Chapter 9
Red Maple Lumber Resources for Glued-Laminated Timber Beams

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Several publications have presented experimental results on the mechanical performance of hardwood glued-laminated (glulam) timbers (Janowiak et al. 1995, Moody et al. 1993, Shedlauskas et al. 1994). These glulam studies are related to broader research efforts in the development of timber bridge systems. Glulam is a vital element for many proposed timber bridge designs. One key issue in bridge research is the use of local, underutilized forest resources. Published performance results of yellow-poplar, red maple, and red oak support the feasibility that hardwood glulam timbers are well-suited for bridge applications. These hardwood species are abundant, with significant saw-timber volume in the northeastern United States where annual growth accumulations exceed harvest.

This chapter evaluates the performance of red maple glulam beams made from two distinctly different lumber resources:

1. logs sawn using practices normally used for hardwood appearance lumber recovery; and
2. lower-grade, smaller-dimension lumber primarily obtained from residual log cants.

Cant refers to the remaining log heart or inner log portion after grade sawing removes the higher quality, outer zone material for appearance-type lumber.

Background

Several studies have emerged to explore the yield recovery and lumber properties of structural graded hardwoods (Green and McDonald 1993, Janowiak et al. 1992, McDonald et al. 1993). These study results indicated that hardwood design property values may only be conservatively estimated on the basis of clear wood computational procedures. Another study investigated joist and plank lumber grade yield from railroad switch ties for five hardwood species (McDonald et al. 1996), in an attempt to develop a structural lumber product that does not compete with hardwood sources used by the furniture industry. Preliminary results with red oak, hickory, yellow-poplar, and red maple switch ties indicate yields of nominal 2- by 7-inch lumber to exceed 90 percent No. 3 and Better lumber.

Railroad switch ties and log cants have significant potential as a source for structural lumber. Hardwood sawmills frequently avoid processing inner log portions because of inadequate appearance grade recovery. Hardwood cants sawn into structural lumber would provide sawmills with an enhanced opportunity for value-added production. In the recovery concept, the sawmill first obtains appearance-type lumber from high quality outer-log portions, then stress-graded dimension lumber from the heart cant. Small 2 by 4 or 2 by 6 nominal cant sawn lumber could be used to manufacture hardwood glulam timbers. Wide-width glulam timber products could be fabricated by manufacturing laminations with two narrow-width lumber specimens laid edge-to-edge. Using laminations made from lumber placed edge-to-edge is an accepted practice for glulam beam fabrication (ANSI 1992). More commonly, this practice is reserved where glulam beam width exceeds the largest available dimension lumber. These two-member laminations can include lumber pieces with either a glued or unglued edge joint.

Several articles have reported on the mechanical properties of edge-glued dimension lumber. Edge-glued southern pine lumber was studied to develop a solution to projected shortages of wider dimension construction lumber (McAlister 1973). Another study was conducted with Douglas-fir clear wood that was edge-glued in various combinations with structural No. 3 and L1, L2, and L3 lamination grades of lumber (Johnson 1978). Both studies suggest that edge-to-edge combinations can provide enhanced lumber products or beams with increased mechanical performance. This is due to the reduced influence of width effect in the laminating stock, as a result of using two narrow-width pieces of lumber.

Prior to this study, no research has been reported that thoroughly evaluated the mechanical performance of glulam products composed of unglued two-member laminations. Design stresses for these structural glulam timbers are established according to ASTM D3737 (ASTM 1993). For laminations, this standard specifies that lumber edge joints must be glued unless calculations or experimental data provide verification of structural performance. In addition, no research has been reported on glulam timber made from two-member laminations when tested in the vertically laminated orientation (loads applied parallel to the wide face of the laminations).

Objectives and Scope

Two studies were conducted on two types of material:

1. a glulam combination designed with E-rated lumber in 25 percent of the outer laminations (top and bottom) and visually graded lumber in 50 percent of the center laminations; and
2. a wide-width glulam combination with laminations made from nominal 2- by 4- and 2- by 6-inch No. 2 grade lumber laid edge-to-edge having staggered end joints (termed 2 by 4/2 by6 glulam combination).

In these studies, three objectives were addressed to examine several aspects of red maple glulam product performance. The first objective was to evaluate the performance of an efficient configuration of red maple glulam made with E-rated outer laminations and visually graded No. 2 grade red maple lumber in 50 percent of the inner laminations; referred to hereafter as Phase I of this research. Lumber for the Phase I portion of this study was obtained by using sawing methods that are common for structural softwood lumber. The second objective was to evaluate a similar combination that utilizes E-rated outer laminations and visually graded No. 3 lumber in the inner laminations; referred to hereafter as Phase II. Lumber for the Phase II portion of this study was obtained by sawing residual log cants obtained from logs that had been processed for removal of furniture-grade stock. The combinations for Phases I and II were developed to provide a target design stress of 2,400 psi with a design stiffness of 1.8×10^6 psi (24F- 1.8E glulam beam). The second study addressed the third objective, or Phase III, which focused on determining the bending strength, shear strength, and bending stiffness properties of glulam beams made with No. 2 grade laminations having unglued nominal 2 by 4's and 2 by 6's laid edge-to-edge, hereafter referred to as 2 by 4/2 by 6 beams.

Experimental Design

Previous research (Moody et al. 1993, Shedlauskas et al. 1994) showed that glulam combinations made from hardwood lumber could achieve design stresses of 2,400 psi in bending strength and 1.8×10^6 psi in bending stiffness. Based on these research studies, E-rated hardwood lumber properties were established for ASTM D3737 analytical procedures. Results of these previous studies provided estimates of the lumber properties **(Table 9.1).**

Phases I and II: 24F-1.8E Glulam Beams

Based on ASTM D3737 analytical procedures and the lumber property information in **Table 9.1,** the experimental 24F-1.8E beam configurations shown in **Figure 9.1, a through d** were developed. The glulam beam combinations were composed of similar outer zones of E-rated lumber and core zones of visually graded lumber. For the 24F-1.8E combinations, allowable edge knot size of the E-rated lumber for the outermost tension laminations was limited to one-sixth the area of the cross section. Edge knot size in the outer compression laminations was restricted to one-third the area of the cross section. Bending stiffness for the outermost tension and compression zones required E-rated lumber meeting an average MOE of 2.0×10^6 psi. Edge knot size in the next inner tension and compression laminations was restricted to one-third the area

Table 9.1. – Estimated property values of red maple lumber for use in ASTM D 3737 procedures.

