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STRENGTH AND STIFFNESS OF SMALL GLUED-LAMINATED BEAMS WITH DIFF--ETC(U)

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UNCLASSIFIED FSRP-FPL-381 NL

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United States
Department of
Agriculture

Forest Service

Forest Products Laboratory

Research Paper FPL 381

May 1981

Strength and Stiffness of Small Glued-Laminated Beams with Different Qualities of Tension Laminations

(12)

LEVEL II

Abstract

A total of 180 small Douglas Fir—Larch (DF-L) or Southern Pine (SP) glued-laminated beams were evaluated to determine the tension lamination quality necessary to obtain desired design stresses. The test beams had either the regular laminating grades of L1 DF-L/No. 1D SP or the special 302-24 laminating grade as tension laminations.

Because an initial set of SP beams did not provide valid strength data due to a high frequency of finger-joint failures, a second set of SP test beams was manufactured. Although the initial set of SP beams could not be used to answer the objectives of this study, it did indicate that current strength requirements for daily finger-joint quality-control bending tests need to be increased.

The 60 DF-L beams and the 60 beams for the second set of SP beams show that specially graded tension laminations are necessary even for 4-lamination beams. A tension lamination grade between the regular laminating grades of L1 or No. 1D and the special laminating grade called 302-24 may be adequate on a 4-lamination beam to obtain a 2,400 lb/in^2 design stress. The 8- and 10-lamination beams, however, appeared to require a 302-24 grade tension lamination to obtain that design stress.

The strength of test beams with L1 or No. 1D grade tension laminations was about 15 percent less than the strength of test beams with 302-24 grade tension laminations. This suggests a 2,000 lb/in^2 design stress for the test beam combinations with L1 or No. 1D grade tension laminations.

The data will provide guidelines to industry committees in recommending design stresses and specifications for glulam beams.

The terms Douglas Fir—Larch and Southern Pine are from the list "Commercial Names for Lumber", p. 343, in *Checklist of United States Trees*, Agric. Handb. No. 541, 1979. At the time this manuscript was prepared it was anticipated that the terms Douglas Fir—Larch and Southern Pine might be adapted for USDA usage.

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United States
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Research
Paper
FPL 381

Strength and Stiffness of Small Glued-Laminated Beams with Different Qualities of Tension Laminations[2]

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Introduction

Almost all of the previous research on glued-laminated (glulam) beams has been conducted on deep beams because these are the prime load-carrying members. Tests of the deep beams led to the development of special tension lamination grades which were found necessary to achieve their desired strength properties *(19)*.[3] Present criteria for predicting the strength of deep beams with those specially graded tension laminations are given in FPL 292 *(15)*.

There have been limited studies on shallow glulam beams. In this report "shallow beams" are defined as beams less than 16-1/4 inches deep. That depth was designated as the cutoff point for the requirement of specially graded tension laminations *(1)*, a decision based on the results of the deep-beam research. As a result of that research, all beams 16-1/4 or more inches deep required special tension laminations graded according to AITC 117-76 *(1)*. Visual laminating grades with no special grading provisions were allowed as tension laminations for beams less than 16-1/4-inch deep.

Previous research on small glulam beams *(12)* demonstrated that beams 12 inches and less in depth, of a single visual grade of lumber, and without specially graded tension laminations had only about 85 percent of the strength predicted by a strength-ratio (SR) concept *(3)*. Because that SR concept was used for developing some of the small beam combinations in AITC 117-76 *(1)*, beams less than 16-1/4 inches deep need to be evaluated to determine if their strength properties are adequate. This study was designed to provide a better understanding of the bending-strength properties of shallow, specification-type beams.

Objective and Scope

The objective of this research study was twofold: (a) to determine at what beam depth specially graded 302-24 *(2)* tension laminations are required to attain a 2,400 lb/in.[2] design stress; (b) to determine the appropriate design stress for specification-type beams with the regular laminating grades of L1 Douglas Fir—Larch (DF-L) or No. 1D Southern Pine (SP) as the tension laminations. The 302-24 grade of lumber required for tension laminations on 24F[4] deep beams is a limited resource and is not as readily available as L1 or No. 1D lumber now used as the tension lamination on 24F shallow beams—thus necessitating objective (b).

The 180 glued-laminated beams evaluated were of near-minimum quality; each selected tension lamination had a near-maximum-size, strength-reducing characteristic positioned in the most highly stressed region of the test beams.

Beam Design and Manufacture

Experimental Design

Two species, two types of tension laminations, and three beam sizes were variously combined in the experimental design of this study, resulting in 12 different beam groups. Ten beam replicates were chosen for each of the 12 groups, giving a total of 120 test beams. However, as will

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

[2] Research conducted in cooperation with the American Institute of Timber Construction (AITC).

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

[4] The symbol "24F" implies beam combinations with a design stress of 2,400 lb/in.[2] in bending. Also, the phrase 'tension lamination' used throughout this report refers to the middle portion of the bottom lamination of each test beam.

be discussed in more detail later, it was necessary to evaluate an additional 60 SP beams to obtain a valid measure of the effect of tension lamination quality on the strength of shallow beams. Therefore, a total of 180 DF-L or SP glued-laminated beams were evaluated for this study. The group of SP beams manufactured first will be referred to as the "initial set of SP beams." The second group of 60 SP beams, manufactured nine months after the first group, will be referred to as the "second set of SP beams."

Half of the beams of those two species had specially graded tension laminations referred to as "302-24" *(2)*, the same as 301-24 in *(1)*, while the remaining half had the regular laminating grades of either L1 DF-L or No. 1D SP as tension laminations. Visually graded DF-L and SP were the two species selected because they are the most commonly used species for laminating.

The three beam sizes of 4-, 8- or 10-laminations were chosen for the following reasons: 4-lamination beams are the minimum depth of beams designated principally for use as horizontally laminated beams *(1)*; 10 laminations of nominal 2-inch-thick lumber result in a 15-inch-deep beam that is near the maximum depth of beams permitted in AITC 117-76 *(1)* without specially graded tension laminations; 8 laminations represent an intermediate depth at which beams become principal load-carrying members.

In designing this study the authors recognized that 10 replicates within each beam group is a small statistical sample size to work with. It was assumed, however, that an analysis of variance of all the test data would permit some of the results to be combined to provide a larger sample.

Design of Test-Beam Combinations

The test beams were fabricated as shown in figure 1. Those beam layups were designed to match the SP combination, 24F-V2, or the DF-L combination, 24F-V4, in AITC 117-79 *(2)* except, in some cases, for the grade of tension lamination required.

For simplification, the DF-L beams with L1 tension laminations, as shown in figure 1, will be referred to in this report as "L1 DF-L." Similarly, the SP combinations with No. 1D tension laminations will be referred to as "No. 1D SP." The test beams with 302-24 tension laminations will be referred to as either "302-24 DF-L" or "302-24 SP."

Lumber properties necessary for the derivation of design stresses are given in table 1 *(5, 16)*. The concept developed in FPL 292 *(15)* of permitting lower grade material on the compression side was used by applying a "compression bonus" of at least 1.3, along with the traditional I_K/I_G approach *(9)* for determining design stresses.

In addition to the design stress determined by the I_K/I_G approach, a design stress was determined following a strength ratio (SR) concept *(3, 12)*. This procedure involved permitting each lamination to be stressed up to a value obtained by multiplying the clear wood design stress in bending from *(5)* by an SR based on the maximum allowable sized knot for each grade. This SR was determined from a ratio of the net cross-sectional area after subtracting the area occupied by the permitted knot to the total area. Because of the different sizes of centerline and edge knots permitted in SP, there are several possible ways to calculate an SR. Experience with DF-L and SP suggested that the strength properties of the L1 DF-L and No. 1D SP grades are probably not that different; thus, an SR of 0.73, based upon the maximum allowable edge knot, was used for No. 1D SP.[5]

Predicted design stresses were then calculated by multiplying the clear wood design stresses in table 1 by the two SR's derived using either the I_K/I_G concept or the SR method. Table 2 gives the predicted design stresses for the 4-, 8-, and 10-lamination beams. The higher of the two predicted design stresses determines the design stress listed in AITC 117.

Table 1.—Assumed lumber grade properties used for beam design

Lumber grade	Modulus of elasticity	Clear wood design stress[1]	Minimum strength ratio[2]	Knot properties[3] $\bar{X}$	Knot properties[3] h_v
	Million lb/in.²	Lb/in.²		Pct	Pct
		SOUTHERN PINE			
No. 1D[4]	2.0	3,500	[5]0.73	0.031	0.324
No. 2D	1.8	3,500	.48	.076	.433
No. 2M	1.5	3,000	.48	.076	.433
		DOUGLAS FIR-LARCH			
L1[4]	2.1	3,500	.75	.069	.324
L2D	1.9	3,500	.67	.103	.381
L2	1.8	3,000	.67	.103	.381
L3	1.6	3,000	.50	.116	.464

[1] From reference *(5)*.
[2] Determined by subtracting the portion of the cross-section of a 2x6 occupied by the maximum permitted knot from unity.
[3] The knot properties are based on several studies; the main reference is *(16)*. $\bar{X}$ = average sum of knot sizes and h_v = difference between the near-maximum and average sum of knot sizes.
[4] 302-24 grade tension laminations assumed to have same properties as No. 1D or L1 grade.
[5] The value shown is based on the maximum allowable edge knot.

Table 2.—Design of 4-, 8-, and 10-lamination beams

Species	Number of laminations	Predicted design levels[1] in bending: I_K/I_G	Predicted design levels[1] in bending: Strength ratio[2]	Modulus of elasticity: Design[3]	Modulus of elasticity: Predicted[4]
		Lb/in.^{2}	Lb/in.^{2}	Million lb/in.^{2}	Million lb/in.^{2}
SP (24F-V2)	4	2,270	2,480	1.7	1.84
	8	2,370	2,370	1.7	1.74
	10	2,380	2,310	1.7	1.70
DF-L (24F-V4)	4	2,010	2,520	1.8	1.86
	8	2,310	2,500	1.8	1.84
	10	2,350	2,460	1.8	1.81

[1] Calculated using a clear wood design stress of 3,500 lb/in.^{2} for dense and 3,000 lb/in.^{2} for medium grain. The outer tension side controls the design in all instances. The beam combinations are from AITC 117-79 *(2)*. Values given are for standard conditions of 12 pct moisture content, 12-in. depth, 21:1 span-to-depth ratio, and uniform loading.

[2] Assume a minimum strength ratio of 0.75 for L1 DF-L and 0.73 for No. 1D SP. Both the strength ratio approach and the I_K/I_G concept assume a minimum strength ratio of 0.50 for L3 DF-L and 0.48 for No. 2 SP inner laminations.

[3] The listed design MOE values are from AITC 117-79 *(2)*.

[4] The listed predicted MOE values were derived by taking 95 pct of the value calculated by a transformed section analysis using the MOE values in table 1.

Lumber Selection and Evaluation

The SP and DF-L test material was selected from the stock on hand at the two laminating plants that manufactured the test beams. The SP lumber was graded according to the 1970 Southern Pine Inspection Bureau (SPIB) rules *(21)* by mill graders supervised by SPIB and by AITC representatives at the plant. Similarly, mill graders supervised by the West Coast Lumber Inspection Bureau (WCLIB) or the Western Wood Products Association (WWPA) and AITC representatives at the plant graded the DF-L material according to the 1970 WCLIB rules *(23)*. Lumber meeting a higher grade than desired was not used. The selected nominal 2 by 6 SP lumber was 8 to 16 feet in length, and the DF-L lumber 12 to 21 feet.

To aid in the analysis of results, the moisture content, weight, and modulus of elasticity (MOE) were determined for each piece of lumber. The moisture content was determined by averaging three readings taken along the length of each lamination with a power-loss-type moisture meter. The weight was found by doubling the reaction of one end as each 2 by 6 was simply supported as a beam. The MOE values were determined with an E-computer which uses a vibration technique. Each piece of lumber was assigned a number, but no attempt was made to randomize the material.

Following finger jointing, the location of each piece of lumber within the beams was recorded, as well as the location of every finger joint. Knot sizes were measured on one face of the No. 2D SP and L2D DF-L grades of material and the No. 1D and L1 material that was not used as tension laminations. To obtain a better estimate of the displacement, knots and local grain deviation were measured on both faces of the L1, No. 1D, and 302-24 material used as tension laminations. Knots were mapped between 2.5 and 8.0, 5.0 and 16.0, and 6.0 and 19.0 feet from a reference end of the 4-, 8-, and 10-lamination beams, respectively.

Selection of Tension Laminations

Figures 2 and 3 illustrate the typical, near-minimum quality of the selected 302-24 and No. 1D SP tension laminations, respectively. The near-minimum quality of the selected 302-24 and L1 DF-L tension laminations is illustrated in appendix A by figures A- 8 and A- 9, respectively, which show some of the beam failures.

Special care was taken in selecting the tension laminations. The criteria used are given in table 3. The number of selected pieces containing pith-associated wood was dependent upon the amount found in representative material. As a result, more SP than DF-L tension laminations contained pith-associated wood.

It was intended that finger joints be positioned so that 30 to 50 percent of the test beams would contain joints in their most highly stressed region. Because of difficulties experienced in cutting the tension laminations to desired lengths, more than 50 percent of the test beams in some groups actually had joints so positioned.

In order to select tension laminations of near-average density and not permit atypical heavy weight pieces, an attempt was made to eliminate SP pieces with specific gravities exceeding 0.55 and DF-L pieces exceeding 0.53. Because of a stock material shortage, however, several of the selected tension laminations for the second set of SP beams have specific gravities greater than 0.55.

Most of the selected 302-24 tension laminations contained grain deviation throughout approximately one-third of the cross section. It was intended that about an equal number of the selected L1/No. 1D tension laminations contain grain deviation throughout more than one-half of the cross section, about one-half of the cross section or between one-third and one-half of the cross section.

[6] It should be noted that in a previous study *(12)*, an SR based on the average of the edge and centerline knot sizes for beams with all No. 2D grade lumber yielded predicted results most consistent with several groups of DF-L beams. However, use of just the edge knot to calculate an SR fit in reasonably well with the other data, while use of just the centerline knot was too conservative.

Table 3.—Tension lamination selection criteria

	Type of tension lamination	
	302-24	No. 1D or L1
Specific gravity	± 0.03 or 0.04 from species average	Not more than 0.04 above species average
SP	0.48 - 0.55	≤0.55
DF-L	.45 - .53	≤ .53
Density requirement	Must be dense the full length (both ends)	Must be dense at least on one end
Knot	20 pct of the cross section	[1]27/41 pct (No. 1D) or 25 pct (L1) of the cross section
Knot plus grain deviation	Near 1/3 of the cross section	> 1/3 (up to 100 pct) of the cross section
Pith associated wood	Near 1/8 of the cross section	> 1/8 of the cross section
Slope-of-grain	1:16 general	[2]1:14 or 1:16
Lightweight (low specific gravity)		
SP	—[3]	< 0.48
DF-L	—	< .45

[1] The first and second numbers indicate the percent of the cross section that an edge or centerline knot, respectively, is allowed to occupy.
[2] The slope-of-grain requirements were 1:14 for the 4-lamination No. 1D SP beams and 1:16 for the rest of the beams with No. 1D or L1 tension laminations.
[3] Not applicable.

That balance was achieved for the DF-L beams and the initial set of SP beams, but the majority of the selected No. 1D tension laminations for the second set of SP beams contained grain deviation throughout more than one-half of the cross section.

The average properties for the selected tension laminations are summarized in appendix A. The selected characteristics were placed in the most highly stressed region of the test beams.

Beam Manufacture

The 180 SP and DF-L test beams were manufactured in 1978 by two commercial laminators following normal plant procedures. The 60 DF-L beams were manufactured as one group by one laminator while the SP beams were manufactured in two groups of 60 beams each by another laminator. All manufacturing conformed to the Voluntary Product Standard for Structural Glued Laminated Timber, PS 56-73 *(22)*.

Finger-joint quality-control tests were conducted before the test material was end jointed to assure that the finger joints met the strength requirements of PS 56-73 *(22)*. A common vertical finger-joint profile was used: 1.1-inch length, 1/4-inch pitch, 0.030-inch finger tip. The finger joints were bonded with a melamine adhesive.

Due to a mixup during manufacture, 12 of the 8-lamination DF-L beams had adhesive spread on the wrong side of the selected tension laminations. The result was that the selected defect was placed toward the inside of the beam rather than toward the outside as intended. This deviation was thought to seriously affect only one of those beams; all of the others had selected defects which were similar on both faces. The beams were bonded using a phenol-resorcinol adhesive.

After removal from clamps the SP beams were surfaced to a 5-inch width and the DF-L beams to a 5-1/8-inch width. The 4-, 8-, and 10-lamination beams were trimmed to lengths of 10.5, 20.0, and 25.5 feet, respectively. The beams were shipped to Madison, Wis., and tested soon after their arrival.

Research Methods

Test Procedures

The beams were tested according to ASTM D 198 *(6)*. Figure 4 shows the 8-lamination beam test setup. (The 4-and 10-lamination test setups were similar.) Two-point loading was used, with the span between the reactions varying from 9.5 to 19.0 to 24.0 feet for the 4-, 8-, and 10-lamination beams, respectively. Similarly, the distance between the load heads varied from 2.0 to 4.0 to 5.0 feet. These dimensions provided a shear span-to-depth ratio of about 15:1 in order to maximize bending-type failures and minimize the chance of horizontal shear failures.

To assure proper arrangement of gages and equipment, a small load was applied to the test beams before they were continuously loaded to failure. The test machine head movement was continued until the load dropped to about 50 percent of the maximum load.

Data Obtained

Just prior to testing, the beams were measured, marked, and weighed. Lines were drawn and then labeled at the centerline and at the two load points so the area of beam failure could be easily located. Cross-sectional dimensions at the load points were recorded as well as the total length of each beam.

An adjustable metal yoke was developed to support a deflectometer which measured the full-span deflection (figs. 4 and 5). An X-Y plotter provided a continuous record of the machine test load versus the full-span deflection (fig. 5). Following failure the moisture content of each lamination was measured near the failure area with a resistance-type meter having 1-1/2-inch-long prongs. The failure area was cut from each beam, photographed, and saved for further inspection.

Analysis Procedures

Adjustment factors applied to MOE data.—MOE values were adjusted to a 12 percent moisture content following ASTM D 2915 *(4)*.

Adjustment factors applied to MOR data.—To compare with AITC design stresses *(1, 2)*, the modulus of rupture (MOR) data were adjusted only with the size factor allowed in design. Because the design stresses apply to beams 12 inches or less in depth and no increase is allowed for beams less than 12 inches deep, that size factor was 1.0 for the 4- and 8-lamination beams and 0.976 for the 10-lamination beams.

The method-of-loading adjustments for all three beam sizes *(7)* were small enough to be neglected. The moisture content adjustments were also neglected for comparison with AITC bending design stresses.

To compare the beam groups with different quality tension laminations, the MOR data were adjusted to standard conditions that imply a 12 percent moisture content and a 12-inch-deep beam with a uniform load and a 21:1 span-to-depth ratio. The moisture-content adjustments were calculated according to ASTM D 2915 *(4)*. Adjustment factors equal to 0.932, 1.006, and 1.032 for the 4-, 8-, and 10-lamination beams, respectively, accounted for the rest of the adjustment to standard conditions; those factors were calculated according to *(7)*.

Calculation of Near-Minimum Values

Estimated near-minimum bending-strength values were needed before the test results could be compared with either the AITC design values or the procedures used to predict those design values. The type of statistical distribution that characterizes the population must be assumed before a near-minimum value can be calculated from a set of data. A sample size of 10 is inadequate to determine the true type of distribution, thus several analyses of variance *(11)* were conducted to determine if any of the data could be combined to provide a larger sample size. These analyses are explained in more detail in appendix B. Judgment was required in combining beam groups because the analyses of variance revealed some unexpected differences between the average strength values of some of the beam groups.

