,071	8,952	4,585	8,094	.395	274	775	1,891	3,358	.382	3,972	7,204	.382	1,950	3,108	.866	.897	1.021	.951
1/8	1	2	.417	7,097	10,724	5,266	7,957	.411	254	716	2,615	3,952	.422	5,526	7,785	.410	2,278	3,427	1.049	.978	.871	.867
3/16	1	2	.358	.....	9,280	.....	7,854	.400	320	701	.....	3,410	.377	.....	7,019	.345	1,498	2,865	.....	.896	.....	.840
Mean																			.874	.891	.959	.906
SEVEN-PLY																						
1/24	1	2	.407	5,039	10,111	3,699	7,422	.400	485	1,013	2,185	4,385	.371	3,192	7,067	.380	2,284	4,429	.863	.952	1.045	1.010
1/16	1	2	.408	5,878	9,917	4,912	8,280	.457	418	1,013	2,536	4,278	.410	3,605	7,174	.432	2,799	5,258	.734	.866	1.104	1.229
1/12	1	2	.357	4,906	8,615	3,439	6,038	.365	278	755	2,082	3,657	.350	3,030	5,792	.359	1,946	3,632	.848	.959	.935	.994
1/8	1	2	.397	6,743	10,759	5,242	8,205	.399	249	775	2,848	4,545	.405	5,026	7,564	.401	3,040	5,301	.978	.922	1.060	1.166
3/16	1	2	.321	4,509	7,319	3,025	4,890	.336	258	596	1,975	3,165	.312	2,571	4,556	.330	1,954	3,452	.850	.935	.990	1.091
Mean	1																		.862	.923	1.027	1.048
NINE-PLY																						
1/24	1	2	.401	5,720	10,590	3,846	7,120	.390	505	947	2,615	4,842	.383	3,167	6,909	.376	2,154	4,847	.823	.925	.824	1.001
1/16	1	2	.452	5,355	10,885	3,551	7,180	.425	312	797	2,406	4,092	.443	3,721	6,881	.410	2,605	5,180	1.054	.958	1.100	1.059
1/12	1	2	.367	5,224	9,478	4,054	7,355	.354	301	684	2,350	4,264	.361	2,921	5,816	.345	1,954	3,749	.721	.791	.831	.879
1/8	1	2	.401	7,520	10,711	5,660	8,062	.412	280	769	3,375	4,807	.424	4,695	7,675	.409	2,916	5,044	.842	.952	.864	1.049
3/16	1	2	.341	4,448	6,652	3,859	5,754	.329	.....	506	2,015	3,004	.340	3,757	5,508	.322	1,856	2,862	.974	.996	.911	.955
Mean	1																		.870	.912	.906	.989

[1] The number of tests applies to each construction. For example, for three-ply, 1/24-inch Tree 1, there were 16 all-parallel, 16 all-perpendicular, and so on.

[2] Specific gravity based upon oven-dry weight of wood (weight of specimen minus weight of glue) and volume at test. Not adjusted to 10 percent moisture content.

FPL-059

Table 8.--Summary of ratios of observed to calculated values of F_1 and S_1 from tables 5, 6, and 7

Number of plies	Item	Ratio $\frac{F_1 \text{ (obs)}}{F_1 \text{ (calc)}}$						Ratio $\frac{S_1 \text{ (obs)}}{S_1 \text{ (calc)}}$					
		Sitka spruce		Douglas-fir		Yellow-poplar		Sitka spruce		Douglas-fir		Yellow-poplar	
		Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2
3	Mean	0.918	0.913	0.924	0.952	0.842	0.844	0.854	0.816	0.908	0.874	0.780	0.792
5	Mean	.878	.859	.958	.880	.874	.....	.903	.888	.901	.871	.891	.....
7	Mean	.904	.896	.857	.888	.862	.....	.894	.900	.866	.952	.923	.....
9	Mean	.836	.881	.960	.945	.870	.....	.919	.897	.882	.891	.912	.....
3, 5, 7, 9	Mean	.898	.898	.924	.931	.884	.....	.876	.850	.897	.887	.816	.....

Table 9.--Summary of ratios of observed to calculated values of F2 and S2 from tables 5, 6, and 7

Number of plies	Item	Ratio $\frac{F_2 \text{ (obs)}}{F_2 \text{ (calc)}}$						Ratio $\frac{S_2 \text{ (obs)}}{S_2 \text{ (calc)}}$					
		Sitka spruce		Douglas-fir		Yellow-poplar		Sitka spruce		Douglas-fir		Yellow-poplar	
		Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2	Tree 1	Tree 2
3	Mean	0.928	0.924	0.745	0.839	1.047	1.071	1.202	1.128	1.145	1.113	1.155	1.156
5	Mean	.881	.886	.979	.911	.959	.....	.947	.960	1.142	1.029	.906	.....
7	Mean	.872	.979	.932	.874	1.027	.....	.929	.993	1.063	1.090	1.098	.....
9	Mean	.895	.925	.978	.940	.908	.....	.999	.987	1.110	1.017	.988	.....
3	Mean	.928	.924	.745	.839	1.047	1.071	1.202	1.128	1.145	1.113	1.155	1.156
5, 7, 9	Mean	.883	.930	.963	.908	.965	.....	.958	.980	1.105	1.045	.997	.....

Table 10.--Comparison of values of modulus of elasticity, fiber stress at proportional limit, and modulus of rupture from tests of all-parallel, outer-parallel, and outer-perpendicular specimens, neglecting effect of transverse plies (Sitka spruce)

Ply thickness	Log No.	Modulus of elasticity: All-parallel E_L (A)	Modulus of elasticity: Outer-parallel E_L (B)	Modulus of elasticity: Outer-perpendicular E_L (C)	$\frac{B}{A}$	$\frac{C}{A}$	Fiber stress at proportional limit: All-parallel F_L (A)	Fiber stress at proportional limit: Outer-parallel F_L (B)	Fiber stress at proportional limit: Outer-perpendicular F_L (C)	$\frac{B}{A}$	$\frac{C}{A}$	Modulus of rupture: All-parallel S_L (A)	Modulus of rupture: Outer-parallel S_L (B)	Modulus of rupture: Outer-perpendicular S_L (C)	$\frac{B}{A}$	$\frac{C}{A}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
In.		1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.			P.s.i.	P.s.i.	P.s.i.			P.s.i.	P.s.i.	P.s.i.		
THREE-PLY																
1/24	1	1,542	1,435	2,794	0.931	1.811	6,287	5,475	9,538	0.871	1.517	10,284	8,235	19,838	0.801	1.929
1/24	2	1,712	1,645	2,939	.961	1.717	7,580	6,645	11,128	.877	1.468	12,254	9,709	21,285	.792	1.737
1/24	1 and 2	1,627	1,539	2,866	.946	1.762	6,934	6,060	10,333	.874	1.490	11,269	8,972	20,562	.796	1.825
1/16	1	1,636	1,638	2,888	1.001	1.765	6,670	6,141	8,606	.921	1.290	10,963	9,028	18,342	.823	1.673
1/16	2	1,739	1,713	2,830	.985	1.627	6,555	5,884	9,055	.898	1.381	11,960	9,546	17,569	.798	1.469
1/16	1 and 2	1,688	1,676	2,860	.993	1.694	6,612	6,012	8,830	.909	1.335	11,462	9,287	17,956	.810	1.567
1/12	1	1,672	1,597	2,983	.955	1.784	6,891	5,855	8,894	.850	1.291	10,839	8,611	16,783	.794	1.548
1/12	2	1,667	1,716	3,112	1.029	1.867	7,250	6,683	9,223	.924	1.276	11,624	9,564	19,095	.823	1.643
1/12	1 and 2	1,670	1,657	3,048	.992	1.825	7,060	6,269	9,058	.888	1.283	11,232	9,088	17,939	.809	1.597
1/8	1	1,641	1,585	3,072	.966	1.872	6,286	5,550	7,911	.880	1.259	9,996	8,288	15,774	.829	1.578
1/8	2	1,586	1,564	2,738	.986	1.726	6,607	5,988	7,442	.906	1.126	11,075	8,935	16,435	.807	1.484
1/8	1 and 2	1,613	1,574	2,905	.976	1.801	6,446	5,759	7,676	.893	1.191	10,536	8,612	16,104	.817	1.528
3/16	1	1,436	1,348	2,765	.939	1.925	6,352	5,571	7,118	.877	1.120	9,075	7,570	15,189	.834	1.674
3/16	2	1,730	1,721	3,183	.995	1.840	6,738	6,180	7,864	.817	1.167	11,256	9,254	17,120	.822	1.521
3/16	1 and 2	1,584	1,534	2,974	.968	1.878	6,545	5,876	7,491	.898	1.145	10,166	8,412	16,154	.827	1.589
Mean	1	1,585	1,521	2,900	.960	1.830	6,497	5,714	8,413	.879	1.295	10,231	8,346	17,185	.816	1.680
Mean	2	1,687	1,672	2,960	.991	1.755	6,942	6,276	8,942	.904	1.288	11,634	9,402	18,301	.808	1.573
Mean	1 and 2	1,636	1,596	2,931	.976	1.792	6,719	5,995	8,678	.892	1.292	10,933	8,874	17,743	.812	1.623
FIVE-PLY																
1/24	1	1,633	1,578	1,636	.966	1.002	7,383	5,748	5,741	.779	.778	11,114	10,001	11,502	.900	1.035
1/24	2	1,785	1,761	1,890	.986	1.059	8,175	6,697	6,730	.819	.823	12,482	10,625	12,219	.851	.979
1/24	1 and 2	1,709	1,669	1,762	.977	1.031	7,779	6,222	6,236	.780	.802	11,798	10,313	11,860	.874	1.005
1/16	1	1,763	1,692	1,821	.960	1.033	6,310	5,690	6,428	.902	1.019	11,273	10,061	11,098	.892	.984
1/16	2	1,768	1,714	1,974	.969	1.116	7,175	6,186	7,858	.862	1.095	11,863	10,153	12,891	.856	1.087
1/16	1 and 2	1,765	1,703	1,898	.965	1.075	6,742	5,938	7,143	.881	1.059	11,568	10,107	11,994	.874	1.037
1/12	1	1,704	1,817	1,791	1.066	1.051	6,257	5,494	5,732	.878	.916	10,721	10,538	10,823	.983	1.010
1/12	2	1,660	1,641	1,853	.989	1.116	5,991	5,211	6,144	.870	1.026	10,854	9,407	11,496	.867	1.059
1/12	1 and 2	1,681	1,728	1,822	1.028	1.084	6,124	5,352	5,938	.874	.970	10,788	9,972	11,160	.924	1.034
1/8	1	1,670	1,654	1,861	.990	1.114	6,871	5,273	6,864	.767	.999	10,469	9,048	11,132	.864	1.063
1/8	2	1,654	1,657	1,866	1.002	1.128	7,261	5,985	6,957	.824	.958	11,468	10,351	11,552	.903	1.007
1/8	1 and 2	1,665	1,656	1,863	.996	1.120	7,066	5,629	6,910	.797	.978	10,968	9,700	11,342	.884	1.034
3/16	1	1,465	1,463	1,496	.999	1.021	4,550	4,761	4,585	1.046	1.008	9,150	7,839	8,996	.857	.983
3/16	2	1,806	1,874	1,913	1.030	1.059	6,790	6,112	5,844	.900	.861	10,738	10,187	11,024	.949	1.027
3/16	1 and 2	1,635	1,668	1,705	1.020	1.043	5,670	5,436	5,214	.959	.920	9,944	9,013	10,010	.906	1.007
Mean	1	1,647	1,641	1,721	.996	1.045	6,274	5,393	5,870	.860	.936	10,545	9,497	10,710	.901	1.016
Mean	2	1,735	1,729	1,899	.997	1.095	7,078	6,038	6,707	.853	.948	11,481	10,145	11,836	.884	1.031
Mean	1 and 2	1,691	1,685	1,810	.996	1.070	6,676	5,715	6,288	.856	.942	11,013	9,821	11,273	.892	1.024

