United States
Department of
Agriculture

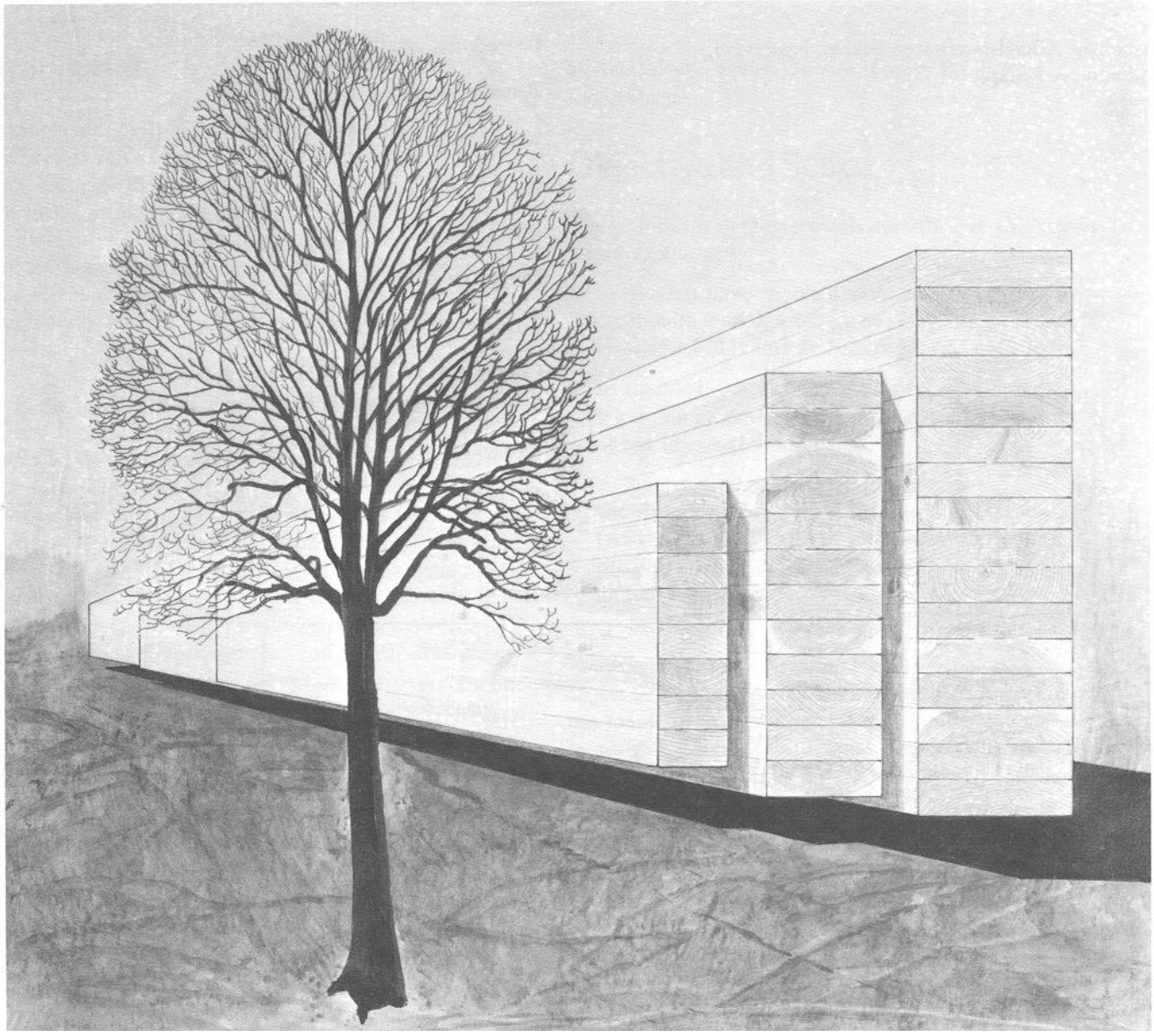
Forest Service

Forest
Products
Laboratory

Research
Paper
FPL-RP-519

Performance of Red Maple Glulam Timber Beams

Harvey B. Manbeck
John J. Janowlak
Paul R. Blankenhorn
Peter Labosky
Russell C. Moody
Roland Hernandez



Abstract

A red maple glued-laminated (glulam) beam combination that would achieve a design bending stress of 2,400 lb/in^2 (16.5 MPa) and modulus of elasticity of 1.8×10^6 lb/in^2 (12.4 GPa) was developed; 45 beams were evaluated. The properties of the lumber grades used in the layup and their placement within the beams were closely monitored during beam fabrication. Another 166 specimens of end-jointed lumber were gathered during manufacture to relate the individual tensile strength performance of end joints to their performance in the beams. The evaluations of the end-jointed specimens and the full-sized beams indicate that a glulam beam combination with the targeted design stress in bending and modulus of elasticity is possible.

Keywords: Glued-laminated beams, hardwood, modeling, red maple

May 1993

Manbeck, Harvey B.; Janowiak, John J.; Blankenhorn, Paul R.; Labosky, Peter; Moody, Russell C.; Hernandez, Roland. 1993. Red maple glulam timber beam performance. Res. Pap. FPL-RP-519. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 30 p.

A limited number of free copies of this publication are available to the public from the Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53705-2398. Laboratory publications are sent to more than 1,000 libraries in the United States and elsewhere.

The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin.

Contents

	Page
Introduction	1
Objective and scope	1
Design of beam combinations	2
Procedures for grading lumber and characterizing knots	3
Lumber sawing and grading	3
Measurement of lumber MOE	3
Characterization of knot properties	3
Beam and end-jointed lumber tests	4
Procedures	4
Beam test results	4
End-jointed lumber tests	6
Analysis	6
Effect of beam size	7
Design levels	7
Comparison with predicted values	8
Comparison of beam and end-joint bending strength	8
Conclusions	8
References	9
Appendix A	15
Appendix B	17
Appendix C	24
Appendix D	29

Red Maple Glulam Timber Beam Performance

Harvey B. Manbeck, Professor, Department of Agricultural Engineering
John J. Janowiak, Assistant Professor of Wood Products
Paul R. Blankenhorn, Professor of Wood Technology
Peter Labosky, Professor of Wood Science and Technology
Pennsylvania State University, University Park, Pennsylvania

Russell C. Moody, Supervisory Research General Engineer
Roland Hernandez, Research General Engineer
Forest Products Laboratory, Madison, Wisconsin

Introduction

Red maple is rapidly becoming a predominant hardwood species in the forests of the Northeastern United States. Because this species has not been traditionally considered for structural applications, there has been little interest in developing engineered red maple products. The emerging prominence of red maple in the forests makes product development of vital interest to landowners and to wood processors, fabricators, and designers.

Red maple has excellent mechanical properties, treats well, and has good gluing characteristics (FPL 1987). Thus, it is a good candidate for structural applications such as glued-laminated (glulam) timber beams. The American Institute of Timber Construction (AITC) established specifications for hardwood glulam timber in AITC 119 (AITC 1985). However, red maple is not included as a candidate species for lamination stock. Moreover, this specification provides conservative design properties of homogeneous combinations of hardwood and does not provide options for developing efficient combinations of glulam timber. Consequently, a cooperative research project was conducted between the Pennsylvania State University and the USDA Forest Service, Forest Products Laboratory to develop efficient combinations of red maple glulam timber. The target design stresses for these combinations were 2,400 lb/in^2 in bending stress and 1.8×10^6 lb/in^2 in modulus of elasticity (MOE). (See Table 1 for SI conversion factors.)

The research reported here was sponsored and funded by the Pennsylvania Department of Transportation (Project No. SS-043), the Pennsylvania Agriculture Experiment Station, and the U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Objective and Scope

The objectives of the research described in this report were as follows:

1. to develop a red maple glulam timber beam combination with a target bending design stress level of 2,400 lb/in^2 and MOE of 1.8×10^6 lb/in^2
2. to establish the technical basis for developing allowable properties for bending strength and MOE of red maple glulam beams
3. to determine if calculation procedures outlined in the American Society for Testing and Materials (ASTM) D 3737 (ASTM 1991a) can be used to predict bending strength and stiffness of red maple glulam beams

We expected that successful completion of the objectives would provide data to support including red maple in glulam timber design specifications. In addition, the procedures developed could provide the glulam timber industry with better methods for developing more efficient hardwood glulam timber beam designs than does the current standard AITC 119 (AITC 1985).

The scope of the study included (1) design of beam combinations, (2) sawing, drying, grading, and characterization of properties of a large sample of red maple structural lumber, (3) manufacture of 45 glulam timber beams, and (4) evaluation of beam bending strength and stiffness.

Results of the laboratory tests of the lumber specimens will be used to develop input lumber properties required by advanced probabilistic models (Hernandez and others 1992). Laboratory test results for end-jointed lumber are presented in this report because they are critical for the development of a glulam standard. Results of the glulam beam modeling will be presented in a separate report.

Design of Beam Combinations

Glulam beam combinations were designed on the basis of assumed lumber properties of red maple lumber, current surveys of mechanical properties of existing red maple lumber, and procedures established in the ASTM D 3737 Standard (ASTM 1991a). The proposed beam combinations targeted a design bending stress of 2,400 lb/in^2 and MOE of 1.8×10^6 lb/in^2.

The lamination material consisted of E-rated grades of lumber for the outer laminations and visually graded lumber for the core laminations. The beams contained 2.0E material in the outer zones, 1.8E material in the next inner zones, and No. 2 material in the core laminations. Edge knots for the lumber grades used for the two zones on the compression side of the beams and for the next inner zone on the tension side were limited to one-third the area of the cross section (two-thirds clear lumber). This represents No. 2 or better lumber and is designated in the text as 2.0-1/3 lumber for the outer zone and 1.8-1/3 lumber for the next inner zone. The E-rated lumber in the outer tension zone had an edge-knot limitation of one-sixth of the cross section (five-sixths clear lumber) (designated 2.0-1/6 lumber).

Three beam combinations were developed and fabricated to represent critical beam sizes with small, medium, and large dimensions (Fig. 1). The smallest beam (8-Lam) had eight laminations with finished dimensions of 3 in. wide by 12 in. deep by 20 ft long. The intermediate beam (12-Lam) had 12 laminations with dimensions of 5 in. wide by 18 in. deep by 30 ft long. The largest beam (16-Lam) had 16 laminations with dimensions of 6.75 in. wide by 24 in. deep by 40 ft long. The beams were manufactured using nominal 2 by 4, 2 by 6, and 2 by 8 lumber, respectively (1.5 by 3.5 in., 1.5 by 5.5 in., and 1.5 by 7.25 in., respectively).

The target beam MOE of 1.8×10^6 lb/in^2 required certain MOE levels of laminating lumber. To determine if the current resource of red maple structural lumber would provide adequate yields of the desired E-rated grades, preliminary results of ongoing research studies at both Pennsylvania State University (Janowiak and others 1992) and the Forest Products Laboratory

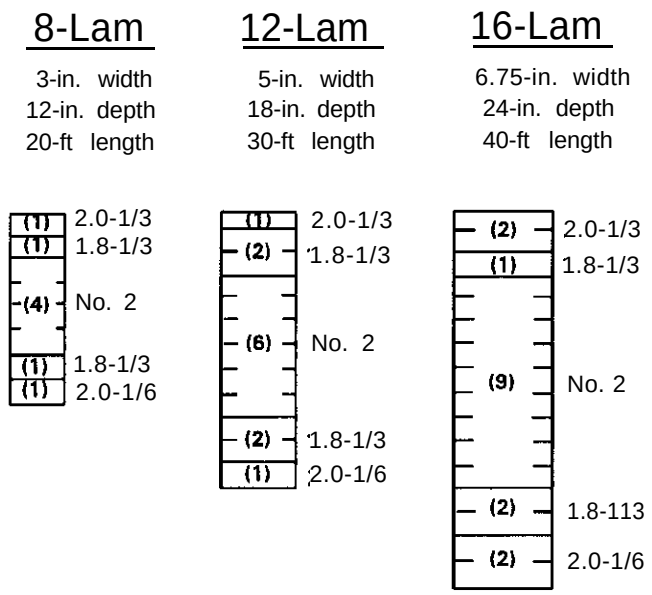


Figure 1—Red maple glulam beam combinations. Location of various lumber grades for 8-, 12-, and 16-lamination beams.