Near-minimum bending-strength values were calculated by assuming a lognormal distribution with 75 percent confidence at the fifth percentile. That distribution and confidence level have been used previously for the analysis of glulam test data. The near-minimum values were determined from the test data by subtracting "k" times the standard deviation from the mean. Necessary "k" factors were found in the appropriate confidence/tolerance table *(20)*. The calculated near-minimum values were further adjusted by dividing by 2.1, a factor widely used in the wood industry to reduce bending test data from a near-minimum stress level to a design stress level. These adjusted near-minimum values, called "test values" in this report, can be compared to AITC design values.

Calculation of Target MOR Values

Target MOR values were calculated by multiplying the 2,400 lb/in.^{2} design stress by 2.1 and the design size factors of 1.0, 1.0, and 0.976 for the 4-, 8-, and 10-lamination beams, respectively. The result was a target MOR value of 5,040 lb/in.^{2} for the 4- and 8-lamination beams and 4,920 lb/in.^{2} for the 10-lamination beams.

Presentation of Results

Lumber Properties

The lumber properties of the test material are given in table 4. More detailed information on tension lamination properties is given in appendix A.

Beam Properties

The average properties of each beam group are listed in table 5. Individual beam test results are given in appendix A.

One of the initial 4-lamination SP beams having a 302-24 tension lamination was inadvertently tested upside do^^n. This error resulted in a No. 1D tension lamination with pith-associated wood throughout more than one-eighth of its cross section. Thus, this beam was placed in the corresponding No. 1D group, giving that group 11 replicates and the 302-24 group 9 replicates.

Test-Beam Failures

Several beams exhibited a gradual type of failure with cracking or splintering of the tension lamination, accompanied by varying amounts of drop in the test machine load. For 20 beams, this drop in load was significant (5 pct or more), and upon further loading the ultimate load exceeded the initial maximum load. For these beams, shown in more detail in appendix A, there is some question as to their possible performance under a true dead load versus the type of load imposed in a screw-type testing machine. However, the ultimate load obtained in the screw-type machine has traditionally been used to calculate the modulus of rupture values, so it was used throughout this study.

General Observations

Several different types of beam failures were expected: tension failures involving the selected characteristic of either pith-associated wood, knot(s) and associated grain deviation, slope of grain, or a low specific gravity; finger-joint failures; and compression. No shear failures were expected and none occurred.

A summary of the beam failure types is presented in table 6. The numbers given in the table may add up to over 100 percent because some of the beam failures were attributed to a combination of characteristics. Appendix A contains a more detailed discussion of some specific beam failures; all of the beams that failed below the expected level are included in that discussion.

Initial set of SP beams.—Two-thirds of the initial set of SP beams failed solely at a finger joint, or at a finger joint in combination with another characteristic, as shown in table 6. Pith-associated wood was involved in about one-third of the finger-joint failures. Finger-joint failure frequency was highest in the 302-24 beams, with almost all failing at a

Table 4.—Summary of the average lumber properties of the 2 by 6 test material selected

Lumber grade	Number of pieces	Moisture content[1]	Specific gravity[2]	Modulus of elasticity[3] — Unadjusted — Average	Unadjusted — Coefficient of variation	Adjusted to 12 percent moisture content — Average	Adjusted — Coefficient of variation
		Pct		Million lb/in.²	Pct	Million lb/in.²	Pct
INITIAL SET OF SOUTHERN PINE							
302-24	112	10	0.55	2.13	13.7	2.06	14.6
No. 1D	172	11	.54	1.90	15.0	1.88	16.1
No. 2D	90	10	.53	1.86	18.0	1.82	18.5
No. 2M	489	9	.49	1.49	18.8	1.42	19.3
SECOND SET OF SOUTHERN PINE							
302-24	164	11	.53	1.89	16.6	1.84	17.4
No. 1D	189	10	.53	1.71	15.8	1.65	16.1
No. 2D	84	9	.51	1.58	22.9	1.51	23.9
No. 2M	577	9	.47	1.33	17.8	1.26	18.3
DOUGLAS FIR-LARCH							
302-24	96	13	.51	2.50	14.0	2.54	15.3
L1	151	12	.49	2.27	14.5	2.26	15.9
L2D	73	12	.49	2.02	13.8	2.02	14.8
L2	115	10	.43	1.77	12.0	1.73	13.1
L3	260	11	.46	1.68	18.0	1.66	20.6

[1] Determined with a power-loss type moisture meter.
[2] Based on weight adjusted to ovendry and volume at the measured moisture content.
[3] Determined with E-computer.

finger joint. Most of those beams had finger joints subjected to 75 percent or more of the maximum moment, but two of the beams failed at finger joints subjected to between 50 and 75 percent of the maximum moment. About half of the No. 1D beam failures involved a finger joint; all of those beams failed at finger joints subjected to 75 percent or more of the maximum moment. Typical finger-joint failures for the initial set of SP beams are shown in figures A-1 and A-2 in appendix A.

Second set of SP beams.—The majority of the second set of SP beams failed at the selected tension-lamination characteristic. However, about one-third of the failures occurred at a tension-lamination characteristic that was not the selected characteristic; the same number of beams failed at a finger joint along with another characteristic.

DF-L beams.—The DF-L beams exhibited failure types similar to the second set of SP beams. About one-third of the DF-L beam failures involved finger joints, but only one of those beam failures was attributed to the finger joint alone. One-third of the DF-L beams failed at a tension-lamination characteristic judged as being less severe than the selected characteristic, but the majority of the DF-L beams failed at the selected tension-lamination characteristic.

Discussion of Results

Modulus of Elasticity (MOE)

The average test MOE values for each beam group can be compared with design values listed in AITC 117-79 *(2)*. They can also be compared with average predicted MOE values, calculated by assuming the average MOE (table 1) for each grade of lumber in the beam combination. Table 7 compares the average test MOE values for each beam group with the corresponding design and predicted MOE values.

Each individual test MOE value can also be compared with an individual predicted MOE value. The straight line portion of each load versus deflection test plot was used to determine the individual test MOE values. Individual predicted MOE values were obtained by multiplying transformed MOE values by 0.95 *(5, 15)*. (The transformed MOE values were calculated by using a transformed section analysis and the E-computer MOE of each piece of lumber in a beam.)

Comparison With Predicted Values

As mentioned, comparisons can be made between the test MOE values and the average predicted value for each group of 10 beams as well as the individual predicted values for each beam.

Average.—As table 7 shows, the average test MOE values for the DF-L beam groups were between 5 and 12 percent higher than the predicted values calculated, assuming the average MOE values in table 1. The higher test MOE values could be expected because the average MOE of the DF-L test material was generally higher than the average assumed MOE of the lumber grades used in the test beam combinations. (Table 4 lists the actual average MOE values of the lumber selected for this study and table 1 lists the assumed average MOE values.) The average test MOE values for both the initial and second sets of SP beams were generally lower than their predicted values

Table 5.—Summary of average beam properties

Number of laminations in beams	Number of beams	Type of tension lamination	Dimensions[1]		Moisture content[2]	Specific gravity[3]	Modulus of rupture (unadjusted)		Modulus of elasticity (unadjusted)	
			Width	Depth			Average	Coefficient of variation	Average	Coefficient of variation
			In.	In.	Pct		Lb/in.²	Pct	Million lb/in.²	Pct
				INITIAL SET OF SOUTHERN PINE						
4	9	302-24	4.99	6.01	9	0.50	6,460	30.8	1.73	9.3
8	10	302-24	4.99	12.03	10	.50	5,380	15.4	1.77	4.4
10	10	302-24	4.99	15.02	11	.50	4,880	18.6	1.70	5.4
4,8,10	29	302-24	4.99	—	10	.50	5,540	25.9	1.73	6.6
4	11	No. 1D	4.99	6.01	10	.49	5,740	22.7	1.68	10.5
8	10	No. 1D	5.01	12.02	10	.51	5,000	18.2	1.66	5.3
10	10	No. 1D	4.99	15.05	11	.50	5,890	12.5	1.62	5.1
4,8,10	31	No. 1D	5.00	—	10	.50	5,550	19.6	1.65	7.5
				SECOND SET OF SOUTHERN PINE						
4	10	302-24	5.01	6.02	10	.49	7,670	20.6	1.64	16.9
8	10	302-24	5.01	12.03	10	.50	7,040	10.7	1.68	7.1
10	10	302-24	5.01	15.02	10	.49	5,510	6.5	1.59	8.6
4,8,10	30	302-24	5.01	—	10	.49	6,740	20.2	1.63	11.5
4	10	No. 1D	5.01	6.03	10	.50	5,300	22.2	1.58	11.2
8	10	No. 1D	5.01	12.04	10	.49	4,840	12.7	1.61	6.8
10	10	No. 1D	5.01	15.02	10	.48	4,630	7.6	1.49	7.3
4,8,10	30	No. 1D	5.01	—	10	.49	4,920	16.6	1.56	9.0
				DOUGLAS FIR—LARCH						
4	10	302-24	5.14	5.82	11	.47	8,160	17.1	2.03	6.2
8	10	302-24	5.12	11.83	11	.47	6,400	18.1	2.04	3.4
10	10	302-24	5.11	14.83	11	.47	5,960	17.1	1.99	3.6
4,8,10	30	302-24	5.12	—	11	.47	6,840	22.1	2.02	4.6
4	10	L1	5.15	5.83	11	.47	6,620	28.8	1.98	8.4
8	10	L1	5.14	11.83	11	.47	5,830	9.7	1.93	6.9
10	10	L1	5.10	14.78	12	.47	5,270	15.9	2.02	4.1
4,8,10	30	L1	5.13	—	11	.47	5,910	22.5	1.97	6.7

[1] Average of measurements made at load points.
[2] Determined following test using resistance-type meter with 1-1/2-in. needles. Recommended species corrections were applied.
[3] Based on weight adjusted to ovendry conditions and volume at time of test.

(maximum difference was 14 pct), as could be expected because of the average to below-average stiffness of the SP lumber used in manufacturing both shipments.

Individual.—Figure 6 compares the individual test MOE values with the transformed MOE values calculated using the E-computer MOE values of all the pieces of lumber in each beam. The unadjusted test MOE values for the 180 beams ranged from 1.04 to 2.26 million lb/in.² while the transformed MOE values ranged from 1.36 to 2.35 million lb/in.². A regression analysis suggested a line of best fit as

$$Y = 0.886X + 0.116 \qquad (3)$$

where

Y is the actual test MOE and

X is the transformed MOE, both in terms of million lb/in.² The coefficient of determination (R^2) was 0.83.

Overall, the test MOE's averaged 94.6 percent of the transformed MOE's, suggesting an equation of the form

$$Y = 0.946X \qquad (4)$$

where factors are as previously described. This compares favorably with previous results *(13, 15)* and supports the use of the 0.95 factor currently used to predict MOE values.

Comparison With Design Values

As shown in table 7, all of the average DF-L test MOE values exceeded their design MOE value in AITC 117-79 *(2)*; the test values ranged from 7 to 13 percent higher than the design value of 1.8 million lb/in.². The initial set of SP beams had average test MOE values that were all within 5 percent of their design MOE value of 1.7 million lb/in.²; however, the second set of SP beams had average test MOE values that were as much as 12 percent lower than that design value.

Finger-Joint Quality

Initial Set of SP Beams

As mentioned earlier, the major cause of failure for most of the initial set of SP beams was a finger joint. In fact, only a few of the 302-24 beams did not fail at a finger joint, while slightly over one-half of the No. 1D beams did not fail at a finger joint. Over one-half of the finger-joint failures resulted in below-target MOR values. As a comparison, only 15 percent of the initial SP beams that did not fail at a finger joint had below-target MOR values.

A general observation from the tests was that the initial SP beams

Table 6.—Summary of beam failure types[1]

Number of laminations	Type of tension lamination	Tension: Tension lamination characteristic: Selected	Tension: Tension lamination characteristic: Other	Tension: Finger joint: Alone	Tension: Finger joint: With other defect	Failure in the lamination above the tension lamination	Compression
		Pct	Pct	Pct	Pct	Pct	Pct
			INITIAL SET OF SOUTHERN PINE				
4	302-24	44	33	33	33	0	0
8	302-24	20	0	60	40	0	0
10	302-24	40	10	60	30	0	0
4	No. 1D	55	27	9	27	0	0
8	No. 1D	60	20	10	30	20	0
10	No. 1D	50	30	10	60	0	0
Average		45	20	30	37	3	0
			SECOND SET OF SOUTHERN PINE				
4	302-24	80	20	0	10	0	0
8	302-24	60	20	0	60	20	10
10	302-24	30	30	10	20	10	0
4	No. 1D	80	40	0	20	0	0
8	No. 1D	60	40	0	30	20	0
10	No. 1D	80	20	0	30	0	0
Average		65	28	2	28	8	2
			DOUGLAS FIR-LARCH				
4	302-24	80	20	0	20	0	20
8	302-24	60	30	0	40	0	10
10	302-24	40	50	0	60	20	10
4	L1	70	20	0	10	0	10
8	L1	80	40	0	20	0	0
10	L1	40	40	10	10	10	10
Average		62	33	2	27	5	10

[1] The numbers in the table represent the percent of beams that failed in the listed manner and may add up to over 100 percent when some of the beams failed for more than one reason.

seemed to consistently fail at a finger joint whenever that joint was subjected to about 75 percent or more of the maximum moment. In fact, only three beams with finger joints subjected to more than 75 percent of the maximum moment did not fail at the joint.

Eleven of the 60 initial SP beams were selected to have pith-associated wood, but 13 beams failed at joints with pith-associated wood. (Several of the end pieces jointed to the selected tension-lamination pieces contained pith-associated wood. The end pieces were not specially selected to be near-minimum quality, so, in general, the end boards were better quality material than the selected tension-lamination pieces.) Only two of the beams selected to have pith-associated wood did not fail for that reason. Pith-associated wood in a finger joint appeared to be the reason nine of the initial SP beams had below-target MOR values, suggesting that pith-associated wood can control the strength of a finger joint and consequently the strength of a beam. Similar results for pith-associated wood were reported in a previous study *(17)*, indicating that the amount of pith-associated wood allowed in joints should be regulated.

However, not all of the finger-joint failures that resulted in below-target MOR values can be explained solely by the presence of pith-associated wood. Close inspection of the failures in the region of pith-associated wood indicated that some of the fingers were also poorly bonded and that bond quality contributed to those failures. Many of the finger-joint failures had small percentages of wood failure. Smooth finger surfaces were common and the phenol-resorcinol adhesive used for face bonding appeared on some of the finger surfaces, indicating there was a gap between those fingers during manufacture. Inspection of the jointed rough lumber revealed nothing unusual about the joints, but spaces between the fingers were easily detected once the lumber was planed. These open fingers were observed consistently in almost all of the initial SP test beams and were a preliminary indication that the finger joints would not perform at the desired strength level.

It was previously mentioned that quality-control tests were performed just prior to finger jointing the test material. It has since been reported that the quality-control strength results were lower than usual during the time the initial SP test beams were manufactured. It was also reported that those quality control bending tests just barely exceeded

Table 7.—Comparison of predicted and design modulus of elasticity (MOE) values with the actual test values

Number of laminations	Type of tension lamination	Actual test MOE[1] Average	Actual test MOE[1] Coefficient of variation	Predicted MOE[2]	Actual MOE ÷ predicted MOE	Design MOE[3]	Actual MOE ÷ design MOE
		Million lb/in.²	Pct	Million lb/in.²		Million lb/in.²	
			INITIAL SET OF SOUTHERN PINE				
4	302-24	1.73	9.3	1.84	0.94	1.7	1.02
8	302-24	1.77	4.4	1.74	1.02	1.7	1.04
10	302-24	1.70	5.4	1.70	1.00	1.7	1.00
4	No. 1D	1.68	10.5	1.84	.91	1.7	0.99
8	No. 1D	1.66	5.3	1.74	.95	1.7	0.98
10	No. 1D	1.62	5.1	1.70	.95	1.7	0.95
			SECOND SET OF SOUTHERN PINE				
4	302-24	1.64	16.9	1.84	.89	1.7	0.96
8	302-24	1.68	7.1	1.74	.97	1.7	0.99
10	302-24	1.59	8.6	1.70	.94	1.7	0.94
4	No. 1D	1.58	11.2	1.84	.86	1.7	0.9[illegible]
8	No. 1D	1.61	6.8	1.74	.93	1.7	0.9[illegible]
10	No. 1D	1.49	7.3	1.70	.88	1.7	0.88
			DOUGLAS FIR-LARCH				
4	302-24	2.03	6.2	1.86	1.09	1.8	1.13
8	302-24	2.04	3.4	1.84	1.11	1.8	1.13
10	302-24	1.99	3.6	1.81	1.10	1.8	1.11
4	L1	1.98	8.4	1.86	1.06	1.8	1.10
8	L1	1.93	6.9	1.84	1.05	1.8	1.07
10	L1	2.02	4.1	1.81	1.12	1.8	1.12

[1] Unadjusted MOE values based on 10 replicates in each group except for the initial set of SP 4-lamination beams with 302-24 and No. 1D grade tension laminations which contained 9 and 11 replicates, respectively.
[2] The listed predicted MOE values are equal to 95 percent of the MOE values calculated using a transformed section analysis with lumber MOE values given in Table 1.
[3] The design MOE values are given in AITC 117-79 *(2)*.

the strength criteria of AITC Test 114 as described in paragraph 5.3.4.2 of the PS 56-73 *(22)*. Therefore, the strength of the initial SP test beam finger joints passed the current quality-control requirements, yet failed to perform at the anticipated strength level when placed in the beams. Similar quality control results during the time the DF-L test beams were manufactured exceeded the AITC strength criteria by about 15 percent. Those two sets of quality control records and the test beam results indicate that the present quality-control bending test techniques must be examined closely and the strength criteria upgraded before adequate end-joint strength and, consequently, beam strength can be assured.

Because the initial set of SP test beams did not provide an accurate measure of the performance of either the No. 1D or 302-24 tension laminations, a second set of SP test beams was manufactured.

Second Set of SP Beams

The frequency of finger-joint failures was much lower for the second set of SP beams. One-third of the 302-24 beams failed at a finger joint along with some other strength-reducing characteristic; four of those 10 failed due to the presence of pith-associated wood in the finger joints. None of the 302-24 beams with finger joint failures had below-target MOR values.

The major cause of failure for eight No. 1D beams was a finger joint; again all of the failures also involved another strength-reducing characteristic. Five of the eight No. 1D beams failed at stresses below the target MOR level. Those five beams, plus two others that failed at a finger joint, had pith-associated wood in more than 1/8 of the cross section. The finger joint strength results from the second set of SP beams reinforce earlier statements that the amount of pith-associated wood needs to be limited in tension laminations.

Based on the frequency of failure and the relative strength of the two SP beam sets, it is obvious that the finger joints in the second set of SP beams were significantly higher in strength than those in the initial set. Because the poor-quality finger joints in the initial set of SP beams had such a large apparent effect on beam performance and did not provide a valid measure of the lumber capabilities, the rest of this "Discussion of Results" will include only the DF-L beam data and the second set of SP beam data.

DF-L Beams

Almost one-half of the 302-24 beam failures involved portions of finger joints, but none of the corresponding MOR values were below the target value.

Two of the six L1 beams that failed at a finger joint had an MOR value below the calculated target level. Two or three fingers on each joint edge showed questionable glue bonds (likely because of a lack of edge pressure during manufacture) but, in general, the DF-L finger joints exhibited good glue bonds. High percentages of wood failure were common in the DF-L finger joints that did fail.

Single Member Tension Tests

Tension tests conducted on a few full-size 2 by 6's manufactured with the beam tension laminations confirm the relatively low strength of the initial SP material compared with the other test material in this study and with previous tension tests of good-quality finger joints. A further discussion of finger-joint strength and frequency is contained in appendix D.

Modulus of Rupture (MOR)

The average MOR value of each beam group is listed in table 5, and the individual unadjusted MOR values for the 180 test beams are presented in appendix A. A limited study, described in appendix C, was conducted to determine if a relationship could be found between the tensile stress in the tension lamination at failure and the predicted tensile strength of the lumber.

