Timber Bridge Hardwood Glulam Deck Connector Evaluations under Static and Repetitive Loads

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Abstract

Timber bridge deck connectors are crucial to predicted bridge behavior and long-term serviceability yet only limited information documents the performance characteristics for these important bridge connections. New data are presented on the load resistance performance of two different fastener installations often utilized for glulam timber deck-to-girder connection in bridge superstructure construction. Fastener installations investigated are the lag bolt connector and deck clip system. Results on lag bolt and deck clip performance are based on tests with hardwood glulam deck-to-girder specimen assemblies. Hardwood glulam timber are a recent innovation to highway bridge construction with no detailed information to describe their connection behavior. Specimen assemblies were tested to evaluate lateral resistance (shear) both in primary and secondary load orientations and withdrawal resistance (axial) properties. Test efforts for lateral resistance with the lag bolt connections included assembly evaluations of load resistance under monotonic conditions and after repetitive shear displacement up to one million (10^6) cycles. Test measurements were made to determine load-deformation response for characterization of initial slope or elastic stiffness (Kl), post-yield slope (K2) and determination of five percent offset load (yield strength) for both connector systems.

Keywords: Connections, Hardwood, Glulam, Lag Bolt, Deck Clip, Deck-to-Girder, Lateral Resistance, Withdrawal, Load-Slip, Static, Repetitive Loading Fatigue.

Introduction and Background

Timber bridge deck connectors must resist vehicular and braking loads and provide partial composite action for a superstructure system. Accordingly, these connections are a vital link in the structural behavior of a timber bridge and its long-term structural serviceability. One typical superstructure for highway bridge construction is the longitudinal stringer with transverse deck panels of glue-laminated (glulam) material (Ritter, 1989). This type superstructure is one of the hardwood-based glulam timber bridge designs in BLC-560 developed for the Pennsylvania Department of Transportation (PennDOT). Manbeck et al. (1994) provides detailed discussion on development of these standard bridge design and construction plans. Document BLC-560 plan series (PennDOT, 1994) cover 18-90 ft clear span highway structures with options for either red maple, yellow poplar or red oak glulam timber bridge construction. Currently, the BLC-560 (1994 edition) relies exclusively on galvanized A307 steel 3/4-in. diameter lag bolt connectors for deck-to-girder bridge installation.

Various activities are underway to modify timber bridge specifications to a metric version (BLC-560M) and update the plan series from ASD (Allowable Stress Design) to LRFD (Load Resistance Factor Design) basis (Manbeck et al., 1996). The update brings PennDOT bridge designs into compliance with the American Association of State Highway Transportation Officials (AASHTO) LRFD specification (AASHTO, 1994). BLC-560M will also be expanded to provide hardwood glulam deck designs with construction details for application to new or retrofit steel girder bridge construction. Activities include investigations on composite behavior for improvements on bridge girder design efficiency. One important effort has been finite element modeling to define interlayer partial composite behavior of the BLC-560 girder with transverse deck system (Witmer, 1996). Critical to this activity are the load-slip properties of bridge deck-to-girder connections and other load transfer mechanisms. Research with softwood bridge designs (Gutkowski et al., 1978) indicate that composite behavior is highly dependent on connection stiffness. Hardwood glulam in highway bridge construction represents a recent innovation. Review of literature fails to reveal detailed information on the performance properties of deck connectors installed with hardwood glulam. With this void in information PSU (Penn State University) researched have instituted an intensive test program to evaluate BLC-560 bridge connector performance.

Connector performance evaluations include standard lag bolts and alternative deck clip installations. Deck clip installations are under consideration as a BLC-560M bridge construction detail. Test program focus also includes other BLC-560 load transfer mechanisms: steel dowels employed for adjacent deck-to-deck connection and hardwood glulam diaphragm versus steel cross frame bracing for stringer-to-stringer connection. Further tests examine connectors for installation of hardwood glulam deck panels on steel girder bridge systems. The intensive scope of this test program has been the subject of two recent studies (Thomforde, 1995 and Witmer, 1996). Today's presentation focuses on lag bolt and deck clip connection performance evaluations (Thomforde, 1995). Connector performance testing includes primary and secondary lateral (shear) resistance and direct withdrawal (axial) resistance for simulated BLC-560 deck-to-girder assemblies. Other bridge connector research findings will be presented at the upcoming IWEC (International Wood Engineering Conference: New Orleans, LA).

Primary lateral resistance refers to connector shear testing in the longitudinal bridge direction and secondary implies a load orientation perpendicular to primary test orientation. Connection data analyses were performed to obtain load-slip properties for elastic stiffness (K1), post-yield stiffness (K2), and yield strength. Evaluation tests for both connectors were conducted under monotonic (single force application) static load conditions. Additional test measurements summarize lag bolted deck-to-girder load-slip behavior after exposure to repetitive shear displacement to examine connection fatigue. One special study consideration was the performance of lag bolt deck correctors installed with glulam girders fabricated with unglued edge-to-edge lumber laminations. Red maple glulam beams with unglued combination 2x4/2x6 lumber laminations were previous investigated (Janowiak, et al., 1995) for inclusion into BLC-560M bridge applications. Edge-to-edge gaps are possible for this type glulam timber and the affect of these dislocations may prove consequential to connector performance.

Experimental

Test Evaluation Objectives

Performance characteristics of assembled deck-to-girder specimens were tested to fullfill several study goals or objectives (Thomforde, 1995):

•To determine yield strength (5% offset load) and stiffness (K1) differences in withdrawal loading between test assemblies having solid lumber lamination glulam girders and combination unglued edge-to-edge multiple piece lumber lamination glulam girders.

•To determine yield strength (5% offset load) and stiffness (Kl) differences between glulam deck-to-girder assemblies connected with lag bolt versus deck clip resistance under monotonic load conditions for both primary and secondary test orientations.

