The
AEWC
Center

Research
Report
Number
AEWC 05 – xx

April 11, 2005

Hardwire Reinforced Glulam Tests

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Introduction

Hardwire, LLC produced and delivered five glulam beams to the AEWC Center to be tested according to ASTM D198, Section 4-11. These tests were conducted on March 22-24, 2005. The beams were produced by reinforcing 24F-V4 DF-DF, 5-1/8"x12" stock glulams as shown in Figure 1. Figure 2 is a sketch of the "T" beam tested. Table 1 lists the section properties of the beams used in the testing.

Table 1: Test Beam Section Properties

Test Beam Designation	Hardwire Reinforcement Thickness (in)	Beam Depth (in)	Beam Width at MidSpan (in)	Gross Section Area (in^2)	Gross Section Modulus (in^3)	Gross Section Moment of Inertia (in^4)	Hardwire® Reinforcement
Control	0	12	5.10	61	122	734	None
R-1	0.06	13	5.09	66	143	932	1 Layer 3x2 – 12
R-2	0.06	13	5.11	66	144	935	1 Layer 3x2 – 23
R-3	0.06	13	5.11	66	144	936	1 Layer 3x2 – 16
R-4	0.15	13 3/16	5.10	67	148	975	2 Layers 3x2 - 23
R-5 (T-Beam)	0.15	13 3/16	8.25 Top	86	166	1225	No designation on beam

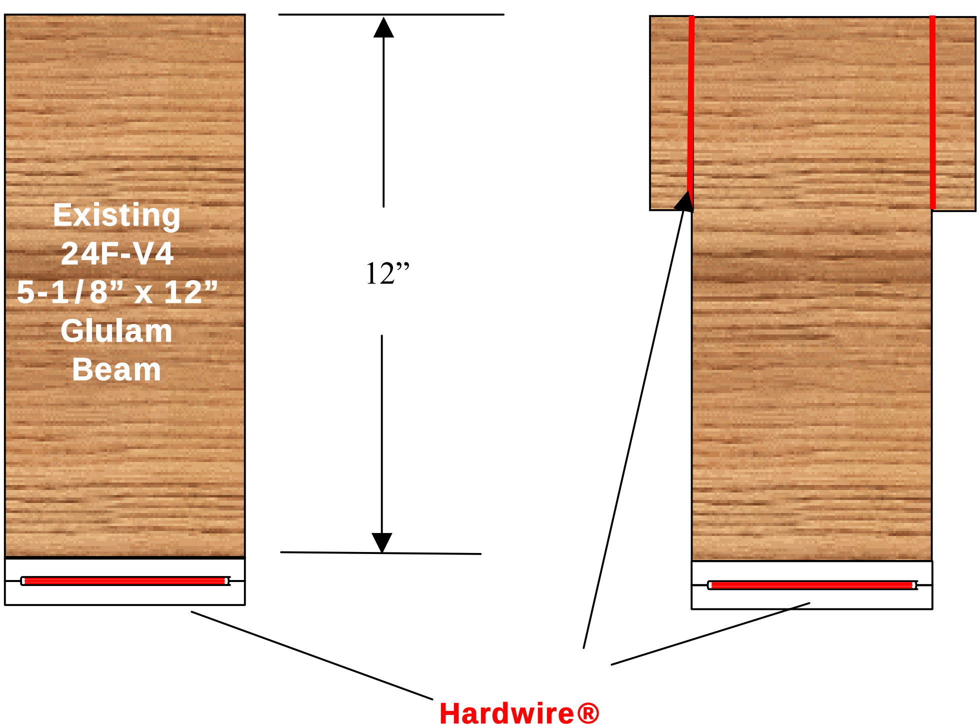

Figure 1 Beam Section Geometry

Test Procedure

Following ASTM D198, a four-point flexure test was set up under a 55-kip Instron Hydraulic Actuator, as shown in Figure 2.

Figure 2: ASTM D 198 Four-Point Bending Test Set up

A span of 21-ft was used, with a load span of 7-ft. Load data were collected from the Instron computer tower, and deflections at mid-span and at the supports were measured using Linear Variable Displacement Transducers (LVDTs).