The MOR values were calculated from the maximum test load and a simple flexural formula. Near-minimum bending-strength values, calculated with the MOR data by assuming a log-normal distribution with 75 percent confidence at the 5th percentile, are given in table 8. Dividing the near-minimum values by 2.1 results in a test value that can be compared with the AITC 2,400 lb/in.^{2} design stress. These values are also given in table 8.

Figures 7 and 8 illustrate the individual unadjusted MOR values for each second set of SP beam group and each DF-L beam group. The graphs provide a means by which to compare the test MOR values with each beam group's target MOR value (calculated as previously discussed). The number of beams with below-target MOR values may be easily determined by examining the graphs.

Comparison of DF-L and Second Set of SP MOR Test Data

Since almost all test-beam failures originated in the tension lamination, it was the quality of the tension lamination that controlled the beam strength. Past research has shown that the bending strength of SP and DF-L beam combinations are approximately the same. Thus, with similar-quality tension laminations the two groups would be expected to perform similarly. On the average, the second set of SP 302-24 beams and the DF-L 302-24 beams appear equivalent as expected. Table 5 shows that there was less than a 2 percent difference between the average of the unadjusted MOR values for the 30 beams in each of the two species groups.

On the other hand, the No. 1D SP beams performed at a lower strength level than the L1 DF-L beams. The average MOR value of the second set of No. 1D beams is 17 percent less than the average MOR value of the L1 beams as shown in table 5. The near-minimum values, given in table 8, differ by 6 percent. Figures 7 and 8 and table 8 show that 17 No. 1D beams failed below the 24F level, while only 7 L1 beams failed below that level. Several reasons for this apparent difference between the No. 1D SP and L1 DF-L beams will be considered.

First, the quality of selected No. 1D tension laminations appears lower than the quality of selected L1 tension laminations. Table A-1 in appendix A shows that the majority of the selected tension laminations for the second set of SP beams contained knots and grain deviation throughout more than one-half of the cross section. In comparison, about an equal number of the DF-L tension laminations were selected for knots and grain deviation throughout 1/3 to 1/2, about 1/2, or more than 1/2 of the cross section.

A second reason could be the quality of the resource available for the study. As shown in tables 1 and 4, the average MOE's of the material for the second set of SP beams were below the assumed averages, while the average MOE's of the DF-L material were generally above the assumed averages. Given a generally accepted correlation between stiffness and strength, the No. 1D SP test material was probably slightly below average in strength, while the L1 DF-L test material was slightly above average in strength. This general difference in the quality of the stock on hand at the two laminating plants probably accounts for most of the difference between the quality of the selected L1 and No. 1D tension laminations as just discussed.

Another factor that might influence the relative performance of the No. 1D and L1 beams was the number of beams selected to have large amounts of pith-associated wood. Ten of the No. 1D tension laminations for the second set of SP beams were selected to have pith-associated wood throughout as much as 100 percent of the cross section, but only two of the L1 DF-L tension laminations were chosen for that reason. The number of pieces chosen because of large amounts of pith-associated wood is consistent with one of the original criteria for selecting the tension laminations: to choose percentages of pith-associated wood for the test beams consistent with the percentage of available stock containing pith-associated wood. The available No. 1D SP material did have a much greater percentage of pith-associated wood than did the available L1 DF-L material. Pith-associated wood was the cause of seven No. 1D beam failures, and five of those failed below the target MOR level. Only one L1 beam with pith-associated wood fell below that level.

A fourth item could have contributed to a strength difference between the No. 1D and L1 beams: a greater percentage of the No. 1D beams had finger joints positioned in their maximum-moment regions. That positioning probably occurred because the available No. 1D material was shorter than the available L1 material (appendix D).

Although the strength difference between the No. 1D and L1 beams appears significant from the test results, it may be explained by one or a combination of the above reasons. On the other hand, there may exist a real difference between the performance of the two grades. There are too many uncertainties to conclude which assessment is correct from this test data.

Comparison With AITC 24F Design Value

The test values for this comparison, given in table 8, have been

Table 8.—Comparison of test values with the AITC 24F design level

Species	Number of laminations	Type of tension lamination	Sample size	Estimated near-minimum[1]	Test value[2]	Ratio of test value to 24F	Number of beams below 24F level	Ratio of test value to 24F level x 0.85	Number of beams below 24F level x 0.85
				Lb/in.²	Lb/in.²				
DF-L and SP	4	302-24	20	5,500	2,620	1.09	0	1.31	0
DF-L and SP	8	302-24	20	4,940	2,350	0.98	0	1.18	0
DF-L and SP	10	302-24	20	4,440	2,110	.88	2	1.06	0
DF-L	4,8,10	L1	30	3,880	1,850	.77	7	.93	2
SP	4,8,10	No. 1D	30	3,660	1,740	.73	17	.87	6

[1] Calculated by dividing the unadjusted modulus of rupture value for each beam by a size factor. The applied size factor was 1.0, 1.0 and .976 for the 4-, 8-, and 10-lamination beams, respectively. A lognormal distribution with 75 percent confidence at the 5th percentile was assumed.

[2] Each test value is equal to the estimated near-minimum divided by 2.1, a factor applied to get from a near-minimum stress to a design stress.

adjusted with the allowable design size factors as previously discussed. The actual data in relation to the target MOR values are shown in figures 7 and 8. The test data for the various groups were combined as suggested by several analyses of variance (appendix B).

The three 302-24 beam groups shown in table 8 have higher test values than the L1 or No. 1D beam groups. This result was expected because the 302-24 grade tension laminations are higher quality material than the L1 or No. 1D grade tension laminations.

The ratio of the test values to 24F is also given in table 8. The L1 and No. 1D test values are about 25 percent lower than the 24F design value and do not appear to qualify for that design level. However, all three 302-24 beam sizes are believed to justify at least the 24F level. The 302-24 4-lamination test value is 9 percent greater than 24F, the 302-24 8-lamination test value is close to 24F, and the 302-24, 10-lamination test value is 12 percent below the expected 24F level. There are three reasons to believe the design stress for all the test-beam combinations with 302-24 tension laminations should be at least 2,400 lb/in.^{2} :

1. Near-minimum-, not random-, quality tension laminations were selected for the test beams, yet the data were statistically analyzed as if the random population were represented instead of a near-minimum population. The actual magnitude of the effect of using near-minimum versus random sampling cannot be quantified at this time.

2. The selected strength-reducing characteristics were purposely positioned in the most highly stressed region of the test beams. In addition, the majority of test beams had finger joints subjected to 75 percent or more of the maximum moment. These conditions, along with selection of near-minimum-quality tension laminations, are likely to result in a conservative estimate for the random population design stress.

3. Figures 7 and 8 and table 8 show that only two out of 60 302-24 test beams (3 pct) failed below the target MOR level. This is a lower frequency than allowed by the criteria currently used in determining an appropriate design level; that is, one out of 20 beams (5 pct) is allowed to fail below the design stress times 2.1.

Beam Depth at Which Specially Graded Tension Laminations Are Required

Separate examination of the test beams with L1 or No. 1D tension laminations did not reveal a significant difference between the average MOR's of beams with various numbers of laminations. In addition, these beams did not appear to justify a 24F level, indicating that in order to obtain a 24F beam some quality of specially graded tension lamination is required for all depths of the test-beam combinations.

Examination of the 302-24 test values in table 8 suggests that the 10-lamination beams, and probably the 8-lamination beams also, require a 302-24 tension lamination in order to attain a 24F design level. However, because the 4-lamination 302-24 beams have a test value greater than the 24F level and the 4-lamination L1 or No. 1D beams have test values less than that level, a tension-lamination quality somewhere between the 302-24 and L1/No. 1D grades may be adequate to obtain a 2,400 lb/in.^{2} design stress for 4-lamination beams.

Comparison Between 302-24 and L1/No. 1D Beams

The discussions of the analyses of variance in appendix B and in the section preceding this one, suggest that the 4-lamination data should be considered separately from the 8- and 10-lamination data. Therefore, for this comparison, the 8- and 10-lamination L1/No. 1D beams will be compared with the 8- and 10-lamination 302-24 beams. Although it has been pointed out that the L1 and No. 1D test samples are different, combining the two groups should provide a conservative, yet reasonable result. Judgment was required in combining the 8- and 10-lamination 302-24 SP beams because the analysis of variance revealed a significant difference between their average MOR values.

Both average and near-minimum values for the two groups of 40 beams are presented in table 9; the values were adjusted to standard conditions. The L1/No. 1D MOR values averaged 83 percent of the 302-24 MOR values, with a 95 percent confidence interval between 77 and 89 percent.[9] The L1/No. 1D near-minimum value is 85 percent of the 302-24 near-minimum value. The 83 and 85 percent values are close, indicating that the L1/No. 1D beams are approximately 15 percent lower in strength than the 302-24 beams. That 15 percent difference implies that if a beam designed as a 24F beam is capable of a 2,400 lb/in.² design stress with a 302-24 tension lamination, it should be capable of about a 2,000 lb/in.² design stress with an L1 or No. 1D tension lamination. These results agree with the results of a previous study *(12)*— that is, shallow beams without specially graded tension laminations fall short of their expected design stress by about 15 percent. Fox *(8)* found the strength of slightly deeper beams (18 inches deep) without specially graded tension laminations to be about 25 percent less than the design stress predicted by the same methods used for this study.

The L1 and No. 1D test values of 1,850 and 1,750 lb/in.², respectively, are still less than 0.85 x 24F (approximately 20F), but probably meet the 20F level for the same reasons given previously in the section comparing test values with the AITC 24F design level. Also, 40 percent of the L1 or No.1D test beams failed below the target MOR value, while 13 percent failed below 0.85 times that level. As shown in figures 7 and 8, most of those failures were extremely close to the target MOR value times 0.85. Considering this and the approximate 15 percent difference between the 302-24 and L1/No. 1D beams, it appears that 2,000 lb/in.² is a more realistic design stress than 2,400 lb/in.² for these test-beam combinations without specially graded tension laminations.

Table 9.—Comparison of 302-24 and L1/No. 1D modulus of rupture values

	Modulus of rupture[1]		
	L1/No. 1D	302-24	Ratio of L1/No. 1D to 302-24
	Lb/in.²	Lb/in.²	
Average[2]	5,080	6,080	[4]0.83 ± .06
Near-minimum[3]	3,780	4,490	0.85
Near-minimum divided by 2.1	1,810	2,140	.85

[1] Adjusted to standard conditions.
[2] Average of 40 tested beams (8- and 10-lamination beams with L1/No. 1D or 302-24 tension laminations).
[3] Calculated with the 40 8- and 10-lamination beams with L1/No. 1D or 302-24 tension laminations, assuming a lognormal distribution with 75 percent confidence at the 5th percentile [illegible].
[4] The 95 percent confidence interval was calculated according to Appendix [illegible] (24).

Conclusions

Modulus of Elasticity (MOE)

The average MOE values of 10 of the 12 SP beam groups were less than the MOE value predicted by assuming the average MOE value for each lumber grade in the beam combinations. However, all of the average MOE values of the DF-L beam groups exceeded their predicted values.

The 0.95 factor currently used to predict MOE beam values *(5, 15)*, was supported by a regression analysis of the 180 individual test-beam MOE values and the corresponding transformed MOE values calculated with the known MOE value of each piece of lumber in a beam.

The average MOE values for all the DF-L test groups exceeded their design value of 1.8 million lb/in.² in AITC 117-79. The initial set of SP test groups were all within 5 percent of their design value of 1.7 million lb/in.² in 117-79, but the second set of SP test groups had average MOE values as much as 12 percent lower than that design value.

Modulus of Rupture (MOR)

The initial set of SP MOR data could not be used to answer the original objectives of this study because of a high frequency of finger-joint failures at low MOR values. However, those data do indicate that daily finger-joint quality-control bending strength requirements now given in the Voluntary Product Standard PS 56-73 must be increased to obtain desired beam strength levels.

The DF-L test results and the second set of SP test results were used in the following manner.

(1) To examine the validity of the 2,400 lb/in.² AITC design stress. All of the test-beam combinations with 302-24 grade tension laminations appear to be capable of at least a 2,400 lb/in.² design stress, but those with L1 or No. 1D grade tension laminations fall short of that design stress.

(2) To determine the depth at which specially graded tension laminations are required. Specially graded tension laminations are required on these beam combinations at all depths to obtain a 2,400 lb/in.² design stress. Although a 302-24 grade tension lamination resulted in that stress level for the 8- and 10-lamination beams, it appeared that a tension lamination quality somewhere between the 302-24 and the L1/No. 1D grades may be adequate for the same stress level in 4-lamination beams.

(3) To examine the relative strength of the beam combinations with regular (L1/No. 1D) or special (302-24) grade tension laminations. The test beams with L1/No. 1D grade tension laminations were about 15 percent lower in strength than the beams with 302-24 grade tension laminations. This result suggests that a 2,000 lb/in.² design stress may be appropriate for shallow beams with the regular laminating grades of L1 DF-L or No. 1D SP as tension laminations.

[9] The 95 percent confidence interval was calculated according to the procedure given in appendix II of *(24)*.

Literature Cited

1. American Institute of Timber Construction.
   1976. Standard specifications for structural glued-laminated timber of Douglas-fir, western larch, southern pine, and California redwood. AITC 117-76, July 20, 1976. Englewood, Colo.

2. American Institute of Timber Construction.
   1979. Standard specifications for structural glued-laminated timber of softwood species. AITC 117-79, June 27, 1979. Englewood, Colo.

3. American Society for Testing and Materials.
   1978. Establishing structural grades and related allowable properties for visually graded lumber. ASTM Stand. D245-74. Philadelphia, Pa.

4. American Society for Testing and Materials.
   1978. Evaluating allowable properties for grades of structural lumber. ASTM Stand. D2915-74. Philadelphia, Pa.

5. American Society for Testing and Materials.
   1979. Methods for establishing stresses for structural glued-laminated timber (glulam) manufactured from visually graded lumber. ASTM Stand. D3737-78. Philadelphia, Pa.

6. American Society for Testing and Materials.
   1978. Static tests of timbers in structural sizes. ASTM Stand. D198-76. Philadelphia, Pa.

7. Bohannan, B.
   1968. Structural engineering research in wood. ASCE J. Struct. Div. 94 (ST2):403-416. Feb.

8. Fox, Selwyn P.
   1978. Bending strength of a proposed Douglas-fir 20f glulam stress grade. West. For. Prod. Lab. Inf. Rep. VP-X-175. Vancouver, Can.

9. Freas, A. D., and M. L. Selbo.
   1954. Fabrication and design of glued-laminated wood structural members. USDA Tech. Bull. No. 1069. For. Prod. Lab., Madison, Wis.

10. Gerhards, C. C.
    1972. Relationship of tensile strength of southern pine dimension lumber to inherent characteristics. USDA For. Serv. Res. Pap. FPL 174. For. Prod. Lab., Madison, Wis.

11. Guttman, I.
    1970. Statistical tolerance regions: Classical and Bayesian. Hafner Publ. Co.

12. Marx, C. M., and R. C. Moody.
    1981. Bending strength of shallow glued-laminated beams of a uniform grade. USDA For. Serv. Res. Pap. FPL 380. For. Prod. Lab., Madison, Wis.

13. Moody, R. C.
    1974. Design criteria for large structural glued-laminated timber beams using mixed species for visually graded lumber. USDA For. Serv. Res. Pap. FPL 236. For. Prod. Lab., Madison, Wis.

14. Moody, R. C.
    1974. Flexural strength of glued-laminated timber beams containing coarse-grain southern pine lumber. USDA For. Serv. Res. Pap. FPL 222. For. Prod. Lab., Madison, Wis.

15. Moody, R. C.
    1977. Improved utilization of lumber in glued-laminated beams. USDA For. Serv. Res. Pap. FPL 292. For. Prod. Lab., Madison, Wis.

16. Moody, R. C.
    1976. A survey of knots in laminating grades of Douglas-fir and southern pine lumber. USDA For. Serv. unnumbered report. For. Prod. Lab., Madison, Wis.

17. Moody, R. C.
1970. Tensile strength of finger joints in pith-associated and nonpith-associated southern pine 2 x 6's. USDA For. Serv. Res. Pap. FPL 138. For. Prod. Lab., Madison, Wis.

18. Moody, R. C., and B. Bohannan.
1971. Flexural properties of glued-laminated southern pine beams—finger joint and specific gravity effects. USDA For. Serv. Res. Pap. FPL 151. For. Prod. Lab., Madison, Wis.

19. Moody, R. C., and B. Bohannan.
1970. Large glued-laminated beams with AITC 301A-69 grade tension laminations. USDA For. Serv. Res. Pap. FPL 146. For. Prod. Lab., Madison, Wis.

20. Natrella, M. G.
1966. Experimental statistics. Nat. Bur. Stand. Handb. 91, U.S. Dep. Comm., Washington, D.C.

21. Southern Pine Inspection Bureau.
1970. Standard grading rules for southern pine lumber. SPIB, Pensacola, Fla.

22. U.S. Department of Commerce.
1973. Voluntary Product Standard PS 56-73 for structural glued-laminated timber. U.S Dep. Comm., Washington, D.C.

23. West Coast Lumber Inspection Bureau.
1970. Standard grading rules for West Coast lumber. WCLIB, Portland, Oreg.

24. Wolfe, R. W., and R. C. Moody.
1978. Bending strength of water-soaked glued-laminated beams. USDA For. Serv. Res. Pap. FPL 307. For. Prod. Lab., Madison, Wis.