FPL-059 (Sheet 1 of 2)

Table 10.--Comparison of values of modulus of elasticity, fiber stress at ID rtional limit and modulus of rupture from tests of all-parallel, outer-parallel, and outer-perpenmar specimens, neglecting effect of transverse plies (Sitka spruce) (continued)

Ply thickness	Log No.	Modulus of elasticity					Fiber stress at proportional limit					Modulus of rupture				
		All-parallel E_L (A)	Outer-parallel E_L (B)	Outer-perpendicular E_L (C)	$\frac{B}{A}$	$\frac{C}{A}$	All-parallel F_L (A)	Outer-parallel F_L (B)	Outer-perpendicular F_L (C)	$\frac{B}{A}$	$\frac{C}{A}$	All-parallel S_L (A)	Outer-parallel S_L (B)	Outer-perpendicular S_L (C)	$\frac{B}{A}$	$\frac{C}{A}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
In.		1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.			P.s.i.	P.s.i.	P.s.i.			P.s.i.	P.s.i.	P.s.i.		
							SEVEN-PLY									
1/24	1	1,739	1,777	1,661	1.022	0.955	6,056	5,239	6,159	0.865	1.017	11,877	10,282	11,862	0.866	0.999
1/24	2	1,706	1,770	1,723	1.038	1.010	6,251	5,966	7,204	.954	1.152	12,512	11,243	12,298	.899	.983
1/24	1 and 2	1,723	1,774	1,692	1.030	.982	6,154	5,602	6,682	.910	1.086	12,194	10,762	12,080	.883	.991
1/16	1	1,647	1,818	1,686	1.104	1.024	5,568	4,706	5,622	.845	1.010	10,636	9,944	10,411	.935	.979
1/16	2	1,627	1,855	2,002	1.140	1.230	5,507	6,172	6,424	1.121	1.167	11,396	11,380	12,256	.999	1.075
1/16	1 and 2	1,637	1,836	1,844	1.122	1.126	5,538	5,439	6,023	.982	1.088	11,016	10,662	11,334	.968	1.029
1/12	1	1,675	1,767	1,704	1.055	1.017	7,085	6,265	6,264	.885	.884	10,939	9,788	10,721	.895	.980
1/12	2	1,801	1,826	1,913	1.014	1.062	8,074	6,396	7,077	.792	.877	11,850	11,079	12,778	.935	1.078
1/12	1 and 2	1,737	1,796	1,808	1.034	1.041	7,578	6,330	6,670	.835	.880	11,394	10,434	11,750	.916	1.031
1/8	1	1,707	1,538	1,424	.901	.834	6,613	5,891	5,832	.891	.882	10,047	8,857	9,390	.882	.935
1/8	2	1,517	1,699	1,848	1.120	1.218	6,791	6,697	7,230	.986	1.065	10,772	11,124	11,815	1.033	1.097
1/8	1 and 2	1,612	1,618	1,635	1.004	1.014	6,702	6,294	6,531	.939	.974	10,410	9,990	10,602	.960	1.018
3/16	1	1,519	1,520	1,482	1.001	.976	6,552	6,317	5,031	.964	.768	9,310	8,853	9,023	.951	.969
3/16	2	1,790	1,774	1,816	.991	1.015	7,553	6,867	6,761	.909	.895	10,764	9,764	10,719	.907	.996
3/16	1 and 2	1,655	1,647	1,649	.995	.996	7,052	6,592	5,896	.935	.836	10,037	9,308	9,871	.927	.983
Mean	1	1,657	1,684	1,591	1.016	.960	6,374	5,684	5,782	.892	.907	10,562	9,545	10,281	.904	.973
Mean	2	1,688	1,785	1,860	1.057	1.102	6,835	6,420	6,939	.939	1.015	11,459	10,918	11,973	.953	1.045
Mean	1 and 2	1,673	1,734	1,726	1.036	1.032	6,605	6,051	6,360	.916	.963	11,010	10,231	11,127	.929	1.011
							NINE-PLY									
1/24	1	1,686	1,689	1,781	1.002	1.056	6,329	5,693	6,716	.900	1.061	11,109	10,576	11,872	.952	1.069
1/24	2	1,893	1,839	2,009	.971	1.061	7,722	6,652	7,319	.861	.948	13,153	12,015	13,010	.913	.989
1/24	1 and 2	1,789	1,764	1,894	.986	1.059	7,026	6,172	7,018	.878	.999	12,132	11,296	12,441	.931	1.025
1/16	1	1,693	1,803	1,748	1.065	1.032	6,071	5,985	6,188	.986	1.019	10,225	10,656	10,571	1.042	1.034
1/16	2	1,689	1,858	1,988	1.100	1.177	6,299	6,094	7,700	.967	1.222	11,763	10.637	12,858	.904	1.093
1/16	1 and 2	1,691	1,831	1,868	1.083	1.105	6,185	6,040	6,944	.977	1.123	10,995	10,646	11,714	.968	1.065
1/12	1	1,713	1,690	1,849	.987	1.079	6,377	4,860	3,527	.762	.867	10,369	9,253	11,353	.892	1.095
1/12	2	1,666	1,748	1,908	1.049	1.145	6,659	5,567	6,501	.836	.976	11,006	10,293	12,431	.935	1.129
1/12	1 and 2	1,689	1,719	1,879	1.018	1.112	6,518	5,214	6,014	.800	.923	10,688	9,773	11,892	.914	1.113
1/8	1	1,659	1,762	1,798	1.062	1.084	7,723	5,908	6,076	.765	.787	10,579	9,781	10,896	.925	1.030
1/8	2	1,653	1,558	1,815	.942	1.098	7,512	5,818	6,077	.774	.809	11,225	9,252	11,189	.824	.997
1/8	1 and 2	1,656	1,661	1,806	1.003	1.091	7,618	5,863	6,076	.770	.798	10,902	9,516	11,042	.873	1.013
3/16	1	1,495	1,537	1,584	1.028	1.060	6,297	5,601	6,186	.889	.982	9,188	8,404	9,554	.915	1.040
3/16	2	1,868	1,832	1,855	.981	.982	6,831	6,852	6,321	1.003	.925	10,884	10,214	10,870	.938	.999
3/16	1 and 2	1,682	1,684	1,708	1.001	1.015	6,564	6,226	6,254	.949	.953	10,036	9,309	10,212	.928	1.018
Mean	1	1,649	1,696	1,752	1.029	1.062	6,559	5,609	6,139	.855	.936	10,294	9,734	10,849	.946	1.054
Mean	2	1,754	1,767	1,911	1.007	1.090	7,005	6,197	6,784	.885	.968	11,607	10,482	12,072	.903	1.040
Mean	1 and 2	1,701	1,732	1,831	1.018	1.076	6,782	5,903	6,461	.870	.953	10,951	10,108	11,460	.923	1.046

FPL-059 (Sheet 2 of 2)

Table 11.--Comparison of values of modulus of elasticity, fiber stress at proportional limit, and modulus of rupture from tests of all-parallel, outer-parallel, and outer-perpendicular specimens, neglecting effect of transverse plies (Douglas-fir)