(FPL) were reviewed. The MOE data indicated that the proposed E-rated grades of 2.0-1/6, 2.0-1/3, and 1.8-1/3 could be readily derived from available red maple lumber populations. Also, results of the knot analysis from the independent sample of red maple lumber indicated that the lumber quality was adequate to achieve the targeted 2,400-lb/in^2 design bending stress (Green and McDonald, in preparation). Therefore, assumed properties were used to develop the glulam beam combinations (Table 2).

To develop glulam beam combinations that would achieve the target bending stress of 2,400 lb/in^2, several assumptions were necessary to estimate the minimum strength ratio, the bending stress indices (clear wood stress), and the knot properties required by the ASTM D 3737 Standard (ASTM 1991a). Values for the minimum strength ratios of the candidate grades of red maple were estimated from values established for E-rated lumber across all species in AITC 117 (AITC 1979). Bending stress indices for the proposed E-rated grades were those recommended by ASTM D 3737. Finally, conservative estimates of knot properties required by ASTM D 3737 procedures were derived for each proposed lumber grade using actual knot measurements obtained on an independent sample of Select Structural (SS), No. 2, and No. 3 grades of red maple lumber (Green and McDonald, in preparation). The visually graded lumber was graded according to inspection rules established by the Northeastern Lumber Manufacturers Association (NELMA 1986).

To achieve the bending stresses predicted with the ASTM D 3737 procedures, special grades of lumber were required in the outer 5 percent of the tension laminations (e.g., 5 percent of 16 laminations equaled 1 lamination). In this study, one 2.0-1/6 lamination of the red maple combinations was replaced with a lamination meeting the special criteria given in Table 3. These special grades, referred to as tension lamination grades, were developed following ASTM D 3737. For each beam size, a sample of 15 beams was selected, which is statistically significant for a 10-percent difference in strength properties with a 90-percent level of confidence.

Procedures for Grading Lumber and Characterizing Knots

Lumber Sawing and Grading

Lumber for manufacturing glulam beams was obtained by sawing red maple (*Acer rubrum*) logs into green 8/4 (2-in.) dimensional material. The lumber was conditioned at a commercial facility, using a predrier, to moisture content of approximately 16 to 18 percent over a 6-week period. Once the target moisture content level was reached, the material was rough-planed to a thickness of 1.75 in. The rough-sawn lumber was then visually graded by NELMA rules and subdivided into Select Structural, No. 1, No. 2, and No. 3 grades (NELMA 1986). The lumber was subsequently shipped to the laminator. Total processed log volume was 33.1×10^3 board feet (fbm).

The sawing yielded approximately 4,700, 6,650, and 14,100 fbm of 2 by 4, 2 by 6, and 2 by 8 material, respectively. These board footage values were based on two independent sawmill runs. The first sawmill run was based on a higher proportion of lower grade logs, which resulted in poor lumber recovery yield for the larger 2 by 8 material. The second run was more heavily predisposed to No. 1 and veneer-grade logs, which enhanced 2 by 8 recovery. Logs in either processing run were sawn leaving the center log portion in the form of 4 by 4 or larger cants. Yields of the various grades were as follows: SS, 32.0 percent; No. 1, 28.7 percent; No. 2, 34.3 percent; No. 3, 2.8 percent; and cull, 1.7 percent. These yields were biased with respect to sawing practices and removal of cant log sections to minimize the inclusion of juvenile wood.

Measurement of Lumber MOE

Stiffness was measured once the lumber attained an average moisture content of 15 percent. The long-span flatwise bending MOE was measured using a deflection apparatus with the following specifications:

- steel strongback support assembly equipped with radius supports
- mechanical lever crane for applying a constant 148-lb load
- calibrated linear variable differential transformer (LVDT) for measuring midspan displacement
- digital voltmeter for reading output transducer voltage
- portable laptop computer for data entry and storage and MOE computation

The 8- and 10-ft-long lumber was tested over a 7.5- and 9.5-ft span, respectively, using a simply supported, center-point loading configuration. No shear correction was made for the apparent MOE calculation as a result of the large span-to-depth ratio. The results of the MOE tests were used to sort the lumber using the criteria listed in Table 4.

The SS and No. 1 material was initially sorted to the 2.0-1/6, 2.0-1/3, or 1.8-1/3 grades using these criteria. Material that did not meet the criteria was either not used (higher stiffness) or added to the No. 2 grade (lower stiffness). The No. 2 material was then sorted to obtain additional amounts of 2.0-1/3 and 1.8-1/3 material. It was expected that much of the No. 2 material would not meet these grades and would be used in the beam core. The sorting of the SS and No. 1 grades provided nearly all the E-rated material.

Although the lumber samples that were measured for MOE were large, we wanted to determine the average MOE for the lumber specimens that actually appeared in the beam layups. We were able to do this because the location of these specimens was specifically mapped. The MOE averages for the lumber that appeared in the beam layups are presented in Table 5. These results show that the average stiffness values of the 2.0E and 1.8E lumber for each size were slightly lower than the target values. Conversely, the average stiffness of the No. 2 lumber for each size significantly exceeded the value of 1.5×10^6 lb/in^2 assumed in Table 2.

Characterization of Knot Properties

To accurately analyze the beams for bending strength using the ASTM D 3737 (ASTM 1991a) procedures, knots were measured for each grade of lumber after the lumber was sorted by MOE. Knots were measured by estimating an equivalent “straight-through” knot and determining the percentage of the lumber cross-section that the knots occupied. The knot properties

were measured for all the tension lamination material and for representative samples of the remaining lumber grades. Knot data were analyzed following the principles in USDA Technical Bulletin 1069 (Freas and Selbo 1954).

The knot properties calculated from the knot measurements are listed in Table 6. The data were based on a minimum of 1,000 lineal fbm examined for each lamination grade for the three lumber widths combined.

Beam and End-Jointed Lumber Tests

Forty-five beams (15 of each combination) were manufactured along with extra specimens for end-jointed lumber tests. The location of each lumber piece was recorded on prepared beam maps so that the lumber properties could later be related to beam performance. In addition, the quality of the critical tension laminations was assessed in relation to the allowable knot and slope-of-grain properties, to determine the relative qualities of the beams.

Procedures

Manufacture of the beams followed the normal production procedures (ANSI 1983). Each grade of lumber included a range of qualities permitted by the grade. Lumber quality was random; the lumber was not sorted to include high as opposed to low quality material in any specific arrangement along the lamination length. The general manufacturing procedure was as follows:

1. Lumber pieces were continuously finger-jointed, with the lamination ribbon cut to beam length. Vertically oriented finger-joints were manufactured with a melamine–formaldehyde adhesive under radio-frequency cure. Special outer-zone laminations were manufactured first, followed by production of core plies to develop the beam depth profile. End-joint geometry was finger length, 1.03 in.; pitch, 0.25 in.; and tip thickness, about 0.03 in. The observed tip gap was approximately 0.038 in.
2. Laminations were planed prior to adhesive application for face bonding. Initial lamination thickness was reduced to 1.5 in. by removing 0.13 in. of material from both faces.
3. The adhesive resin for face lamination was a room-temperature curing resorcinol-formaldehyde. Adhesive application was through a single glueline with an 80.lb/1,000-ft^2 spread rate. Surface adhesive was spread with a roll-coat applicator. Open assembly time was not modified from that typically used within the operation for Southern Pine beam fabrication. Total closed-assembly time to applied clamp pressure was approximately 50 min. Clamp pressure was similar to that used for Southern Pine fabrication.
4. Adhesive cure was at ambient temperature (75°F to 80°F) under pressure for a minimum 12-h period. Beams were dressed to a surface finish acceptable under the category of industrial grade glulam.

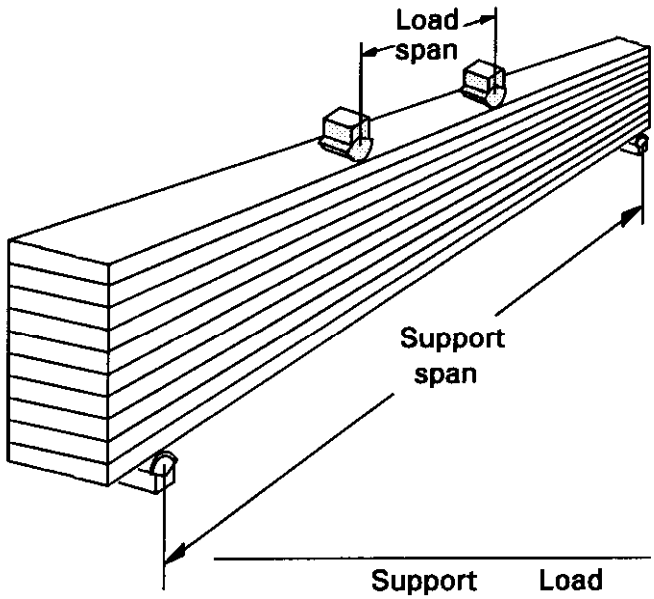
Following manufacture, the beams were visually inspected to assure conformance to ANSI A190.1 (ANSI 1983) and to determine the relative qualities of the tension laminations in the midlength region subjected to ≥85 percent of the maximum moment during test. Using the maximum allowable strength-reducing characteristics listed in Table 3, a relative rating system was developed to systematically assign a quality to the tension lamination. Table 7 lists the allowable percentages of lumber cross-sectional areas that can be occupied by knots, the slope-of-grain limitations, and the MOE restrictions for classification of low, medium, or high quality.

Beam Test Results

Inspection of the beams following manufacture revealed that two beams (beams RM8-5 and RM8-9) in the 16-Lam group had end joints in adjacent laminations in the outer tension zone spaced closer than the 6 in. required by ANSI A190.1 (ANSI 1983). Also, one beam of each combination had a tension lamination that did not meet the visual criteria of Table 3 (beams RM4-3, RM6-5, and RM8-10). However, the designated compression side of the two smaller beams (RM4-3 and RM6-5) met the criteria, and they were tested with the tension and compression sides reversed (these were balanced combinations). It was not possible to test the third beam (RM8-10) as a result of both the unbalanced layup of the 16-Lam beam and the quality of the compression-side lamination. Therefore, although the 15 beams in the 16-Lam group were tested, only 12 were included in the final analysis.

The percentage of beams categorized as having low, medium, or high quality tension laminations is shown in Table 8. Additional details on the quality of the individual tension laminations are provided in Appendix A.

All the full-sized glulam beams were tested following the procedures given in the ASTM Standard D198 (ASTM 1991b). The loading configuration used to test the full-sized beams is illustrated in Figure 2. Physical properties (moisture content, weight, and dimensions), stiffness properties (full-span deflections), and failure



	Support span (ft)	Load span (ft)
8-Lam	19	4
12-Lam	28.5	6
16-Lam	38	8

Figure 2—Loading configurations for bending tests

load were measured for each beam. In addition, notes were taken on failures, typical failure types were photographed, and high-speed videotapes were made of failures on selected beams. Moisture contents were measured with a resistance-type moisture meter near the midspan of all laminations after ultimate failure of the beams. Weights were measured on a mobile scale to the nearest 10-lb increment. Dimensions were measured at each load point.