Lamination grade	Modulus of elasticity	$\bar{x}$[a]	$\bar{x} + h$[b]	SR_{min}[c]	Bending stress index
	($\times 10^6$ psi)	- - - - - - - (%)	- - - - - - -		(psi)
2.0-1/6	2.0	3.0	27.0	0.70	3,250
2.0-1/3	2.0	5.0	35.0	0.60	3,250
1.8-1/3	1.8	5.0	35.0	0.60	2,750
No. 2	1.5	8.0	42.0	0.54	2,470
No. 3	1.4	10.0	50.0	0.39	2,470

[a] $\bar{x}$ is average of sum of all knot sizes within each 1-foot length, taken at 0.2-foot intervals.
[b] $\bar{x} + h$ = 99.5 percentile knot size (ASTM 1993).
[c] SR_{min} is minimum bending strength ratio.

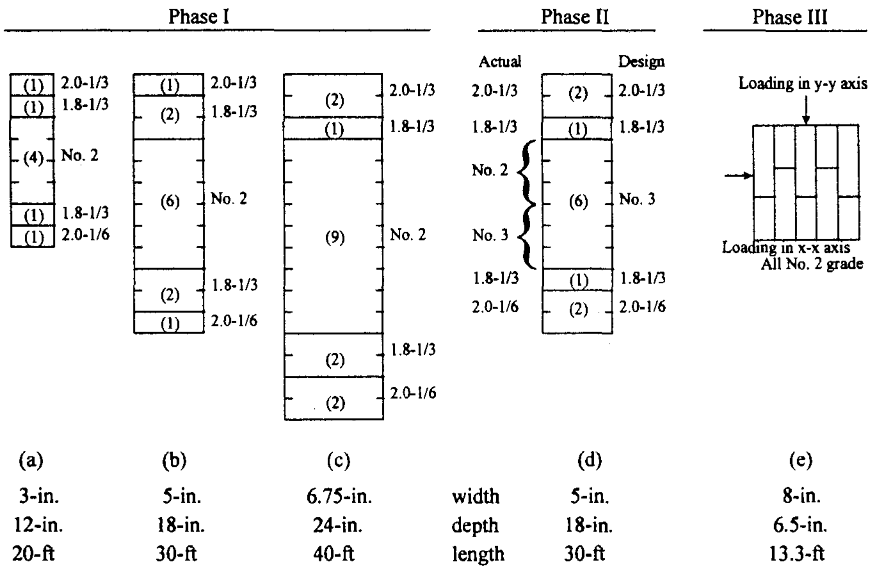


Figure 9.1. – Illustration of red maple glulam. Phase I beams (a-c) are 24F-1.8E combinations made from lumber sawn from whole trees. Phase II (d) is a 24F-18E combination made from lumber sawn from log cants. Phase III (e) is a wide-width combination made from cant-sawn 2 by 4 and 2 by 6 lumber.

of the cross section. Bending stiffness for the next inner zones required average lumber MOE values of 1.8×10^6 psi. In **Figure 9.1,** note that slight differences exist in the proportion of laminations comprising the E-rated lumber grades. However, in all configurations, at least 50 percent of the inner laminations were visually graded lumber. In addition, ASTM D3737 procedures require that 5 percent of the outermost tension laminations be replaced with a special tension grade lumber. The tension lamination criteria required by Phase I and II of this research are summarized in **Table 9.2.**

Phase III: 2 by 4/2 by 6 Wide-Width Glulam Beams

Phase III of this research also targeted the evaluation of the 2 by 4/2 by 6 beams for bending strength about the y-y beam axis and horizontal shear strength about the same y-y beam axis. The dimensions of the 2 by 4/2 by 6 beams in Phase III were designed with a staggered arrangement of nominal 2 by 4's and 2 by 6's **(Fig. 9.1),** having a total of five laminations. Visually graded No. 2 red maple lumber was used throughout the layup, and the edge interface between the 2 by 4 and 2 by 6 plies was not glued. In the AITC 119 standard (AITC 1996), vertically laminated red maple glulam beams with four or more

Table 9.2. – Maximum allowable tension lamination criteria for 24F-1.8E glulam beam combinations.

	Maximum allowable characteristic[a]			
	Phase I			Phase II
Characteristic	(a)[b]	(b)[b]	(c)[b]	(d)[b]
Edge knot + grain deviation	40%	30%	30%	30%
Center knot + grain deviation	45%	33%	33%	40%
Slope of grain	1:14	1:16	1:16	1:16

[a] Knots plus grain deviations are given in percentages of cross section per ASTM D 3737 (ASTM 1993).

[b] Letters correspond to the glulam beam combinations in Figure 9.1.

laminations of No. 2 grade lumber have assigned design bending stresses about the y-y beam axis (F_{by}) of 1,450 psi, and design horizontal shear about the y-y beam axis (F_{vy}) of 160 psi. When laminations are made using edge-to-edge lumber, F_{vy} values are reduced to 65 psi.

Materials and Methods

The following sections discuss the methods for processing, grading, testing, and laminating the red maple lumber. For additional details of these methods, refer to the comprehensive reports by Manbeck et al. (1993) for material relating to Phase I and by Janowiak et al. (1995) for material relating to Phase II and III.

Lumber Manufacture

Lumber for manufacture of the 24F-1.8E glulam combinations for Phase I was obtained by sawing red maple logs into green 8/4 (2-in.) dimensional material. After drying, the material was rough-planed to a thickness of 1.75 inches. The rough-sawn lumber was then visually graded by NELMA (1991) rules to obtain Select Structural, No. 1, No. 2, and No. 3 grades of structural lumber.