Ply thickness	Log No.	Modulus of elasticity: All-parallel E_L (A)	Modulus of elasticity: Outer-parallel E_L (B)	Modulus of elasticity: Outer-perpendicular E_L (C)	Modulus of elasticity: B/A	Modulus of elasticity: C/A	Fiber stress at proportional limit: All-parallel F_L (A)	Fiber stress at proportional limit: Outer-parallel F_L (B)	Fiber stress at proportional limit: Outer-perpendicular F_L (C)	Fiber stress at proportional limit: B/A	Fiber stress at proportional limit: C/A	Modulus of rupture: All-parallel S_L (A)	Modulus of rupture: Outer-parallel S_L (B)	Modulus of rupture: Outer-perpendicular S_L (C)	Modulus of rupture: B/A	Modulus of rupture: C/A
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
In.		1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.			P.s.i.	P.s.i.	P.s.i.			P.s.i.	P.s.i.	P.s.i.		
							THREE-PLY									
1/24	1	1,931	1,965	4,098	1.018	2.122	9,271	8,335	12,597	0.899	1.359	14,145	12,650	26,211	0.894	1.853
1/24	2	1,558	1,547	3,137	.993	2.013	7,288	6,596	9,146	.905	1.255	11,838	9,565	19,556	.808	1.652
1/24	1 and 2	1,744	1,757	3,618	1.007	2.075	8,280	7,466	10,872	.902	1.313	12,990	11,108	22,884	.855	1.762
1/16	1	2,016	1,929	4,262	.957	2.114	9,395	7,935	12,728	.845	1.355	14,466	12,250	28,688	.847	1.983
1/16	2	1,311	1,424	2,912	1.086	2.221	6,339	6,626	7,634	1.045	1.204	10,124	9,554	18,755	.924	1.851
1/16	1 and 2	1,663	1,677	3,586	1.008	2.156	7,867	7,280	10,181	.925	1.294	12,295	10,802	23,712	.879	1.929
1/12	1	2,031	1,934	3,553	.952	1.749	9,077	7,587	8,814	.836	.971	14,200	12,031	21,741	.847	1.531
1/12	2	1,634	1,565	2,852	.958	1.745	6,880	6,053	7,657	.880	1.110	10,184	8,528	16,766	.837	1.646
1/12	1 and 2	1,832	1,749	3,203	.955	1.748	7,978	6,820	8,226	.855	1.031	12,192	10,280	19,254	.843	1.579
1/8	1	1,987	1,897	3,441	.955	1.732	8,091	7,496	8,151	.926	1.007	12,275	11,422	21,841	.931	1.779
1/8	2	1,162	1,414	2,921	1.217	2.514	4,837	5,425	8,538	1.122	1.765	8,805	9,111	16,643	1.035	1.890
1/8	1 and 2	1,574	1,655	3,181	1.051	2.021	6,464	6,460	8,344	.999	1.291	10,540	10,266	19,242	.974	1.826
3/16	1	2,190	2,091	4,032	.955	1.841	7,961	7,623	9,025	.958	1.134	12,591	10,968	22,358	.871	1.776
3/16	2	1,431	1,388	3,369	.970	2.354	5,540	5,617	7,378	1.014	1.332	8,882	8,456	15,623	.952	1.759
3/16	1 and 2	1,810	1,740	3,701	.961	2.045	6,750	6,620	8,202	.981	1.215	10,736	9,712	18,990	.905	1.769
Mean	1	2,031	1,963	3,877	.967	1.909	8,759	7,795	10,263	.890	1.172	13,535	11,864	24,168	.877	1.786
Mean	2	1,419	1,468	3,038	1.035	2.141	6,177	6,063	8,067	.982	1.306	9,967	9,003	17,463	.903	1.752
Mean	1 and 2	1,725	1,716	3,458	.995	2.005	7,468	6,929	9,165	.928	1.227	11,751	10,434	20,816	.888	1.771
							FIVE-PLY									
1/24	1	1,804	1,783	2,788	.988	1.545	8,384	7,626	11,150	.910	1.330	12,766	11,030	19,130	.864	1.499
1/24	2	1,287	1,546	1,752	1.201	1.361	6,733	5,846	7,402	.868	1.099	10,857	10,249	12,363	.944	1.139
1/24	1 and 2	1,546	1,665	2,272	1.077	1.470	7,558	6,736	9,276	.891	1.227	11,812	10,640	15,746	.901	1.333
1/16	1	1,875	2,013	2,320	1.074	1.237	8,596	8,562	9,788	.996	1.139	14,424	12,415	17,400	.861	1.206
1/16	2	1,338	1,589	1,615	1.188	1.207	5,528	6,097	6,123	1.103	1.108	10,483	10,620	11,708	1.013	1.117
1/16	1 and 2	1,606	1,800	1,966	1.121	1.224	7,062	7,330	7,956	1.038	1.127	12,454	11,518	14,554	.925	1.169
1/12	1	2,112	2,080	2,241	.985	1.061	7,957	8,118	7,549	1.020	.949	13,499	13,715	16,541	1.016	1.225
1/12	2	1,568	1,702	2,151	1.085	1.372	6,424	5,748	7,201	.895	1.121	10,683	10,192	13,221	.954	1.238
1/12	1 and 2	1,839	1,890	2,196	1.028	1.194	7,190	6,933	7,375	.964	1.026	12,091	11,954	14,881	.989	1.231
1/8	1	1,917	1,880	2,207	.981	1.151	8,901	7,888	8,449	.886	.949	12,987	11,485	15,047	.884	1.159
1/8	2	1,387	1,417	1,542	1.022	1.112	5,961	5,586	5,647	.937	.947	9,891	8,714	10,766	.881	1.088
1/8	1 and 2	1,653	1,648	1,875	.997	1.134	7,431	6,737	7,048	.907	.948	11,439	10,100	12,906	.883	1.128
3/16	1	2,027	2,156	2,132	1.064	1.052	6,443	6,841	7,028	1.062	1.091	10,670	10,160	13,535	.952	1.269
3/16	2	1,511	1,273	1,534	.842	1.015	6,197	5,232	4,556	.850	.740	9,561	7,832	10,305	.819	1.078
3/16	1 and 2	1,769	1,714	1,833	.969	1.036	6,300	6,036	5,792	.958	.919	10,116	8,996	11,920	.889	1.178
Mean	1	1,947	1,982	2,338	1.018	1.201	8,056	7,807	8,793	.969	1.091	12,869	11,761	16,331	.914	1.269
Mean	2	1,418	1,505	1,719	1.061	1.212	6,161	5,702	6,186	.925	1.004	10,295	9,521	11,673	.925	1.134
Mean	1 and 2	1,685	1,743	2,028	1.036	1.205	7,108	6,754	7,489	.950	1.054	11,582	10,642	14,001	.919	1.209

FPL-059 (Sheet 1 of 2)

Table 11.--Comparison of values of modulus of elasticity, fiber stress at proportional limit, and modulus of rupture from tests of all-parallel, outer-parallel, and outer-perpendicular specimens, neglecting effect of transverse plies (Douglas-fir) (continued)

Ply thickness	Log No.	Modulus of elasticity: All-parallel E_L (A)	Modulus of elasticity: Outer-parallel E_L (B)	Modulus of elasticity: Outer-perpendicular E_L (C)	Modulus of elasticity: B/A	Modulus of elasticity: C/A	Fiber stress at proportional limit: All-parallel F_L (A)	Fiber stress at proportional limit: Outer-parallel F_L (B)	Fiber stress at proportional limit: Outer-perpendicular F_L (C)	Fiber stress at proportional limit: B/A	Fiber stress at proportional limit: C/A	Modulus of rupture: All-parallel S_L (A)	Modulus of rupture: Outer-parallel S_L (B)	Modulus of rupture: Outer-perpendicular S_L (C)	Modulus of rupture: B/A	Modulus of rupture: C/A
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
In.		1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.			P.s.i.	P.s.i.	P.s.i.			P.s.i.	P.s.i.	P.s.i.		
							SEVEN-PLY									
1/24	1	2,094	2,004	2,330	0.957	1.113	9,699	7,956	10,715	0.820	1.105	15,219	12,613	16,735	0.829	1.100
1/24	2	1,664	1,774	2,079	1.066	1.249	8,049	6,560	8,645	.815	1.074	11,209	11,813	15,439	1.054	1.377
1/24	1 and 2	1,878	1,890	2,205	1.006	1.174	8,874	7,258	9,680	.818	1.091	13,214	12,213	16,087	.924	1.217
1/16	1	1,994	2,161	2,224	1.084	1.115	9,387	7,772	9,180	.828	.978	14,412	13,055	15,909	.906	1.104
1/16	2	1,457	1,340	1,617	.920	1.110	6,882	5,576	6,305	.810	.916	10,592	9,436	12,053	.891	1.138
1/16	1 and 2	1,725	1,750	1,920	1.016	1.113	8,134	6,674	7,742	.821	.952	12,502	11,246	13,981	.900	1.118
1/12	1	1,949	2,016	2,314	1.034	1.187	9,148	8,205	9,100	.897	.995	13,435	12,044	16,561	.896	1.233
1/12	2	2,015	1,889	1,948	.937	.967	7,740	6,467	7,449	.836	.962	12,194	9,550	12,550	.783	1.029
1/12	1 and 2	1,981	1,952	2,129	.985	1.075	8,444	7,336	8,274	.869	.980	12,814	10,797	14,556	.843	1.136
1/8	1	1,942	2,099	2,337	1.081	1.203	8,620	8,354	8,343	.969	.968	13,456	11,841	14,645	.880	1.088
1/8	2	1,315	1,280	1,375	.973	1.046	6,321	6,000	4,436	.949	.702	8,908	9,185	10,220	1.031	1.147
1/8	1 and 2	1,629	1,690	1,856	1.037	1.139	7,470	7,177	6,390	.961	.855	11,182	10,513	12,432	.940	1.112
3/16	1	2,004	2,008	2,167	1.002	1.081	9,109	8,217	8,838	.902	.970	10,864	10,293	12,876	.947	1.185
3/16	2	1,487	1,456	1,677	.979	1.128	6,722	6,115	7,223	.910	1.075	9,228	8,223	11,119	.891	1.205
3/16	1 and 2	1,746	1,732	1,922	.992	1.101	7,916	7,166	8,030	.905	1.014	10,046	9,258	11,998	.922	1.194
Mean	1	1,997	2,058	2,274	1.031	1.139	9,193	8,101	9,235	.881	1.005	13,477	11,969	15,345	.888	1.139
Mean	2	1,588	1,548	1,739	.975	1.095	7,143	6,144	6,812	.860	.954	10,426	9,641	12,276	.925	1.177
Mean	1 and 2	1,792	1,803	2,006	1.006	1.119	8,168	7,122	8,023	.872	.982	11,952	10,805	13,811	.904	1.156
							NINE-PLY									
1/24	1	2,063	2,238	2,322	1.085	1.126	9,417	9,220	9,280	.979	.985	14,753	12,972	15,190	.879	1.030
1/24	2	1,790	1,620	1,840	.905	1.028	8,011	6,251	8,132	.780	1.015	12,551	10,611	13,521	.859	1.095
1/24	1 and 2	1,926	1,930	2,083	1.002	1.081	8,714	7,736	8,706	.888	.999	13,552	11,792	14,356	.870	1.059
1/16	1	1,837	2,094	2,212	1.140	1.204	8,606	9,202	8,958	1.069	1.039	13,789	13,498	14,973	.979	1.086
1/16	2	1,461	1,504	1,533	1.029	1.049	7,102	6,943	6,814	.978	.959	10,291	10,326	11,447	1.003	1.112
1/16	1 and 2	1,649	1,798	1,870	1.090	1.134	7,854	8,072	7,876	1.028	1.003	12,040	11,912	13,210	.989	1.097
1/12	1	1,957	2,117	2,131	1.082	1.089	8,707	9,826	8,354	1.129	.959	11,741	12,733	15,858	1.084	1.349
1/12	2	1,919	1,880	1,952	.980	1.017	8,213	7,205	7,489	.877	.912	12,299	9,899	13,173	.805	1.071
1/12	1 and 2	1,937	1,998	2,039	1.031	1.053	8,460	8,516	7,922	1.007	.936	12,020	11,316	14,506	.941	1.207
1/8	1	1,922	2,119	2,207	1.102	1.148	9,051	8,267	8,536	.913	.943	11,596	10,568	14,081	.911	1.214
1/8	2	1,411	1,647	1,574	1.167	1.116	5,714	6,876	5,790	1.203	1.013	9,590	9,295	10,373	.969	1.082
1/8	1 and 2	1,667	1,883	1,890	1.130	1.134	7,382	7,572	7,163	1.026	.970	10,593	9,932	12,227	.938	1.154
3/16	1	2,062	2,025	2,110	.982	1.023	7,027	7,508	9,020	1.068	1.284	9,758	8,733	12,030	.895	1.233
3/16	2	1,362	1,352	1,565	.993	1.149	6,149	5,969	6,990	.971	1.137	9,367	8,094	10,193	.864	1.088
3/16	1 and 2	1,713	1,689	1,837	.986	1.072	6,588	6,738	8,005	1.023	1.215	9,562	8,414	11,112	.880	1.162
Mean	1	1,968	2,119	2,196	1.077	1.116	8,562	8,805	8,826	1.028	1.031	12,327	11,701	14,422	.949	1.170
Mean	2	1,589	1,601	1,693	1.008	1.065	7,038	6,649	7,043	.945	1.001	10,780	9,645	11,741	.895	1.089
Mean	1 and 2	1,778	1,860	1,944	1.046	1.093	7,800	7,727	7,934	.991	1.017	11,553	10,673	13,082	.924	1.132