During the application of load, beam deflections were measured using a precision rule (0.02-in. markings) attached to the beam. Deflections were recorded at mid-depth with respect to a stringline attached over each support. The readings were taken at specified load increments with the use of a surveyor's scope; this allowed the recorder to take readings to the nearest 0.01 in. During the load-deflection readings, elapsed time readings were also taken. The purpose for the elapsed time readings was to record when initial cracking occurred (noise) and when compression wrinkling was first detected. The time-of-occurrence readings were then traced back to applied load.

After the beams failed, detailed descriptions of the failure propagations were recorded (Fig. 3), along with an assessment of the cause of failure (end joint,

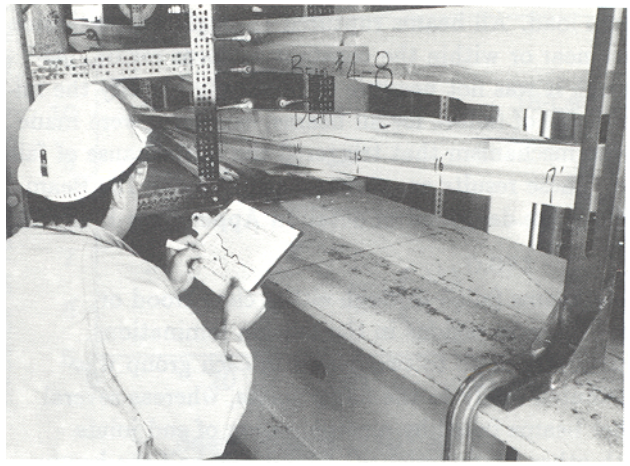


Figure 3—Mapping of failure propagations in glulam beams. (M91 0266-50)

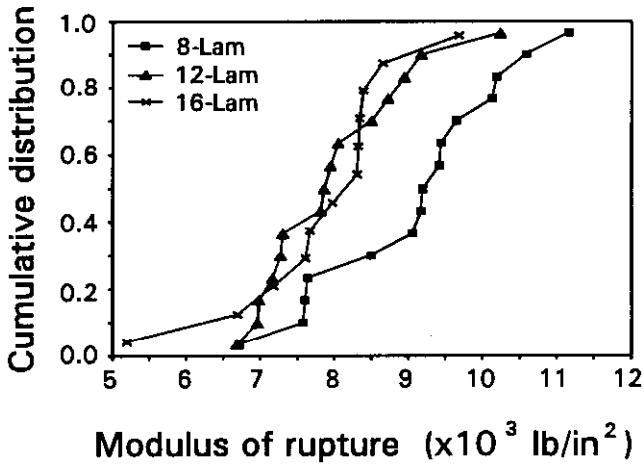


Figure 4—Cumulative distribution of modulus of rupture (MOR) for three sizes of glulam beams.

knot, etc.). Each beam failure was photographed for future reference. Modulus of rupture (MOR) and MOE were calculated using standard flexural formulas. Dead load stress was included in the MOR calculations. The MOE values were calculated based on the slope of the load-deflection curve determined by a linear regression up to design load.

Strength and Stiffness

Results of the bending tests on the beams are summarized in Table 9. Individual beam results are given in Appendix B. Figure 4 compares the cumulative distribution function of MOR for the 8-, 12-, and 16-lamination beams.

Beam Failure

Most beams failed abruptly at ultimate load and many emitted cracking sounds as the ultimate load was approached. Several beams exhibited compression

wrinkling at or between the load points prior to maximum load. All beams ruptured throughout the tension zone near or within the constant moment region. Although it was not possible to positively identify the initial point of failure for all beams, estimates were made of the mechanism that triggered the initial cause of failure. These results are summarized in Table 10. Beam failures are described in detail in Appendixes B and C.

Most beams failed through either clear wood or slope-of-grain regions in the tension laminations. The failure of up to two beams in each group was attributed solely to the finger joints, whereas several other beams failed by a combination of end joints with other characteristics. About one-half the beams exhibited areas of shallow or little wood failure at the bonds between laminations as the rupture progressed. These failures are referred to as glueline failures (GLF) in Appendix B. Although these face bonds were not believed to affect the beam strength, they could hamper long-term durability. The face bonds are not perceived to be critical in the development of commercial red maple glulam lumber. Examination of the failed glueline areas suggested that the problem of durability may well be resolved through slight modification of the lamination assembly, such as slower planing speeds and higher face-bonding pressures (private conversation with Bryan River, Research Forest Products Technologist, FPL).

End-Jointed Lumber Tests

End-jointed lumber specimens from each grade and size were tested in tension. The test specimens were 8-ft long with the end joint located near midspan. Prior to testing, specimens were face- and edge-planed to the same dimensions of the laminating lumber used in the glulam beams.

For the purpose of characterizing lumber properties for probabilistic models (Hernandez and others 1992), short-span stiffness properties were obtained on the 2-ft lumber segment on each side of the joint and on the 2-ft segment across the joint. These bending tests were conducted on a screw-driven bending machine with a load cell and LVDT setup for measuring the shear-free deflections between the load points. The loading configuration for the bending test was 5.5 ft between the supports and 2 ft between the applied load points. Load-deflection readings were taken in 5-lb increments. The 2 by 4 specimens were loaded to a maximum load of 300 lb and the 2 by 6 and 2 by 8 specimens to a maximum load of 400 lb. The MOE values were calculated using the slope of the load-deflection readings.

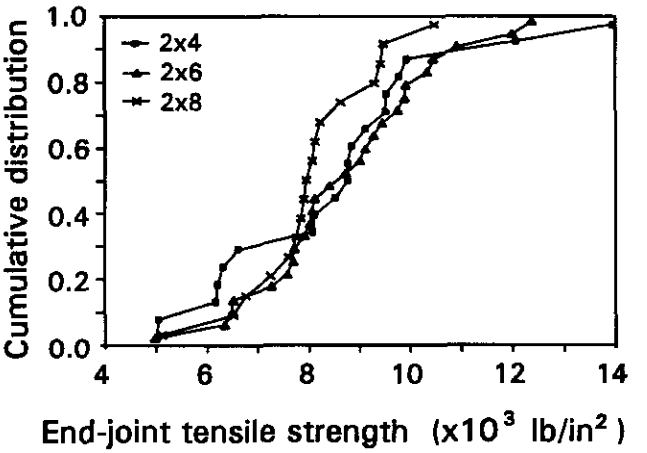


Figure 5—Cumulative distribution of tensile strength of finger-jointed 2.0E-1/6 grade lumber for nominal 2 by 4, 2 by 6, and 2 by 8 material.

After the nondestructive static bending tests, the specimens were tested to failure in tension according to the procedures specified in the ASTM Standard D 198 (ASTM 1991b), which specify a 5- to 10-min time-to-failure. Normal quality control practices for testing end joints would follow the AITC 200 (1991a) procedures, which specify a 2-min time-to-failure. End joints for this research project were tested according to the ASTM D 198 (ASTM 1991b) procedures as a result of the similar failure times of the full-sized beams. The tension testing machine was adjusted such that the grips were 30 in. apart. The specimens were placed in the machine with end joints located near the center of the 30-in. span. A 30-in. span was used because of the minimum span limitations of the tension machine; thus, the 24-in. segment tested in bending was centered within the 30-in. span. After testing, the short-span stiffness data and the visual grade of the end-joint specimens between the grips were used to reclassify the end joints with respect to grade. The strength and stiffness data provided information to relate the relationship of the individual performance of end joints to their performance in the beams.

Results of tension tests on the end-jointed tension lamination material are given in Table 11 and shown in Figure 5. Results on tests of the other grades of finger joints are in Appendix D.

Analysis

The glulam beam strength and stiffness results in Table 9 were calculated assuming both the normal and lognormal distributions. However, to analyze the data, the ASTM D 3737 Standard (ASTM 1991a) recommends that a lognormal distribution be

used. Therefore, our analysis assumes a lognormal distribution.

Effect of Beam Size

By evaluating three beam sizes, it was possible to determine if beam volume exerted a significant effect on the strength of red maple beams. The results indicated that the small beams (8-Lam) had significantly higher strength than the other two sizes (Table 9). However, there was no significant difference between the strength of the other two sizes (12- and 16-Lam). The following equation is used in the National Design Specification for Structural Wood (NFPA 1991) to account for the effect of varying beam size on bending strength.

$$C_v = (5.125/b)^x(21/L)^y(12/d)^z \qquad (1)$$

where

b is beam width (in.),

L beam length (ft), and

d beam depth (in.)

and x, y, and z are exponents that determine the relative adjustments for width, length, and depth.

When width, depth, and length are combined to obtain volume, the following relationship is used in place of Equation (1) (assuming x = y = z).

$$(V_0)/V)^k = C_v \qquad (2)$$

where

V_0 is standard volume (5.125 in. by 12 in. by 21 ft)

V volume of actual beam (b by d by L)

k exponent that represents x = y = z

Moody and others (1988, 1990) found that exponents of x = y = z = 1/10 adequately explained the variation in strength for Douglas-fir beams. A volume effect equation has been adopted by ASTM Committee Section D07.02.02 with exponents x = y = z = 1/10 for all species. The American Institute of Timber Construction (AITC), on the other hand, has adopted the x = y = z = 1/10 exponents for all species of glulam except Southern Pine. The parameters adopted by AITC for Southern Pine are x = y = z = 1/20 (AITC 1991b).

To determine the most appropriate method of accounting for variation in beam strength resulting from beam size. a confidence interval on the ratio of the beam sizes

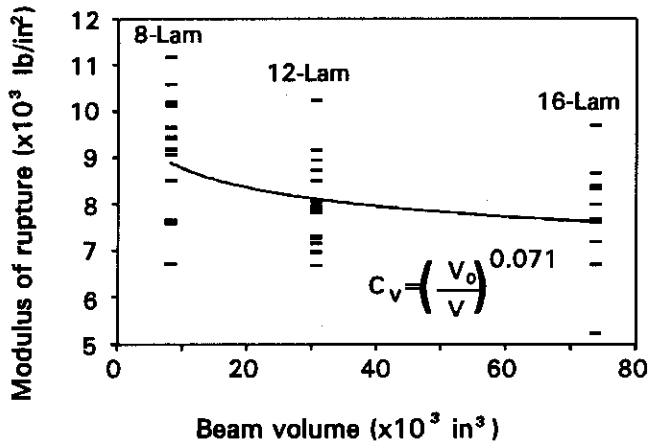


Figure 6—Variation in beam MOR with beam volume showing a line approximating an exponent of 0.071.

was conducted. First, the ratio between the volume effect factors of each beam size was determined using both the 1/10 and 1/20 exponents. Next, the ratio between the averages of the various paired groupings of beams were determined along with a confidence interval using the procedures described in Appendix II of an FPL report (Wolfe and Moody 1978). Table 12 lists the results of this analysis.

These results indicate that neither exponent can be statistically rejected because predicted results using both exponents fell within the confidence interval.

For the comparison of the 16- and 12-Lam beams, the predicted results with the 1/10 exponent were at the edge of the confidence interval whereas those with the 1/20 exponent were near the middle of the confidence interval.

Next, a regression analysis was conducted to determine a single exponent to use for x, y, and z that best fit all the data. This exponent was 0.071. The resulting equation is plotted with the bending strength data in Figure 6. Thus, for further analysis, an exponent value of 0.071 was used to adjust the beam results to a standard volume.