Test Results

Table 2 provides a summary of the beam test results including the average Moisture Content (MC), failure mode, maximum load reached, midspan deflection at maximum load, Modulus of Rupture (MOR) based on the gross section area, load/deflection (P/Δ) in the linear elastic range, and apparent Modulus of Elasticity (MOE) based on gross area in the linear elastic range. The MOR is the calculated extreme fiber bending stress at maximum load using the gross section properties, assuming linear elastic behavior. While it does not represent a true stress at maximum load, the MOR concept is used to simplify the design of conventional glulam beams, whose outer laminations are stronger and stiffer than the core laminations. The apparent MOE reported in Table 2 is smaller than the true flexural MOE because it includes the effects of shear deformations. The average moisture content (MC) of the beams at the time of testing ranged between 10.1 and 14.1 %. .

Table 2 Summary of Beam Test Results

Beam #	MC %	Failure Mode	Max Load		Deflection @ Max Load (in)	MOR[1]		P/Δ[2]		MOE[3]		Allowable F_b[4,5]	Service Load Deflection[6]	
			(kips)	% Change		(psi)	% Change	(lb/in)	% Change	(Msi)	% Change	psi	inches	% Change
Control	11.2	Tension	20.2	-	3.96	6,930	-	5320	-	2.05[7]	-	1,320[5]	0.5	-
R-1	11.6	Tension in reinforcement	25.5	26	4.27	7,480	8%	6436	21%	1.96	-4.5%			
R-2	10.1	Tension in Reinforcement	20.0	0	3.32	5,830	-16%	6014	13%	1.83	-11%	1,730[4]	0.86	72%
R-3	14.1	Tension in Reinforcement	25.5	26	4.04	7,430	7%	6467	22%	1.96	-4.4%			
R-4	13.5	Compression in wood that extended down from top of beam	27.7	37	5.29	7,870	14%	7100	33%	2.07	0.8%	1,490[5]	0.64	28%
R-5	11.5	Tension in bottom glulam lamination	31.2	58	4.60	7,900	14%	8904	67%	2.06	0.64%	1,500[5]	0.56	12%

1 *Based on gross section area of the beam (including the reinforced tension lamination)*
2 *Applied Load / midspan deflection in linear elastic range*
3 *Apparent Modulus of Elasticity (includes shear deformations), based on gross area, measured in the linear-elastic range.*
4 *Allowable bending stress F_b is 5th percentile with 75% confidence/2.1 as per ASTM D3737; Assuming a COV of 15%, and 3.152 standard deviations to 5% LTL with 75% confidence (ASTM D2915 Table 3) then,*

$$Fb = [\text{Mean } MOR_{3\ data\ points} - 3.152 \text{ Mean } MOR_{3\ data\ points} \times 0.15]/2.1$$

5 *Allowable bending stress F_b is 5th percentile with 75% confidence/2.1 as per ASTM D3737; Assuming a COV of 15%, and 4 standard deviations to 5% LTL with 75% confidence (ASTM D2915 Table 3), extrapolate, then*

$$F_b = [MOR_{1\ data\ point} - 4\ MOR_{1\ data\ point} \times 0.15]/2.1$$

6 *Using the load which corresponds to the full allowable bending stress F_b*
7 *Based on one laboratory beam test only. The NDS-tabulated MOE value for a 24F-V4 beam is MOE=1.8Msi.*

Figure 3 provides the load-deflection plots for all 6 beams. Using the plots, note the brittle failures of the control beam, as well as beams R-1, R-2 and R-3. On the other hand, beam R-4 with the higher reinforcement level showed a ductile nearly elasto-plastic load-deflection response. The beams with the lower reinforcement level (R-1, R-2 and R-3) all failed in tension in the hardwire layer in the region of constant maximum moment between the two load heads. In these three beams, the hardwire fibers showed a 'broomstick' type of failure, and the failed fibers, which protruded from the sides of the beams at the location of failure had little to no resin on them, as may be seen in Figure 4.