FPL-059

Table 12.--Comparison of values of modulus of elasticity, fiber stress at proportional limit, and modulus of rupture from tests of all-parallel, outer-parallel, and outer-perpendicular specimens, neglecting effect of transverse plies (yellow-poplar)

Ply thickness	Log No.	Modulus of elasticity: All-parallel E_L (A)	Modulus of elasticity: Outer-parallel E_L (B)	Modulus of elasticity: Outer-perpendicular E_L (C)	$\frac{B}{A}$	$\frac{C}{A}$	Fiber stress at proportional limit: All-parallel F_L (A)	Fiber stress at proportional limit: Outer-parallel F_L (B)	Fiber stress at proportional limit: Outer-perpendicular F_L (C)	$\frac{B}{A}$	$\frac{C}{A}$	Modulus of rupture: All-parallel S_L (A)	Modulus of rupture: Outer-parallel S_L (B)	Modulus of rupture: Outer-perpendicular S_L (C)	$\frac{B}{A}$	$\frac{C}{A}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
In.		1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.			P.s.i.	P.s.i.	P.s.i.			P.s.i.	P.s.i.	P.s.i.		
THREE-PLY																
1/24	1	1,396	1,403	2,901	1.005	2.078	6,368	5,433	10,978	0.853	1.724	10,600	8,360	18,443	0.789	1.740
1/24	2	1,647	1,698	3,221	1.031	1.956	6,961	5,769	10,585	.829	1.521	12,109	9,702	20,418	.801	1.686
1/24	1 and 2	1,522	1,551	3,062	1.019	2.012	6,664	5,601	10,782	.840	1.618	11,354	9,031	19,430	.795	1.711
1/16	1	1,415	1,524	3,074	1.077	2.172	6,357	6,240	10,100	.982	1.589	10,655	9,305	18,872	.873	1.771
1/16	2	958	1,065	2,390	1.112	2.495	3,913	3,582	7,022	.915	1.795	7,007	5,974	13,556	.853	1.935
1/16	1 and 2	1,186	1,294	2,733	1.091	2.304	5,135	4,911	8,561	.956	1.667	8,831	7,640	16,214	.865	1.836
1/12	1	1,282	1,304	2,761	1.017	2.154	4,894	4,419	7,474	.903	1.527	8,824	6,710	14,426	.760	1.635
1/12	2	1,374	1,311	2,803	.954	2.040	5,033	4,600	7,755	.914	1.541	9,371	7,222	15,072	.771	1.608
1/12	1 and 2	1,328	1,307	2,782	.984	2.095	4,964	4,510	7,614	.909	1.534	9,098	6,966	14,749	.766	1.621
1/8	1	1,655	1,916	3,301	1.158	1.995	5,904	5,684	8,449	.963	1.431	10,439	8,751	16,313	.838	1.563
1/8	2	1,265	1,412	2,616	1.116	2.068	4,485	4,564	7,394	1.018	1.649	8,203	7,271	13,585	.886	1.632
1/8	1 and 2	1,460	1,664	2,959	1.140	2.027	5,194	5,124	7,922	.987	1.525	9,321	8,011	14,849	.859	1.593
3/16	1	1,286	1,219	2,641	.948	2.054	4,916	4,748	6,216	.966	1.264	8,410	6,789	13,501	.807	1.605
3/16	2	1,547	1,585	3,042	1.025	1.966	5,555	5,588	7,050	1.006	1.269	9,818	8,101	14,901	.825	1.518
3/16	1 and 2	1,416	1,403	2,842	.991	2.007	5,236	5,168	6,633	.987	1.267	9,114	7,445	14,201	.817	1.558
Mean	1	1,407	1,473	2,956	1.047	2.087	5,688	5,305	8,643	.933	1.520	9,786	7,983	16,311	.816	1.667
Mean	2	1,358	1,414	2,814	1.041	2.072	5,189	4,821	7,961	.929	1.534	9,302	7,654	15,466	.823	1.663
Mean	1 and 2	1,382	1,444	2,876	1.045	2.081	5,439	5,063	8,302	.931	1.526	9,544	7,819	15,889	.819	1.665
FIVE-PLY																
1/24	1	1,245	1,522	1,673	1.222	1.344	5,038	5,075	6,339	1.007	1.298	9,412	10,136	11,133	1.077	1.183
1/16	1	1,556	1,456	1,653	.936	1.062	6,744	4,703	5,529	.697	.820	11,948	9,075	10,488	.760	.878
1/12	1	1,295	1,475	1,540	1.139	1.189	5,071	5,013	5,560	.989	1.096	8,952	9,173	8,951	1.025	1.000
1/8	1	1,806	1,694	1,870	.938	1.035	7,097	6,977	6,565	.983	.925	10,724	9,830	9,875	.917	.921
3/16	1	1,528	1,630	1,411	1.067	.923	.....	.....	4,261	.....	.....	9,280	8,861	8,143	.955	.877
Mean	1	1,486	1,555	1,629	1.046	1.096	5,988	5,442	6,048	.909	1.010	10,063	9,415	9,718	.936	.966
SEVEN-PLY																
1/24	1	1,448	1,492	1,282	1.030	.885	5,039	4,486	5,643	.890	1.120	10,111	9,934	10,950	.982	1.083
1/16	1	1,424	1,675	1,815	1.176	1.275	5,878	5,067	6,931	.862	1.179	9,917	10,083	13,013	1.017	1.312
1/12	1	1,284	1,267	1,386	.987	1.079	4,906	4,258	4,812	.868	.981	8,615	8,142	8,986	.945	1.043
1/8	1	1,723	1,848	2,170	1.073	1.259	6,743	7,070	7,451	1.048	1.105	10,759	10,634	13,073	.988	1.215
3/16	1	1,082	1,007	1,427	.931	1.319	4,565	3,614	4,838	.792	1.060	7,319	6,378	8,544	.871	1.167
Mean	1	1,392	1,458	1,616	1.047	1.161	5,426	4,899	5,935	.903	1.094	9,344	9,034	10,914	.967	1.168
NINE-PLY																
1/24	1	1,431	1,445	1,522	1.010	1.064	5,720	4,762	4,993	.833	.873	10,590	9,903	11,238	.935	1.061
1/16	1	1,763	1,747	1,846	.991	1.047	5,353	5,594	6,203	1.045	1.159	10,883	10,343	12,055	.950	1.108
1/12	1	1,326	1,546	1,273	1.166	.960	5,224	4,392	4,534	.841	.868	9,478	8,742	8,701	.922	.918
1/8	1	1,824	2,062	1,866	1.130	1.023	7,520	6,993	6,773	.930	.901	10,711	11,536	11,713	1.077	1.094
3/16	1	876	1,140	1,025	1.301	1.170	4,448	5,648	4,248	1.270	.955	6,632	8,097	6,625	1.221	.999
Mean	1	1,444	1,588	1,506	1.100	1.043	5,653	5,478	5,350	.969	.946	9,639	9,724	10,066	1.007	1.042

FPL-059

Table 13.--Ratios of exact to approximate values of modulus of elasticity to be expected from neglecting transverse plies for various values of $r = E_T/E_L$