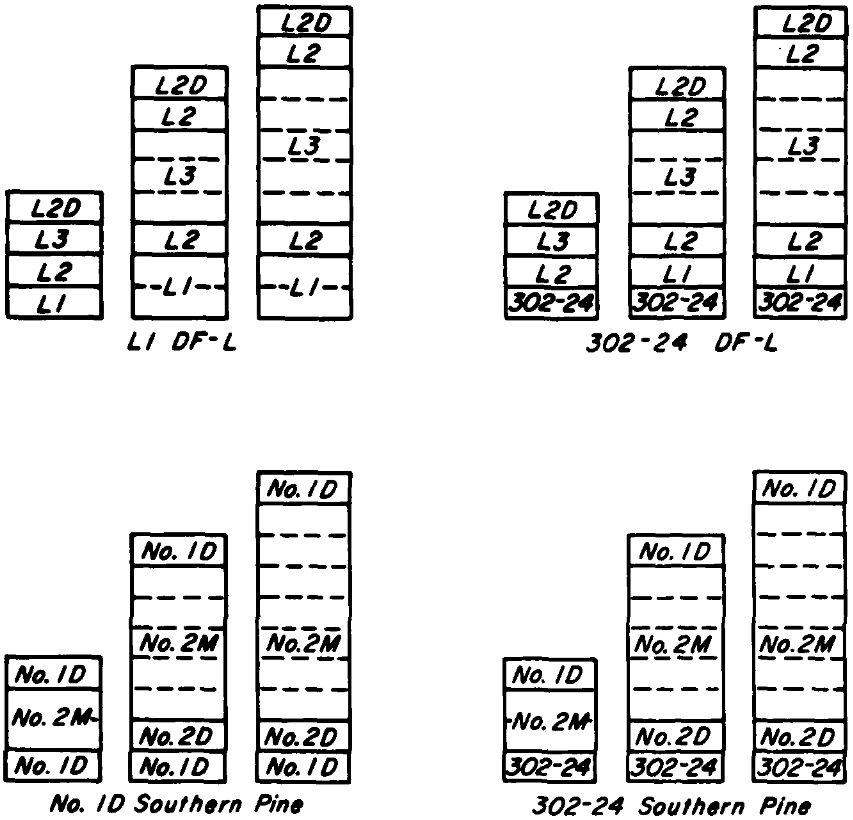

Figure 1.—Test-beam combinations. The DF-L combinations with L1 tension laminations are referred to as L1 DF-L in this report. Similarly, the SP combinations with No. 1D tension laminations are referred to as No. 1D SP. Beam combinations with 302-24 tension laminations are referred to as either 302-24 DF-L or 302-24 SP. (M 148 967)

(M 148 967)

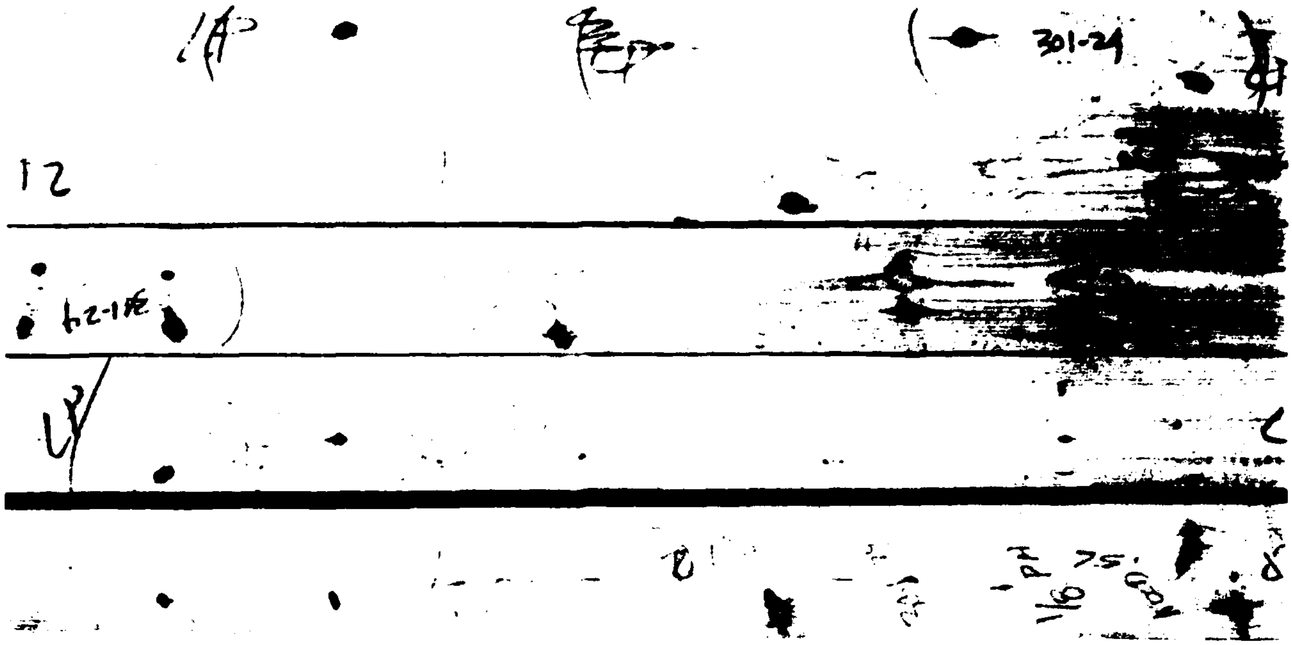

Figure 2.—Some 302-24 SP boards that illustrate the quality of 302-24 tension laminations selected for this study.
(M 147 050-9)

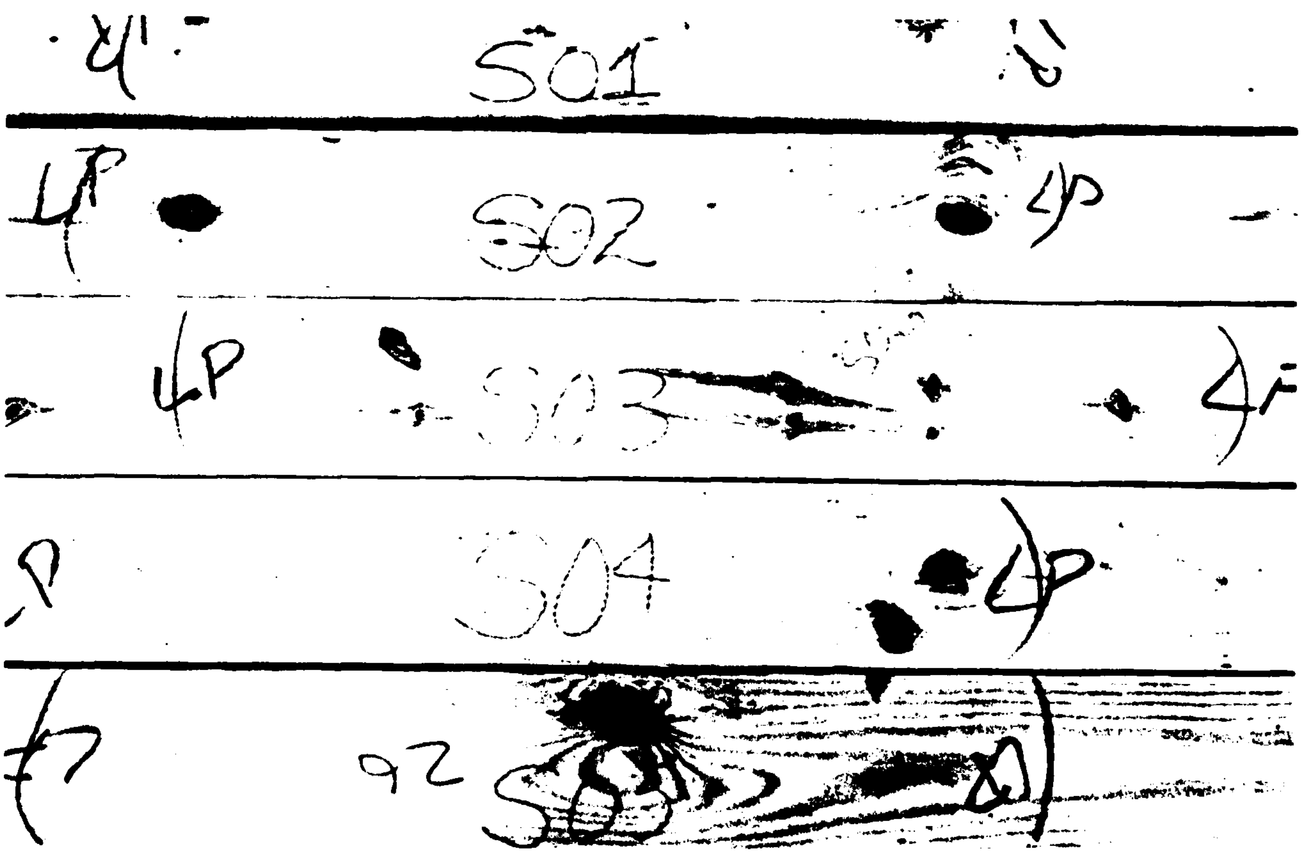

Figure 3.—Some No. 1D SP boards that illustrate the quality of No. 1D tension laminations selected for this study.
(M 147 050-11)

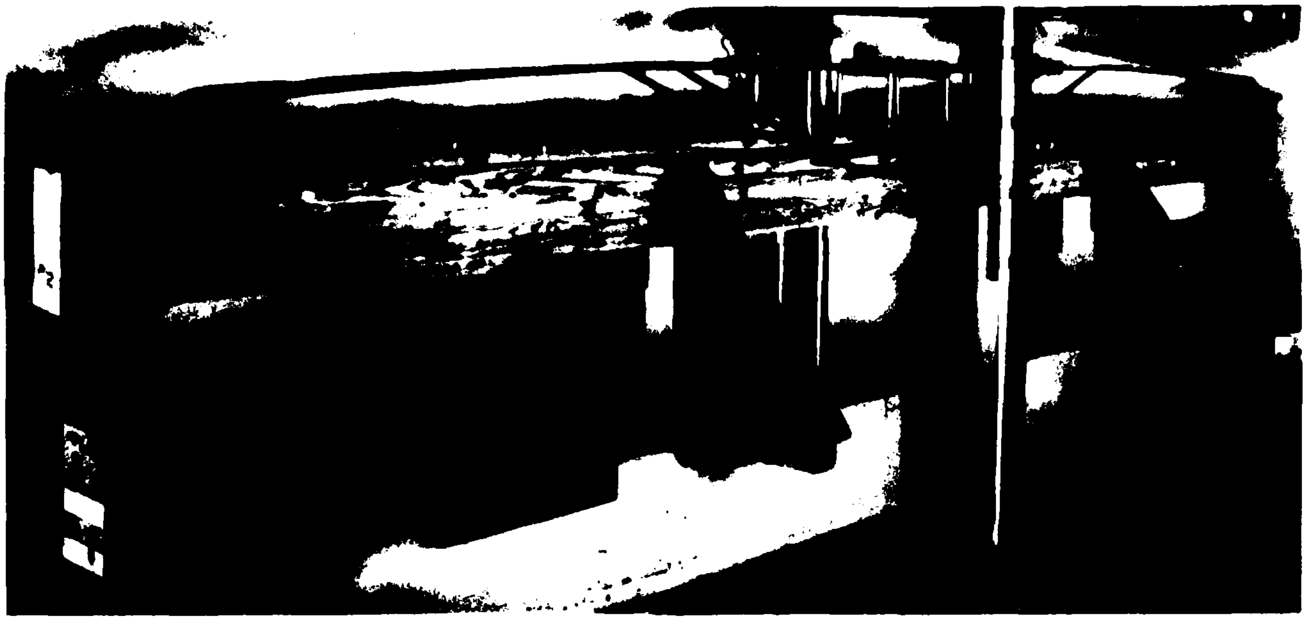

Figure 4.—Floor-level view of the 8-lamination beam test setup. The 4- and 10-lamination beam test setups were similar. (M 147 997)

Figure 5.—Close-up view of the equipment used to obtain the required data: A. deflection yoke; B. linear potentiometer; C. Riehle 160,000-pound testing machine; D. x-y recorder. (M 146 984)

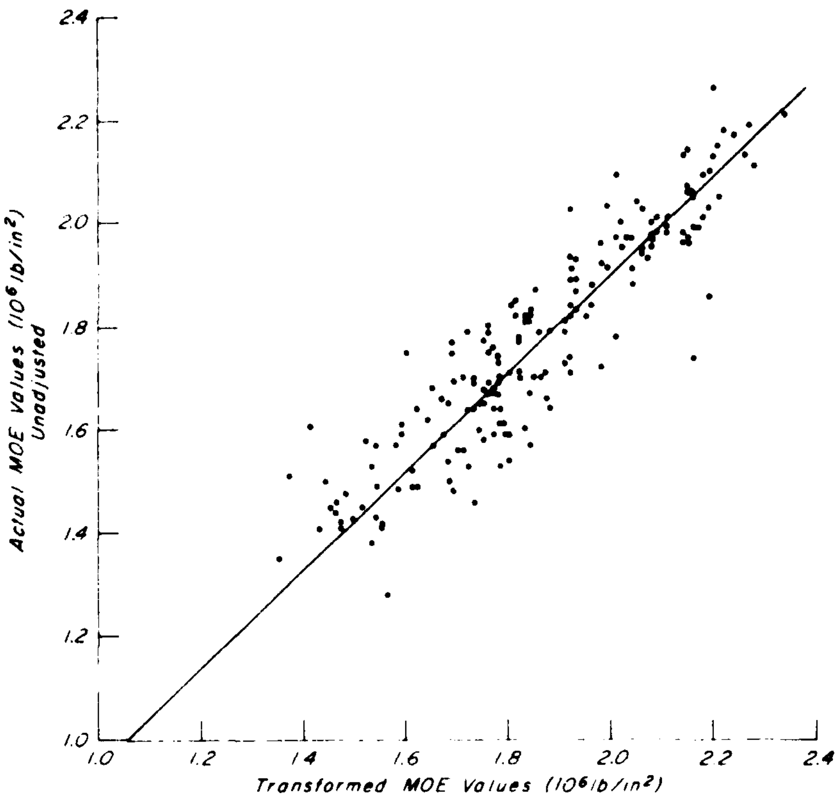

Figure 6.—Comparison of actual and transformed MOE values. Calculations for transformed values were based on actual stiffness of inidivdual pieces of lumber used in the beams.

(M 148 950)

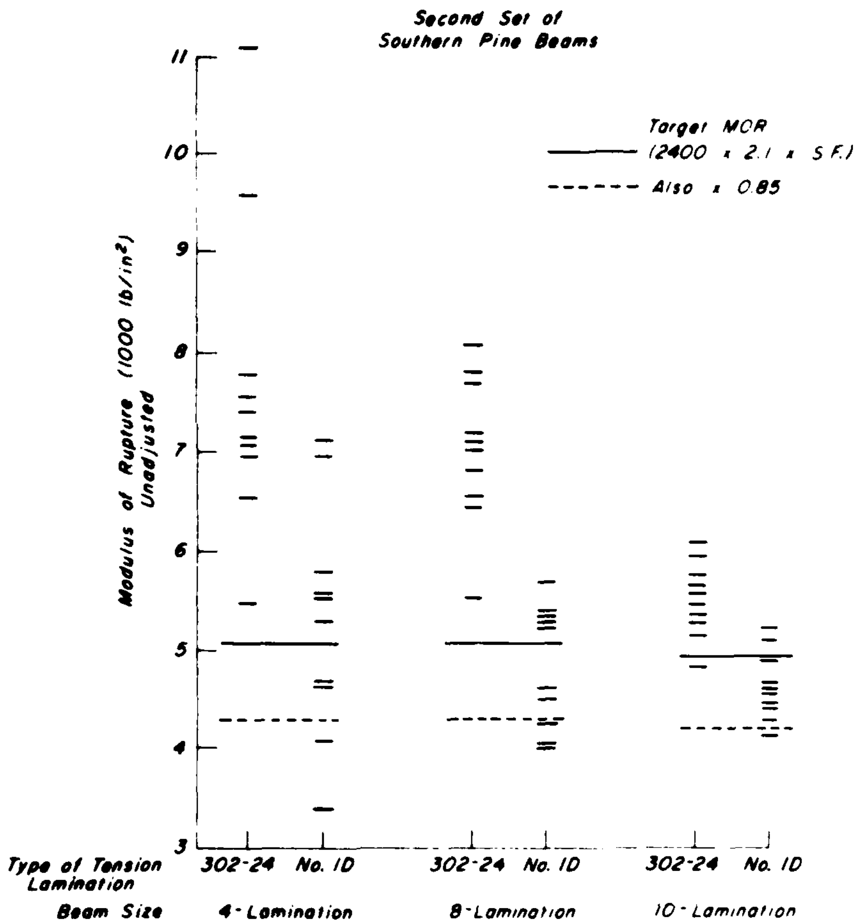

Figure 7.—Comparison of the second set of SP test MOR values with the appropriate target MOR value.

(M 148 952)

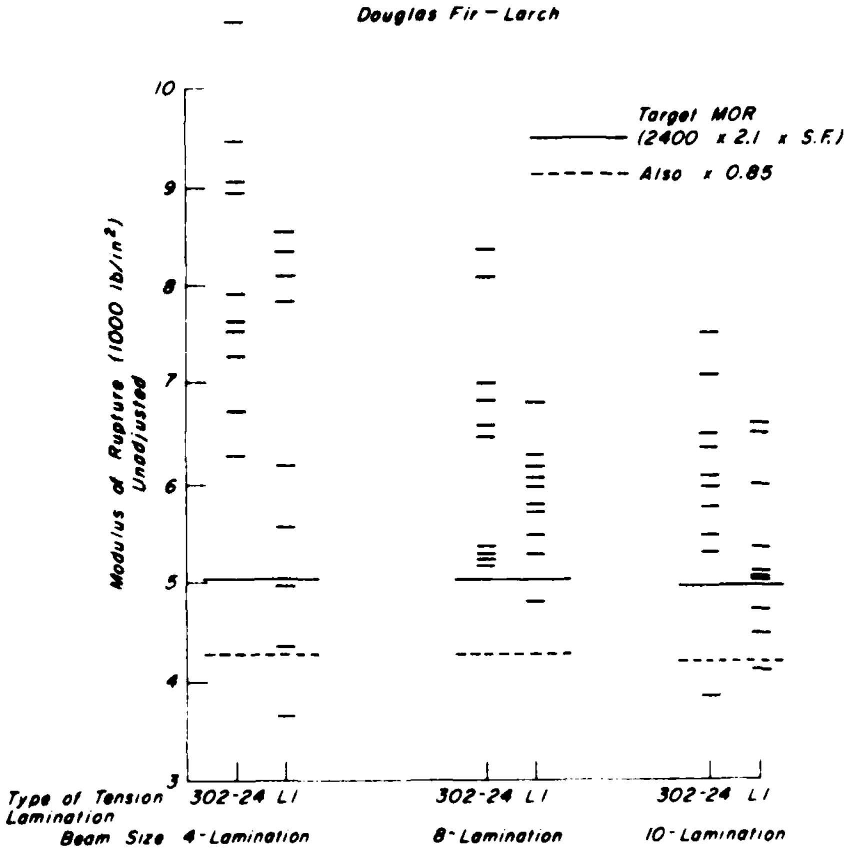

Figure 8.—Comparison of the DF-L test MOR values with the appropriate target MOR value.

(M 148 951)

Appendix A: Midlength Tension Laminations and Beam Test Results

Table A-1 summarizes the average properties of selected midlength tension laminations. Properties of the individual tension laminations are presented in table A-2. Test results for the 180 beams are given in table A-3.

Beam Identification

Beams were identified by a letter followed by a number. The lettering system was as follows:

Group	Letter Code
Southern Pine (SP)	
No. 1D tension lamination	S
302-24 tension lamination	P
Douglas fir-larch (DF-L)	
L1 tension lamination	D
302-24 tension lamination	F

The numbering system was as follows:

Group	Number Code
DF-L or initial set of SP	1 through 30
Second set of SP	31 through 60
4-laminations	1 to 10, 31 to 40
8-laminations	11 to 20, 41 to 50
10-laminations	31 to 30, 51 to 60

Example. P14 was one of the 10 initial 302-24 SP beams with 8-laminations.

Discussion of Some Specific Beam Failures

This discussion includes all of the beams that had an MOR value below the target MOR value calculated assuming a 24F beam. Several other beam failures are also discussed. Unless otherwise specified, each beam mentioned had an MOR value below the target MOR value.

Initial Set of 302-24 SP Beams

Figure A-1 shows all of the below-target MOR beam failures with the exception of P18. Beam P30 was the only beam in that below target MOR group that did not fail at a finger joint. It failed at one of the selected knots (center-line knot and grain deviation occupying 17 pct of the cross section) and at what was likely an undetected timber break at the same cross section. Close inspection of the failure revealed some compression wrinkles in the tension lamination within a few inches of the abrupt break.

Beams P02, P03, P09, P12, P16, P18, P19, P22, P27, P28, and P29 all failed at a finger joint. Beam P29 failed at a finger joint in combination with the selected knot (centerline knot and grain deviation occupying 21 pct of the cross section). Pith-associated wood was present in the failed finger joints of P02, P09, P12, and P28. The other listed beams failed solely at a finger joint.

Beam P24 also failed at a finger joint, but its MOR value was above the target MOR value. Compression wood was discovered in the end piece of the tension lamination upon examination of the failure with a light box, but it was judged that it did not have a severe amount of compression wood. About 20 percent of the cross section appeared to have a moderate amount of compression wood, while another 20 percent appeared to have a small amount of compression wood.

Initial Set of No. 1D SP Beams

With the exception of S20, the failure of each beam with a below-target MOR value is shown in figure A-2. A finger joint was judged to be the main cause of failure for nine beams: S08, S10, S15, S21, S23, S26, S27, S30, and P04. The failed finger joints of S15, S23, S27, and P04 contained pith-associated wood. A small knot was also involved in the failure of S27. The failure of S10 involved one of the selected knots (edge knot and grain deviation occupying 1/3 of the cross section) and a large edge knot in the lamination directly above the tension lamination. An unusual, abrupt wood failure was observed close to the failed finger joint of S21. Beams S08 and S30 failed only at a finger joint.