The beam with the higher reinforcement level (R-4) displayed a compression wrinkle in the top of the wood beam between the two load heads. This compression wrinkle was *visible* at a load of approximately 23-kips and propagated down through the top laminations (see Figure 5). The compression failure of beam R-4 explains the ductile, nearly elasto-plastic load-deflection curve in Figure 3.

For the "T" beam, R-5, a shear failure began right under the bonded 2x6 under the left load head in Figure 13, then propagated towards the right load head, causing a tension failure in the bottom wood lamination of the original beam, followed by a shear failure directly above the reinforcement from the right load head in Figure 13 to the right end support.

The maximum load for beams R-1, R-2, and R-3 was 26%, 0%, and 26% over the control or on the average 17% over the control. The maximum load for beam R-4 was 37% over the control and R-5 was 58% over the control. The MOR for beams R1, R2, and R3 was 8%, -16%, and 7% over the control or on the average 0% over the control. The MOR for beam R-4 was 14% over the control, and R-5 was 14% over than the control.

The stiffness of the reinforced beams, measured using the ratio of applied load / midspan deflection in the elastic range was higher than the controls (see Table 2). However, the apparent MOE based on the increased gross section moment of inertia was not. The stiffness measured using applied load / midspan deflection in the linear elastic range for beams R1, R2, and R3 was 21%, 13%, and 22% over the control, respectively, or on the average 19% over the control. The applied load / midspan deflection in the linear elastic range for beam R-4 was 32% over the control and R-5 was 67% over the control. On the other hand, the apparent MOE for beams R1, R2, and R3 was –4.5%, -11%, and -4.4% under the control, or on the average -6.6% under the control. The apparent MOE for beam R-4 was 0.8% over the control and R-5 was 0.64% over the control.

Although the MOE for the 24F-V4 DF/DF control beam tested for this project was higher than the MOE of the three low-reinforced beams, it should be noted that the National Design Specification for Wood Construction (NDS) lists an MOE = 1.8 Msi for a 24F-V4 DF-DF glulam. Based on this value and the average MOE for the three low-reinforced beams (mean MOE =1.91 Msi), there is a 5.5% increase over the published value. For the high reinforced beam, R-4, there is a 15% MOE increase over the published value as well as for R-5, the "T"-beam. Figures 6 though 15 provide additional photographs of the beam failures.