Number of plies	Outer-parallel	Outer-perpendicular	Outer-parallel	Outer-perpendicular	Outer-parallel	Outer-perpendicular	Outer-parallel	Outer-perpendicular
	RATIOS - SITKA SPRUCE							
	r = 0.0305		r = 0.0379		r = 0.0399		r = 0.0454	
3	1.0011	1.7930						
5			1.0099	1.1443				
7					1.0162	1.0984		
9							1.0228	1.0902
	RATIOS - DOUGLAS-FIR							
	r = 0.0439		r = 0.0561		r = 0.0564		r = 0.0552	
3	1.0016	2.1414						
5			1.0147	1.2136				
7					1.0228	1.1390		
9							1.0277	1.1097
	RATIOS - YELLOW-POPLAR							
	r = 0.0347		r = 0.0381		r = 0.0449		r = 0.0414	
3	1.0013	1.9022						
5			1.0100	1.1452				
7					1.0182	1.1107		
9							1.0208	1.0823

GPO 812-915-3

Table 14.--Comparison of expected and actual values of the ratios of exact to approximate modulus of elasticity resulting from neglect of transverse plies

Number of plies	Outer-parallel		Outer-perpendicular	
	Expected value	Ratio from tables 10, 11, and 12	Expected value	Ratio from tables 10, 11, and 12
		SITKA SPRUCE		
3	1.0011	0.976	1.7930	1.792
5	1.0099	.997	1.1438	1.071
7	1.0162	1.037	1.0984	1.032
9	1.0228	1.018	1.0902	1.076
		DOUGLAS-FIR		
3	1.0016	.996	2.1414	2.009
5	1.0147	1.038	1.2136	1.212
7	1.0228	1.007	1.1390	1.120
9	1.0277	1.048	1.1097	1.095
		YELLOW-POPLAR		
3	1.0013	1.045	1.9022	2.081
5	1.0100	1.046	1.1451	1.096
7	1.0182	1.047	1.1107	1.161
9	1.0208	1.100	1.0823	1.043

Table 15.--Results of static bending tests on standard specimens cut from peeler blocks

Log No. 1									Log No. 2								
Specimen No.	Specific gravity[1]	Test moisture content	Modulus of elasticity: At test moisture content	Modulus of elasticity: Adjusted to 10 percent moisture content	Modulus of rupture: At test moisture content	Modulus of rupture: Adjusted to 10 percent moisture content	Fiber stress at proportional limit: At test moisture content	Fiber stress at proportional limit: Adjusted to 10 percent moisture content	Specimen No.	Specific gravity[1]	Test moisture content	Modulus of elasticity: At test moisture content	Modulus of elasticity: Adjusted to 10 percent moisture content	Modulus of rupture: At test moisture content	Modulus of rupture: Adjusted to 10 percent moisture content	Fiber stress at proportional limit: At test moisture content	Fiber stress at proportional limit: Adjusted to 10 percent moisture content
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
		Percent	1,000 p.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.			Percent	1,000 p.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.
SITKA SPRUCE																	
18-1-1	0.333	13.6	1,373	1,456	7,990	9,188	4,720	5,594	19-1-1	0.372	11.6	1,744	1,790	11,490	12,230	6,530	7,042
-2	.341	13.2	1,405	1,480	8,300	9,397	4,960	5,769	-2	.383	11.7	1,765	1,814	11,270	12,040	6,530	7,076
18-20-1	.350	13.5	1,584	1,677	8,890	10,180	5,490	6,476	19-13-1	.348	11.2	1,607	1,639	9,290	9,733	6,220	6,583
-2	.339	13.3	1,497	1,580	7,990	9,081	4,960	5,796	-2	.365	11.8	1,696	1,746	11,010	11,810	6,520	7,098
18-37-1	.319	13.0	1,432	1,504	8,080	9,077	3,910	4,505	19-25-1	.364	11.7	1,675	1,722	10,650	11,380	6,010	6,512
-2	.327	13.0	1,443	1,515	7,970	8,954	4,430	5,104	-2	.364	11.6	1,592	1,634	10,410	11,080	6,540	7,053
-3	.337	13.4	1,422	1,503	8,060	9,196	4,960	5,824	19-21-1	.351	11.7	1,558	1,602	9,660	10,320	6,000	6,501
18-55-1	.335	12.9	1,303	1,366	7,810	8,740	4,950	5,676	-2	.359	11.8	1,663	1,712	10,790	11,370	6,000	6,532
-2	.321	12.2	1,160	1,203	8,170	8,898	4,670	5,181	-3	.364	11.8	1,657	1,706	10,810	11,590	6,260	6,815
-3	.323	12.3	1,276	1,325	7,960	8,703	4,670	5,206	-4	.356	11.9	1,552	1,601	9,900	10,660	5,980	6,541
Av.	.332	13.0	1,390	1,461	8,122	9,141	4,772	5,513	Av.	.363	11.7	1,651	1,697	10,528	11,241	6,259	6,775
DOUGLAS-FIR																	
21-1-1	.492	11.5	2,120	2,178	13,080	13,800	7,820	8,349	20-1-1	.442	11.6	1,806	1,858	11,810	12,510	7,840	8,407
-3	.489	11.2	2,036	2,080	13,250	13,830	7,830	8,250	-2	.450	12.8	1,770	1,861	12,160	13,450	7,860	8,881
21-7-1	.445	11.6	1,543	1,588	11,200	11,860	6,550	7,023	20-6-1	.437	11.7	1,725	1,778	11,540	12,270	7,340	7,905
-2	.448	11.7	1,588	1,637	11,520	12,250	6,820	7,345	-2	.420	12.0	1,554	1,610	9,750	10,480	6,550	7,147
-3	.446	11.3	1,595	1,632	10,160	10,650	6,550	6,932	20-11-1	.414	11.2	1,734	1,771	11,540	12,050	6,560	6,912
21-13-1	.474	11.8	1,641	1,695	12,490	13,330	6,790	7,344	20-16-1	Cull	.....	.....	.....	.....	.....	.....	.....
-2	.468	11.9	1,584	1,639	11,650	12,470	6,550	7,116	-2	Cull	.....	.....	.....	.....	.....	.....	.....
21-19-1	.480	11.7	1,985	2,046	12,800	13,610	7,540	8,120	-3	Cull	.....	.....	.....	.....	.....	.....	.....
-2	.493	11.6	2,046	2,105	13,380	14,170	7,840	8,407	20-18-1	.451	11.6	1,740	1,790	11,290	11,960	6,980	7,484
-3	.488	11.7	1,887	1,945	12,880	13,690	8,380	9,025	-2	.455	11.7	1,844	1,901	11,710	12,450	7,060	7,603
Av.	.472	11.6	1,802	1,854	12,241	12,966	7,267	7,791	Av.	.438	11.8	1,739	1,796	11,400	12,167	7,170	7,763

[1] Specific gravity based on ovendry weight and volume at test. Not adjusted to 10 percent moisture content basis.

Table 16.--Values of the ratio $r = E_T/E_L$ as found from tests of all-parallel and all-perpendicular specimens

Number of plies	Ply thickness	$r = E_T/E_L$		
		Sitka spruce	Douglas-fir	Yellow-poplar
	Inch			
3	1/24	0.0281	0.0468	0.0315
3	1/16	.0296	.0495	.0364
3	1/12	.0296	.0404	.0368
3	1/8	.0326	.0451	.0342
3	3/16	.0327	.0379	.0348
Average	.....	.0305	.0439	.0354
5	1/24	.0411	.0650	.0504
5	1/16	.0427	.0616	.0366
5	1/12	.0371	.0582	.0394
5	1/8	.0361	.0530	.0328
5	3/16	.0325	.0426	.0312
Average	.....	.0379	.0561	.0381
7	1/24	.0418	.0703	.0538
7	1/16	.0428	.0632	.0496
7	1/12	.0419	.0501	.0368
7	1/8	.0360	.0559	.0332
7	3/16	.0369	.0424	.0510
Average	.....	.0399	.0564	.0449
9	1/24	.0506	.0676	.0521
9	1/16	.0477	.0666	.0370
9	1/12	.0465	.0465	.0379
9	1/8	.0461	.0549	.0358
9	3/16	.0360	.0402	.0441
Average	.....	.0454	.0552	.0414
Grand average		.0350	.0490	.0371

Table 17.--Results of tests of single veneers matched to luminated wood and plywood. (All values except specific gravity adjusted to 10 percent moisture content basis.)