Design Levels

All beam strengths were adjusted to a standard beam size of 5.125 in. by 12 in. by 21 ft using the best fit volume effect relationship (exponent of 0.071). Then, results were pooled and analyzed to determine the appropriate design level using the procedures of ASTM D 2915 (ASTM 1991c). A lognormal distribution was assumed and the 5th percentile (75 percent tolerance

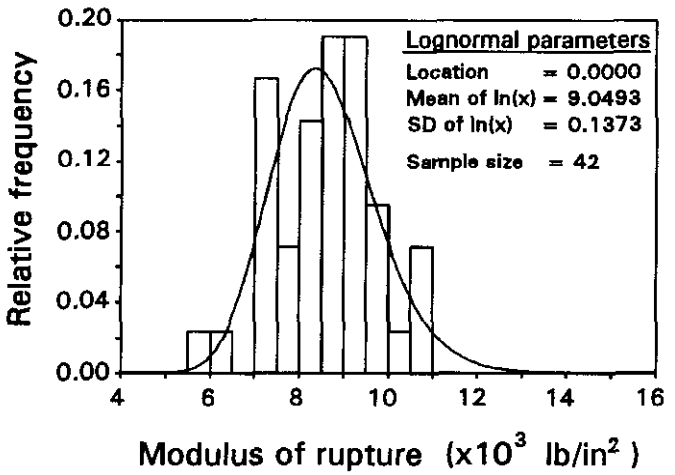


Figure 7—Distribution of MOR adjusted to standard beam size and compared to lognormal distribution.

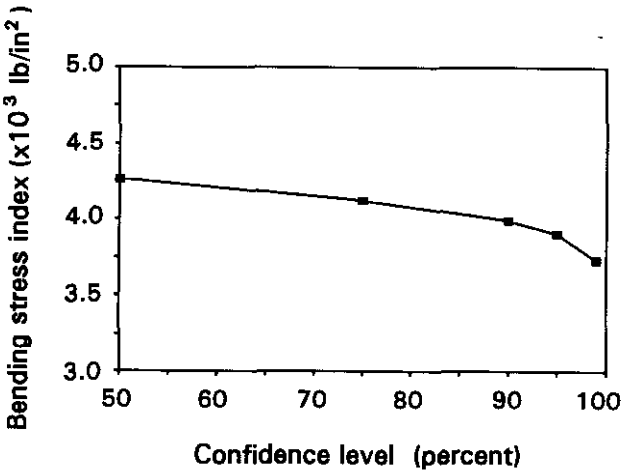


Figure B—Analysis of bending stress index values for 2.0E grade red maple lumber based on results of 42 glulam beam tests.

limit) was adjusted by dividing by 2.1 to obtain the design level. The 2.1 factor includes adjustments for safety and load duration effects. Figure 7 shows that the data closely fit the assumed lognormal distribution. Results shown in Table 13 indicate that the calculated adjusted 5th percentile (75 percent tolerance limit) significantly exceeded the target level of 2,400 lb/in^2.

The average MOE of the three groups of beams was essentially the same, averaging 1.78×10^6 lb/in^2, which rounds off to the target average value of 1.8×10^6 lb/in^2. As would be expected with E-rated lumber, the variability of the MOE values was quite low.

Comparison with Predicted Values

Strength

The same procedure used to design the combinations was used to reanalyze them with the actual MOE and knot data (Table 5). Because the actual knot sizes were significantly smaller than that assumed (Table 2), the calculated design stress level exceeded the 2,400 lb/in^2 value originally predicted.

A comparison of the actual results with those from the reanalysis indicated that the actual results still exceeded the predicted values. The next step in the reanalysis was to permit the bending stress index value to be increased from the 3,250 lb/in^2 value assumed in Table 2. An analysis of the bending stress index values is presented in Figure 8; it shows that a value of at least 3,500 lb/in^2 is justified for the 2.0E1/6 grade lumber used for the outer tension lamination.

Stiffness

Beam stiffness can be predicted by using the actual stiffness data for the lumber (Table 5) and the procedures of ASTM D 3737 (ASTM 1991a). Results are compared in Table 14 and show that the beam MOE values were within 2 percent of the values predicted for the three sizes.

Comparison of Beam and End-Joint Bending Strength

According to ANSI A190.1, the required end-joint strength is 1.67 times the nominal design strength in bending. By pooling all of the joint-associated tensile strength data (lumber size exerted little apparent effect; Table 10), a 5th percentile (75 percent tolerance limit using the lognormal distribution) of 5,590 lb/in^2 was calculated. This value greatly exceeds the value of 4,000 lb/in^2 commonly targeted for 24F (2,400 lb/in^2) beams. The ratio of the 5th percentile (75 percent tolerance limit) of the combined end-joint data to the adjusted 5th percentile (75 percent tolerance limit) of the combined beam data in Table 13 is 1.78, which is slightly higher than the ANSI A190.1 requirements.

Conclusions

1. Structural glued-laminated (glulam) timber beams manufactured with E-rated red maple lumber in the outer zones and No. 2 lumber in the core met or exceeded the target bending design stress of 2,400 lb/in^2 and modulus of elasticity (MOE) of 1.8×10^6 lb/in^2.

2. A red maple combination of glulam timber with design properties of at least 2,400 lb/in^2 in bending and MOE of 1.8×10^6 lb/in^2 is technically feasible. Both the lumber grades and the finger joints used would provide adequate strength and stiffness for this combination.

3. The ASTM D 3737 procedures developed for softwood species accurately predict beam stiffness and provide conservative strength estimates for beams made with E-rated red maple lumber.

References

AITC. 1979. Determination of design values for structural glued laminated timber. AITC 117-79. Vancouver, WA: American Institute of Timber Construction.

AITC. 1985. Standard specifications for hardwood glued laminated timber. AITC 119-85. Vancouver, WA: American Institute of Timber Construction.

AITC. 1988. Standard specifications for structural glued-laminated timber of softwood species. AITC 117-88—Manufacturing, Vancouver, WA: American Institute of Timber Construction.

AITC. 1991a. Inspection manual. AITC 200-91. Vancouver, WA: American Institute of Timber Construction.

AITC. 1991b. Use of a volume effect factor in the design of glued laminated timber beams. Tech. Note 21, October. Vancouver, WA: American Institute of Timber Construction.

ANSI. 1983. Structural glued laminated timber. ANSI A190.1. Englewood, CO: American National Standards Institute.

ASTM. 1991a. Standard test method for establishing stresses for structural glued-laminated timber (glulam). ASTM D 3737-91. Philadelphia, PA: American Society for Testing and Materials.

ASTM. 1991b. Standard methods of static tests of timbers in structural sizes. ASTM D198-84. Philadelphia, PA: American Society for Testing and Materials.

ASTM. 1991c. Standard practice for evaluating allowable properties for grades of structural lumber. ASTM D2915-90. Philadelphia, PA: American Society for Testing and Materials.

Forest Products Laboratory. 1987. Wood handhook–Wood as an engineering material. Agric. Handb. 72 (Rev.). Washington, DC: U.S. Department of Agriculture. 466 p.

Freas, A.D.; Selbo, M.L. 1954. Fabrication and design of glued laminated wood structural members. Tech. Bull. 1069. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Hernander, R.; Bender, D.A.; Richburg, B.A.; Kline, K.S. 1992. Probabilistic modeling of glued-laminated timber beams. Wood and Fiber Science. 24(3): 294-306.

Janowiak, J.J.; Manbeck, H.B.; Wolcott, M.P.; Dawlos, J.F. 1992. Final project report on special project SS-047-Preliminary refinement of hardwood design values. Harrisburg, PA: Pennsylvania Dept. of Transportation.

Moody, R.C.; Dedolph, C. Jr.; Plantinga, P.L. 1988. Analysis of size effect for glulam beams. Vol. 1. In: Proceedings of the international conference on timber engineering; 1988 September; Seattle, WA. Madison, WI: Forest Products Research Society: 892-898.

Moody, R.C.; Falk, R.; Williamson, T. 1990. Strength of glulam beams-volume effects. Vol. 1. In: Proceedings of the international timber engineering conference; 1990 October 23-25; Tokyo. Tokyo: Steering Committee of the International Timber Engineering Conference: 176-182.

NELMA. 1986. Grading rules for northeastern lumber. Cumberland Center, ME: Northeastern Lumber Manufacturers Association.

NFPA. 1991. National design specification for structural wood. Washington, DC: National Forest Products Association.

Wolfe, R.W.; Moody; R.C. 1978. Bending strength of water-soaked glued-laminated beams. Res. Pap. FPL-RP-307. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Table 1—SI conversion factors

English unit	Conversion factor	SI unit
board foot (fbm)	0.0024	cubic meter (m^3)
foot (ft)	0.3048	meter (m)
inch (in.)	25.4	millimeter (mm)
Fahrenheit (°F)	(°F - 32)/1.8	centigrade (°C)
pound (lb)	0.4535	kilogram (kg)
pound per square inch (lb/in^2)	6.894	Pascal (Pa)

Table 2—Assumed properties of red maple lumber grades for ASTM D 3737 procedures

Lamination grade	MOE ($\times 10^6$ lb/in^2)	$\bar{x}$[a] (%)	$\bar{x}$ + h[a] (%)	Bending stress index (lb/in^2)[b]
2.0-1/6	2.0	0.27	12.9	3,250
2.0-1/3	2.0	2.63	31.8	3,250
1.8-1/3	1.8	2.63	31.8	2,800
No. 2	1.5	2.63	31.8	2,500

[a]$\bar{x}$ = average of sum of all knot sizes within each 1-ft length, taken at 2-in. intervals.
$\bar{x}$ + h = 99.5 percentile knot size (ASTM 1991a).
[b]Clear wood design bending stress.

Table 3—Maximum allowable tension lamination criteria[a]

Beam type and lamination criterion	Maximum allowable characteristic
8-Lam	
Edge knot + grain deviation	40 percent
Center knot + grain deviation	45 percent
Slope of grain	1:14
12-Lam	
Edge knot + grain deviation	30 percent
Center knot + grain deviation	33 percent
Slope of grain	1:16
16-Lam	
Edge knot + grain deviation	30 percent
Center knot + grain deviation	33 percent
Slope of grain	1:16

[a]ASTM 1991a. Knots plus grain deviations are given in percentage of cross section.

Table 4—Target MOE values and sorting scheme

Lamination grade	Sorting and grading criteria
2.0-1/6	Average MOE of 2.0 to 2.1 × 10^6 lb/in^2 No MOE value < 1.60 × 10^6 lb/in^2 5th percentile at 1.67 × 10^6 lb/in^2 No MOE value > 2.4 × 10^6 lb/in^2 Edge knot limitation of 1/6
2.0-1/3	MOE restrictions same as for 2.0-1/6 grade Edge knot limitation of 1/3
1.8-1/3	Average MOE of 1.8 to 1.9 × 10^6 lb/in^2 No MOE value < 1.40 × 10^6 lb/in^2 5th percentile at 1.45 × 10^6 lb/in^2 No MOE value > 2.2 × 10^6 lb/in^2 Edge knot limitation of 1/3

Table 5—MOE properties of laminating lumber

Lumber type and grade	Sample size	Average MOE (× 10^6 lb/in^2)	COV[a] (%)
2 by 4 Lumber			
2.0-1/6	39	1.96	5.9
2.0-1/3	40	1.96	5.8
1.8-1/3	80	1.72	8.2
No. 2	50	1.80	16.2
2 by 6 Lumber			
2.0-1/6	52	1.93	7.7
2.0-1/3	48	1.92	8.9
1.8-1/3	215	1.74	10.6
No. 2	50	1.73	14.3
2 by 8 Lumber			
2.0-1/6	141	1.93	9.8
2.0-1/3	144	1.90	8.5
1.8-1/3	193	1.74	10.3
No. 2	50	1.69	14.9

[a]COV is coefficient of variation

Table 6—Knot properties of laminating lumber

Lumber type and grade	Lineal footage (ft)	$\bar{x}$[a] (%)	$\bar{x}$ + h[a] (%)
2 by 4 Lumber			
2.0-1/6	386	0.2	14.8
2.0-1/3	420	0.3	16.8
1.8-1/3	524	0.6	25.5
No. 2	442	0.9	29.2
2 by 6 Lumber			
2&1/6	572	0.1	13.6
2.0-1/3	488	0.4	18.5
1.8-1/3	376	0.1	7.1
No. 2	362	2.0	35.3
2 by 8 Lumber			
2.0-1/6	304	0.5	11.2
2.0-1/3	334	0.7	16.6
1.8-1/3	436	0.1	7.0
No. 2	666	1.7	33.6

[a]$\bar{x}$ = average of sum of all knot sizes within each 1-ft length, taken at 2-in. intervals.
$\bar{x}$ + h = 99.5 percentile knot size.