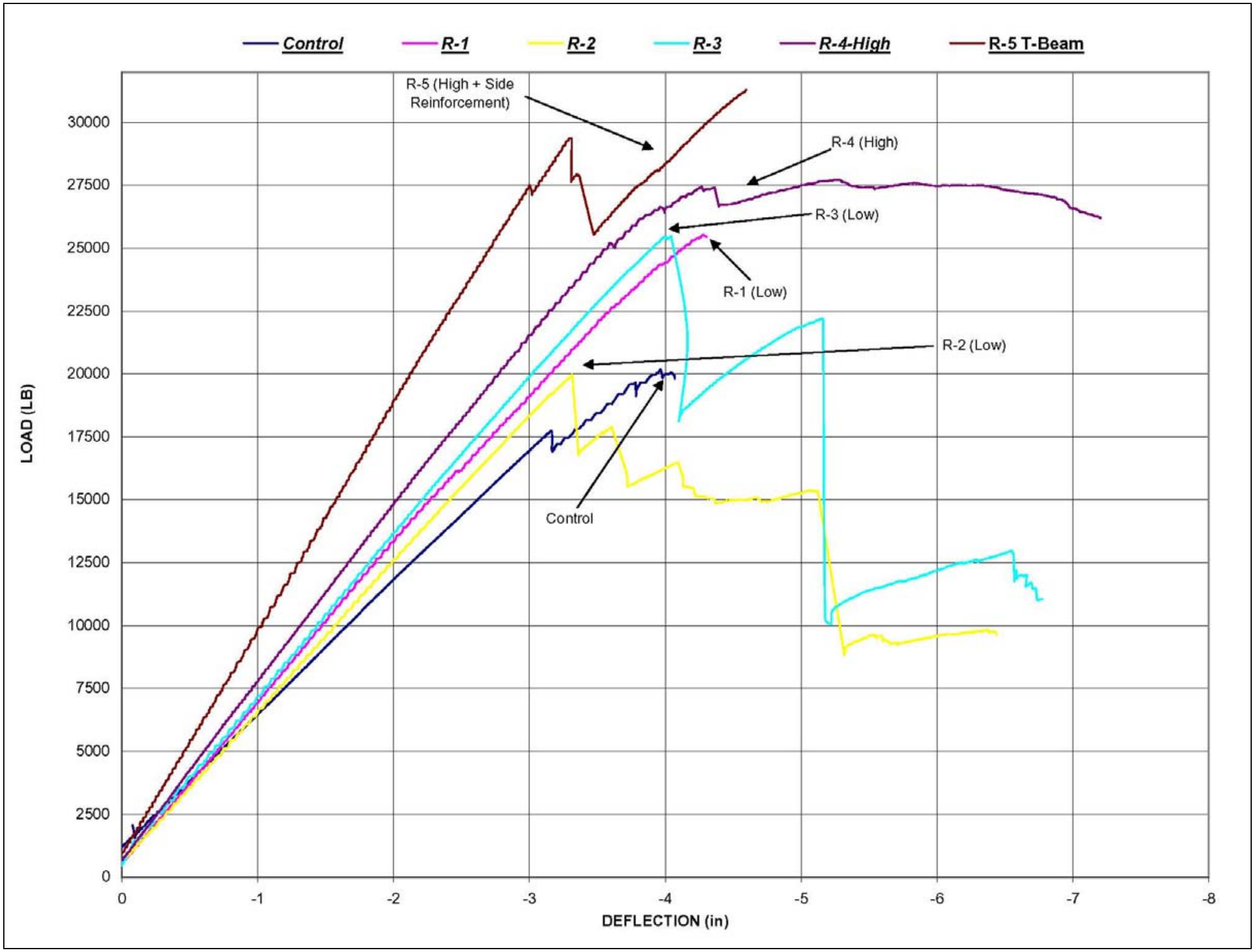

Figure 3: Load-Deflection Plots for all 6 Beams (Low and high refer to reinforcement level)