Lumber for manufacture of the 24F-1.8E and 2 by 4/2 by 6 glulam combinations evaluated in Phases II and III was processed from residual red maple log cants. Red maple logs were harvested from several north central Pennsylvania sites. Logs were first processed with primary breakdown to recover appearance grade hardwood lumber. Primary breakdown included sawing of appearance-type lumber to recovery down to a No. 3A Common National Hardwood Lumber Association grade face (20). After appearance material was removed, the log hearts (approximate 6-in. to a minimum 4-1/2-in. dimension cants) were processed through a secondary bandmill resaw operation. Cants were sawn to a heavy 6/4 (final dressed thickness will equal 1.5 in.) hardwood lumber thickness tolerance. Immediately after sawing, the rough lumber was tallied to monitor the amount of 2 by 4 and 2 by 6 material available for experimental beam fabrication and graded green according to NELMA grading rules.

Grading, Sorting, and Stiffness Evaluation

For all Phases, the sawn lumber was visually sorted into the desired lumber grades. Both studies included tension lamination-quality lumber, lumber with one-sixth and one-third edge-knot size restrictions, as well as the visually graded No. 2 and No. 3 lumber. In both studies, lumber that failed to meet both of the edge-knot requirements was assigned to the visually graded lumber for each study. For Phase III, additional sorting was conducted to separate supplies of nominal 2 by 4 and 2 by 6 No. 2 lumber for fabrication of the 2 by 4/2 by 6 glulam beams.

When the lumber grades were visually sorted, similar procedures were used in both studies to test the lumber for stiffness. Testing was conducted using commercial transverse vibration equipment (Metriguard 1993). Each piece of lumber was marked with an identification number, and the corresponding stiffness was recorded. In each study, a small sample of lumber was tested for flatwise MOE as specified in AITC T116 (AITC 1992) to establish a regression relationship between dynamic and static lumber MOE. Special tension lamination material meeting the criteria in **Table 9.2** was selected from the available E-rated 2.0-1/6 lumber.

Knot Properties

After the required amounts of lumber were sorted, knot property data were measured for most of the grades. Knot data were collected for all specimens of special tension lamination material, all 2.0-1/6 pieces, and randomly selected samples of the 2.0-1/3, 1.8-1/3, No. 2, and No. 3 lumber intended for the 24F-1.8E glulam beams. Additional knot data were collected for the No. 2 grade 2 by 4 lumber intended for the 2 by 4/2 by 6 beam fabrication. Knot data were later analyzed according to procedures in USDA Technical Bulletin 1069 (Freas and Selbo 1954).

Glulam Beam Manufacture

24F-1.8E glulam beams. – For Phase I, 45 beams (15 of each of 3 combinations in **Fig. 9.1, a-c**) were manufactured along with extra specimens of finger-jointed lumber. Finger-joint specimens were fabricated for test evaluation purposes. For Phase II, 15 beams of a single combination **(Fig. 9.1, d)** were manufactured along with finger-jointed lumber test specimens.

For Phase I, manufacture of the beams followed production procedures (ANSI 1992) normally used for softwood glulam. This included the types of adhesives for finger jointing and face jointing the lumber, planing speeds of finger-jointed laminations, spread rates for the adhesives, open assembly times for the adhesives, and clamping pressures used during curing. Based on results (discussed later) of the manufacture of Phase I beams, two slight modifications were made to the manufacture of the Phase II beams. The lumber feed rates into the surface planer were reduced and clamping pressures applied during glulam beam curing were increased.

During Phase II, greater than anticipated drying losses of No. 3 grade lumber resulted; therefore, approximately half the core laminations of No. 3 grade lumber were replaced with No. 2 grade lumber. The No. 3 grade laminations were placed on the more critical tension side of the core, and No. 2 grade laminations were placed in the compression side of the core as shown in **Figure 9.1.**

Finger-joints used in both studies were vertically oriented (fingers visible on the wide face of the lumber). Because of the low-quality cant-sawn lumber resource for Phases II and III, it was difficult to obtain adequate sample sizes of lumber specimens meeting the special tension lamination grade requirements for both glulam beam and finger-joint specimen manufacture of Phase II. Thus, beam manufacture was given greater priority for allocation of available tension lamination material compared with finger-joint sampling. The resulting shortage of tension lamination-quality material resulted in finger-joint specimens that were heavily weighted toward the maximum characteristics allowed in the grade, which may not have been representative of those used in beam manufacture.

2 by 4/2 by 6 glulam beams. – The 2 by 4/2 by 6 glulam beams (Phase III) were manufactured with five laminations that resulted in approximately a 6.5-inch depth, 8-inch width, and 13.3-foot length. Procedural steps followed for manufacture of 2 by 4/2 by 6 glulam beams were almost identical to conventional lumber lamination procedures. One major difference was that lumber widths were staggered in adjacent beam lamination layers during final layup **(Fig. 9.1,e).** No attempt was made to bond the lumber on the longitudinal edge-to-edge joint. Some edge-to-edge joints became partially bonded as adhesive flowed into a joint as a result of the application of clamp pressure during beam assembly. Edge-joint quality varied from having tight-edge surface contact to open gaps observed along the lamination edge length. **Figure 9.2** shows a cross section of a 2 by 4/2 by6 glulam beam to illustrate the variable nature of edge-joint gaps. Fifteen 13.3-foot-long 2 by 4/2 by 6 beams were fabricated for evaluation of bending strength and twelve 7.5-foot-long 2 by 4/2 by 6 beams were fabricated for evaluation of horizontal shear strength.