The selected tension-lamination knots were determined to be the cause of failure for S02 and S20. Beam S02 failed at an edge knot and grain deviation occupying 87 percent of the cross section; S20 failed at a centerline knot and grain deviation occupying 80 percent of the cross section.

Second Set of 302-24 SP Beams

Only one of these 30 beams, P52, failed below the target MOR value. The tension lamination of P52 was selected because it contained pith-associated wood in about 1/8 of its cross section; however, it failed at a combination of an edge knot and a centerline knot occupying 13 and 7 percent of the cross section, respectively. The edge knot was in the pith-associated wood. The failure portion of P52 is shown in the top of figure A-3.

The appearance of the second set of SP finger-joint failures in figure A-4 can be compared with the initial set of SP finger-joint failures in figures A-1 and A-2.

Second Set of No. 1D SP Beams

Over 50 percent of these beams (17 of 30) failed below their target MOR value. Figure A-5 shows the failure portions of the six beams that failed below 0.85 times the target MOR value. The other 11 beams failed between that value and the target MOR value; their failures are illustrated in figure A-6.

Beams S34, S43, S46, S57, and S58 failed at finger joints that contained pith-associated wood. The selected knot(s) was the major cause of failure for S32, S33, S42, S47, S51, S53, S54, S55, and S56.

Beam S38 failed at a centerline knot in the tension lamination with a large amount of grain deviation. A combination of a small centerline knot in the tension lamination and a poor glue bond due to a large centerline knot in the next lamination caused the failure of S44. Beam S59 failed at an edge and centerline knot combination with some erratic grain deviation.

302-24 DF-L Beams

Beam F23 was the only beam in this group of 30 beams that failed below the target MOR value. The

Table A-1.—Summary of average properties of midlength tension laminations[1]

Number of laminations in beams	Type of tension lamination	Specific gravity[2]	Moisture content[3]	Modulus of elasticity[4]	Knot plus grain-deviation[5]: 1/3	Knot plus grain-deviation[5]: 1/3 to 1/2	Knot plus grain-deviation[5]: 1/2	Knot plus grain-deviation[5]: >1/2[6]	Pith-associated wood[5]: 1/8	Pith-associated wood[5]: >1/8[6]	Slope of grain[5]: 1:16 or 1:14	Slope of grain[5]: 1:12	Light weight[7]
			Pct	Million lb/in.²									
INITIAL SET OF SOUTHERN PINE													
4	302-24	0.52	12	2.01	70	0	0	0	20	0	10	0	0
8	302-24	.51	11	1.92	80	0	0	0	20	0	0	0	0
10	302-24	.53	10	2.04	70	0	0	0	20	0	10	0	0
4	No. 1D	.50	12	1.78	0	30	30	30	0	0	0	20	0
8	No. 1D	.51	13	1.92	0	40	10	20	0	30	0	10	0
10	No. 1D	.51	12	1.75	0	10	30	30	0	30	0	0	0
SECOND SET OF SOUTHERN PINE													
4	302-24	.55	10	2.07	90	0	0	0	10	0	0	0	0
8	302-24	.53	11	1.91	60	0	0	0	30	0	0	0	10
10	302-24	.53	11	1.85	80	0	0	0	20	0	0	0	0
4	No. 1D	.52	9	1.69	0	0	10	60	0	30	0	10	0
8	No. 1D	.53	8	1.83	0	0	10	60	0	30	0	0	0
10	No. 1D	.51	9	1.67	0	10	10	40	0	40	0	0	0
DOUGLAS FIR-LARCH													
4	302-24	.49	13	2.45	90	0	0	0	10	0	0	0	0
8	302-24	.50	13	2.49	90	0	0	0	10	0	0	0	0
10	302-24	.50	12	2.55	90	0	0	0	10	0	0	0	0
4	L1	.47	12	2.17	0	20	40	30	0	0	0	0	20
8	L1	.48	12	2.29	0	20	40	20	0	10	10	0	10
10	L1	.50	13	2.32	0	0	50	30	0	10	0	0	10

[1] Averages are for the 10 pieces of lumber used.
[2] Based on weight determined with E-computer, and adjusted to ovendry weight and volume at 12 percent moisture content.
[3] Determined with power-loss type moisture meter.
[4] Modulus of elasticity (MOE) determined with E-computer.
[5] Percent of beams with the listed characteristic chosen to be placed within the maximum moment section. Some of the tension laminations contained more than one characteristic. In addition to the listed characteristics, 30 to 50 percent of the beams were selected to have finger joints in the maximum moment section.
[6] Portion of the cross section occupied by the listed characteristic.
[7] One 302-24 SP beam had a tension lamination with the minimum allowable specific gravity.

Table A-2. Data for midlength tension laminations

Beam No	Length	Specific gravity	Moisture content	MOE	Location[1]	Knot type	Knot size	Grain deviation	Other near maximum allowable characteristics[2]
							Critical Characteristic		
	Lumber data								
	Ft		Pct	Million lb/in	Ft		Pct	Pct	
INITIAL SET OF SOUTHERN PINE BEAMS WITH 302 24 GRADE TENSION LAMINATIONS									
[illegible]									
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]

failure occurred at the selected centerline knot and grain deviation occupying 1/3 of the cross section and then propagated to some slight damage caused by a nail driven into the tension lamination by the trucking company delivering the beams. The nail hole was located 7 inches from the failure knot. It was believed that the nail hole did not have a significant effect upon the strength of F23. The failure of F23 is shown in figure A-7 along with those failures occurring at a level just above the target level. Figure A-8 shows some of the other 302 24 DF-L beam failures.

L1 DF-L Beams

Seven beams in this group had MOR values below the target MOR value. Two of these failed at a finger joint in combination with another characteristic. Beam D10 failed at a finger joint and a small edge knot while D21 failed at a centerline knot and a finger joint that contained pith associated wood.

The other five beams (D05, D06, D16, D23, and D26) failed at the selected tension lamination knot(s). D05 and D06 failed at knots with large amounts of grain deviation (65-75 pct of the cross section). In addition, it was suspected that a preexisting timber break was involved in the failure of D06, while the density of D05's tension lamination was questionable. Beam D16 failed at both the selected edge knot with grain deviation occupying 1/3 of the cross section and at the 1:14 slope of grain in the [illegible] of the tension lamination. The main cause of failure for D23 was the selected centerline knot and grain deviation occupying 36 percent of the cross section, but a finger joint in the lamination directly above the tension lamination was involved in the failure. Beam D26 failed at the selected centerline knot and grain deviation occupying almost 1/2 of the cross section.

The density of D28's tension lamination was questioned even though this beam had an MOR value above the target level. As with beam D05, careful inspection of both ends of the piece indicated that it did not have one third summerwood.

Figure A-9 shows the failure sections of all the L1 DF-L beams with MOR values below the target MOR

Table A-2.—Data for midlength tension laminations—continued

Beam No.	Lumber data: Length	Specific gravity[1]	Moisture content[2]	MOE[3]	Critical Characteristic: Location[4]	Knot type[5]	Knot size[6]	Grain deviation[7]	Other near-maximum allowable characteristics[8]
	Ft		Pct	Million lb/in.[2]	Ft		Pct	Pct	
INITIAL SET OF SOUTHERN PINE BEAMS WITH NO. 1D GRADE TENSION LAMINATIONS									
4-LAMINATIONS									
S01	14	0.48	13	1.79	4.2	Ed	13	46	
S02	14	.52	12	1.83	4.0	Ed	14	87	
S03	12	.49	12	1.53	4.0-6.0	—	—	—	1:12 S.O.G.
S04	14	.44	15	1.32	4.4-4.5	C	24	48	
S05	14	.51	13	2.01	5.0	Ed	23	50	
S06	14	.53	13	2.05	4.1	C	31	53	
S07	14	.51	13	1.99	6.2-6.4	C	31	52	
S08	14	.49	11	1.59	4.4	Ed	29	51	
S09	14	.47	10	1.69	6.1	C	10	30	1:12 S.O.G.—6.7
S10	14	.51	8	1.98	3.7, 4.4	C, Ed	31	63	
P04[10]	16	(.54)	(11)	(1.93)	-6.4	—	—	—	> 1/8 P.A. wood
8-LAMINATIONS									
S11	14	.54	9	1.82	9.8-	—	—	—	> 1/8 P.A. wood
S12	14	.55	13	2.10	10.2	C	17	43	
S13	14	.49	13	1.49	11.6	C	19	34	
S14	14	.50	13	1.68	8.5	Ed	19	57	
S15	14	.51	14	1.73	11.5	C	7	16	1/8 P.A. wood 8.8-14
S16	14	.50	14	2.06	8.7	Ed	13	100	
S17	14	.51	15	1.93	8.0-11.0	—	—	—	1:12 S.O.G.
S18	14	.51	12	2.09	8.3-9.1	Ed, C	16	62	
S19	14	.53	14	2.30	10.0-10.3	Ed, C	29	62	
S20	14	.46	12	1.95	9.1	C	29	80	
10-LAMINATIONS									
S21	14	.51	13	1.72	15.0	C	20	58	
S22	14	.51	9	1.14	4.2-17.9	—	—	—	> 1/8 P.A. wood
S23	14	.50	12	1.68	11.0-11.8	Ed	21	53	
S24	14	.45	12	1.36	15.2-15.7	C, Ed	37	62	
S25	14	.48	13	2.04	10.7	Ed	21	49	
S26	14	.55	8	1.73	-14.2	—	—	—	> 1/8 P.A. wood
S27	14	.50	12	1.94	-16.4	—	—	—	> 1/8 P.A. wood
S28	14	.56	10	1.87	14.2	Ed	26	41	
S29	14	.53	10	2.12	15.2	C	22	57	
S30	14	.52	15	1.85	15.5-15.9	C	28	51	

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value, as well as other selected failures.

Gradual Beam Failures

Figure A-10 and table A-4 describe 20 beams that failed in a gradual manner; as shown, more DF-L than SP beams failed gradually. Figure A-10 shows a typical plotted curve of a gradual beam failure and helps explain the symbols used in table A-4. That table lists a ratio of the load at the initial drop to the load at failure for each beam. (Failure was defined as the maximum-ultimate-load reached before the load dropped to 50 pct or less of that maximum level.) Those ratios indicate the percent of the ultimate load at the point where the load first dropped off. The ratio of the total deflection to the deflection at the point where the load first dropped off is also shown in table A-4 for each beam. Those ratios indicate the amount of the total deflection that took place after the load first dropped off.

Some criteria and judgment were required to determine which beams belonged in table A-4. One criterion was that only those beams with a value less than 0.95 in column two of table A-4 were listed. Judgment was necessary for those beams that did not fail in the definite manner illustrated in figure A-10. In some cases there were several points that could be considered as the first point at which the load dropped off. In other instances, it was questionable whether the load dropoff was significant. In the latter cases, a beam was listed in the table if the curve after the load dropoff appeared different than the curve before the load dropoff.

Table A-2.—Data for midlength tension laminations—continued

Beam No.	Lumber data: Length	Specific gravity[1]	Moisture content[2]	MOE[3]	Critical Characteristic: Location[4]	Knot type[5]	Knot size[6]	Grain deviation[7]	Other near-maximum allowable characteristics[8]
	Ft		Pct	Million lb/in.[2]	Ft		Pct	Pct	
SECOND SET OF SOUTHERN PINE BEAMS WITH 302-24 GRADE TENSION LAMINATIONS									
4-LAMINATIONS									
P31	12	0.52	9	1.28	4.5-5.2	C, Ed	18	33	
P32	12	.58	9	2.00	4.3-5.1	C	20	33	
P33	12	.50	9	1.94	6.0-6.3	Ed	13	22	
P34	16	.57	11	2.39	5.1-5.6	C	22	33	
P35	14	.55	11	1.79	4.2(5.4)	Ed(C)	12(8)	30(30)	
P36	12	.56	7	1.97	6.5-6.8	C	8	33	
P37	14	.57	10	2.65	5.5	Ed	8	33	
P38	16	.52	12	1.82	—	—	—	—	1/8 P.A. wood
P39	8	.57	12	2.32	4.9	C	7	27	
P40	16	.57	13	2.55	6.2	C	8	33	
8-LAMINATIONS									
P41	16	.53	10	2.26	10.3-11.2	C	17	33	
P42	12	.52	12	1.68	8.9-9.5	C	12	36	
P43	16	.53	13	1.80	10.7	C	18	26	
P44	16	.52	12	2.07	—	—	—	—	1/8 P.A. wood
P45	16	.56	14	2.07	—	—	—	—	1/8 P.A. wood
P46	12	.55	9	1.74	8.9	C	12	37	
P47	8	.53	13	2.06	11.5	C	6	40	
P48	16	.47	10	1.86	—	—	—	—	Minimum weight
P49	12	.53	10	2.04	10.0-10.1	C	13	33	
P50	16	.59	12	1.56	—	—	—	—	1/8 P.A. wood
10-LAMINATIONS									
P51	16	.52	11	1.65	14.5	C	14	33	
P52	14	.48	11	1.67	—	—	—	—	1/8 P.A. wood
P53	16	.54	12	1.85	11.8	C	18	33	
P54	10	.56	11	1.39	12.4	C	9	20	
P55	16	.51	11	2.15	11.1-11.5	C	13	40	
P56	12	.56	10	2.21	—	—	—	—	1/8 P.A. wood
P57	14	.51	11	2.03	11.2	C	8	33	
P58	16	.53	12	1.97	14.0-14.8	Ed, C	10	33	
P59	12	.55	19	1.79	11.5	Ed	12	34	
P60	12	.53	10	1.77	12.4	Ed	10	30	

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Table A-2.—Data for midlength tension laminations—continued

Beam No.	Length	Specific gravity[1]	Moisture content[2]	MOE[3]	Location[4]	Knot type[5]	Knot size[6]	Grain deviation[7]	Other near-maximum allowable characteristics[8]
	Lumber data					Critical Characteristic			
	Ft		Pct	Million lb/in.²	Ft		Pct	Pct	
				SECOND SET OF SOUTHERN PINE BEAMS WITH NO. 1D GRADE TENSION LAMINATIONS					
				4-LAMINATIONS					
S31	12	0.50	8	1.67	—	—	—	—	> 1/8 P.A. wood
S32	12	.49	9	1.85	4.7	Ed	11	100	
S33	12	.57	10	1.83	4.8	Ed	22	85	
S34	12	.52	8	1.68	—	—	—	—	> 1/8 P.A. wood
S35	12	.51	8	1.59	6.5	Ed	18	75	>1/12 S.O.G.
S36	12	.48	9	1.87	5.4	C	17	89	
S37	12	.56	9	1.24	—	—	—	—	> 1/8 P.A. wood
S38	12	.53	8	1.22	6.3	Ed	20	75	
S39	12	.54	7	1.91	6.3(4.7)	Ed(C)	28(37)	80(100)	
S40	12	.53	9	2.05	5.2	Ed	28	56	
				8-LAMINATIONS					
S41	12	.54	8	1.93	10.4	C, Ed	23	64	
S42	12	.52	9	1.58	9.0(10.4)	2-C, Ed	24(13)	62(62)	
S43	12	.53	8	1.53	—	—	—	—	> 1/8 P.A. wood
S44	12	.53	7	1.94	9.6	C	30	71	
S45	12	.54	8	1.46	—	—	—	—	> 1/8 P.A. wood
S46	12	.54	9	2.09	—	—	—	—	> 1/8 P.A. wood
S47	12	.49	7	1.74	9.9	Ed	13	50	
S48	12	.55	7	2.34	11.5	C	27	62	
S49	12	.54	10	2.08	11.2	C	29	60	
S50	12	.50	11	1.64	11.5-12.0	Ed, C	38	71	
				10-LAMINATIONS					
S51	12	.53	11	1.35	13.0-13.5	Ed, C	42	100	
S52	12	.53	10	1.69	13.4-14.0	Ed, C	37	60	
S53	12	.48	8	1.76	12.4	Ed	16	40	
S54	12	.51	10	1.88	14.5	C	21	71	
S55	12	.52	9	1.63	12.0	Ed	28	62	
S56	12	.51	7	1.76	14.1	Ed	28	48	
S57	12	.49	9	1.64	—	—	—	—	> 1/8 P.A. wood
S58	12	.50	7	1.93	—	—	—	—	> 1/8 P.A. wood
S59	12	.50	7	1.57	—	—	—	—	> 1/8 P.A. wood
S60	12	.54	10	1.50	—	—	—	—	> 1/8 P.A. wood

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Table A-2.—Data for midlength tension laminations—continued

Beam No.	Lumber data				Critical Characteristic				Other near-maximum allowable characteristics[8]
	Length	Specific gravity[1]	Moisture content[2]	MOE[3]	Location[4]	Knot type[5]	Knot size[6]	Grain deviation[7]	
	Ft		Pct	Million lb/in.[2]	Ft		Pct	Pct	
DOUGLAS FIR-LARCH BEAMS WITH 302-24 GRADE TENSION LAMINATIONS									
4-LAMINATIONS									
F01	13	0.51	13	2.36	6.7-7.2	Ed, C	12	25-30	
F02	20	.49	11	2.50	-5.5	—	—	—	1/8 P.A. wood
F03	20	.52	14	2.36	5.6	C	9	30	
F04	16	.45	14	2.11	5.1-5.7	Ed, C	•	33	
F05	20	.51	12	2.68	4.8	C	9	33	
F06	20	.48	11	2.19	5.1-5.2	Ed, C	•	30	
F07	20	.48	12	2.46	3.9-4.2	C	20	33	
F08	14	.45	10	2.25	5.3-5.5	Ed, C	20	33	
F09	16	.53	13	2.66	5.3-5.4	C	14	33	
F10	20	.50	12	2.35	5.1	C	20	33	
8-LAMINATIONS									
F11	20	.49	13	2.45	11.6-12.1	C, Ed	19	28	
F12	16	.45	10	1.92	8.3-8.8	C	19	30	
F13	20	.47	12	2.15	10.3	C	20	33	
F14	20	.52	15	2.76	10.3	Ed	16	33	
F15	16	.50	13	2.27	9.8-10.6	Ed	•	33	
F16	18	.49	13	2.39	7.6-8.5	Ed, C	•	33	
F17	14	.49	13	2.70	8.6	Ed	18	33	
F18	13	.53	13	2.77	9.2	C	18	33	
F19	16	.50	12	2.61	10.1-	—	—	—	1/8 P.A. wood
F20	20	.53	12	2.85	9.9-10.3	C	20	33	
10-LAMINATIONS									
F21	20	.51	12	2.54	-13.9	—	—	—	1/8 P.A. wood
F22	16	.52	13	2.84	13.2-13.5	Ed, C	21	29	
F23	20	.50	11	2.60	13.0	C	13	33	
F24	20	.48	13	2.36	13.1	Ed	17	29	
F25	16	.48	13	2.58	11.7	Ed	19	32	
F26	14	.52	12	2.77	13.2-13.6	C	•	33	
F27	20	.48	13	2.39	13.4	Ed	20	33	
F28	20	.50	11	1.94	15.2-15.4	Ed	22	33	
F29	20	.52	12	2.88	12.8-13.4	C	22	33	
F30	20	.49	13	2.60	13.0	C	15	33	

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Table A-2.—Data for midlength tension laminations—continued

Beam No.	Lumber data: Length	Specific gravity[1]	Moisture content[2]	MOE[3]	Critical Characteristic: Location[4]	Knot type[5]	Knot size[6]	Grain deviation[7]	Other near-maximum allowable characteristics[8]
	Ft		Pct	Million lb/in.²	Ft		Pct	Pct	
DOUGLAS FIR-LARCH BEAMS WITH L1 GRADE TENSION LAMINATIONS									
4-LAMINATIONS									
D01	16	0.50	13	2.60	5.5-5.6	C	26	50	
D02	14	.45	13	1.82	5.5	Ed	15	50	
D03	16	.48	12	2.19	5.5	C	17	50	
D04	20	.43	10	1.86	5.6	Ed	15	40	Lightweight 2.3-
D05	16	.48	11	1.90	5.3-6.1	Ed	*	75	
D06	14	.47	12	1.97	5.5	C	26	65-75	
D07	20	.50	13	2.57	5.5	Ed	17	40	
D08	12	.48	12	2.44	5.6-6.0	C	*	50	
D09	12	.49	13	2.45	5.4	C	20	60	
D10	20	.43	10	1.86	-5.4	—	—	—	Lightweight
8-LAMINATIONS									
D11	14	.50	12	2.30	8.1-8.5	C, Ed	17	61	
D12	14	.50	11	2.64	9.6-10.0	Ed, C	20	38	
D13	20	.45	12	2.14	10.2	Ed	17	45	
D14	16	.51	14	2.76	11.1	C	20	43	
D15	20	.50	11	1.94	10.3	Ed	17	42	
D16	20	.48	12	2.39	10.2	Ed	17	34	1:14 S.O.G. 7-12
D17	16	.48	9	2.05	12.3	Ed	21	64	
D18	16	.47	11	2.51	10.0-	—	—	—	> 1/8 P.A. wood
D19	14	.46	12	2.36	8.8	C	22	45	
D20	16	.44	11	1.78	8.4-	—	—	—	Lightweight
10-LAMINATIONS									
D21	16	.49	11	2.39	14.0-	—	—	—	> 1/8 P.A. wood
D22	16	.44	12	1.92	14.3-	—	—	—	Lightweight
D23	14	.53	14	2.22	13.5	C	15	38	
D24	16	.51	13	2.58	12.2	Ed, C	20	60	
D25	20	.52	13	2.62	10.5	C	21	41	
D26	20	.50	13	2.59	13.5	C	*	40-50	
D27	16	.53	14	2.46	11.3	C	22	50	
D28	16	.45	12	1.83	11.0	C	28	60-70	
D29	20	.54	13	2.70	14.3-14.6	C	*	70	
D30	14	.48	13	1.90	13.4-13.9	C	*	60	

[1] Based on ovendry weight and volume at time of test.
[2] Average of three values taken with a surface-type meter.
[3] Modulus of elasticity determined with an E-computer.
[4] Location of defect in beam measured from reference end of beam.
[5] Edge (Ed) or centerline (C) as defined in AITC 117-76 *(1)*.
[6] Whenever no number is listed, the actual measurements of the knot sizes on both faces was not obtained but was judged to be the maximum permitted in the grade (i.e., 20 pct in the 302-24 grade and 25 pct in the L1 grade).
[7] In some instances, the amount of grain deviation was based on preliminary measurements of the characteristics.
[8] P.A. = Pith Associated; S.O.G. = slope of grain.
[9] Beam P04 was inadvertently tested upside down. The data given pertain to the selected tension lamination, not the lamination actually stressed in tension during testing.
[10] The data given pertain to the lamination stressed in tension during testing. The numbers in parentheses were not included in the average values.