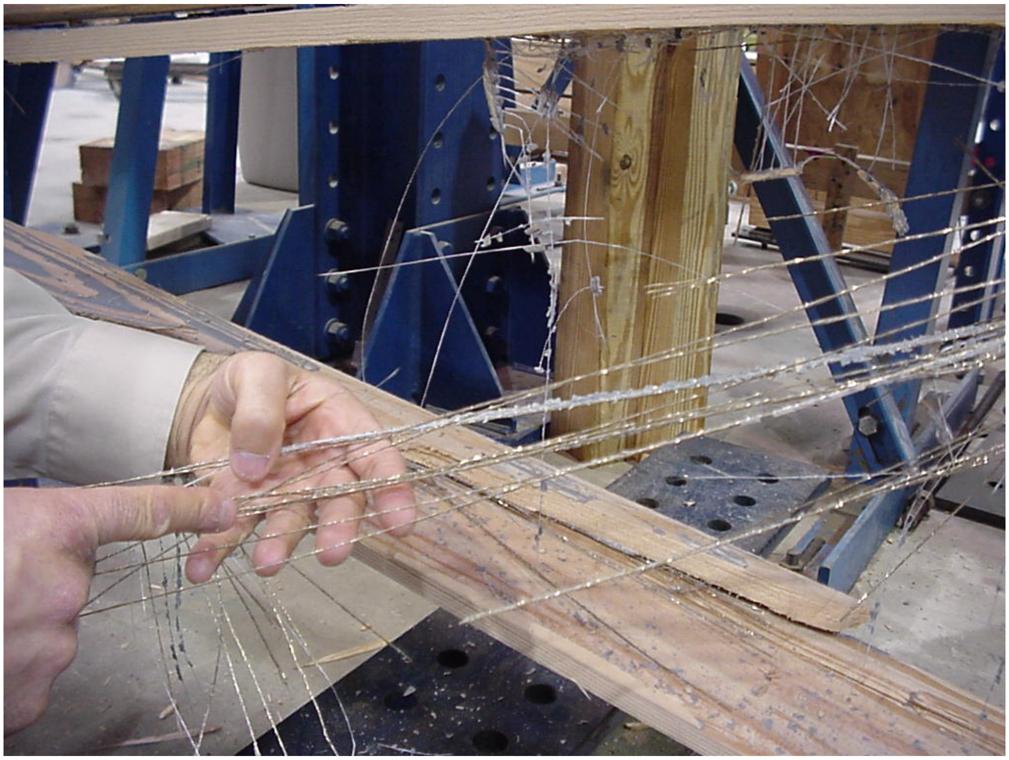

Figure 4: Typical condition of steel wires after beam failure for R-1, R-2, & R-3