Table 7—Relative rating system for tension lamination quality

Beam type and lamination criterion	D 3737 allowable value	Lamination quality		
		Low[a]	Medium	High
8-Lam				
Edge knot + grain deviation	40%	>30%	15%-30%	<15%
Center knot + grain deviation	45%	>30%	15%-30%	<15%
Slope of grain	1:14	>1:16	1:16-1:18	>1:18
MOE ($\times 10^6$ lb/in^2)	2.0E (avg.)	<1.7E w/char	<1.7E and clear	
12-Lam				
Edge knot + grain deviation	30%	>20%	10%-20%	<10%
Center knot + grain deviation	33%	>20%	10%-20%	<10%
Slope of grain	1:16	>1:18	1:18-1:20	>1:20
MOE ($\times 10^6$ lb/in^2)	2.0E (avg.)	<1.7E w/char	<1.7E and clear	
16-Lam				
Edge knot + grain deviation	30%	>20%	10%-20%	<10%
Center knot + grain deviation	33%	>20%	10%-20%	<10%
Slope of grain	1:16	>1:18	1:18-1:20	>1:20
MOE ($\times 10^6$ lb/in^2)	2.0E (avg.)	<1.7E w/char	<1.7E and clear	—

[a]w/char designates lumber with characteristics. For example, if a board has an MOE of <1.7E and edge-knot, center-knot, or slope-of-grain characteristics, it is classified as low quality.

Table 8—Relative quality of tension laminations in midlength region of beams

Beam type	Sample size	Percentage of beams by lamination quality		
		Low	Medium	High
8-Lam	15	20	27	53
12-Lam	15	33	40	27
16-Lam[a]	12	75	17	8

[a]Three beams did not meet manufacturing or grade criteria.

Table 9—Results of bending tests on red maple glulam beams

Property	7-Lam	12-Lam	16-Lam[a]	16-Lam
Sample size	15	15	15	12
Moisture content (%)	12	12	12	12
Normal distribution				
Average MOR (lb/in^2)	9,070	7,970	7,890	7,840
COV of MOR (%)	13.8	12.4	13.9	14.3
$M0R_{0.05}$ at 75% tolerance	6,580	6,000	5,720	5,540
Average MOE (× 10^6 lb/in^2)	1.78	1.77	1.78	1.78
COV of MOE (%)	4.3	3.0	2.5	2.7
Lognormal distribution				
Average MOR (lb/in^2)	9,080	7,980	7910	7,860
COV of MOR (%)	14.4	12.1	15.1	15.8
$MOR_{0.05}$ at 75% tolerance	6,760	6,230	5,800	5,630

[a]Data in column four exclude the 16-Lam beams that either did not meet tension lamination requirements (RM8-10) or end-joint spacing requirements (RM8-5, RM8-9).

Table 10—Estimated initial cause of glulam beam failures

	Number of beams		
Failure type	8-Lam	12-Lam	16-Lam
Compression followed by tension	4	1	3
Tension in strength-reducing characteristic	2	1	3
Tension in lumber	2	2	2
Tension in end joint	7	11	4

Table 11—Results of tension tests on end-jointed red maple tension lamination material using lognormal distribution[a]

Property	2 by 4	2 by 6	2 by 8	All sizes combined
All specimens				
Sample size	20	27	19	66
Average TS (lb/in^2)	8,310	8,690	8,120	8,410
COV TS (%)	28.4	20.7	16.8	22.2
Specimens with failure involving end joint				
Sample Size	19	26	18	63
Average SG[b]	0.57	0.57	0.56	0.57
Average MC (%)	8.6	8.6	7.8	8.3
Average TS (lb/in^2)	8,470	8,720	8,010	8,430
COV TS (%)	27.6	21.1	16.2	21.9

[a]TS is tensile strength; SG, specific gravity; and MC, moisture content.
[b]Based on volume at time of test and ovendry weight.

Table 12—Comparison of beam strength using different volume effect exponents

Beam comparison	Ratio of predicted mean MOR: x = y = z = 0.1	Ratio of predicted mean MOR: x = y = z = 0.05	Ratio of actual mean MOR (average (lower, upper))[a]
12-Lam and 8-Lam	0.876	0.936	0.879 (0.810, 0.948)
16-Lam and 8-Lam	0.803	0.896	0.864 (0.785, 0.943)
16-Lam and 12-Lam	0.910	0.954	0.983 (0.909, 1.057)

[a]90 percent confidence interval

Table 13—Adjusted glulam beam bending strength results[a]

Property	Result
Sample size	42
Average MOR (lb/in^2)	8,590
COV (%)	13.8
5th percentile (75% tolerance limit)	6,620
Adjusted 5% tolerance limit	3,150

[a]Data adjusted to standard dimensions of 5.125 in. width by 12 in. depth by 21 ft length.

Table 14—Comparison of actual and predicted MOE values based on actual lumber properties

Beam type	Actual MOE (A)	Predicted MOE (P)	Ratio of A/P
8-Lam	1.78	1.78	1.00
12-Lam	1.77	1.73	1.02
16-Lam	1.78	1.74	1.02

Appendix A

Properties of Red Maple Lumber Used for Midlength Region of Outer Tension Lamination

Tables A1 through A3 list the lumber properties used for the tension lamination of 8-Lam, 12-Lam, and 16-Lam beams, respectively. All lumber ranged from 13 to 16 percent moisture content.

Table Al-Properties of 2 by 4 lumber used in tension lamination

Beam no.	MOE	Characteristic[a]	Relative quality of midlength region[b]
RM4-1	1.89	Clear	M
	1.93	1:16 GS	
RM4-2	2.02	Clear	H
	2.03	5% GD	
RM4-3[c]	1.89	1:10 GS	L
	2.08	Clear	
RM4-4	1.90	40% CK + GD	L
	1.84	Clear	
RM4-5	1.95	Clear	H
	1.87	Clear	
RM4-6	2.03	Clear	H
	2.18	Clear	
RM4-7	1.92	Clear	H
	2.19	Clear	
RM4-8	1.92	30% EK + GD and 1:16 GS	M
RM4-9	2.02	33% EK + GD	L
	1.97	Clear	
RM4-10	1.99	Clear	H
RM4-11	2.07	Clear	H
	2.20	Clear	
RM4-12	1.82	25% EK + GD	M
	1.93	Clear	
RM4-13	2.11	Clear	H
	1.89	Clear	
RM4-14	1.99	Blue stain	H
RM4-15	1.86	1:14 GS	M
	2.12	Clear	

[a]CK is center knot, GD grain deviation, and GS slope of grain.
[b]M is medium, H high, and L low.
[c]Tested upside down because of below-grade tension lamination.

Table A2—Properties of 2 by 6 lumber used in tension lamination

Beam no.	MOE	Characteristic	Relative quality of midlength region
RM6-1	1.97	Clear	M
	2.19	20% GD	
RM6-2	1.84	Clear	H
	1.71	Clear	
RM6-3	1.95	Clear	M
	1.70	Low MOE	
RM6-4	1.93	30% EK + GD	L
	1.84	1:8-1:10 GS	
RM6-5[a]	2.04	Clear	M
	1.80	1:16 GS	
RM6-6	2.01	1:6-1:8 Edge GS	L
	1.84	Clear	
RM6-7	1.64	Low MOE	M
	2.00	Clear	
RM6-8	2.11	Clear	L
	1.81	33% EK + GD	
RM6-9	2.03	1:12 GS	L
	1.91	1:16 GS	
RM6-10	1.98	Clear	H
	2.25	Clear	
RM6-11	2.02	1:12 GS	L
	2.04	Clear	
RM6-12	1.88	Clear	H
	1.85	Clear	
RM6-13	1.65	Worm holes Low MOE	M
RM6-14	1.98	1:18 GS	M
	1.97	Clear	
RM6-15	1.83	Clear	H
	1.90	Clear	

[a]Tested upside down because of below-grade tension lamination.

Table A3—Properties of 2 by 8 lumber used in tension lamination

Beam no.	MOE	Characteristic	Relative quality of midlength region
RM8-1	2.22	Clear	H
	2.12	Clear	
	2.14	Clear	
RM8-2	2.21	Clear	L
	2.13	40% GD	
RM8-3	2.19	35% CK + GD	L
	2.21	Clear	
RM8-4	2.02	Clear	L
	2.00	1:6 GS	
	1.96	1:8 GS	
RM8-5a	2.06	Clear	L
	2.01	50% EK + GD	
	1.90	Clear	
RM8-6	2.03	Clear	L
	1.56	50% GD + Low MOE	
	2.10	30% EK + GD	
RM8-7	1.64	Clear + Low MOE	L
	1.88	1:12 Edge GS	
RM8-8	1.67	Clear	L
	1.97	1:8 Edge GS	
RM8-9[a]	1.71	1:12 GS	L
	1.55	1:12 GS + Low MOE	
RM8-10[a]	1.71	Clear	M
	1.62	Clear + Low MOE	
RM8-11	2.04	Clear	L
	1.81	1:16 GS + 20% GD	
	1.90	Clear	
RM8-12	2.08	Clear	M
	2.54	1:10 GS + 10% CK +GD	
RM8-13	1.40	40% CK + GD	L
	1.84	15% CK + GD	
	1.88	30% CK + GD	
RM8-14	1.79	1:8-1:11 GS	L
	1.74	1:13 GS	
	1.98	10% GD	
RM8-15	1.75	Clear	H
	1.96	Clear	

[a]Below-grade tension lamination. Beams were tested in their original orientation as a result of unbalanced layup.

Appendix B

Glulam Beam Results and Failure Descriptions

Tables B1 through B3 list the results of bending tests on 8-Lam, 12-Lam, and 16-Lam beams, respectively.