Ply thickness	Log No.	Sitka spruce: Number of tests	Specific gravity	Modulus of elasticity	Fiber stress at proportional limit	Modulus of rupture	Douglas-fir: Number of tests	Specific gravity	Modulus of elasticity	Fiber stress at proportional limit	Modulus of rupture	Yellow-poplar: Number of tests	Specific gravity	Modulus of elasticity	Fiber stress at proportional limit	Modulus of rupture
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
In.				1,000 p.s.i.	P.s.i.	P.s.i.			1,000 p.s.i.	P.s.i.	P.s.i.			1,000 p.s.i.	P.s.i.	P.s.i.
MATCHED TO THREE-PLY SPECIMENS																
1/24	1	16	0.345	1,080	5,710	8,070	16	0.516	1,650	9,040	12,330	8	0.376	1,230	6,230	9,500
1/24	2	16	.362	1,140	5,890	9,260	16	.393	1,080	5,870	8,530	8	.391	1,140	5,980	9,690
1/24	1 and 2	32	.353	1,110	5,800	8,660	32	.454	1,370	7,460	10,430	16	.383	1,190	6,110	9,600
1/16	1	16	.364	1,560	5,640	9,080	16	.509	1,930	9,990	14,170	12	.422	1,340	6,500	10,090
1/16	2	16	.381	1,450	6,150	10,090	16	.391	1,240	5,620	8,920	16	.296	850	3,930	6,200
1/16	1 and 2	32	.372	1,410	5,900	9,590	32	.450	1,590	7,800	11,540	28	.359	1,090	5,220	8,140
1/12	1	16	.356	1,450	6,370	9,510	16	.512	1,880	9,510	13,770	8	.381	1,260	6,220	9,440
1/12	2	16	.386	1,460	6,160	10,230	16	.425	1,410	5,950	8,710	16	.391	1,290	6,140	9,550
1/12	1 and 2	32	.371	1,450	6,260	9,870	32	.468	1,650	7,720	11,230	24	.386	1,280	6,180	9,490
1/8	1	16	.367	1,560	6,550	9,120	16	.486	1,810	8,560	12,210	12	.415	1,460	6,460	9,780
1/8	2	16	.372	1,540	5,540	9,550	16	.389	1,270	5,340	9,010	16	.360	1,120	4,810	7,620
1/8	1 and 2	32	.370	1,450	6,040	9,340	32	.437	1,540	6,950	10,610	28	.388	1,290	5,640	8,700
3/16	1	16	.355	1,370	5,700	8,700	16	.484	1,910	8,580	11,740	12	.376	1,350	5,500	8,970
3/16	2	16	.380	1,660	6,790	10,670	16	.404	1,360	5,670	8,740	16	.394	1,390	5,480	9,270
3/16	1 and 2	32	.367	1,510	6,240	9,690	32	.444	1,640	7,120	10,240	28	.385	1,370	5,490	9,120
MATCHED TO FIVE-PLY SPECIMENS																
1/24	1	4	.347	1,240	6,100	9,560	4	.498	1,620	8,100	11,950	2	.414	1,480	8,060	11,330
1/24	2	4	.382	1,470	7,100	10,810	4	.378	1,010	5,560	8,670					
1/24	1 and 2	8	.365	1,350	6,600	10,090	8	.438	1,310	6,830	10,300					
1/16	1	4	.358	1,430	5,180	9,000	4	.506	1,780	7,810	13,340	2	.442	1,290	6,320	9,800
1/16	2	4	.392	1,550	5,950	10,760	4	.372	1,120	4,520	7,860					
1/16	1 and 2	8	.375	1,480	5,550	9,880	8	.440	1,450	6,160	10,600					
1/12	1	4	.360	1,470	6,440	9,610	4	.518	1,920	9,560	14,000	2	.351	1,050	5,000	7,670
1/12	2	4	.403	1,390	5,540	9,420	4	.418	1,430	6,270	8,650					
1/12	1 and 2	8	.381	1,430	5,990	9,520	8	.468	1,670	7,920	11,330					
1/8	1	4	.374	1,700	6,800	9,700	4	.490	1,820	8,020	11,760	2	.382	1,380	5,360	8,730
1/8	2	4	.404	1,690	7,370	11,260	4	.384	1,140	5,420	8,130					
1/8	1 and 2	8	.388	1,700	7,090	10,480	8	.437	1,480	6,720	9,950					
3/16	1	4	.357	1,320	5,100	8,690	4	.480	1,920	7,060	10,740	2	.364	1,220	5,720	8,630
3/16	2	4	.382	1,630	6,700	10,590	4	.403	1,320	5,740	8,530					
3/16	1 and 2	8	.370	1,480	5,900	9,640	8	.442	1,620	6,400	9,640					
MATCHED TO SEVEN-PLY SPECIMENS																
1/24	1	4	.348	1,190	6,340	9,140	4	.502	1,600	7,880	12,300	2	.364	1,050	5,900	8,860
1/24	2	4	.358	1,220	6,740	9,450	4	.395	1,220	5,910	9,510					
1/24	1 and 2	8	.353	1,200	6,540	9,500	8	.448	1,410	6,890	10,900					
1/16	1	4	.343	1,370	5,550	10,040	4	.495	2,160	9,410	13,840	2	.444	1,430	7,760	11,240
1/16	2	4	.380	1,380	4,950	10,370	4	.386	1,410	6,810	10,100					
1/16	1 and 2	8	.362	1,370	5,250	10,200	8	.440	1,780	8,110	11,970					
1/12	1	4	.348	1,320	5,610	9,410	4	.502	1,740	8,670	12,320	2	.360	1,140	5,350	8,660
1/12	2	4	.378	1,580	7,110	10,970	4	.468	1,780	7,250	9,900					
1/12	1 and 2	8	.363	1,450	6,360	10,190	8	.485	1,760	7,960	11,110					
1/8	1	4	.365	1,580	6,150	9,180	4	.512	2,100	9,020	13,810	2	.412	1,500	7,120	10,580
1/8	2	4	.378	1,440	6,240	10,600	4	.370	1,080	5,160	8,390					
1/8	1 and 2	8	.372	1,510	6,190	9,990	8	.441	1,590	7,090	11,100					
3/16	1	4	.350	1,380	6,130	9,200	4	.483	1,910	8,080	11,470	2	.339	1,040	4,900	7,700
3/16	2	4	.386	1,530	6,860	10,390	4	.408	1,370	5,610	8,410					
3/16	1 and 2	8	.368	1,450	6,500	9,800	8	.446	1,640	6,840	9,940					
MATCHED TO NINE-PLY SPECIMENS																
1/24	1	4	.367	1,250	6,260	9,070	4	.512	1,960	10,340	13,760	2	.416	1,280	6,870	11,070
1/24	2	4	.382	1,330	7,200	10,520	4	.370	1,050	5,850	8,140					
1/24	1 and 2	8	.374	1,290	6,730	9,790	8	.441	1,500	8,080	10,960					
1/16	1	4	.360	1,480	5,970	10,230	4	.526	1,740	8,600	13,620	2	.483	1,610	7,970	12,780
1/16	2	4	.413	1,500	5,490	10,980	4	.360	980	4,580	7,840					
1/16	1 and 2	8	.386	1,490	5,730	10,600	8	.443	1,360	6,590	10,730					
1/12	1	4	.372	1,610	5,810	10,200	4	.518	1,760	8,530	12,760	2	.373	1,170	6,120	8,600
1/12	2	4	.406	1,610	5,800	11,200	4	.410	1,380	6,100	8,240					
1/12	1 and 2	8	.389	1,610	5,810	10,700	8	.464	1,570	7,320	10,500					
1/8	1	4	.369	1,680	6,260	9,950	4	.468	1,900	8,370	11,340	2	.393	1,350	5,700	9,200
1/8	2	4	.381	1,660	6,790	10,810	4	.407	1,270	5,550	8,080					
1/8	1 and 2	8	.375	1,670	6,530	10,370	8	.438	1,580	6,950	9,710					
3/16	1	4	.361	1,470	6,240	9,380	4	.483	1,970	8,490	10,850	2	.322	890	3,880	6,430
3/16	2	4	.374	1,700	7,730	10,950	4	.392	1,330	5,930	8,560					
3/16	1 and 2	8	.368	1,580	6,980	10,160	8	.438	1,650	7,210	9,710					

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

FPL-059

Table 18.--Values of the factor e for use in correcting beam deflections for the effect of shear deformations

Number of plies	Values of e			
	Sitka spruce		Douglas-fir	
	Outer-parallel	Outer-perpendicular	Outer-parallel	Outer-perpendicular
3	184.8	8.6	141.7	9.9
5	160.8	46.3	118.4	36.5
7	147.1	63.5	108.5	48.8
9	138.8	73.3	102.5	55.7

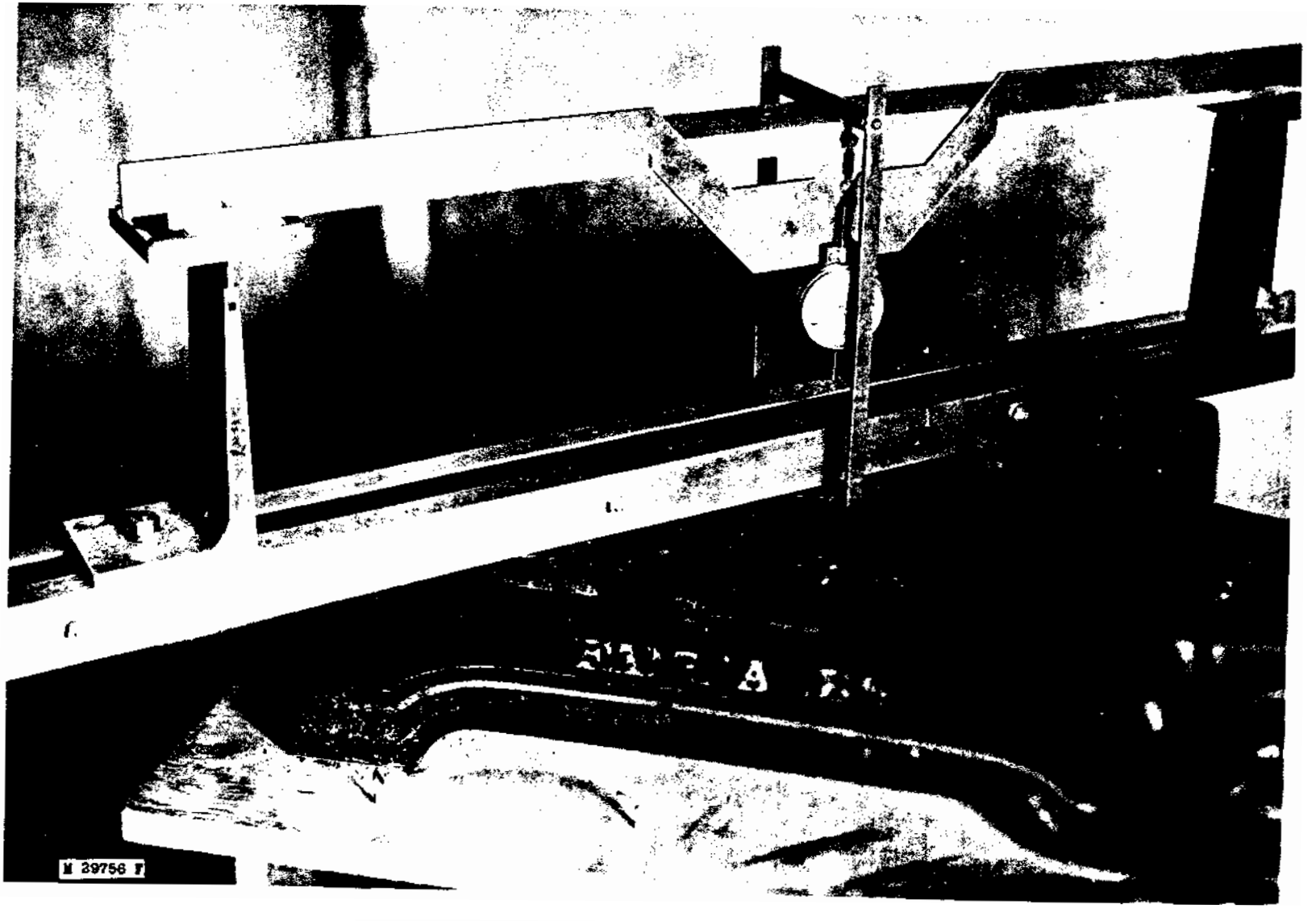

Figure 1.--Details of apparatus for bending test of plywood.