Figure 5: Compression failure of beam R-4

Figure 6: Control Beam Failure: 24F V4 DF/DF, no Reinforcement

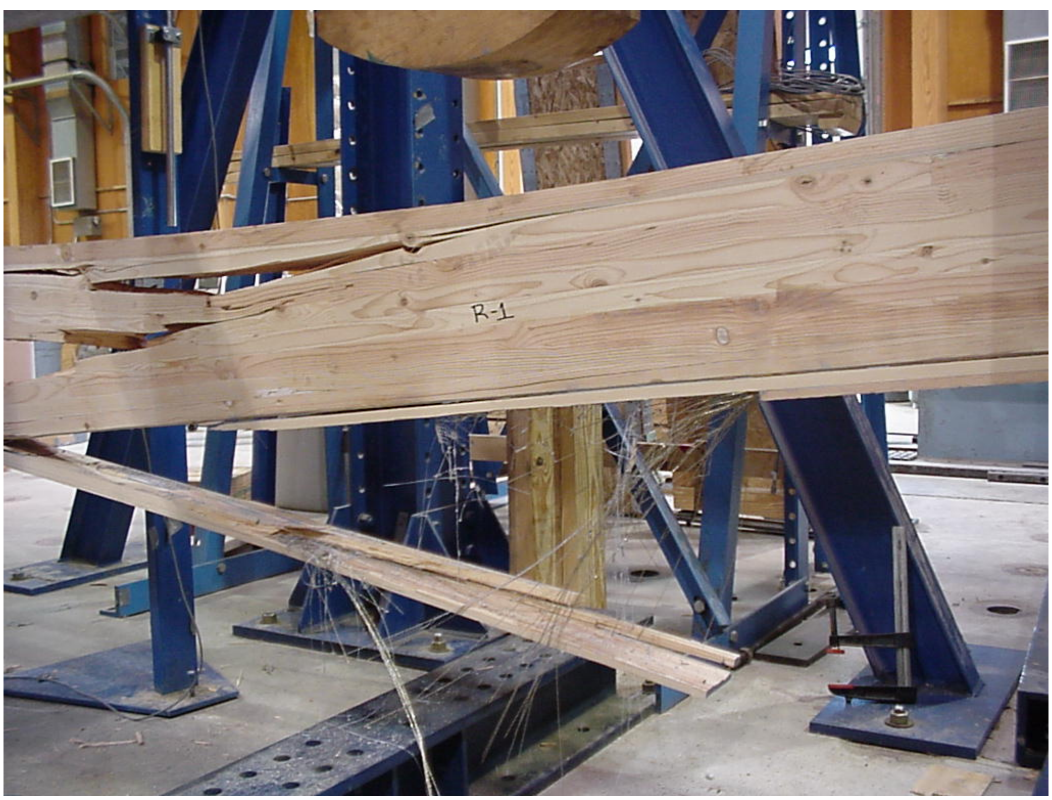

Figure 7: Hardwire Reinforced Beam R-1 Tension Failure

Figure 8: Hardwire Reinforced Beam R-2 Tension Failure

Figure 9: Hardwire Reinforced Beam R-2: Close-up of Tension Failure

Figure 10: Hardwire Reinforced Beam R-3 Tension Failure

Figure 11: Hardwire Reinforced Beam R-3 – Close-up of Tension Failure

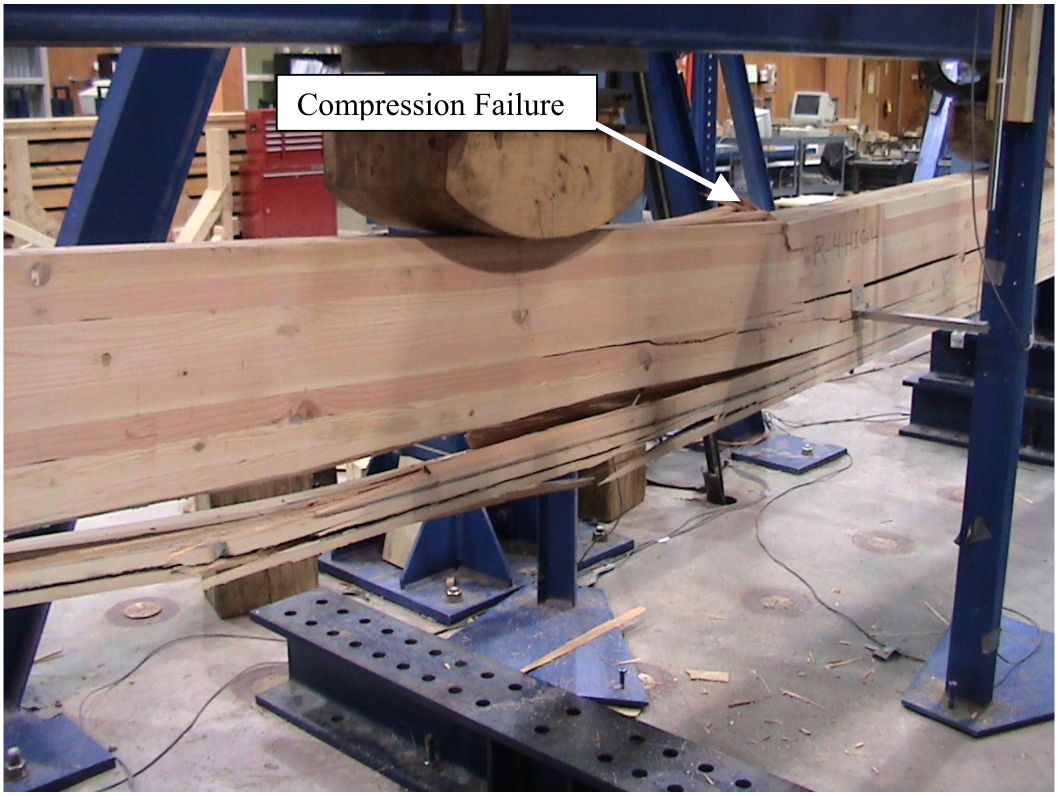

Figure 12: Hardwire Reinforced Beam R-4 - Note Compression Failure on the Wood

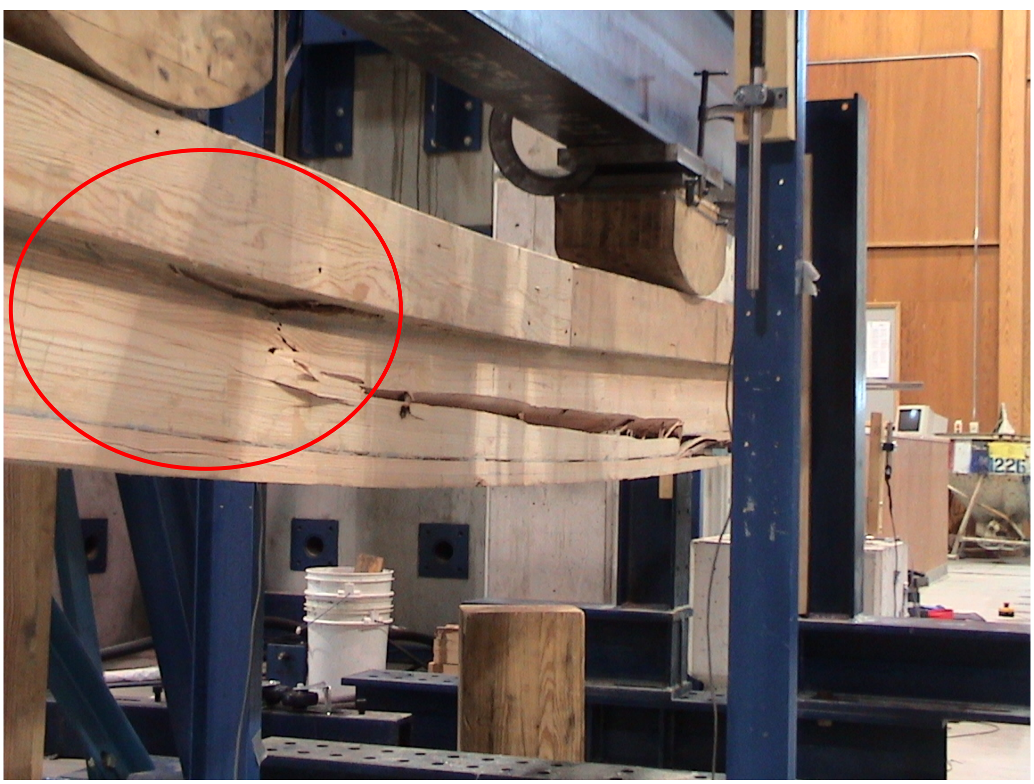