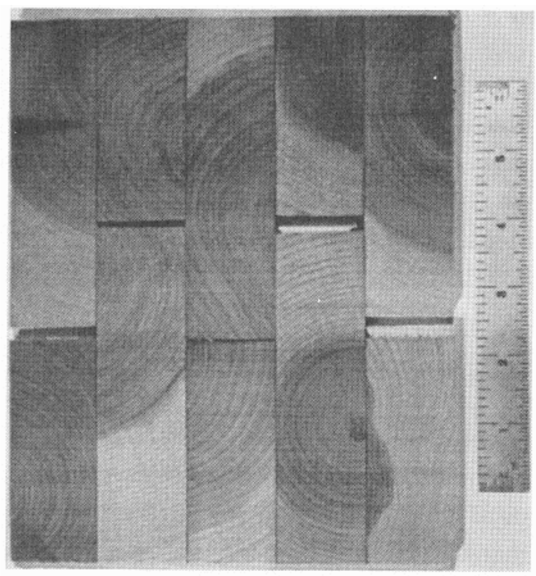


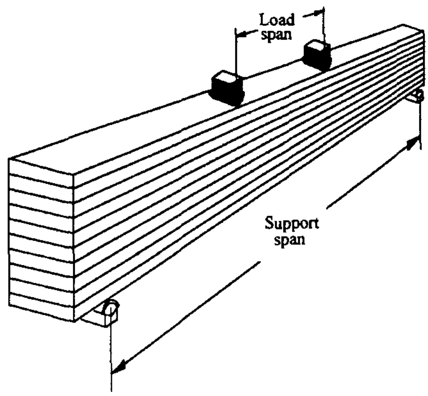
Figure 9.2. – Cross section of 2 by 4/2 by 6 glulam beam with glueline gaps.

Evaluation Procedures

Testing equipment and procedures for evaluating the glulam beams and the end-jointed lumber specimens followed criteria in ASTM D198 (ASTM 1993).

Phases I and II: 24F-1.8E glulam beams. –The glulam beams were destructively evaluated using ASTM D 198 procedures. Loading configurations for both Phases are shown in **Figure 9.3a.** Long-span deflection was measured at the neutral axis over the unsupported beam length. Physical properties of weight, moisture content (MC), and dimensions were measured on individual beam specimens. Measurements were recorded for the failure load and time-to-failure tests. Efforts were also made to characterize failure type with sketches of beam failure pattern. MC was determined after failure using a resistance-type moisture meter with measurements on each lamination near a mid-span location. Beam weights were measured prior to testing on a mobile scale to an approximate 10-pound accuracy. Dimensions of width and depth

(a)



Combination from Fig. 1	Support span (ft)	Load span (ft)
(a)	19	4
(b)	28.5	6
(c)	38	8
(d)	28.0	6
(e)	12.5	4.17

(b)

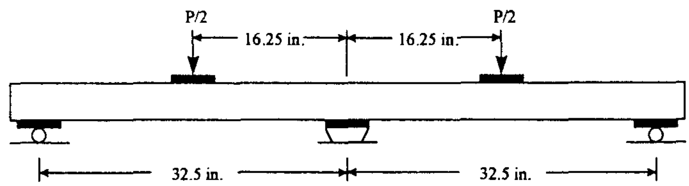


Figure 9.3. – Loading configurations for bending (a) and shear (b) tests of red maple glulam beams.

were taken at beam load positions. During loading, full-span deflection readings were recorded at specified incremental loads to compute beam stiffness from a regressed fit of load-deflection data up to design load.

Phases I and II: Finger-jointed lumber. – The finger-jointed specimens were evaluated to determine their ultimate joint tensile strength. Test specimens were face- and surface-planed prior to testing to similar dimensions as the laminations used for beam manufacture. Prior to test, each specimen was evaluated with an E-computer to obtain a dynamic modulus of elasticity (MOE) measurement. Specimens were approximately 8 feet long with the finger-joint located near mid-length. Tests included a 30-inch gage length centered between machine grips, with increasing tensile load applied until failure. Loading rate was calibrated to achieve an approximate 5- to 10-minute time to failure. This loading is longer than the 3- to 5-minute test duration recommended by AITC TI 19 (AITC 1992) for daily quality control testing. The 5- to 10-minute duration used here coincides with the failure times targeted for the full-size glulam beam tests, which followed ASTM D198 procedures.

Phase III: 2 *by 4/2 by 6 glulam beams.* – Flexural tests followed ASTM D198 procedures for all 2 by 4/2 by 6 glulam beam specimens. A computerized data-acquisition system was used to monitor load-deflection response. Loading rate for maximum load was adjusted for a 5- to 10-minute time-to-failure test duration. Deflection measurements were taken using a linear variable differential transformer (LVDT) on a yoke affixed to the neutral axis of the specimen. The MOE values were computed from a linear regression analysis of load-deflection data up to design load.

The 2 by 4/2 by 6 specimens of 80-inch (7.5-ft.) length were also processed from the 2 by 4/2 by 6 glulam material to characterize beam shear strength. Beam shear strength evaluation was conducted utilizing a five-point loading scheme recommended by Soltis and Rammer (1994). The test apparatus consists of three reaction supports, located at either beam end and mid-span, and two loading points, each located equidistant from mid-span **(Fig. 9.3b).** Specimen length was 10 times the member depth, with span between the reaction supports equal to 5 times the depth. Concentrated loads were applied through bearing plates to minimize compressive failure. Test speed was selected so that shear failures would occur between 5 and 10 minutes after load application. After failure, beam shear failure zones were sketched and MC determined with a resistance-type meter.

ASTM D143 (ASTM 1993) shear block specimens were fabricated using wood samples obtained from locations adjacent to the shear failure zones of the 2 by 4/2 by 6 glulam beams. An evaluation could include one or more observations of shear strength relative to the multiple lumber piece construction. Individual observations were averaged as a measurement of ASTM D143 shear strength for each failed 2 by 4/2 by 6 lamination. Two data sets were developed with one set tested at ambient or unconditioned MC and the other after conditioning to constant weight at 12 percent equilibrium MC.