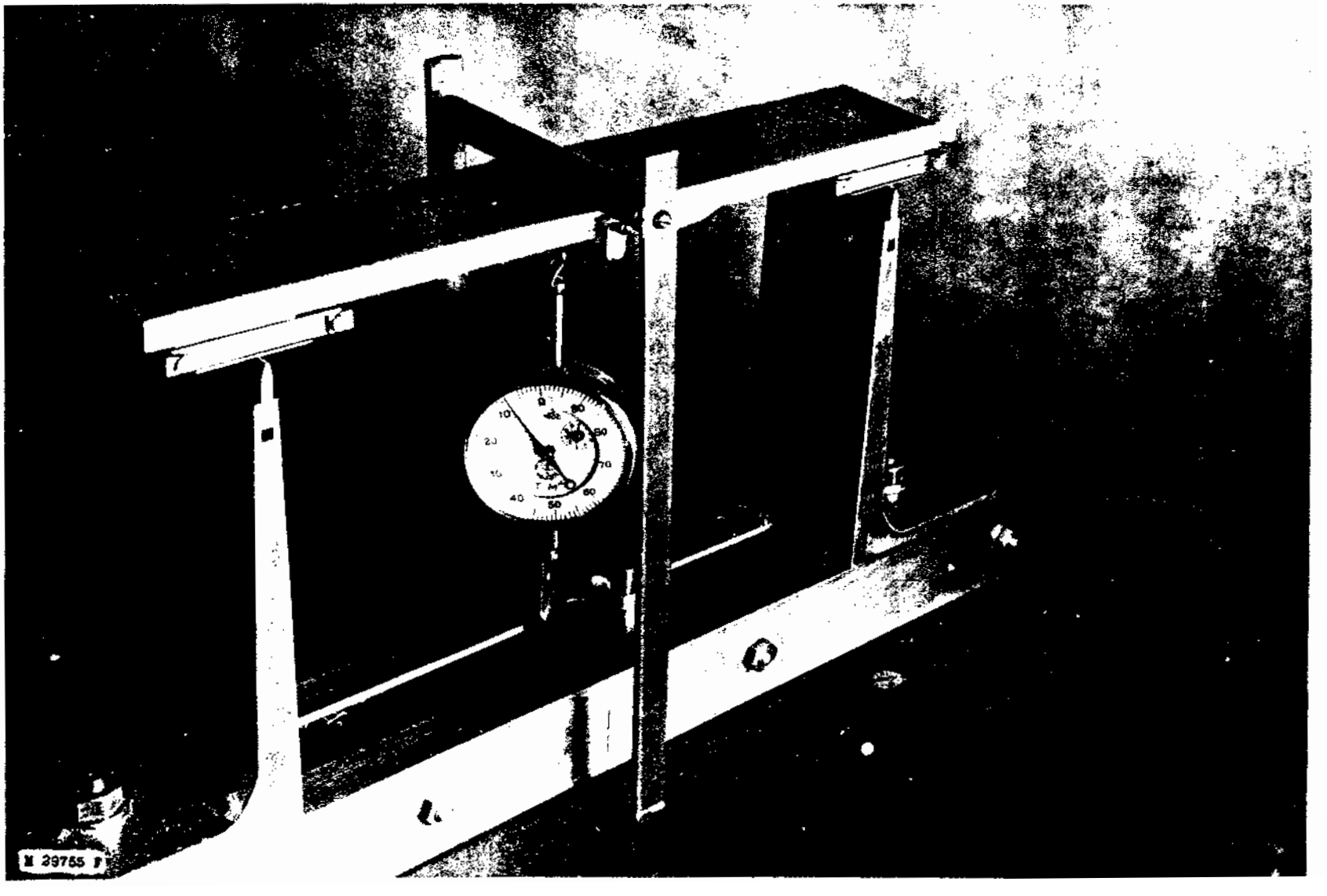

Figure 2.--Details of apparatus for bending tests of plywood, showing method of attachment of dial gage to specimens too short to permit use of supporting yoke as shown in figure 1.

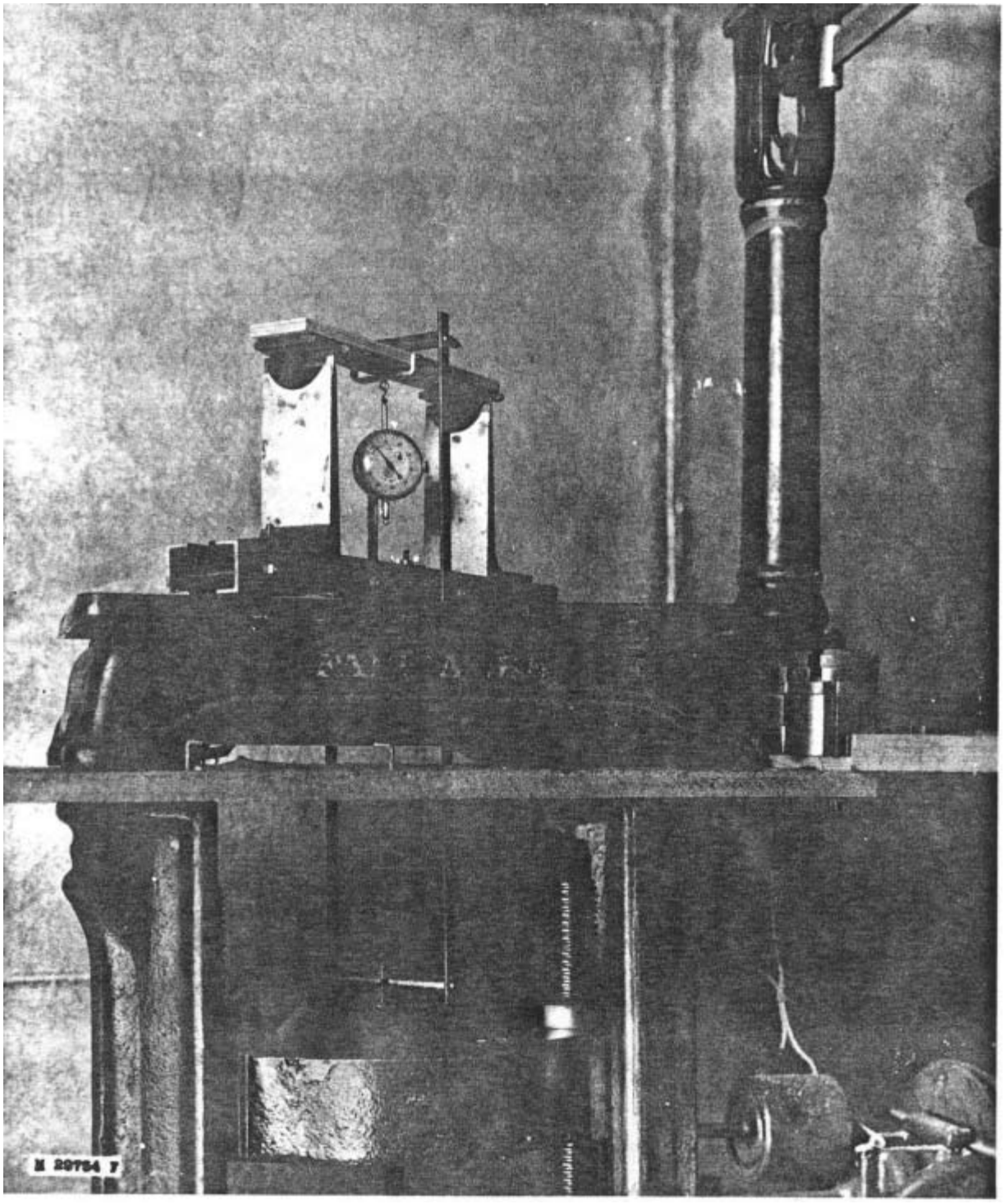

Figure 3.--Details of apparatus for bending tests of plywood, showing the use of a platform scale for measuring small loads.