Figure 13: R-5 Failure: Possibly starts as horizontal shear failure under the left load head

Figure 14: R-5 secondary tension failure in the bottom wood lamination of the original glulam. This was accompanied by a horizontal shear failure between the steel reinforcement and the wood directly above it from the load head to the right beam support (See Figure 15)

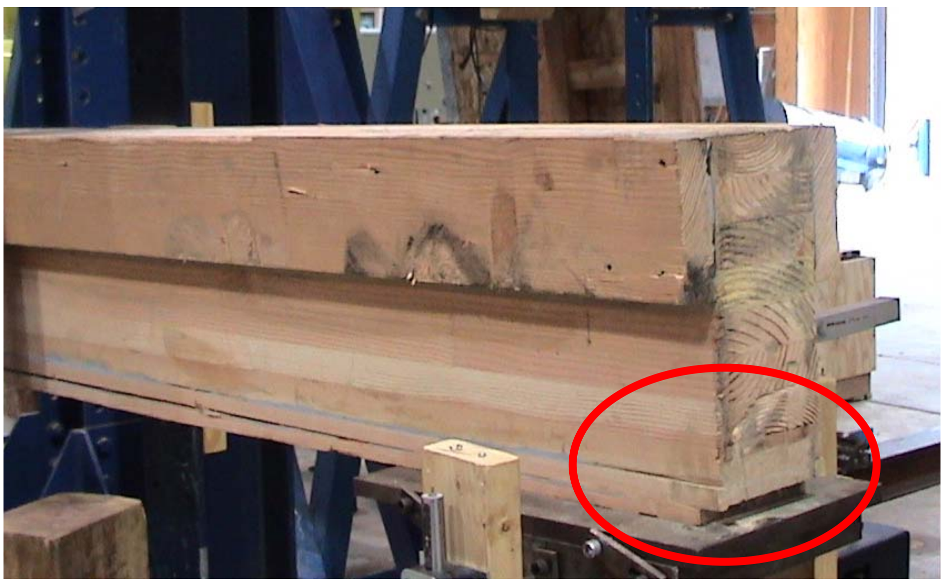

Figure 15: R-5 horizontal shear failure between the steel reinforcement and the wood directly above it from the load head to the right beam support. Note bottom half of reinforcement lamination pulled toward load head.