Evaluation Results

Glulam Manufacture

The glulam beam maps compiled during beam manufacture were analyzed to determine if the targeted laminating lumber MOE criteria in **Table 9.1** were achieved. **Table 9.3** gives a statistical summary of MOE measurements of those lumber specimens used in the fabricated beams for the 24F-1.8E glulam combinations from Phases I and II and the 2 by 4/2 by 6 glulam combinations from Phase III. Note that the special tension lamination, and all the E-rated grades (2.0-1/6,2.0-1/3,1.8-1/3) were close, met, or slightly exceeded the targeted average MOE values. Both visual grades (No. 2 and No. 3) greatly exceeded the assumed property value in **Table 9.1.**

Table 9.3. – Modulus of elasticity values of sorted laminating lumber in glulam beams.

Lumber section	Lumber grade	No. of pieces	Average MOE	Coefficient of variation
(in.)			(× 10^6 psi)	(%)
Phase I				
2 by 8	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
2 by 6	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 4	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	1.8	16.2
Phase II				
2 by 6	TL[a]	55	2.15	7.8
	2.0-1/6	56	2.05	9.7
	2.0-1/3	113	2.02	9.4
	1.8-1/3	114	1.79	9.1
	No. 3	25	1.68	11.4
Phase III				
2 by 6	No. 2	160	1.84	10.9
2 by 4	No. 2	161	1.82	15.3

[a] TL is tension lamination.

The measured knot properties on the sorted lumber grades were also analyzed to determine knot size statistics. **Table 9.4** includes a statistical summary of the knot sizes observed in each grade for lumber used in both the 24F-1.8E and 2 by 4/2 by 6 glulam beam combinations.

Phases I and II: 24F-1.8E glulam beams. – During testing, beams emitted fiber fracture sounds before reaching ultimate failure load. Some beams were observed with localized compressive wrinkling between the load points prior to ultimate failure on the tension side. Most failures were attributed to finger-joints, and other beams failed because of a combination of finger-joint and other intrinsic strength-controlling characteristics. In Phase I, shallow wood

Table 9.4. – Actual knot sizes of sorted laminating lumber.

Nominal lumber size	Lumber grade	Lineal footage	$\bar{x}$[a]	$x + h$[b]
		(ft)	------- (%) -------	
Phase I				
2 by 8	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
2 by 6	2.0-1/6	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 4	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
Phase II				
2 by 6	TL[c]	212	0.5	15.0
	2.0-1/6	282	1.5	34.8
	TL and 2.0-1/6	494	0.9	29.3
	No. 3	221	5.2	51.5
Phase III				
2 by 6	No. 2	221	2.3	27.4
2 by 4	No. 2	200	3.0	47.5
2 by 4/2 by 6	No. 2	421	2.7	36.4

[a] $\bar{x}$ is average of sum of all knot sizes within each 1-foot length, taken at 0.2-foot intervals.
[b] $\bar{x} + h$ = 99.5 percentile knot size (ASTM 1993).
[c] TL is tension lamination.

failures were observed at the gluelines of the failed beams. Examination of the gluelines suggested this related to a probable inadequacy in clamping pressure. These types of glueline failures were not observed in the failed beams of Phase II. Therefore, the modifications to the manufacturing process (discussed earlier) appeared to be successful. Results of 24F-1.8E beam strength and stiffness test evaluations are summarized in **Table 9.5.** All calculations of glulam beam MOR include the dead weight of the beams.

Phases I and II: finger-jointed lumber. –Tensile strength, MC, and specific gravity results for the finger-jointed special tension lamination specimens are given in **Table 9.6.**

Table 9.5. – Summary of bending test results on red maple glulam beams.[a]

	Phase I			Phase II	Phase III
	(a)[b]	(b)[b]	(c)[b]	(d)[b]	(e)[b]
Sample size	15	15	12	15	15
Moisture content (%)	12	12	12	13	9
Modulus of rupture[c]					
Average (psi)	9,080	7,980	7,860	7,980	6,630
Coefficient of variation (%)	14.4	12.1	15.8	12.1	10.8
5th percentile at 75% tolerance (psi)	6,760	6,230	5,630	6,230	5,320
Adjusted to design[d] (psi)	3,020	3,180	3,140	3,180	2,360
Modulus of elasticity					
Horizontally laminated					
Average (psi)	1.78	1.77	1.78	1.77	1.86
Coefficient of variation (%)	4.3	3.0	2.7	3.0	8.3
Vertically laminated					
Average (psi)					1.87
Coefficient of variation (%)					7.1

[a] Lognormal distribution assumed for strength properties: normal distribution assumed for stiffness and moisture content.
[b] Letters in parentheses refer to glulam beam combinations from Figure 9.1.
[c] For 24F-1.8E glulam beams, load was applied perpendicular to wide face of laminations; for 2 by 4/2 by 6 glulam beams, load was applied parallel to wide face of laminations.
[d] Adjusted MOR equals 5th percentile divided by $Cy = (5.125/W)^{0.1}$ $(21/L)^{0.1}$ $(12/d)^{0.1}$ and by 2.1.

Table 9.6. – Results of finger-jointed red maple tension lamination material (specimens with failure involving end joint).[a]

	Phase I			Phase II
Property	2 by 4	2 by 6	2 by 8	2 by 6
Sample size	19	26	18	15
Average moisture content (%)	8.6	8.6	7.8	13.1
Average specific gravity[b]	0.57	0.57	0.56	0.55
Average tensile strength (psi)	8,470	8,720	8,010	6,490
COV tensile strength (%)	27.6	21.1	16.2	27.0

[a] Moisture content is based on ovendrying methods; strength calculations assume a lognormal distribution.
[b] Based on volume at time of test and ovendry weight.