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Table A-3.—Results of bending tests

Beam No.	Dimensions[1] Width	Depth	Moisture content[2]	Specific gravity[3]	Modulus of rupture (UNADJ)	Modulus of elasticity (UNADJ)	Finger joints in tension laminations[4]	Failure comments[5] Selected tension lamination knot	Tension lamination finger joint	Other
	In.	In.	Pct		Lb/in.²	Million lb/in.²	Pct			
INITIAL SET OF SOUTHERN PINE BEAMS WITH 302-24 GRADE TENSION LAMINATIONS										
4-LAMINATIONS										
P01	4.99	6.01	11	0.50	7440	1.64	70		Maj. at 7.3	
P02	5.00	6.02	9	.49	4230	1.50	100		Maj. at 5.3	1/8 P.A. wood in joint
P03	5.00	6.02	7	.53	3680	1.91	88		Maj. at 6.7	
P05	4.98	6.01	8	.51	9510	1.93	—	Maj. at 5.5		
P06	5.00	6.01	9	.51	6020	1.85	100		Maj. at 4.9	
P07	4.99	6.01	9	.48	6500	1.78	40			Maj. at knot at 3.9
P08	4.98	6.01	8	.50	6850	1.50	55	Maj. at 6.8, 6.5		S.O.G. 4.5-6.5
P09	4.99	6.01	12	.50	5000	1.72	100		Maj. at 4.5	1/8 P.A. wood in joint
P10	4.98	6.01	8	.50	8950	1.70	60		35 pct at 7.8	1:16 S.O.G. 5-7.8
Av.	4.99	6.01	9	.50	6460	1.73				
C.O.V. (%)			17.6	2.7	30.8	9.3				
8-LAMINATIONS										
P11	4.99	12.03	8	.50	6390	1.82	95		Maj. at 7.6	
P12	4.98	12.01	10	.50	4960	1.63	75		Maj. at 13.9	1/8 P.A. wood in joint
P13	4.96	12.03	10	.50	6070	1.79	90		Maj. at 7.2	
P14	5.01	12.01	8	.51	6470	1.73	100	Maj. at 9.9	Maj. at 10.3	
P15	5.01	12.06	9	.40	5750	1.67	85		Maj. at 6.8	1/8 P.A. wood in joint
P16	5.00	12.03	10	.50	4590	1.84	100		Maj. at 9.7	
P17	4.98	12.03	11	.51	5300	1.78	100		Maj. at 10.3	1/8 P.A. wood in joint
P18	4.98	12.02	10	.51	4410	1.88	100		Maj. at 10.3	
P19	4.99	12.03	10	.51	4150	1.82	100		Maj. at 10.8	
P20	4.99	12.02	8	.50	5710	1.76	90		Maj. at 12.8	
Av.	4.99	12.03	10	.50	5380	1.77				
C.O.V. (%)			10.7	1.5	15.4	4.4				
10-LAMINATIONS										
P21	5.00	15.02	12	.50	5940	1.71	95		Maj. at 15.8	
P22	4.99	15.03	12	.51	4270	1.77	100		Maj. at 10.8	
P23	5.00	15.02	10	.50	5400	1.84	95		Maj. at 15.6	1/8 P.A. wood in joint
P24	5.00	15.01	10	.50	5370	1.69	80[7]		Maj. at 7.7	
P25	5.00	15.04	10	.50	5970	1.68	75		Maj. at 17.4	
P26	5.02	15.02	12	.49	5050	1.65	100		Maj. at 15.4	
P27	4.98	14.98	11	.50	4900	1.64	80		Maj. at 17.3	
P28	4.98	15.03	11	.50	2920	1.56	100		Maj. at 12.7	1/8 P.A. wood in joint
P29	4.95	15.02	12	.50	4650	1.82	100	Maj. at 14.7	Maj. at 15.2	
P30	4.97	15.02	12	.50	4330	1.61	75	Maj. at 11.6		Timber break at 11.6
Av.	4.99	15.02	11	.50	4880	1.70				
C.O.V. (%)			9.1	.7	18.6	5.4				

(Page 1)

Table A-3.—Results of bending tests—continued

Beam No.	Dimensions[1] Width	Depth	Moisture content[2]	Specific gravity[3]	Modulus of rupture (UNADJ)	Modulus of elasticity (UNADJ)	Finger joints in tension laminations[4]	Failure comments[5] Selected tension lamination knot	Tension lamination finger joint	Other
	In.	In.	Pct		Lb/in.[2]	Million lb/in.[2]	Pct			
INITIAL SET OF SOUTHERN PINE BEAMS WITH NO. 1D GRADE TENSION LAMINATIONS										
4-LAMINATIONS										
S01	4.99	6.02	10	0.49	5430	1.60	—	Maj. at 4.2		
S02	4.99	6.00	10	.48	4850	1.58	—	Maj. at 4.0		
S03	4.99	6.03	8	.49	7330	1.70	—			Maj. at knots at 4.2 and 4.6
S04	5.00	6.01	9	.47	6210	1.46	—	Maj. at 4.5		S.O.G. 5.0 to 6.0
S05	4.98	6.00	12	.50	7000	1.96	—	Maj. at 5.0		
S06	4.98	6.02	11	.49	6820	1.82	—	Maj. at 4.1		Maj. at knot at 6.1
S07	4.98	6.02	9	.50	7340	1.64	75	Maj. at 6.2, 6.4		
S08	4.97	6.01	8	.49	3550	1.93	100		Maj. at 6.0	
S09	4.99	6.00	13	.50	5550	1.79	90		Maj. at 6.7	> 1/8 P.A. wood in joint
S10	4.99	6.01	8	.50	4870	1.46	100	Inv. at 4.4	Maj. at 6.2	Edge knot at 6.2 (2nd lam.)
P04[6]	4.99	6.01	8	.48	4190	1.53	95		Maj. at 6.4	> 1/8 P.A. wood in joint
Av.	4.99	6.01	10	.49	5740	1.68				
C.O.V. (%)			18.0	2.1	22.7	10.5				
8-LAMINATIONS										
S11	5.01	12.00	9	.49	5050	1.65	100		Maj. at 9.8	> 1/8 P.A. wood in joint
S12	5.02	12.03	10	.51	6380	1.59	45	Maj. at 10.2		Maj. at knot at 8.4
S13	5.00	12.01	9	.50	5390	1.52	90		Maj. at 12.9	Maj. at 2nd lam. f. j. at 10.9[9]
S14	5.01	12.02	9	.51	5710	1.59	55			Maj. at knots at 11.8
S15	5.01	12.02	9	.53	4510	1.66	100		Maj. at 8.8	> 1/8 P.A. wood in joint
S16	5.02	12.01	10	.49	6870	1.82	70			Maj. at 2nd lam. f. j.[10]
S17	5.00	12.03	10	.51	8120	1.61	75		Maj. at 13.8	
S18	5.02	12.01	11	.52	5550	1.74	65	Maj. at 8.3, 9.1		
S19	5.01	12.02	10	.51	6400	1.74	—	Maj. at 10.0, 10.3		
S20	5.01	12.02	10	.50	4940	1.64	100	Maj. at 9.1		
Av.	5.01	12.02	10	.51	5890	1.66				
C.O.V. (%)			6.5	2.3	18.2	5.3				
10-LAMINATIONS										
S21	4.99	15.06	12	.49	4590	1.67	100		30 pct at 13.2	Abrupt at 13.4-13.7
S22	5.00	15.06	12	.51	5920	1.54	70			Maj. at knot at 13.5
S23	4.99	15.06	12	.49	4170	1.48	80		Maj. at 8.3	> 1/8 P.A. wood in joint
S24	5.00	15.03	12	.50	5710	1.56	85	Maj. at 15.7	35 pct at 16.5	
S25	4.99	15.05	13	.50	5420	1.65	65	Maj. at 10.7		
S26	5.00	15.07	10	.51	4610	1.69	100		Maj. at 14.2	> 1/8 P.A. wood in joint
S27	4.99	15.09	11	.50	4660	1.53	90		Maj. at 16.4	Inv. knot at 10.8[9]
S28	5.00	15.07	10	.50	5030	1.69	95	Inv. at 14.2	40 pct at 15.8	
S29	5.00	15.03	11	.50	5620	1.71	65	Maj. at 15.2		
S30	4.97	15.01	12	.51	4310	1.68	85		Maj. at 8.8	
Av.	4.99	15.05	11	.50	5000	1.62				
C.O.V. (%)			9.3	1.4	12.5	5.1				

Table A-3.—Results of bending tests—continued

Beam No.	Dimensions[1] Width	Depth	Moisture content[2]	Specific gravity[3]	Modulus of rupture (UNADJ)	Modulus of elasticity (UNADJ)	Finger joints in tension laminations[4]	Failure comments[5] Selected tension lamination knot	Tension lamination finger joint	Other
	In.	In.	Pct		Lb/in.[2]	Million lb/in.[2]	Pct			
SECOND SET OF SOUTHERN PINE BEAMS WITH 302-24 TENSION LAMINATIONS										
4-LAMINATIONS										
P31	4.99	6.02	9	0.49	5480	1.04	65	Maj. at 5.2		
P32	5.01	6.01	9	.50	7600	1.54	—			Maj. at knot in P.A. wood at 3.6
P33	5.04	6.03	11	.48	6920	1.69	—	Maj. at 6.0		
P34	5.03	6.02	11	.52	7760	1.83	55	Maj. at 5.1-5.6		
P35	5.00	6.02	9	.48	6540	1.41	75	Maj. at 4.2		
P36	5.00	6.02	8	.50	7120	1.73	—			Maj. at knot at 4.2[11]
P37	5.01	6.04	12	.49	7400	1.97	—	Maj. at 5.5		
P38	5.01	6.04	12	.49	7180	1.48	100		Maj. at 5.4	1/8 P.A. wood in joint
P39	5.03	6.02	11	.47	9610	1.81	—	Maj. at 4.9		
P40	5.01	6.03	11	.51	11060	1.87	—	Maj. at 6.2		
Av.	5.01	6.02	10	.49	7670	1.64				
C.O.V. (%)			11.3	3.3	20.6	16.9				
8-LAMINATIONS										
P41	4.99	12.04	10	.51	6830	1.79	80	Maj. at 10.3-11.2		
P42	4.99	12.03	10	.50	8130	1.75	100			Maj. at 2nd lam. knots at 9.4, 9.5[12]
P43	5.02	12.04	11	.51	6580	1.67	85		Maj. at 13.1	Maj. at knot at 12.3[13]
P44	5.01	12.03	9	.52	7220	1.69	100		Maj. at 10.1	Inv. S.O.G. 10-11[9]
P45	5.01	12.02	9	.49	7170	1.59	100		Maj. at 10.9	1/8 P.A. wood in joint
P46	5.00	12.05	11	.49	7690	1.57	75			Maj. at 11.9
P47	5.01	12.03	8	.51	7780	1.48	35		20 pct at 6.8	Slight S.O.G. 6.8-11.8
P48	5.00	12.03	10	.49	7020	1.85	100		Maj. at 9.9	Min. weight piece
P49	5.02	12.02	9	.50	6410	1.80	100	Maj. at 10.0-10.1		
P50	5.00	12.00	9	.50	5550	1.59	100		Maj. at 10.6	1/8 P.A. wood in joint
Av.	5.01	12.03	10	.50	7040	1.68				
C.O.V. (%)			8.9	1.9	10.7	7.1				
10-LAMINATIONS										
P51	5.01	15.02	9	.48	5130	1.44	80	Maj. at 14.5		
P52	5.00	15.00	9	.48	4870	1.46	80			Maj. at knots at 10.6, 11.1
P53	5.01	15.02	9	.49	5900	1.50	100		Maj. at 12.8	Marginal density
P54	5.01	15.01	10	.48	5750	1.41	85	Inv. at 12.4		Maj. at 2nd lam. knots 12.0-12.2
P55	5.01	15.00	10	.50	5600	1.70	70	Maj. at 11.1-11.5		
P56	5.01	15.01	9	.51	5480	1.75	100			Maj. at G. D. at 10.3
P57	5.02	15.04	10	.48	5300	1.57	100		Maj. at 15.0	Inv. 2nd lam. f. j. at 15.8
P58	5.01	15.04	10	.50	5390	1.57	85		Maj. at 16.5	
P59	5.02	15.06	10	.50	6080	1.68	100			Abrupt at 17.5[14]
P60	5.00	15.05	9	.49	5570	1.79	95	Maj. at 12.4		Inv. slight S.O.G. 10.3-12.8
Av.	5.01	15.02	10	.49	5510	1.59				
C.O.V. (%)			6.8	2.1	6.5	8.6				

(Page 3)

Table A-3.—Results of bending tests—continued

Beam No.	Dimensions[1] Width	Depth	Moisture content[2]	Specific gravity[3]	Modulus of rupture (UNADJ)	Modulus of elasticity (UNADJ)	Finger joints in tension laminations[4]	Failure comments[5] Selected tension lamination knot	Tension lamination finger joint	Other
	In.	In.	Pct		Lb/in.²	Million lb/in.²	Pct			
SECOND SET OF SOUTHERN PINE BEAMS WITH NO. 1D TENSION LAMINATIONS										
4-LAMINATIONS										
S31	4.99	6.02	9	0.52	5270	1.71	100			Maj. at knot at 4.7
S32	5.01	6.02	9	.50	3390	1.59	95	Maj. at 4.7		
S33	5.02	6.03	9	.48	4670	1.67	—	Maj. at 4.8		Maj. at knot at 6.8
S34	5.01	6.02	13	.49	4630	1.28	100		Maj. at 5.8	> 1/8 P.A. wood in joint
S35	5.00	6.03	9	.50	6930	1.74	—	Maj. at 6.5		Inv. S.O.G. 5.0-7.5
S36	5.02	6.01	9	.52	7120	1.79	70	Maj. at 5.4		Inv. S.O.G. 2-5
S37	5.00	6.02	10	.53	5600	1.62	100		Maj. at 5.7	Inv. knot at 6.5[9]
S38	5.02	6.04	12	.49	4050	1.35	55			Maj. at knot at 5.6
S39	5.04	6.06	11	.50	5540	1.66	60	Maj. at 6.3		Inv. knots at 4.7 & 5.5
S40	4.99	6.03	12	.49	5780	1.38	80	Maj. at 5.2		
Av.	5.01	6.03	10	.50	5300	1.58				
C.O.V. (%)			15.0	2.9	22.2	11.2				
8-LAMINATIONS										
S41	5.02	12.04	12	.48	5360	1.61	85		Maj. at 13.3	Inv. 2nd lam. knot at 13.3
S42	5.02	12.05	10	.49	4080	1.49	50	Maj. at 9.0, 10.4		
S43	5.00	12.04	10	.50	4500	1.68	100		Maj. at 10.6	> 1/8 P.A. wood in joint
S44	5.03	12.06	12	.47	4640	1.49	90			Maj. at knot at 10.8[15]
S45	5.02	12.03	11	.48	5360	1.61	100			Maj. at knots at 9.8[16]
S46	5.00	12.05	10	.49	4000	1.49	100		Maj. at 8.5	> 1/8 P.A. wood in joint
S47	5.02	12.03	11	.48	4270	1.64	85	Maj. at 9.9		Maj. at knot at 11.7
S48	5.02	12.03	9	.50	5700	1.77	65	Maj. at 11.5		
S49	5.00	12.04	11	.50	5280	1.77	70	Maj. at 11.2		
S50	5.00	12.03	9	.48	5230	1.53	80			Maj. at 9.4
Av.	5.01	12.04	10	.49	4840	1.61				
C.O.V. (%)			11.5	2.1	12.7	6.8				
10-LAMINATIONS										
S51	5.02	15.02	9	.50	4580	1.45	90	Maj. at 13.0-13.5		
S52	5.00	15.01	9	.48	5080	1.75	75	Maj. at 13.4-14.0		
S53	5.00	15.01	10	.47	4640	1.43	90	Maj. at 12.4		
S54	5.00	15.02	8	.48	4440	1.42	95	Maj. at 14.5		Maj. at knot at 11.6
S55	5.03	15.02	9	.48	4150	1.42	90	Maj. at 12.0		Inv. knot at 13.6
S56	5.02	15.01	10	.47	4550	1.41	100	Maj. at 14.1		Inv. f. j. at 12.6[17]
S57	5.01	15.01	11	.47	4250	1.45	100		Maj. at 11.8	Inv. P.A. wood 15.0-15.5
S58	5.01	15.02	10	.48	4900	1.57	100		Maj. at 11.7	> 1/8 P.A. wood in joint
S59	5.00	15.01	10	.50	4430	1.58	100			Maj. at knots at 15.2, 15.3[18]
S60	5.02	15.02	10	.51	5240	1.43	100		Maj. at 11.0	> 1/8 P.A. wood in joint
Av.	5.01	15.02	10	.48	4630	1.49				
C.O.V. (%)			8.5	3.0	7.6	7.3				

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Table A-3.—Results of bending tests—continued