Table B1—Results of bending tests on 8-Lam red maple beams

Beam no.	Dimension Width (in.)	Dimension Depth (in.)	MC[a] (%)	Time to failure (min:s)	Load at failure ($\times 10^3$ lb)	Beam MOR[b] ($\times 10^3$ lb/in^2)	Beam MOE ($\times 10^3$ lb/in^2)	Failure type[c] (EJ/Lam)	Comment[d]
RM4-1	3.00	12.03	12	5:40	14.68	9.173	1.77	Lam	Mostly TL failure; 5% EJ failure at 10.5 ft, propagated through 2d Lam; observed GLF from 6.5 to 11 ft between 2d and 3d Lams.
RM4-2	2.91	12.03	12	10:30	17.72	11.162	1.87	Lam	Noise at 17 × 10^3 lb; mostly TL failure from 11 to 12 ft; 30% EJ failure in TL at 12.8 ft, propagated through EJ in 2nd Lam at 10.5 ft (95%).
RM4-3	2.98	12.00	10	6:39	12.08	7.645	1.73	Lam	Beam tested upside-down due to below-grade TL; TL failure (GS) from 6 to 7 ft, propagated to GLF between 2d and 3d Lams from 0 to 7 ft.
RM4-4	3.00	12.03	13	9:16	14.52	9.060	1.62	Lam	Noise at 11.5 × 10^3 lb, mostly TL failure at 9.8 ft; 25% EJ failure in TL at 7.8 ft.
RM4-5	2.99	12.50	12	10:02	16.24	10.131	1.81	Lam	Noise at 14 × 10^3 lb; brittle TL failure at 11.9 ft; more TL failure from 5 to 7 ft, propagated to EJ (100%) in 2d Lam at 12.5 ft.
RM4-6	3.00	12.03	12	8:36	13.62	8.501	1.75	EJ/Lam	Noise at 12.24 × 10^3 lb; failure in TL from 8 to 13 ft; also 10% EJ failure in TL at 10.5 ft; GLF between 1st and 2d Lams from 13 to 15 ft.
RM4-7	3.00	12.03	12	12:38	15.46	9.645	1.75	Lam	Noise at 12.5 × 10^3 lb; compression wrinkling in 8 to 12 ft region, initiated at 13.5 × 10^3 lb through failure; all TL failure at 7 to 8 ft
RM4-8	2.98	12.07	12	8:03	14.72	9.185	1.77	Lam	Noise at 14.2 × 10^3 lb; TL failure (GS) from 9 to 12 ft; several GLFs in gluelines between 4th and 5th Lams.
RM4-9	2.98	12.07	13	6:32	12.16	7.580	1.70	Lam	Noise at 10.2 × 10^3 lb; 10% EJ failure in TL at 10.6 ft, propagated through EJ in 3d Lam at 11.8 ft.
RM4-10	3.01	12.03	14	14:02	17.04	10.592	1.86	Lam	TL failure from 12.5 to 13.8 ft, propagated to EJ (5%) in 2d Lam at 9.6 ft; compression wrinkling in 8 to 12 ft region, initiated at 15,200 × 10^3 lb.

(Page 1 of 2)

Table B1—Results of bending tests on 8-Lam red maple beams-con.

Beam no.	Dimension Width (in.)	Dimension Depth (in.)	MC[a] (%)	Time to failure (min:s)	Load at failure (× 10^3 lb)	Beam MOR[b] (× 10^3 lb/in^2)	Beam MOE (× 10^3 lb/in^2)	Failure type[c] (EJ/Lam)	Comment[d]
RM4-11	3.00	12.07	12	8:23	15.18	9.410	1.88	EJ	No noise until failure; 100% EJ failure in TL at 12.5 ft; GLF between 4th and 5th Lams.
RM4-12	2.95	12.05	12	11:04	16.12	10.192	1.75	EJ	No noise until failure; 100% EJ failure in TL at 10.3 ft; brittle failure through 2d and 3d Lams; GLF between 5th & 6th and 6th & 7th Lams.
RM4-13	2.97	12.05	13	5:15	10.68	6.717	1.77	Lam	No noise until failure; brittle TL failure at 11.3 ft; GLF between 2d & 3d and 5th & 6th Lams.
RM4-14	2.97	12.03	12	8:13	14.98	9.441	1.92	Lam	Noise at 10.7 × 10^3 lb; compression wrinkling, initiated at 13.6 × 10^3 lb at 12 ft; brittle TL failure at 10.5 ft; GLF between 2d and 3d Lams from 13 to 17 ft.
RM4-15	3.00	12.05	13	6:45	12.23	7.611	1.81	Lam	Noise at 6.5 × 10^3 lb; TL failure at 7 to 10 ft to EJ (25%) in 2d Lam at 11.3 ft; slight compression wrinkling at failure at 12.5 ft.

[a]MC is moisture content.
[b]MOR calculations included dead load stress.
[c]EJ is end joint, GLF glueline failure, GS slope of grain, and TL tension lamination.

(Page 2 of 2)

Table B2—Results of bending tests on 12-Lam red maple beams

Beam no.	Dimension Width (in.)	Dimension Depth (in.)	MC (%)	Time to failure (min:s)	Load at failure (× 10^3 lb)	Beam MOR[a] (× 10^3 lb/in^2)	Beam MOE (× 10^3 lb/in^2)	Failure type (EJ/Lam)	Comment[b]
RM6-1	5.00	18.09	12	5:40	28.36	7.16	1.85	Lam	Noise at 15 × 10^3 lb; TL failure at 12 to 17 ft; 5% EJ failure in TL at 11.6 ft.
RM6-2	5.00	18.06	12	7:23	33.75	8.503	1.78	EJ	Noise at 15 × 10^3 lb; 60% EJ failure in TL at 12.5 ft; GLF between 7th and 8th Lams from 6 to 8 ft.
RM6-3	5.00	18.09	11	9:38	40.99	10.240	1.73	EJ	Noise at 23 × 10^3 lb; 100% EJ failure in TL at 15 ft; compression wrinkling at failure at 15.3 and 17.2 ft.
RM6-4	5.00	18.10	11	5:31	27.89	6.982	1.76	EJ/Lam	Noise St 13 × 10^3 lb; 50% EJ failure in TL at 16.3 ft, propagated to 100% EJ failure in 3d Lam at 17.3 ft.
RM6-5	5.00	18.10	12	6:23	31.20	7.808	1.73	EJ/Lam	Beam tested upside-down due to below-grade TL; noise at 25.5 × 10^3 lb; 40% EJ failure in TL at 17.5 ft; several GLFs between 6th and 7th Lams.
RM6-6	5.00	18.05	12	8:15	35.60	8.945	1.78	EJ/Lam	Noise at 14.2 × 10^3 lb; 70% EJ failure in TL at 20.6 ft, also TL failure at 17.5 ft; GLF between 5th and 6th Lams; secondary EJ failure (75%) in 2nd Lam at 16.6 ft.
RM6-7	5.00	18.05	13	8:24	36.51	9.172	1.78	Lam	Noise at 26 × 10^3 lb; all TL failure from 13 to 14 ft; GLF between 4th and 5th Lams from 0 to 9 ft.
RM6-8	5.00	18.05	13	7:08	32.00	8.050	1.78	Lam	Noise at 18.5 × 10^3 lb; TL failure (GD) from 14 to 16 ft; GLF between 6th and 7th Lams from 22 to 25 ft.
RM6-9	5.00	18.06	12	5:20	27.65	6.961	1.83	EJ/Lam	Noise at 21.5 × 10^3 lb; 30% EJ failure in TL at 14.5 ft, propagated through EJ (50%) in 2d Lam at 16 ft.
RM6-10	4.95	18.06	11	5:47	28.59	7.267	1.78	EJ/Lam	Noise at 21 × 10^3 lb; 40% EJ failure in TL at 11.8 ft, also TL failure from 11.8 to 14.5 ft, then to EJ (50%) in 2d Lam at 14.3 ft; GLF between 4th and 5th Lams.

(Page 1 of 2)

Table B2—Results of bending tests on 12-Lam red maple beams-con.

Beam no.	Dimension Width (in.)	Dimension Depth (in.)	MC (%)	Time to failure (min:s)	Load at failure ($\times 10^3$ lb)	Beam MOR[a] ($\times 10^3$ lb/in^2)	Beam MOE ($\times 10^3$ lb/in^2)	Failure type (EJ/Lam)	Comment[b]
RM6-11	5.00	18.10	10	5:07	26.64	6.681	1.82	Lam	Noise at 25 × 10^3 lb; mostly TL failure at 16.5 ft; 5% EJ failure at 17 ft; GLF between 1st and 2d Lams from 11 to 16 ft.
RM6-12	5.00	18.10	11	8:38	34.90	8.723	1.67	EJ/Lam	Noise at 16.5 × 10^3 lb; 25% EJ failure at 17.6 ft, to 100% EJ failure in 2d Lam at 18.3 ft; GLF between 4th and 5th Lams from 21 to 24 ft.
RM6-13	4.95	18.05	12	6:22	30.90	7.855	1.79	Lam	Noise at 23.5 × 10^3 lb; all TL failure at 14.3 ft, to 100% EJ failure in 2d Lam at 14.5 ft; GLF between 2d and 3d Lams from 12 to 14 ft.
RM6-14	5.00	18.05	13	5:47	29.00	7.304	1.76	EJ	Noise at 17 × 10^3 lb; 75% EJ failure in TL at 11.3 ft, propagated to 30% EJ failure in 4th Lam at 17.7 ft.
RM6-15	5.00	18.08	12	7:15	31.71	7.952	1.67	EJ/Lam	Noise at 9.5 × 10^3 lb; 100% EJ failure in TL at 11.7 ft; TL failure from 9 to 11.7 ft; GLF between 1st and 2d Lams.

[a]MOR calculations included dead load stress.
[b]EJ is end joint, GD grain direction, GLF glueline failure, GS slope of grain, and TL tension lamination.

(Page 2 of 2)

Table B3—Results of bending tests on 16-Lam red maple beams

Beam no.	Dimension Width (in.)	Dimension Depth (in.)	MC (%)	Time to failure (min:s)	Load at failure (× 10^3 lb)	Beam MOR[a] (× 10^3 lb/in^2)	Beam MOE (× 10^3 lb/in^2)	Failure type (EJ/Lam)	Comment[b]
RM8-1	6.75	24.12	14	8:52	69.60	9.690	1.82	Lam	Noise at 43 × 10^3 lb; TL failure from 16 to 20 ft.
RM8-2	6.75	24.09	11	6:25	57.00	7.980	1.82	Lam	Noise at 41 × 10^3 lb; TL failure (GD) at 24.5 ft, propagated to 50% EJ failure in 2d Lam at 24 ft.
RM8-3	6.74	24.09	11	6:52	60.00	8.399	1.79	EJ	Noise at 43 × 10^3 lb; 100% EJ failure in TL at 18.3 ft; compression wrinkling at failure at 22 ft.
RM8-4	6.70	24.13	11	5:15	47.50	6.697	1.77	EJ/Lam	Noise at 13 × 10^3 lb; 50% EJ failure in TL at 25 ft.
RM8-5	6.70	24.00	12	8:36	48.50	6.907	1.75	Lam	Noise at 20.5 × 10^3 lb; stacked EJ in Lams 2 and 3 (18.7 ft and 18.6 ft)[c]; joints not associated in failure–all TL failure from 24 to 25 ft.
RM8-6	6.75	23.97	12	12:38	54.30	7.681	1.77	Lam	Noise at 18 × 10^3 lb; TL failure (GD) at 16.5 ft, propagated to 50% EJ failure in 2d Lam at 17 ft.
RM8-7	6.75	24.00	13	8:03	59.20	8.342	1.78	EJ/Lam	Noise at 20 × 10^3 lb; 75% EJ failure in TL at 18 ft; 1:12 edge GS in TL at 17.5 ft leading into 75% EJ failure in 2d Lam at 17 ft.
RM8-8	6.75	23.94	13	6:32	50.60	7.184	1.81	Lam	Noise at 38 × 10^3 lb; TL failure (GS) from 20 to 21 ft, propagated to 80% EJ failure in 2nd Lam at 20.5 ft.
RMB-9	6.75	23.94	12	14:02	58.00	8.217	1.77	Lam	Noise at 33 × 10^3 lb; 10% EJ failure in TL at 20 ft, propagated through EJ (100%) in 2d Lam at 22.5 ft; compression wrinkling at failure in top Lam at 19 ft; EJ stacked in 1st and 2nd Lams at 12 ft–not involved in failure.[c]
RM8-10	6.75	24.20	11	8:07	66.50	9.202	1.79	Lam	Noise at 34 × 10^3 lb; all TL failure at 15 ft, propagated to 15% EJ failure in 2d Lam at 14 ft; GLF between 4th and 5th Lams; TL did not meet criteria.