Phase III: 2 by 4/2 by 6 combination glulam beams. – For bending tests of the 2 by 4/2 by 6 glulam beams, the majority of failures involved a strength-reducing characteristic, such as knots, slope of grain, or grain deviation. The use of the edge-to-edge laminations did not appear to affect the bending strength results. Summary results from the flexural testing are presented in **Table 9.5.**

For the horizontal shear tests of the 2 by 4/2 by 6 glulam beams, the first audible sound of failure was emitted at ultimate load; then the load-carrying capacity was observed to decrease. Because no catastrophic failure was observed during this loading sequence, cross sections of each of the 12 beams were cut at the location of failure, and the propagation of horizontal shear failure was observed. Summary test results for beam horizontal shear and the ASTM D143 shear-block are given in **Table 9.7.**

Table 9.7. – Results of shear strength (τ) for Phase III.[a]

	Average MC	Average τ	COV of τ	$\tau_{0.05}$ at 75% tolerance	$(\tau_{adjusted})$[b]
	(%)	(psi)	(%)	(psi)	
2 by 4/2 by 6 glulam beams	--	1,730	7.4	1,490	--
ASTM D 143 block shear specimens					
Unconditioned	8.7	1,940	11.8	1,490	364
Conditioned to 12% EMC	12.7	1,830	8.5	1,540	384

[a] EMC is equilibrium moisture content; COV is coefficient of variation; MC is moisture content based on ovendrying method. All shear calculations assume a lognormal distribution.
[b] $(\tau_{adjusted}) = \tau_{0.05}$ divided by 4.1 per ASTM D 3737 for block shear values.

Analysis of Results

The analysis conducted in this section assumes the lognormal distribution for strength property characterization, recommended by ASTM D3737. Analysis of glulam MOE, MC, and specific gravity were conducted assuming the normal distribution.

Design Strength and Stiffness Comparison

Phases I and II: 24F-1.8E glulam beams. – The design bending strength values of the 24F-1.8E glulam beams were calculated and are reported in **Table 9.5.** Note that the design bending strength levels calculated for each combination from Phases I and II far exceed the targeted 2,400 psi. More importantly, the results for all combinations between the lowest and highest calculated design bending strengths were approximately 5 percent. This provides strong evidence that the E-rating process can assure that the properties of the laminating lumber are adequate, regardless of the lumber resource.

For glulam beam bending stiffness, average MOE values are reported in **Table 9.5.** Note that in both studies, average glulam beam MOE values met or exceeded the targeted 1.8×10^6 psi beam stiffness. In addition, as is typical with the use of E-rated lumber in glulam manufacture, the variability of beam MOE was quite low, as shown by the coefficient of variation in beam MOE reported in **Table 9.5.**

Phases I and II: finger-jointed lumber. – For structural finger-joints, the ANSI A190.1 (3) standard requires that the 5th percentiles of finger-joint tensile strength (at 75% tolerance) meet a strength level that is 1.67 times the targeted design bending strength of the glulam beams. For the 2,400 psi glulam combinations, the finger-joints were required to meet a 5th percentile tensile strength of approximately 4,010 psi. **Table 9.6** summarizes the finger-joint test results. For the finger-joints tested in Phase I, the 2 by 6 and 2 by 8 finger-joints exceeded the targeted strength level, whereas the 2 by 4 finger-joints were approximately 2 percent short of meeting the targeted level.

In Phase II, however, the 2 by 6 finger-joints fell short of the targeted strength level by approximately 15 percent. Taking into consideration that the Phase II beams had nearly identical design bending strength performance as the Phase I beams, and that the sample of finger-joints reported in **Table 9.6** is heavily weighted toward the maximum allowable strength-reducing characteristics, all evidence indicates that the finger-joints used for beam manufacture in Phase II were adequate for the 2,400 psi design bending strength.

Phase III: 2 by 4/2 by 6 glulam beams. – The results in Table 9.5 show that the calculated design bending strength for the 2 by 4/2 by 6 glulam beam combination was 2,360 psi, which greatly exceeds the published design bending stress for No. 2 red maple of 1,450 psi (AITC 1996).

From **Table 9.7,** the calculated 5th percentile (at 75% tolerance) of horizontal shear strength for the 2 by 4/2 by6 glulam beams was 1,490 psi. Methods for determining horizontal shear design values from glulam beam test results are not established. For small, clear test specimens, design values for horizontal shear strength are determined by dividing the calculated 5th percentile horizontal shear strength of ASTM D143 shear block specimens by a factor of 4.1, which accounts for a combined effect of duration of load, stress concentration, and safety. Given that published design horizontal shear strength for No. 2 red maple glulam with multiple-piece laminations and having four or more laminations is 65 psi, the results observed in **Table 9.7** would greatly exceed published values, even with a factor of 4.1.

For bending stiffness, the AITC 119 standard publishes the same value for orientations loaded with respect to the y-y and x-x beam axes (see **Fig. 9.1** for orientations). For No. 2 red maple glulam, the published MOE is 1.3×10^6 psi, which is very conservative compared with the 1.87×10^6 psi experimental value observed in the y-y orientation and the 1.86×10^6 psi value observed in the x-x orientation (Table 9.5).

Predicted Strength and Stiffness Comparison

In this section, ASTM analysis procedures were used to predict the performance of the glulam test results using the available lumber properties information.

Phases I and II: bending strength of 24F-1.8E. –Actual MOE data from **Table 9.3** and actual knot property data from **Table 9.4** were used to predict the performance of the 24F-1.8E glulam combinations using ASTM D3737 procedures. Knot property information from Phase I was used for the 2.0-1/3 and 1.8-1/3 grades in both Phases I and II. Minimum strength ratios were used as originally planned **(Table 9.1).** For bending stress indices, a value of 3,250 psi for E-rated lumber having an average MOE of 2.0×10^6 psi (2.0E) was originally used **(Table 9.1)** for development of the 24F-1.8E glulam combinations. This value is currently in the ASTM D3737 standard, which is based on a linear interpolation between a bending stress index value of 3,000 psi for 1.9E lumber to a bending stress index of 3,500 psi for 2.1E lumber. In Phase I, an analysis was conducted to determine appropriate bending stress index levels for 2.0E red maple lumber. Based on the analysis of 42 red maple glulam beams, a bending stress index of 3,500 psi was found to be applicable for 2.0E red maple lumber. Thus, we concluded that the bending stress indices specified in the D3737 standard for E-rated grades of lumber, which are based on softwood data from past research, are conservative when applied to red maple. Based on the findings of Phase I, a bending stress index of 3,500 psi was used for 2.0E red maple lumber, and a bending stress index of 3,000 psi was used for 1.8E red maple lumber in the following analysis.