Beam No.	Dimensions[1] Width	Dimensions[1] Depth	Moisture content[2]	Specific gravity[3]	Modulus of rupture (UNADJ)	Modulus of elasticity (UNADJ)	Finger joints in tension laminations[4]	Failure comments[5] Selected tension lamination knot	Failure comments[5] Tension lamination finger joint	Failure comments[5] Other
	In.	In.	Pct		Lb/in.²	Million lb/in.²	Pct			
DOUGLAS FIR-LARCH BEAMS WITH 302-24 GRADE TENSION LAMINATIONS										
4-LAMINATIONS										
F01	5.19	5.84	10	0.45	7290	1.99	—	Inv. at 6.7,3.9		S.O.G. 2.5-7.0
F02	5.16	5.82	11	.50	7600	1.97	100		Maj. at 5.5	1/8 P.A. wood in joint
F03	5.15	5.82	12	.49	8920	2.03	—	Maj. at 5.6		
F04	5.14	5.81	11	.47	7910	1.99	—	Maj. at 5.7		Compression
F05	5.15	5.81	11	.49	9020	2.09	—	Inv. at 4.8		Slight S.O.G. 2.0-6.6
F06	5.16	5.81	11	.46	7540	2.03	55	Maj. at 5.1, 5.2		
F07	5.13	5.83	11	.49	6730	2.26	—	Maj. at 3.9, 4.2		
F08	5.12	5.81	11	.46	6280	1.88	90	Maj. at 5.3, 5.5	35 pct at 6.7	
F09	5.10	5.83	10	.49	10870	2.21	65	Maj. at 5.3, 5.4		
F10	5.11	5.81	11	.44	9470	1.88	65	Maj. at 5.1		Compression
Av.	5.14	5.82	11	.47	8160	2.03				
C.O.V. (%)			4.6	4.3	17.1	6.2				
8-LAMINATIONS										
F11	5.11	11.85	11	.48	5380	1.97	100			Maj. at knots at 7.6 and 7.8
F12	5.10	11.80	11	.47	5250	2.01	100	Maj. at 8.8	15 pct at 11.7	
F13	5.13	11.82	12	.46	6500	1.98	—			S.O.G. 8.5-15
F14	5.12	11.82	10	.48	8380	2.18	50	Inv. at 10.3		Inv. knot at 7.8; compression
F15	5.10	11.79	11	.47	8090	2.00	55	Inv. at 10.6	50 pct at 4.8	
F16	5.11	11.81	12	.48	6560	2.09	—	Maj. at 7.6		
F17	5.13	11.84	10	.46	5270	2.05	100	Maj. at 8.6	80 pct at 7.8	
F18	5.12	11.81	11	.42	5200	1.99	60			Maj. at knots at 11.3
F19	5.12	11.92	10	.49	6830	2.11	100		Maj. at 10.1	1/8 P.A. wood in joint
F20	5.12	11.82	11	.48	6520	1.98	—	Maj. at 9.9, 10.3		
Av.	5.12	11.83	11	.47	6400	2.04				
C.O.V. (%)			6.4	4.1	18.1	3.4				
10-LAMINATIONS										
F21	5.12	14.77	12	.49	6460	1.94	100		Maj. at 13.9	1/8 P.A. wood in joint
F22	5.13	14.78	11	.47	7500	1.98	85	Maj. at 13.2	50 pct at 8.9	F. j. at 13.2 in 2nd lam.
F23	5.11	14.90	12	.46	3810	1.95	85	Maj. at 13.0		Nail hole at 13.5
F24	5.11	14.82	12	.48	5490	2.03	95		20 pct at 15.8	S.O.G. 15.8 to 19.0
F25	5.10	14.86	11	.48	5270	1.91	100	Inv. at 11.7	Maj. at 13.7	
F26	5.12	14.82	11	.47	6340	1.94	90		Maj. at 9.4	Compression
F27	5.12	14.83	12	.45	6050	1.97	50	Inv. at 13.4		Maj. at knot at 7.1
F28	5.08	14.82	10	.49	5910	2.15	60			Maj. at knot at 12.8
F29	5.12	14.87	11	.47	7070	2.06	80		50 pct at 17.0	Abrupt (40 pct) at 15.7
F30	5.09	14.83	10	.48	5740	1.95	100		90 pct at 10.1	Maj. at 2nd lam. timber break
Av.	5.11	14.83	11	.47	5960	1.99				
C.O.V. (%)			6.8	2.6	17.1	3.6				

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Table A-3.—Results of bending tests—continued

Beam No.	Dimensions[1] Width	Dimensions[1] Depth	Moisture content[2]	Specific gravity[3]	Modulus of rupture (UNADJ)	Modulus of elasticity (UNADJ)	Finger joints in tension laminations[4]	Failure comments[5] Selected tension lamination knot	Failure comments[5] Tension lamination finger joint	Failure comments[5] Other
	In.	In.	Pct		Lb/in.[2]	Million lb/in.[2]	Pct			
DOUGLAS FIR-LARCH BEAMS WITH L1 GRADE TENSION LAMINATIONS										
4 LAMINATIONS										
D01	5 13	5 85	10	0 48	8110	2 00	—	Maj at 5 6, 5 5		
D02	5 15	5 83	11	46	5620	1 70	—	Maj at 5 5		
D03	5 13	5 84	11	45	8350	1 96	50	Maj at 5 5		Compression
D04	5 17	5 82	11	48	6160	2 13	50			Clear wood 3 7-4 3
D05	5 12	5 83	10	46	4330	1 83	90	Maj at 5 6, 5 3		
D06	5 13	5 82	11	48	3650	1 89	—	Maj at 5 5		
D07	5 17	5 84	11	47	8530	2 13	—	Maj at 5 5		
D08	5 16	5 83	10	47	8700	2 19	—	Maj at 5 6-6 0		S O G 3 7-5 8
D09	5 15	5 83	10	46	7830	2 13	—	Maj at 5 4		
D10	5 17	5 34	11	46	4960	1 81	100		60 pct at 5.4	Knot at 6 3
Av	5 15	5 83	11	47	6620	1 98				
C O V			5 7	2 3	28 8	8 4				
8-LAMINATIONS										
D11	5 12	11 81	12	48	5970	1 84	100	Maj at 8 1		Maj at knots at 10 1
D12	5 16	11 83	10	47	6290	1 92	70	Maj at 9 6		Inv knots at 11 8
D13	5 16	11 82	11	45	6190	1 87	—	Maj at 10 2		Inv knots at 12 4 and 6 2
D14	5 16	11 83	11	49	5460	2 06	—	Maj at 11 1		
D15	5 13	11 82	10	46	5770	1 81	—			Maj. at knot at 6 0. S.O.G. 6-10
D16	5 11	11 86	12	47	4790	2 01	—	Maj at 10 2		S.O.G. 10 to 7 feet
D17	5 12	11 84	11	47	5710	1 96	65	Maj at 12.3		
D18	5 12	11 81	11	47	6800	2 17	100		Maj at 10 0	> 1/8 P.A wood in joint
D19	5 15	11 85	11	46	6020	1 97	100	Inv at 8 8	Maj at 10.6	
D20	5 16	11 83	11	46	5260	1 71	100			Maj at edge knot at 10 0
Av	5 14	11 83	11	47	5830	1 93				
C O V			5 0	2 2	9 7	6 9				
10-LAMINATIONS										
D21	5 10	14 76	12	46	4490	2 05	100		60 pct at 14 0	Maj at knot at 12 5
D22	5 10	14 80	12	48	5980	2 03	100		Maj at 14 3	
D23	5 11	14 75	12	48	4710	2 10	80	Maj at 13 5		Inv f j at 10 5 in 2nd lam
D24	5 13	14 78	11	48	5340	2 01	70	Inv at 12 2		Maj at knot at 16 4
D25	5 10	14 77	12	47	6610	2 06	85	Inv at 10 5		Inv at 15 2
D26	5 08	14 82	11	48	4100	2 14	—	Maj at 13 5		
D27	5 09	14 78	12	48	4950	1 92	100	Maj at 11 3		
D28	5 10	14 78	11	46	5070	1 93	—			Maj at knot at 9 2, 11 2, 13 4
D29	5 10	14 78	12	46	4930	2 04	55			Maj at knots at 10 5, 10 7
D30	5 08	14 77	11	46	6480	1 88	95	Inv at 13 4	5 pct at 15 6	Compression
Av	5 10	14 78	12	47	5270	2 02				
C O V			3 5	2 2	15 9	4 1				

[1] *Dimensions are averages of measurements made at the two load points*

[2] Determined immediately following test using a resistance-type meter with 1 1/2-in.-long needles. Data given are averages of readings taken for each lamination at point of failure. Readings were corrected using factors published by the manufacturer

[3] *Based on weight and volume of complete beam at time of test.* Weight was adjusted to ovendry

[4] Percent of the calculated maximum moment at the finger joint

[5] Locations are given in feet with reference to one end of the beam. Maj = major cause, Inv = involved in failure, S O G = slope of grain, G D = grain deviation, f.j. = finger joint; P.A. = pith associated.

[6] Coefficient of variation = (standard deviation ÷ average) x 100

[7] This beam failed at a finger joint subjected to 75 pct of the maximum moment (less than listed). All other finger joint failures occurred at the listed values

[8] Beam P04 was intended to have a 302 24 tension lamination but was inadvertantly tested upside down and placed with the No. 1D tension lamination beams for analysis.

[9] These beams also had > 1/8 P A (pith associated) wood in the failed finger joint

[10] Involved knots at 8.8.

[11] Major at G D at 3.5

[12] Compression failure

[13] Abrupt at 13.9 (100 pct) in 2nd lamination

[14] Failure occurred in the area of some shipping damage *but it was questionable* how much the damage influenced the failure

[15] Poor glue bond above failure knot because of large centerline knot in 2nd lamination

[16] Major at 2nd lamination knot at 10.0

[17] Involved 2nd lamination f j at 14.6

[18] Involved G.D. at 10.3

Table A-4.—Gradual beam failures

Beam No.	P_l/P_u[1]	Δ_u/Δ_l[1]
	INITIAL SET OF SOUTHERN PINE BEAMS	
PO1	0.94	1.21
PO3	.89	1.21
SO8	.91	1.32
	SECOND SET OF SOUTHERN PINE BEAMS	
S32	.94	1.16
S38	.92	1.16
S40	.58	2.13
S48	.70	1.81
S59	.94	1.28
	DOUGLAS FIR-LARCH BEAMS	
F20	.84	1.41
F26	.91	1.20
F28	.81	1.98
DO3	.83	1.51
DO7	.93	1.17
DO8	.85	1.41
D11	.84	1.29
D13	.67	2.00
D17	.90	1.13
D22	.78	1.73
D24	.91	1.16
D29	.89	1.44

[1] P_l = load and Δ_l = deflection at first failure; P_u = ultimate load and Δ_u deflection at the ultimate load.

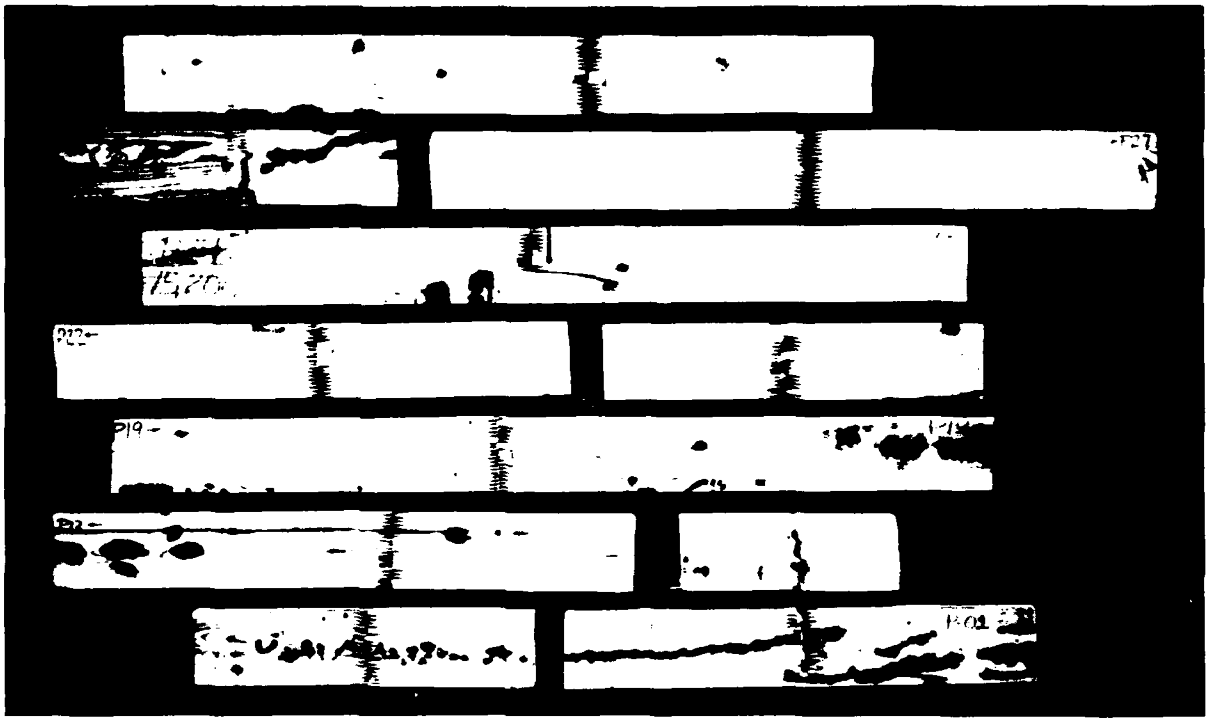

Figure A-1.—Failure sections of the initial set of 302-24 SP beams that failed below the target MOR level. (P18 is missing from the photograph.) Also illustrated is the typical appearance of the initial 302-24 SP finger-joint failures.

Figure A-2.—Failure sections of the initial set of No. 1D SP beams that failed below the target MOR level. (S20 is missing from the photograph.) Also illustrated is the typical appearance of the initial No. 1D finger-joint failures.

Figure A-3. – Selected failures from the second set of 302 24 SP beams. P52 [illegible] was the only beam that failed below the target MOR level.

Figure A-4. – Failure sections of the beams from the second set of 302 24 SP beams that had a finger joint involved in the failure. Also illustrated is the typical appearance of the second set of SP finger joint failures.

Figure A-5.—Failure sections of the beams from the second set of No. 1D SP beams that failed more than 15 percent below the target MOR level. (M 147 310)

Figure A-6.—Failure sections of the beams from the second set of No. 1D SP beams that failed below the target MOR level, but by less than 15 percent. (M 147 313)

Figure A-7.—Most of these 302-24 DF-L beam failures occurred at a level slightly above the target level. Beam F23 failed below the target level. (M 147 128)

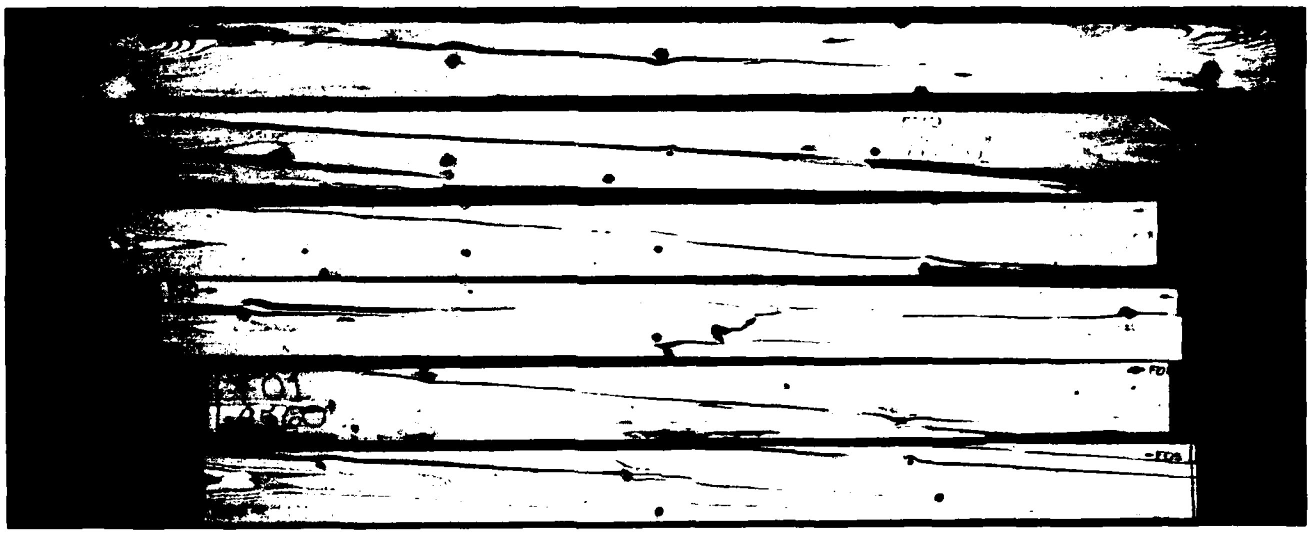

Figure A-8.—These 302-24 DF-L failures illustrate the typical, near-minimum quality of 302-24 tension laminations selected. (M 147 136)

Figure A-9.—All of the below-target L1 DF-L beam failures are shown here along with some selected failures just above the target level. The photograph also illustrates the typical, near-minimum quality of L1 tension laminations selected. (M 147 138)

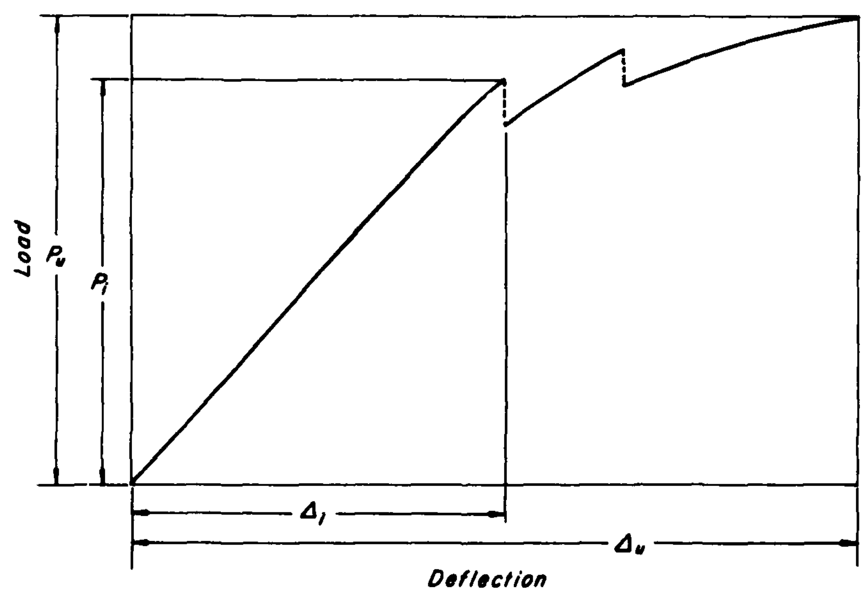

Figure A-10.—A typical example of a load versus deflection curve for a beam that failed gradually. Load (P_i) and deflection (Δ_i) at first failure are shown along with ultimate load (P_u) and deflection (Δ_u). The slope of the initial P-Δ curve is the basis for calculating the modulus of elasticity (MOE). (M 148 953)

Appendix B: Analysis of Variance

The results of the analyses of variance on the test data are presented in table B-1. Sources of variation that had a significant effect on the dependent variable (MOR or MOE) at the 95 percent probability level are shown with a "yes" designation in the table. The MOR data, adjusted to standard conditions, were included in the analysis, as well as the unadjusted MOR data divided by the appropriate design size factor (1.0 for the 4- and 8-lamination beams and 0.976 for the 10-lamination beams). The MOE data, adjusted to a 12 percent moisture content, and the unadjusted MOE data were included. Unless otherwise specified with a footnote, the results for both MOR or both MOE conditions were the same.

The results from the inital set of SP beams and the DF-L beams were analyzed and written up in a preliminary report. The results of the analysis of variance on those 120 beams were the same as those given in the first part of table B-1. The rest of table B-1 has the 4-lamination data separated from the 8- and 10-lamination data as suggested by the first analysis of just the DF-L data.