GPO 812–915–2

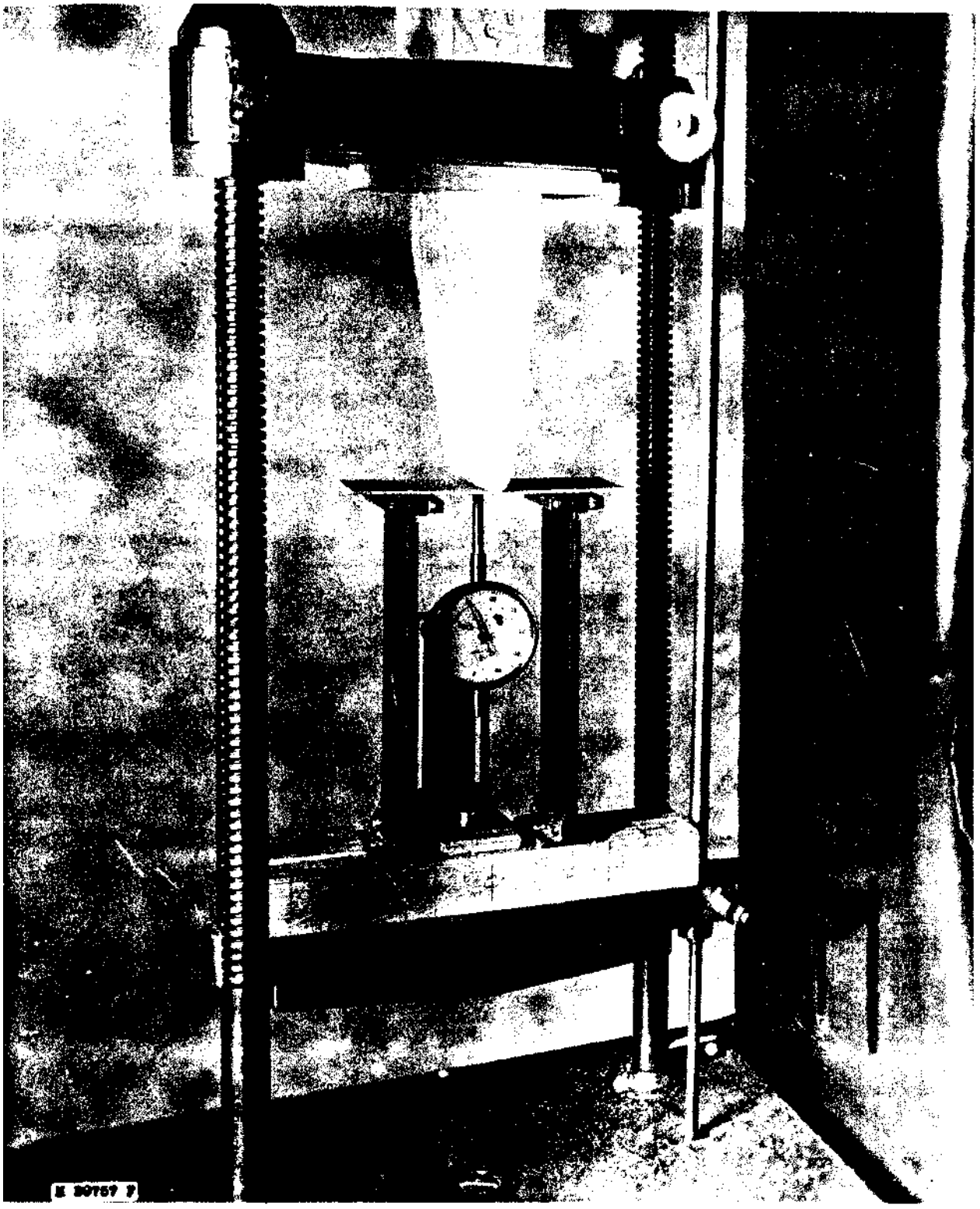

Figure 4.--Details of apparatus for bending tests of single-ply veneer.

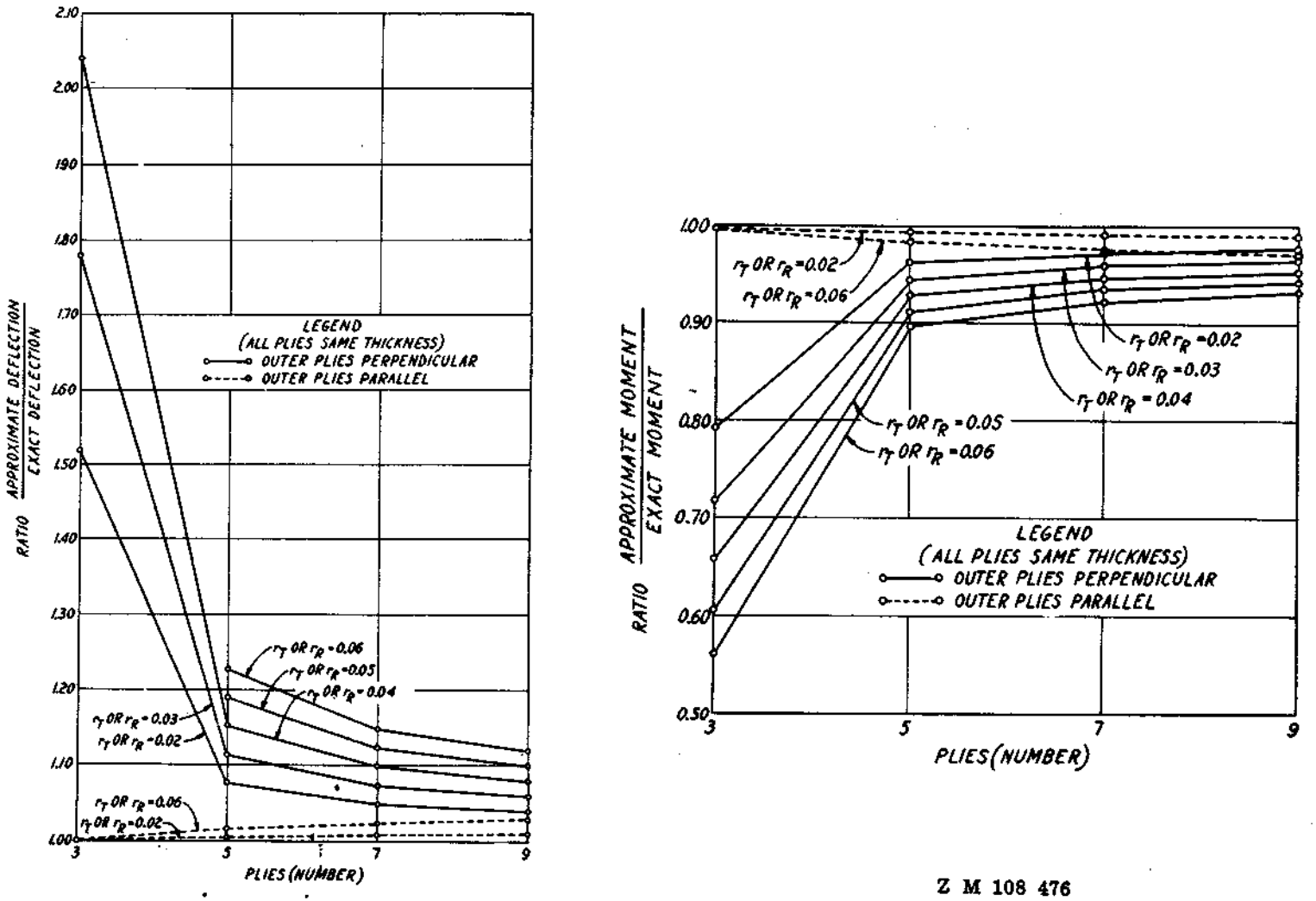

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Figure 5.--Ratios of deflections (left) and moments (right) calculated by neglecting transverse plies to deflections calculated by considering transverse plies when all plies are of the same thickness.

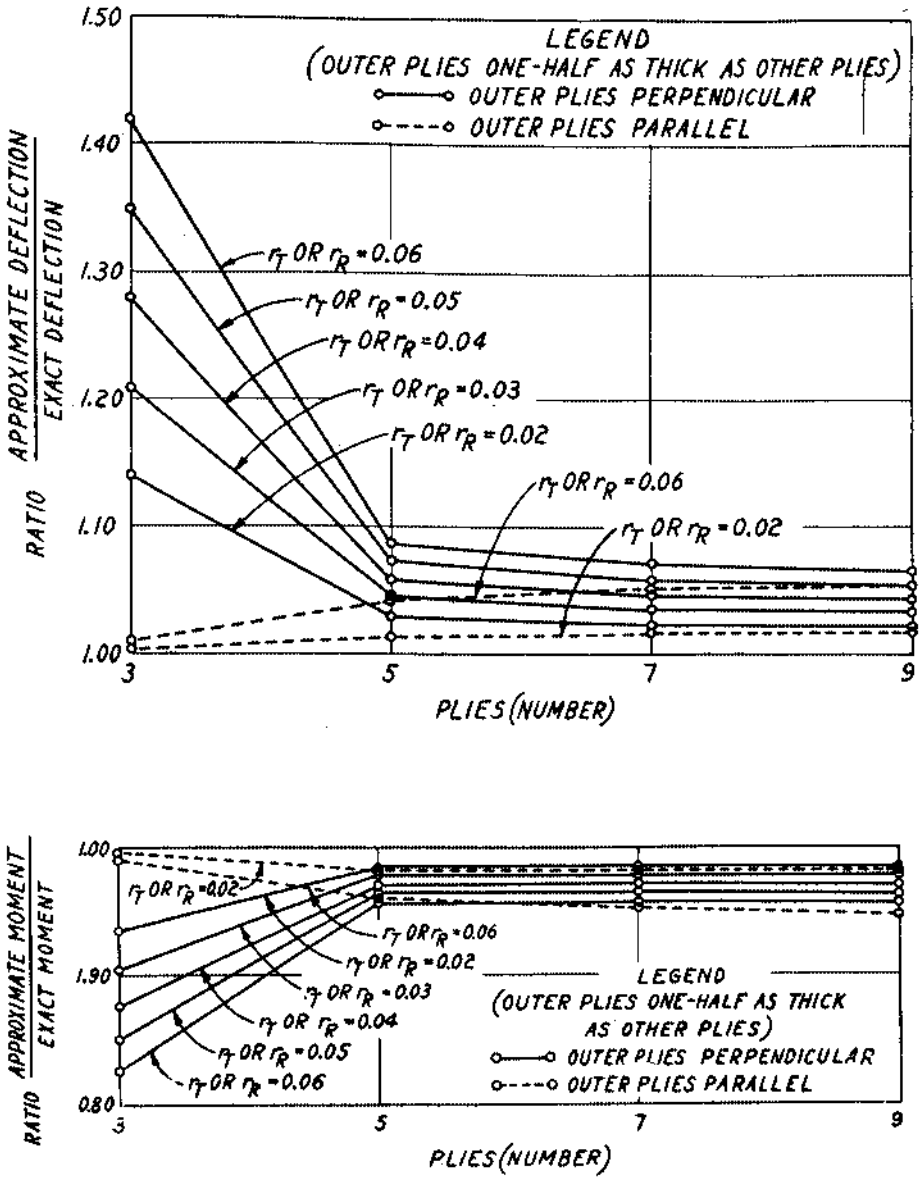

Figure 6.--Ratios of deflections (top) and moments (bottom) calculated by neglecting transverse plies to deflections calculated by considering transverse plies when the outer plies are one-half as thick as the other plies.

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