(Page 1 of 2)

Table B3—Results of bending tests on 16-Lam red maple beams—con.

Beam no.	Dimension Width (in.)	Dimension Depth (in,)	MC (%)	Time to failure (min:s)	Load at failure ($\times 10^3$ lb)	Beam MOR[a] ($\times 10^3$ lb/in^2)	Beam MOE ($\times 10^3$ lb/in^2)	Failure type (EJ/Lam)	Comment[b]
RM8-11	6.75	24.03	10	6:28	54.10	7.615	1.87	EJ/Lam	Noise at 22 × 10^3 lb; 80% EJ failure in TL at 15.5 ft, propagated to 15% EJ failure in 2d Lam at 19.5 ft; GLF between 3d and 4th Lams from 1 to 7 ft.
RM8-12	6.75	24.08	11	5:15	59.50	8.328	1.75	EJ	Noise at 38 × 10^3 lb; 100% EJ failure in TL at 22.5 ft; compression wrinkling first detected in top Lam at 53 × 10^3 lb.
RM8-13	6.75	24.00	12	8:13	36.60	5.203	1.68	EJ/Lam	Noise at 28 × 10^3 lb; 50% EJ failure in TL at 14 ft; GLF between 7th and 8th Lams from 24 to 30 ft.
RM8-14	6.75	24.00	13	7:40	59.00	8.313	1.75	EJ	Noise at 34.5 × 10^3 lb; 95% EJ failure in TL at 15.5 ft, propagated to 25% EJ failure in 2d Lam at 17 ft; compression wrinkling first detected in top Lam at 55 × 10^3 lb; GLF between 9th and 10th Lams from 24 to 33 ft.
RMB-15	6.75	24.00	12	7:33	61.50	8.662	1.76	Lam	Noise at 16 × 10^3 lb; all TL failure at 18 ft; GLF between 7th and 8th Lams at 12 ft.

[a]MOR calculations include dead load stress.
[b]EJ is end joint, GD grain direction, GLF glueline failure, GS slope of grain, and TL tension lamination.
[c]Did not meet ANSI A190.1 requirements.

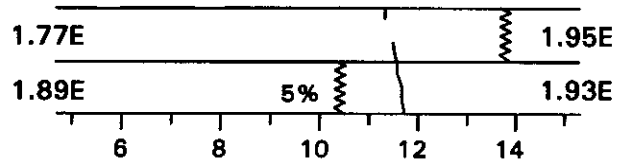
(Page 2 of 2)

Appendix C

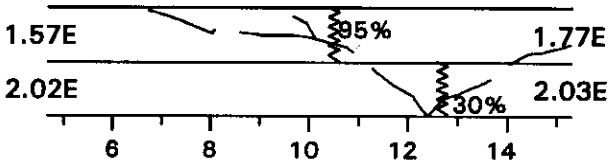
Glulam Beam Failure Maps and Lumber Properties

Location of failures in the tension zone of the beams is given in the figures. Failure through end joints is reported by an indication of the percentage of the failure that occurred at the joint itself. Modulus of elasticity values are given for each piece of lumber in the outer tension zone; the locations with reference to one end are given at the bottom of each figure.