In Phase I, the predicted design bending strength values for the combinations shown in **Figure 9.1, a through c** were 3,080 psi, 3,180 psi, and 3,230 psi, respectively. These values were within 2 percent, 0 percent, and 3 percent of the actual calculated design bending strength values reported in Table 9.5. For the combination in Phase II, the predicted design bending strength was 2,800 psi, which was within 14 percent of the actual calculated design bending strength.

A comparison between the 2.0-1/6 knot properties from Phase II ($\bar{x}$ = 1.5% and $\bar{x}$ + h = 34.8%) and those from Phase I ($\bar{x}$ = 0.1% and $\bar{x}$ + h = 13.6%) shows a significant difference, especially with the $\bar{x}$ + h values. The knot properties reported in Phase I (13) for the 2.0- 1/6 grade resemble the properties of the Phase I tension lamination grade ($\bar{x}$ = 0.5% and $\bar{x}$ + h = 15.0%). When the same combination was analyzed using the tension lamination knot properties instead of the 2.0-1/6 knot properties from this study, the maximum calculated design bending strength was 3,080 psi, which is within 3 percent of the actual design bending strength.

One possible explanation for the difference in calculated knot sizes of the 2.0-1/6 grade between Phases I and II is that the resource of cant-sawn lumber in Phase II may have different knot characteristics (e.g., pith-associated wood, spike knots,) than lumber sawn from full-sized logs (Phase I). Analysis of knot sizes on two types of timber resources may have resulted in vastly different calculated knot properties for Phases I and II. Consequently, this would affect the predicted design bending strength values using standard ASTM D3737 procedures, albeit, D3737 predictions of design bending strength values for the glulam beams made with E-rated red maple lumber were very conservative for the targeted 2,400 psi level.

Phases I and II: 24F-1.8E bending stiffness. – For glulam stiffness, actual lumber MOE values from individual beam maps were used in a transformed section analysis to predict each individual glulam beam. The calculated glulam MOE values were then reduced by a factor of 0.95 to account for shear deformation effects. The transformed section method of analysis and the 0.95 factor are specified in the ASTM D3737 standard for calculating horizontally laminated glulam beam MOE. Analysis of the Phase I beams resulted in predicted average glulam MOE values that fell within 2 percent of the actual values for each of the three combinations. Analysis of the Phase II beams resulted in a predicted average glulam beam MOE of 1.85×10^6 psi. This compares well with the actual average glulam beam MOE of 1.77×10^6 psi (less than 5% difference in the average). For both studies, the differences between the actual and predicted results can be attributed to the variations in the regression relationship between dynamic and static MOE, used to determine lumber MOE values.

Phase III: 2 by 4/2 by 6 bending strength. – The 2 by 4/2 by 6 glulam beams were evaluated for loads applied parallel to the wide face of the laminations (y-y beam axis). The ASTM D3737 standard specifies procedures for determining the design bending strength of vertically laminated glulam beams (F_{by}). The procedures are based on the characteristics of the single-ply laminations using the allowable edge- and center-knot sizes and allowable slope-of-grain for the particular grade of lumber. For No. 2 red maple vertically laminated glulam, D 3737 analyses predicted a design bending strength of 1,310 psi. This prediction was based on the controlling strength ratio for slope of grain. If the analysis were based solely on the calculated strength ratios for the allowable knot sizes (overriding the slope-of-grain strength ratio), the predicted design bending strength would be 1,550 psi.

Published design bending stress for vertically laminated glulam beams (F_{by}) made from No. 2 red maple lumber is 1,450 psi (AITC 1996). All predicted and published F_{by} values are very conservative when compared with the calculated design bending strength of 2,360 psi given in **Table 9.5.**

Phase III: 2 by 4/2 by 6 bending stiffness. – For stiffness of the 2 by 4/2 by 6 glulam beam combination, ASTM D3737 procedures were used to determine the glulam MOE of the members tested in both the horizontally (MOE_x) and vertically laminated (MOE_y) orientations. The analysis resulted in a predicted average glulam beam MOE_x of 1.74×10^6 psi, which is approximately 7 percent less than the observed value of 1.86×10^6 psi. Predicted glulam MOE_y was 1.75×10^6 psi, which was also approximately 7 percent less than the observed value of 1.87×10^6 psi. As was the case with the 24F-1.8E glulam beams, differences between actual and predicted glulam MOE were attributed to the variation in the regression relationship between dynamic and static MOE.

Phase III: 2 by 4/2 by 6 horizontal shear strength. – Procedures are also given in ASTM D3737 for determining design horizontal shear stresses for vertically laminated glulam timber. Based on these procedures, vertically laminated glulam timber manufactured with 2 by 4/2 by 6 laminations of No. 2 red maple lumber have a calculated design horizontal shear stress of 111 psi.

This value is similar to the design horizontal shear stress of 65 psi published in the AITC 119 standard. However, both the predicted and published values are very conservative when compared with the actual values given in **Table 9.7.**

In addition to establishing design horizontal shear values for the full-size glulam beams with ASTM D3737 procedures, a different approach to determining horizontal shear strength of glulam timber was studied. Soltis and Rammer (22) established a method of predicting the horizontal shear strength of full-size glulam timber based on the tests of ASTM D143 shear-block specimens. Results from the ASTM shear-block tests are shown in **Table 9.7.** For shear-block specimens conditioned to 12 percent equilibrium MC, the average shear strength of 1,830 psi is almost identical to the average shear strength of 1,850 psi published in the *Wood Handbook* (USDA 1999) for red maple.