Modulus of Rupture (MOR)

As mentioned earlier, this study was designed with only 10 replicates in each beam group. It was realized that 10 is a small sample size to work with statistically with much confidence. However, it was expected that some of the beam groups would not be significantly different and their results could be pooled together. A sample size of 60 versus 60 was thought to be possible. The type of tension lamination (302-24 or L1/No. 1D) was expected to have a significant effect on MOR, but neither the species nor the number of laminations was expected to have a significant effect on MOR. No difference was expected between the species (SP or DF-L) or the number of laminations (4,8, or 10) because all of those beam groups were designed at the 24F level. In addition, SP and DF-L beams have been found to have similar bending-strength properties.

DF-L Data Only

As previously mentioned, the DF-L and initial set of SP data were analyzed and some conclusions drawn before the second set of SP beams was manufactured. The DF-L data were examined separately because of the species effect on MOR due to the high frequency of finger-joint failures for the initial set of SP beams. The analysis of variance of just the DF-L data still revealed that both the number of laminations and the type of tension lamination had a significant effect on MOR. As mentioned, the type of tension-lamination effect was expected but the number of laminations was not. The number of laminations did not have a significant effect on MOR when just the 8- and 10-lamination DF-L beams were examined, which suggested that the average of the 4-lamination DF-L beams was significantly different from the average of the 8- and 10-lamination beams. Table 8 shows that the estimated near-minimum for the 4-lamination 302-24 DF-L beams was higher than both the near-minimums for the 8- and 10-lamination 302-24 beams. Because of that difference the DF-L and the second set of SP 4-lamination beams were analyzed separately from the 8- and 10-lamination beams.

DF-L and Second Set of SP Beam Data

The analysis of variance of these 120 beams (first part of table B-1) showed that the species, number of laminations, and type of tension lamination all had a significant effect on MOR. There was also a significant interaction between the species and the type of tension lamination. That interaction indicates that the difference between the 302-24 and L1 DF-L MOR values was not the same as the difference between the 302-24 and No. 1D SP MOR values. A closer examination of the data showed the significant effect of species and the interaction of species and the type of tension lamination on MOR to be due to the 40 L1 and No. 1D 8- and 10-lamination beams.

The number-of-laminations effect appears to be due to a significant difference between the 8- and 10-lamination 302-24 SP beams. The significant effect of the number of laminations, even after current size factors were applied, implies that the effect of size on average MOR is greater than what is now assumed.

In summary, the analyses of variance do not justify combining all six 302-24 beam groups and comparing those with all six L1/No. 1D beam groups as expected when this study was designed. Judgment was required in deciding which beam groups should be combined to determine the depth at which specially graded tension laminations are required and to give the most accurate estimate of the difference between the 302-24 and L1/No. 1D beams.

Modulus of Elasticity (MOE)

The analysis of variance revealed that both the type of tension lamination and the species had a statistically significant effect on MOE. The differences between the MOE values of the beams with various tension lamination grades was less than 5 percent, however.

Examination of the average MOE values of the lumber data (table 4) do show that the DF-L material was significantly stiffer than both groups of SP material. A further comparison of the average MOE values of the species revealed that the initial set of SP beams averaged 85 ± 2 percent[B1] as stiff as the DF-L beams. The second set of SP beams averaged 80 ± 2 percent[B1] as stiff as the DF-L beams and 94 ± 3 percent[B1] as stiff as the initial SP beams.

[B1] The 95 pct confidence interval was calculated according to the procedure given in appendix II of (24).

Table B-1.—Summary of analysis of variance results[1]

Source of variation	Modulus of rupture (MOR)	Modulus of elasticity (MOE)
DOUGLAS FIR-LARCH AND SECOND SET OF SOUTHERN PINE BEAMS (120)[2]		
Species (S)	yes	yes
Number of laminations (N)	yes	no
Type of tension lamination (T)	yes	yes
S x N	no	no
S x T	yes	no
N x T	no	no
S x N x T	no	no
8- AND 10-LAMINATION 302-24 DOUGLAS FIR LARCH AND SECOND SET OF SOUTHERN PINE BEAMS (40)		
S	no	—[4]
N	yes[3]	—
S x N	no[5]	—
8- AND 10-LAMINATION L1 DOUGLAS FIR-LARCH AND SECOND SET OF No. 1D SOUTHERN PINE BEAMS (40)		
S	yes	—
N	no	—
S x N	no	—
4-LAMINATION 302-24 DOUGLAS FIR-LARCH AND SECOND SET OF SOUTHERN PINE BEAMS (20)		
S	no	—
4-LAMINATION L1 DOUGLAS FIR-LARCH AND SECOND SET OF No. 1D SOUTHERN PINE BEAMS (20)		
S	no	—

[1] "Yes" indicates that the source of variation has a significant effect on either MOR or MOE with 95 percent probability.
[2] The numbers in parentheses indicate the total sample size considered.
[3] A further breakdown of the data revealed that the number of laminations had a significant effect on the SP beams only.
[4] Not obtained.
[5] Not significant at 95 percent probability level for the unadjusted MOR values, but was significant at that level for MOR values adjusted to standard conditions.

APPENDIX C: LUMBER TENSILE STRENGTH AND BEAM PERFORMANCE

Most glued-laminated beam failures appear to initiate in the outer tension lamination. Thus, it follows that the tensile strength of this lamination may relate quite closely with beam performance.

A limited study was conducted to try to determine the relationship between the best estimate of the maximum tensile stress in the outer tension lamination of a beam at failure and the predicted tensile strength of this outer ply based on nondestructive parameters.

Beam Tensile Stress

The tensile stresses in the beams were estimated at the extreme outer tensile fiber by assuming a linear stress distribution within the beam at failure and the E-computer MOE values of the individual pieces of lumber. This procedure is given in Research Paper FPL 292 *(15)*.

Different estimates of the tensile stresses were obtained by averaging the value at the extreme outer tensile fiber and the value calculated at the inside edge of the outer tension lamination. However, those average tensile stresses did not appear to correlate as well with predicted tensile strengths as did the extreme outer tensile fiber stresses. Therefore, the extreme outer tensile fiber stresses were considered to be the best estimate of the tensile stresses in a beam at failure. Average tensile stresses in the tension lamination will not be discussed further.

Predicted Tensile Strength

Predicted tensile-strength values were obtained from a regression equation that correlates tensile strength with two nondestructive parameters, MOE and knot size. The equation used was derived from a study by Gerhards *(10)* on the tensile strength of SP lumber. Gerhards' equations for 2 by 4's and 2 by 8's are shown in table C-1. The 2 by 8 equation contains a third nondestructive parameter, specific gravity. If an average specific gravity of 0.50 (approximate for SP and DF-L) is assumed, and the 2 by 4 and 2 by 8 equations are combined and then averaged, the resulting equation is:

$$PTS = 662(TAR) - 430(MOE) + 3042.5(TAR)(MOE) - 454 \quad (1)$$

where

TAR is the tensile-area ratio or the residual area stressed in tension,

MOE is the modulus of elasticity of each tension lamination as determined by the E-computer, and

PTS is the predicted tensile strength.

TAR is explained more fully in Research Paper FPL 174 *(10)*. Because most failures of glued-laminated beams appear to involve edge knots, no centerline knots were considered when calculating TAR values for this analysis.

Regressions Based on Equation (1) and the Data from This Study or a Previous Study *(12)*

Equation (1) was derived as the best available equation to predict the tensile strength of 2 by 6's. Two regression equations were developed, one with some of the data from this study and the other with the data from a previous study (12). The purpose was to to determine how well tensile-strength values predicted by equation (1) correlate with estimates of the tensile stresses in the beams at failure.

All 90 of the test beams from a previous study *(12)* were included in this analysis. The resulting regression equation is:

$$ETS(I) = 0.463(PTS) + 1477.0 \quad (2)$$

where

PTS is the predicted tensile strength using the previous study's MOE and TAR data in equation (1) and

ETS(I) is the estimated tensile stress in the beam.

The coefficient of determination (R^2) of equation (2) was 0.53.

Only 52 of the test beams in this study were included in the analysis. The initial set of SP beams was excluded because of high frequency of finger-joint failures; also excluded were those DF-L beams with tension laminations selected for some characteristic other than the near-maximum allowable sized knot. The second set of SP beams was not included either because that data was not yet available when this analysis was completed. The resulting regression equation is:

$$ETS(II) = 0.745(PTS) + 2779.0 \quad (3)$$

where

PTS is the predicted tensile strength using this study's MOE and TAR data in equation (1) and

ETS(II) is the estimated tensile stress in the beam.

The coefficient of determination (R^2) of equation (3) was 0.21.

The low coefficients of determination (0.53 and 0.21) suggest that equation (1) did not provide a method of predicting tensile-strength values that relate closely to the estimated tensile stresses in the beams. It explained 53 percent of the estimated tensile-stress variation in the previous study's data *(12)*, but only 21 percent of the variation in this study's data.

Development of New Regression Equations

The MOE and TAR values for all 90 beams from the previous study *(12)* and 52 DF-L beams from this study were used to develop equations (4) and (5), respectively:

$$PTS(I) = 641.7 + 3360(MOE)(TAR) \quad (4)$$

with a coefficient of determination (R^2) of 0.55 and

$$PTS(II) = 2368 + 2157(MOE)(TAR) \quad (5)$$

with a coefficient of determination (R^2) of 0.21.

MOE, TAR, and PTS are as previously described.

Table C-1.—Regression equations developed to predict tensile strength values

Data used to develop regression equations	Number of beams	Nominal lumber size	Regression equations developed to predict tensile strength values	Coefficient of determination (R^2)
FPL 174 *(10)*[1]	—	2 x 4	PTS = 35-860(MOE) + 3,886(TAR)(MOE)	—
FPL 174 *(10)*	—	2 x 8	PTS = 7,561-12,846(TAR)-17,008(SPG) + 28,339(TAR)(SPG) + 2,199(TAR)(MOE)	—
(12)	90	2 x 6	PTS(I) = 641.7 + 3,360(MOE)(TAR)	0.55
This study	[2]52	2 x 6	PTS(II) = 2,368 + 2,157(MOE)(TAR)	0.21

[1] See Literature Cited.
[2] Only the DF-L beams having tension laminations selected because of the maximum allowable sized knot were included in this analysis.

Specific-gravity values were also considered but were found to provide little improvement in the resulting regression equations.

Equation (4), developed using the previous study's data *(12)*, accounts for 55 percent of the estimated tensile-stress variation, while equation (5), developed using this study's data, accounts for only 21 percent of the variation.

Summary

Lumber used for the outer tension laminations of glued-laminated beams has been graded to obtain material of high tensile strength, suggesting a strong correlation between lumber tensile strength and beam performance. In this limited study, relatively low correlation coefficients were found between values of the estimated maximum tensile stresses in test beams at failure and the predicted tensile strengths of the outer tension plies. Those low correlations suggest that either improved methods are needed to predict lumber tensile strength or the method used to estimate tensile stresses in test beams is incorrect.

Future work should consider predicting tensile strengths of lumber by improved methods which may be based on a short-span stiffness determination. Also, the method of estimating tensile stresses in the outer tension lamination of glued-laminated beams at failure should be examined more closely.

Appendix D: Finger-Joint Strength and Frequency

Finger-Joint Tension Tests

Some of the finger-jointed test material left after manufacturing the test beams was shipped to Forest Products Laboratory and tested in tension, following the general procedure given in *(17)*. Figure D-1 shows the failure portions of seven 302-24 grade tension test specimens. The results of the SP and DF-L 302-24 grade material are presented in table D-1. This table also gives the results of tension tests from other reports.

The average of the three 302-24 SP pieces from the initial set of beams tested is 3,610 lb/in.². This is much less than the averages of the tension tests in *(14)*, *(17)*, and *(18)*. It is even lower than the minimum tension test values in *(14)* and *(17)*.

The average of three SP tension specimens from the second set of beams, listed in table D-1, is 5,650 lb/in.², much higher than the average for the SP pieces from the initial set of beams. Although these three pieces were No. 1D quality material or better, they did fail at a finger joint and can provide a measure of the relative strengths of the finger joints in the two SP groups.

The average of the four 302-24 DF-L pieces tested is 5,120 lb/in.². This is less than the averages in *(14)* and *(17)*, but greater than the average in *(18)*. The lowest DF-L tension-test value of 3,780 lb/in.² was the result of a knot failure, not a finger-joint failure. The average of the three DF-L pieces that did fail at a portion of the finger joint is 5,560 lb/in.², which is close to the average of the SP pieces from the second set of beams.

Although no definite conclusion can be made from the tension-test data because of the small number of samples, the results of the tension tests agree with the results of the beam tests. That is, the initial set of SP finger joints has relatively low strengths compared to the DF-L and second set of SP finger joints, as well as previous tests of good-quality finger joints.

Finger-Joint Frequency

The number of beams that had finger joints in the tension laminations subjected to 75 percent or more of the maximum moment was examined. The purpose of this scrutiny was to see if the location and frequency of occurrence of joints in the initial set of SP beams were significantly different than in the DF-L or the second set of SP beams, as well as previous Forest Products Laboratory test beams. Table D-2 gives the information necessary to make the comparisons.

Present Study

A higher percentage of the SP beams had finger joints subjected to at least 75 percent of the maximum

Figure D-1 —Failure sections of seven 302-24 grade tension test specimens.

(M 147 127)

Table D-1.—Results of tension tests on finger-jointed 2 by 6 material[1]

Species	Specimen No.	Number of specimens	Specific gravity[2] A	Specific gravity[2] B	Moisture content[2] A	Moisture content[2] B	Modulus of elasticity[3] A	Modulus of elasticity[3] B	Tensile strength Mean (range)	Number of joint failures	Percent of joint that failed
					Pct		Million lb/in.^{2}		Lb/in.^{2}		Pct
					PREVIOUS STUDIES						
SP	— (17)	22	—	—	—	—	—	—	5230 (4660-6270)	17	—
	— (18)	18	—	—	—	—	—	—	4770 (3030-6560)	18	—
	— (14)	28	—	—	—	—	—	—	5750 (3680-7190)	27	—
					PRESENT STUDY						
Initial set of SP	ISP2	—	0.56	0.55	6	6	2.21	2.11	[4]4380	—	100
	ISP10	—	.56	.53	10	5	2.05	1.88	[4]2970	—	45
	ISP13	—	.58	.61	7	5	2.53	2.45	[4]3490	—	100
	Average	3							3610	3	
Second set of SP[5]	Average	3							5650 (5410-6100)	3	
DF-L	DF1	—	.51	.54	9	9	2.68	[3]—	[4]3780	—	0
	DF3	—	.49	.51	12	10	2.44	2.65	[4]5200	—	40
	DF17	—	.63	.53	12	10	2.99	[3]—	[4]5830	—	35
	DF19	—	.47	.47	9	9	2.37	[3]—	[4]5660	—	45
	Average	4							5120	3	

[1] All lumber except the second set of SP at least met the grading requirements of AITC 302-24 tension laminations *(2)*. (See footnote 4.)
[2] Values for A and B are based on small clear specimens cut from each side of the failed finger joints. Specific gravity values are based on ovendry weight and volume at the time of test.
[3] The modulus of elasticity (MOE) values were determined with an E-computer when the beams were manufactured. No value for B indicates that the board number was lost.
[4] These seven values are the individual strength results for pieces tested in tension for this study.
[5] Only five SP specimens from the second set of beams were tested in tension. Although the three listed specimens were only No. 1D or better quality material, they did fail at a finger joint and can provide an idea of their finger joint quality compared to the DF-L and initial set of SP finger joint quality.

moment than the DF-L beams (column 8 of table D-2). There was quite a large difference in the finger joint frequency for the 302-24 8-lamination beams in particular. Most of the difference in finger joint frequency may be attributed to the difference in the lengths of the SP and DF-L tension lamination lumber. The average length of the second set of SP tension laminations was about 5 percent less than the initial set of SP and about 25 percent less than the DF-L.

The frequency of failure at a finger joint (column 10 of table D-2) was much higher in the initial set of SP beams than in the DF-L or second set of SP beams.

Previous Studies

The frequency of finger joints subjected to high tensile stresses in this study was compared to four previous studies *(13, 14, 15, 24)*. In two of the studies *(13, 14)*, no attempt was made to control the location of the finger joints in the tension laminations of the beams. It was the intent, however, that a number of the beams have finger joints within the maximum-moment region. All 20 of the SP beams in Research Paper FPL 222 *(14)* contained a finger joint that was subjected to 75 percent or more of the maximum moment. Seventy-five percent of those beams failed at a finger joint. Nineteen of the 20 DF-L beams in Research Paper FPL 236 *(13)* also contained a finger joint that was subjected to 75 percent or more of the maximum moment. Only 45 percent of those 20 beams failed at a finger joint.

It was intended that 30 to 40 percent of the beams in the other two studies *(15, 24)* have finger joints located within the maximum-moment region. Although only 20 percent of the 30 SP beams actually contained a finger joint in the maximum-moment region, 63 percent of the beams had a finger joint subjected to 75 percent or more of the maximum moment. Sixty percent of those 30 beams failed at a finger joint.

Thus, a comparison of the present study with four previous studies indicates that the frequency and critical placement of finger joints in the beams is not greatly different than the frequency and critical placement of joints in past studies.

Table D-2.—Finger joint frequency

Beam description				Length		Finger joints[1]			
Number of laminations	Species	Type of tension lamination	Number of beams	Constant moment section	Tension laminations	100[3]	>75[3]	>50[3]	Failure frequency[2]
				Ft	Ft	Pct	Pct	Pct	Pct
				PRESENT STUDY					
4	SP (Initial set)	302-24	9	2.0	12.6	33	44	78	67
8		302-24	10	4.0	14.2	50	100	100	100
10		302-24	10	5.0	12.8	40	100	100	90
4		No. 1D	11	2.0	13.8	18	45	45	36
8		No. 1D	10	4.0	14.0	30	50	80	40
10		No. 1D	10	5.0	14.0	20	70	100	70
4	SP (Second set)	302-24	10	2.0	13.2	10	20	40	10
8		302-24	10	4.0	14.0	60	100	100	60
10		302-24	10	5.0	13.8	40	90	100	30
4		No. 1D	10	2.0	12.0	30	50	80	20
8		No. 1D	10	4.0	12.0	30	70	100	30
10		No. 1D	10	5.0	12.0	50	100	100	30
4	DF-L	302-24	10	2.0	17.9	10	20	50	20
8		302-24	10	4.0	17.3	40	40	70	40
10		302-24	10	5.0	18.6	30	80	100	70
4		L1	10	2.0	16.0	10	20	40	10
8		L1	10	4.0	16.6	40	40	60	20
10		L1	10	5.0	16.8	30	60	80	30
				PREVIOUS STUDIES					
17	SP *(14)*	[4]302-24	10	8.0	—	60	100	100	80
		[4]302-20	10	8.0	—	80	100	100	70
	Average		20	8.0	—	70	100	100	75
16	DF-L *(13)*	[4]302-24	10	8.0	13.2	80	100	100	50
		[4]302-20	10	8.0	13.6	60	90	100	40
	Average		20	8.0	13.4	70	95	100	45
8	SP *(15, 24)*	[4]302-24	30	4.0	14.4	20	63	77	60

[1] The percent of beams with finger joints subjected to the given percentages of the maximum moment.
[2] The percent of beams that failed at a finger joint in the tension lamination.
[3] The percent of the maximum moment the finger joint were subjected to.
[4] Similar or identical in quality to the current grades in AITC 117-79 *(2)*.

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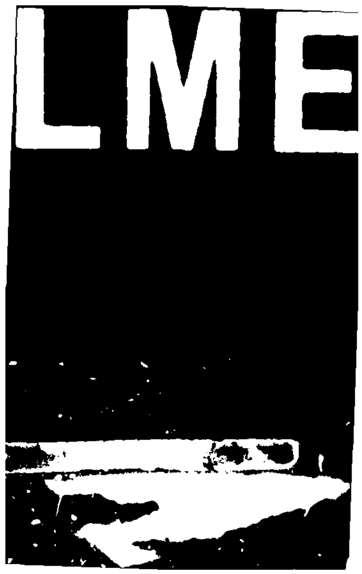
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