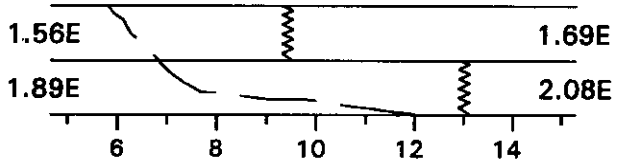
Beam No. RM4-1



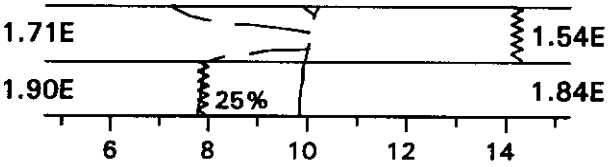
Beam No. RM4-2



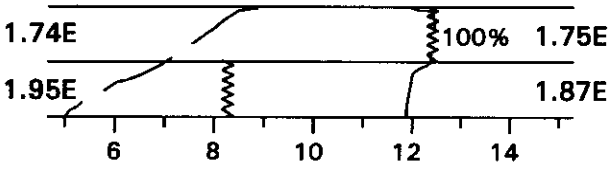
Beam No. RM4-3



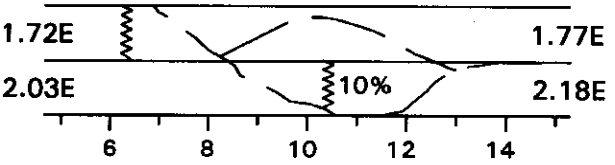
Beam No. RM4-4



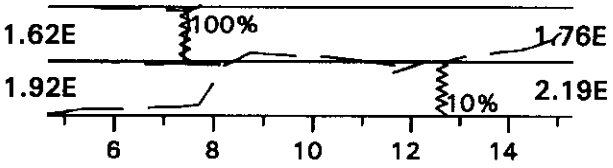
Beam No. RM4-5



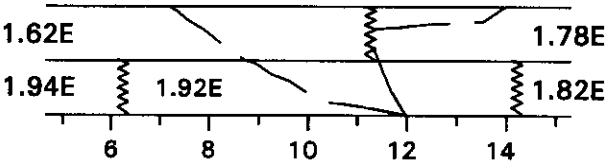
Beam No. RM4-6



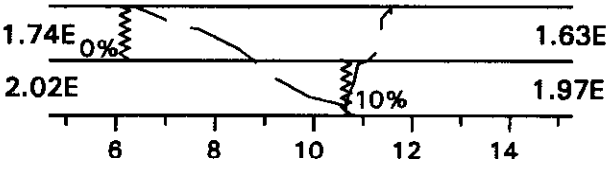
Beam No. RM4-7



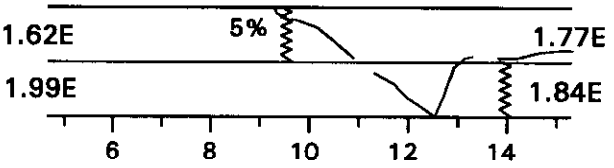
Beam No. RM4-8



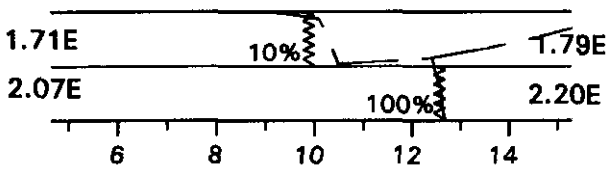
Beam No. RM4-9



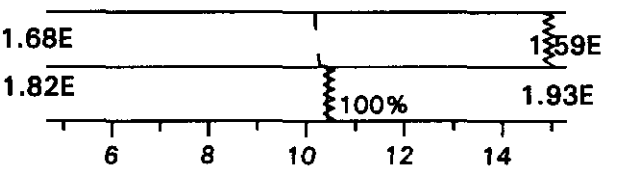
Beam No. RM4-10



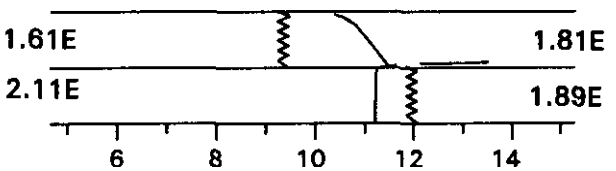
Beam No. RM4-11



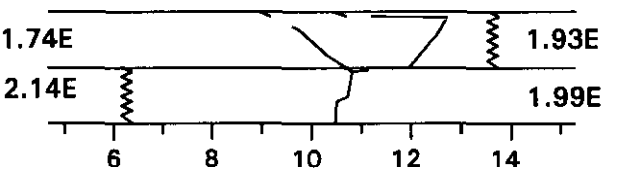
Beam No. RM4-12



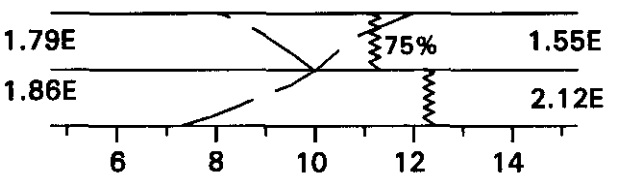
Beam No. RM4-13



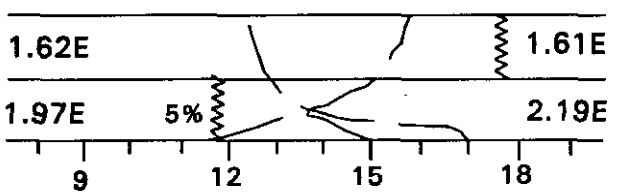
Beam No. RM4-14



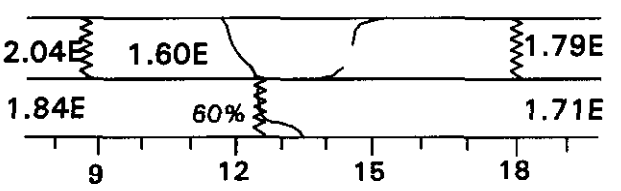
Beam No. RM4-15



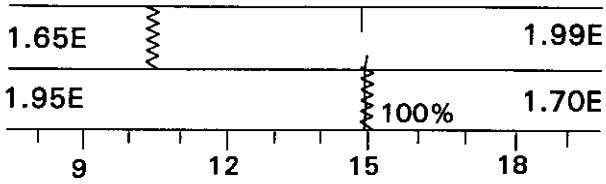
Beam No. RM6-1



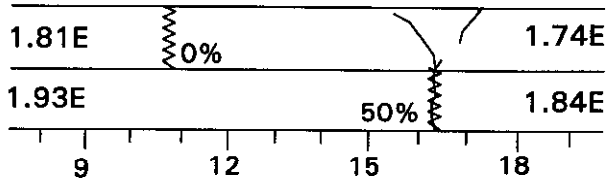
Beam No. RM6-2



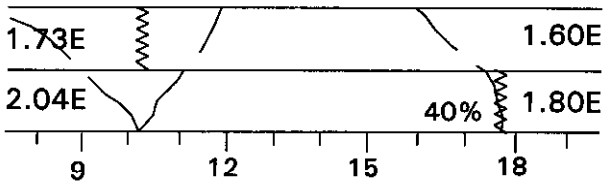
Beam No. RM6-3



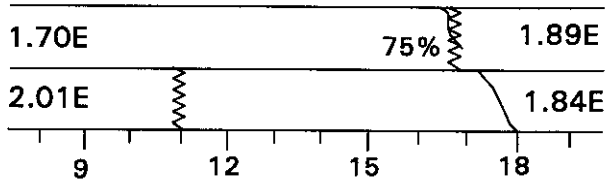
Beam No. RM6-4



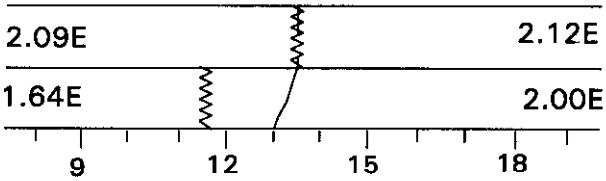
Beam No. RM6-5



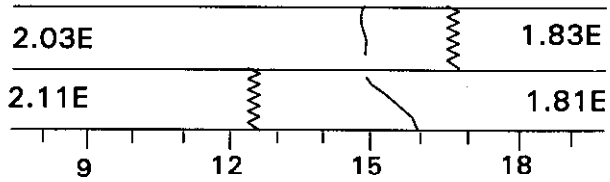
Beam No. RM6-6



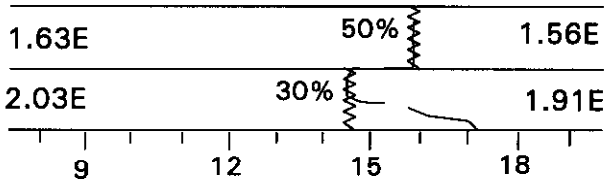
Beam No. RM6-7



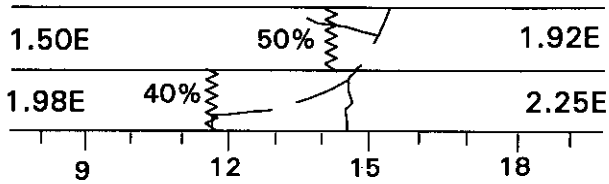
Beam No. RM6-8



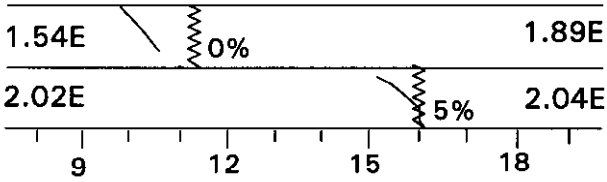
Beam No. RM6-9



Beam No. RM6-10

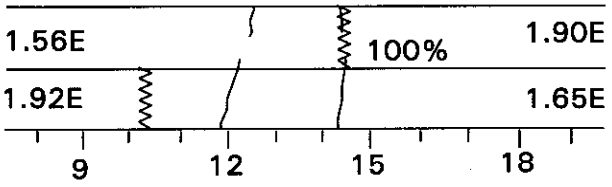


Beam No. RM6-11

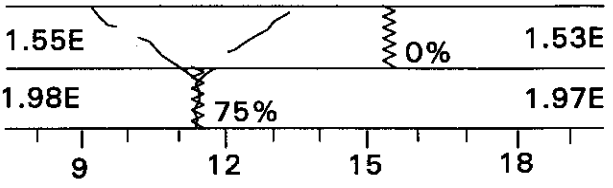


Beam No. RM6-12

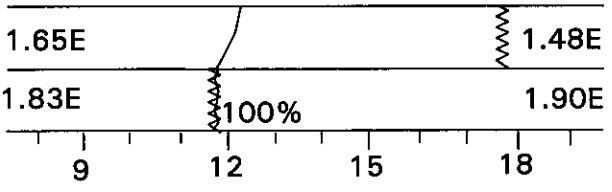
Beam No. RM6-13



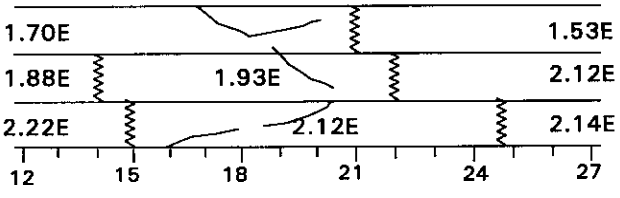
Beam No. RM6-14



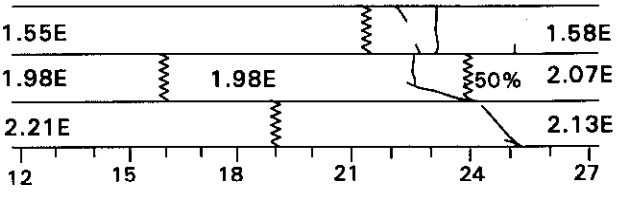
Beam No. RM6-15



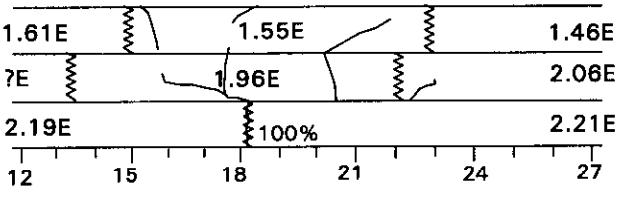
Beam No. RM8-1



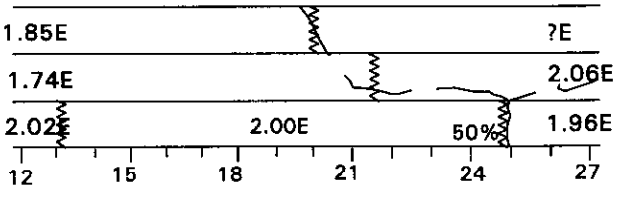
Beam No. RM8-2



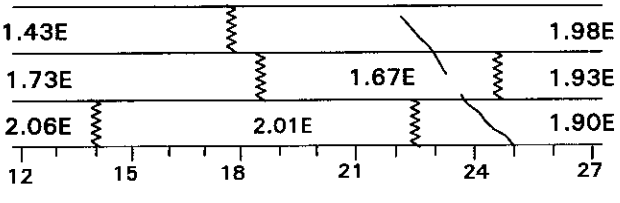
Beam No. RM8-3



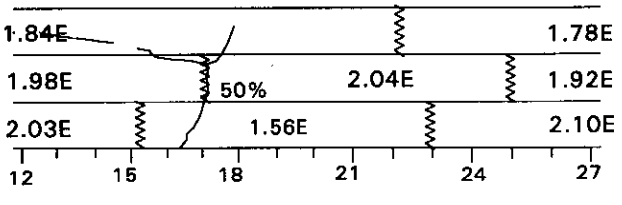
Beam No. RM8-4



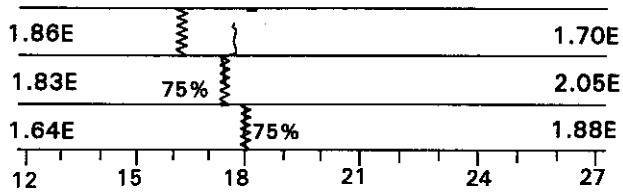
Beam No. RM8-5



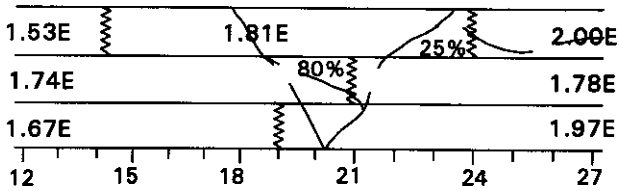
Beam No. RM8-6



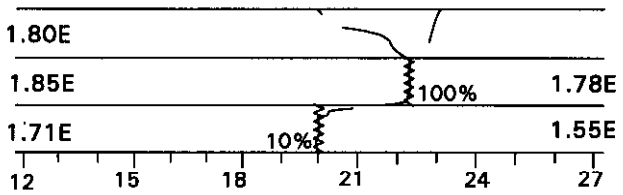
Beam No. RM8-7



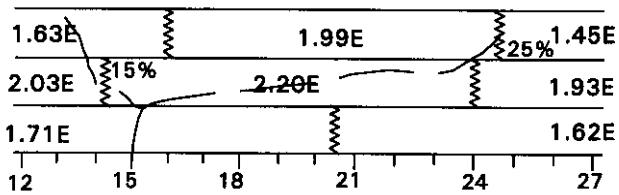
Beam No. RM8-8



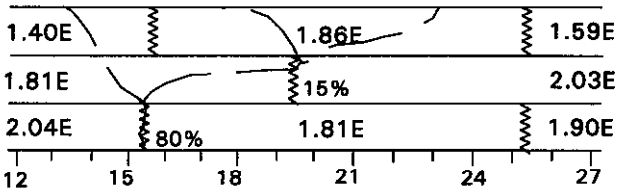
Beam No. RM8-9



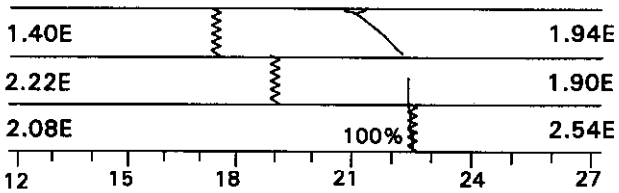
Beam No. RM8-10



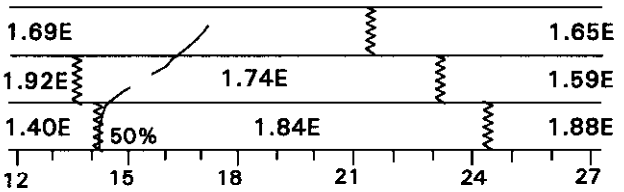
Beam No. RMB-11



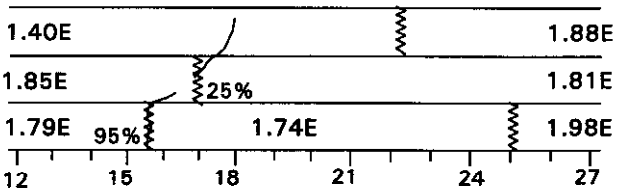
Beam No. RM8-12



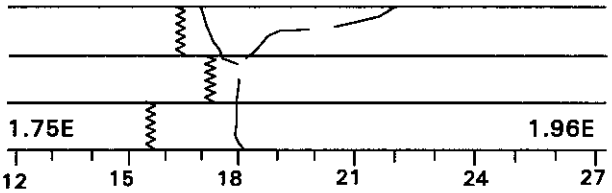
Beam No. RM8-13



Beam No. RM8-14



Beam No. RM8-15



Appendix D

Properties of Red Maple End-Jointed Lumber for Grades Other Than Tension Lamination Quality

Statistics reported include results for all end-joint specimens considered and for those specimens with joint-associated failures.

Table D—Results of tension tests on red maple end-jointed lumber for grades other than tension lamination quality using the lognormal distribution

Grade and property[a]	Lumber size 2 by 4	2 by 6	2 by 8	All sizes combined
2.0-1/6				
All specimens				
Sample size	10	20	5	35
Average TS (lb/in^2)	6,950	7,130	6,880	7,020
TS COV (%)	26.6	20.7	59.3	28.9
End-joint failures				
Sample size	8	16	5	29
Average SG	0.57	0.57	0.57	0.57
Average MC (%)	8.7	8.9	7.1	8.5
Average TS (lb/in^2)	7,030	7,160	6,880	7,050
TS COV (%)	30.0	21.1	59.3	31.0
1/3 EK[c]				
All specimens				
Sample size	14	19	21	54
Average TS (lb/in^2)	7,060	6,450	6,520	6,630
TS COV(%)	23.3	29.3	25.2	26.1
End-joint failures				
Sample size	9	12	13	34
Average SG	0.54	0.52	0.55	0.54
Average MC (%)	8.7	8.5	7.4	8.1
Average TS (lb/in^2)	7,040	6,580	6,830	6,790
TS COV (%)	15.2	31.9	20.1	23.6
No. 2				
All specimens				
Sample size	4	4	3	11
Average TS (lb/in^2)	5,720	5,180	4,990	5,270
TS COV (%)	35.1	43.7	3.9	30.9
End-joint failures				
Sample size	1	3	1	5
Average SG.	0.64	0.52	0.59	0.56
Average MC (%)	8.7	8.8	8.4	8.7
Average TS (lb/in^2)	6,230	5,740	5,160	5,670
TS COV (%)		50.6	—	35.9

[a]TS is tensile strength, SG specific gravity, and MC moisture content.
[b]Specimens with failures involving an end joint.
[c]Because of the percentage of small sample sizes, results for 2.0-1/3 and 1.8-1/3 grades were combined.