Soltis and Rammer (1994) developed a relationship between average results of ASTM shear-block tests and full-size horizontal shear tests of glulam timber, represented by the following equation:

$$\tau = (1.3 C_f \tau_{ASTM}) / A^{1/5} \quad [1]$$

where:

τ = average glulam horizontal shear strength (psi)

C_f = 2, a stress concentration factor for an ASTM shear-block notch

τ_{ASTM} = average shear strength from ASTM D143 test (psi)

A = shear area of glulam beam (in.^{2})

Substituting the average ASTM shear-block values (unconditioned specimens) in **Table 9.7** and the shear area of the 2 by 4/2 by 6 glulam beams into Equation [**1**] resulted in an estimated average glulam horizontal shear strength of 1,660 psi. This predicted result is within 4 percent of the actual average horizontal shear strength of 1,730 psi reported in **Table 9.7.** Thus, it appears that the ASTM D143 shear-block approach developed by Soltis and Rammer (1994) provides more accurate predictions of glulam horizontal shear stresses than the current ASTM D3737 procedures.

Conclusions

The results of studies by Manbeck et al. (1993) and Janowiak et al. (1995) showed it is technically feasible to manufacture structural glulam timber using red maple lumber. Specific points observed in this paper include:

- Structural glued-laminated (glulam) timber beams manufactured with E-rated red maple lumber in the outer zones and either No. 2 or No. 3 lumber in the core met or exceeded the target design bending stress of 2,400 psi and MOE of 1.8×10^6 psi. Thus, it appears that the E-rating process assures the required strength and stiffness performance of the laminating lumber, regardless of the lumber resource.
- Structural glulam timber beams manufactured with laminations made from No. 2 red maple 2 by 4's and 2 by 6's are technically feasible. Test results indicate that target design stresses were exceeded for vertically laminated bending strength (F_{by}), MOE in both the

horizontally and vertically laminated orientations (MOE, and MOE,), and horizontal shear strength in the vertically laminated orientation (F_{vy}).

- The ASTM D3737 procedures developed for softwood species accurately predict beam stiffness and provide conservative bending and horizontal shear strength estimates for glulam beams made with red maple lumber.
- Using results from ASTM D143, shear-block tests accurately predicted the horizontal shear strength of red maple glulam timber made from 2 by 4/2 by 6 laminations.

The results of this red maple glulam research was incorporated into the AITC 119 hardwood glulam standard (AITC 1996) as the 24F-E4 combination.

Literature Cited

American Institute of Timber Construction (AITC). 1996. Standard specifications for hardwood glued-laminated timber. AITC 119-96. AITC, Vancouver, WA.

American Institute of Timber Construction (AITC). 1992. Inspection Manual. AITC 200-92. AITC, Vancouver, WA.

American National Standards Institute (ANSI). 1992. American national standard for wood products – structural glued laminated timber. ANSI/AITC A190.1. ANSI, Vancouver, WA.

American Society for Testing and Materials (ASTM). 1993. Standard method for establishing stresses for structural glued-laminated timber (glulam). ASTM D3737-93. Standard methods of static tests of timbers in structural sizes. ASTM D198-84. Standard methods of testing small, clear specimens of timbers. ASTM D143-83. ASTM, Philadelphia, PA.

Freas, A.D. and M.L. Selbo. 1954. Fabrication and design of glued-laminated wood structural members. Tech. Bulletin 1069. USDA Forest Service, Forest Products Laboratory, Madison, WI.

Green, D.W. and K.A. McDonald. 1993. Investigation of the mechanical properties of red oak 2 by 4's. Wood and Fiber Sci. 25(1): 35-45.

Janowiak, J.J., H.B. Manbeck, M.P. Wolcott, and J.F. Davalos. 1992. Preliminary refinement of hardwood stress values. Final Rep. Project SS-047. Pennsylvania Dept. of Transportation, Office of Special Studies, Harrisburg, PA.

Janowiak, J.J., H.B. Manbeck, R. Hernandez, R.C. Moody, P.R. Blankenhorn, and P. Labosky. 1995. Efficient utilization of red maple lumber in glued-laminated timber beams. Res. Pap. FPL-RP- 541. USDA Forest Service, Forest Products Laboratory, Madison, WI.

Johnson, J.W. 1978. Edge-gluing Douglas-fir lumber to improve strength properties. Forest Prod. J. 28(11): 37-43.

Manbeck, H.B., J.J. Janowiak, P.R. Blankenhorn, P. Labosky, RC. Moody, and R. Hernandez. 1993. Performance of red maple glulam timber beams. Res. Pap. FPL-RP-519. USDA Forest Service, Forest Products Laboratory, Madison, WI.

McAlister, R.H. 1973. Edge-glued dimension lumber from low-grade southern pine. Forest Prod. J. 24(7): 17-22.

McDonald, K.A., C.C. Hassler, J.E. Hawkins, and T.L. Pahl. 1996. Hardwood dimension lumber from log heart cants. Forest Prod. J. 46(6): 55-62.

McDonald, K.A., D.W. Green, J. Dwyer, and J.W. Whipple. 1993. Red maple stress-graded 2 by 4 dimension lumber from factory-grade logs. Forest Prod. J. 43(11/12): 13-18.

Metriguard. 1993. Precision testing equipment for wood. Catalog 201. Metriguard, Inc., Pullman, WA.

Moody, R.C., R. Hernandez, J.F. Davalos, and S.S. Sonti. 1993. Yellow-poplar timber beam performance. Res. Pap. FPL-RP-520. USDA Forest Service, Forest Products Laboratory, Madison, WI.

National Hardwood Lumber Association (NHLA). 1992. Grading Rules for Hardwood Lumber. NHLA, Memphis, TN.

Northeastern Lumber Manufacturers Association (NeLMA). 1991. Grading Rules for Northeastern Lumber. NeLMA, Cumberland Center, ME.

Shedlauskas, J.P., H.B. Manbeck, J.J. Janowiak, et al. 1994. Efficient use of red oak for glue-laminated beams. ASAE Paper 94-4575. Am. Soc. of Agri. Engineers, Transactions Vol. 39(1): 201-209.

Soltis, L.A. and D.R. Rammer. 1994. Shear strength of unchecked glued-laminated beams. Forest Prod. J. 44(1): 51-57.

USDA Forest Service, Forest Products Laboratory (USDA). 1999. Wood Handbook Wood as an Engineering Material. Forest Products Society, Madison, WI.

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