•To determine the lag screw lateral resistance yield strength (5% offset load) and stiffness (Kl) after exposure to cyclic loading of deck-to-girder connections with both solid lamination glulam girders and combination unglued edge-to-edge lamination glulam girders for both primary and secondary test orientations.

•To determine the stiffness and lateral resistance of lag bolted red maple glulam deck-to-girder connections after exposure to cyclic shear displacements.

Fulfilling these study objectives were of primary concern but additional analyses were made to characterize post-yield stiffness (K2). This paper concentrates on the elastic stiffness connection data.

Experimental Deck-to-Girder Evaluations

Experimentation to evaluate deck-to-girder load resistance characteristics did not include all possible test subsets of BLC-560 glulam timber or wood species (Red Maple, Yellow Poplar and Red Oak) with respect to deck connector type (lag bolt versus deck clip installation), glulam type (combination 2x4/2x6 versus solid lamination). Figure 1 depicts the overall experimental design for lateral resistance and withdrawal resistance connector performance evaluations under static and cyclic loading test modes. With red maple glulam (Figure 1) two A307 3/4-in. lag bolt connection test series were included for experimentation (e.g. 9-in. versus 12-in. Lag Bolt). Different deck-to-girder assemblies included a 3.125-in. deck (9-in. lag bolt connection) and a thicker 5.125-in. deck (12-in. lag bolt connection). Both installations correspond to typical BLC-560 decks. Alternative deck-to-girder connectors (WEYCO DECK CLIP) for evaluation are a cast aluminum 90 degree comer bracket with offset toothed cleat for deck connection.

Deck-to-Girder Specimen Preparation

Deck-to-girder connection specimens were derived from glued-laminated timbers that met recognized manufactured standards (ANSI, 1992) with fabrication from No. 2 & better grade lumber. Thomforde, 1995 provides explanation on glulam timber with deck-to-girder connection test specimen preparation. Specimen assemblies were devised so that installation hole placement for all test connections compiled with minimum end and edge requirements for full NDS (National Design Specifications) connector design load (NFPA, 1991). Pilot holes for the threaded lag screw installation into the glulam girder section were drilled 5/8-in., 9/16-in., and l/2-in. diameter for red oak, red maple, and yellow poplar, respectively. These diameters meet NDS recommendations for pilot hole sizing. Clearance holes for the unthreaded lag bolt shanks through the deck were drilled 3/4-in. diameter. Pilot and clearance hole drilling were conducted with wood boring bits to minimize wood fiber tear out.

Assemblage of deck-to-girder specimens followed a detailed installation procedure including pilot hole swabbing with creosote to ease connector penetration and a specific torque schedule to mate deck-to-girder assemblies. Torque schedules were developed from a separate deck-to-girder test series to evaluate applied torque versus resultant compressive perpendicular-to-grain load level to establish torque limits with respect to individual glulam material. (Thomforde, 1995). Lag bolt installations were achieved through a devised gear box drive mechanism equipped with torque sensor. Installation procedures with torque limit were followed to control variation between connector specimens. Figures 2-5 show assembled test specimens with respect to deck thicknesses (3.125-in. versus 5.125-in.), lag bolt versus deck clip installation, and also the solid lamination compared to combination 2x4/2x6 lamination glulam girders used for lateral resistance and direct withdrawal evaluations.

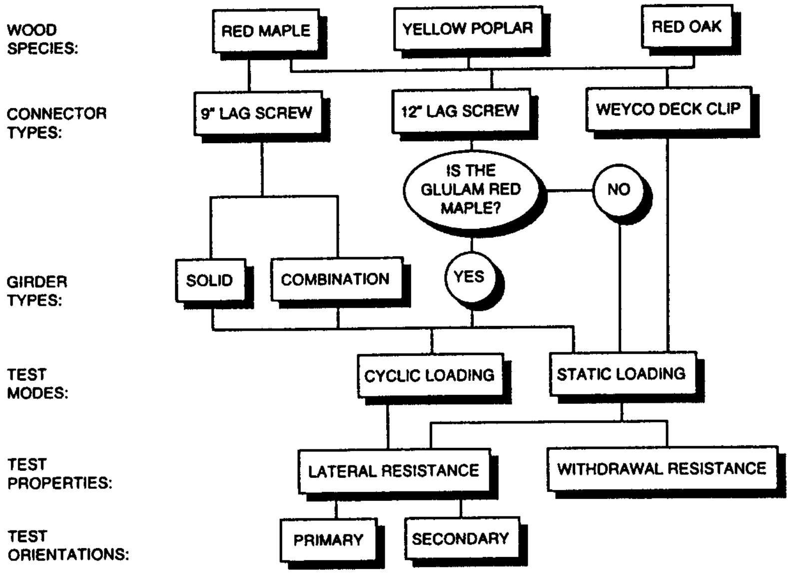

Figure 1. Flow chart of the deck-to-girder test connection experimental design.

Deck-to-Girder Test Protocol

Assembled deck-to-girder connections lateral resistance specimens with unique test size geometry excluded following standard ASTM D1761 (ASTM, 1994) test protocol. Specially constructed test apparatus jigs were employed to handle evaluation of the large sized glulam specimens. A single shear loading fixture was developed for the monotonic test evaluations (Figure 6). Apparatus development was based on a similar device (Pellicane, et al, 1984) used to study load slip of nail-jointed connections. This apparatus was attached to an Ametek (60,000 lb capacity) test machine for force application. Load induced displacements were monitored with paired system of linear potentiometers and real time data acquisition with tests terminated after 0.20-in. connection slip. The two-tenths in. end point for testing was well-beyond elastic limit response for the deck-to-girder connections. All monotonic test series were conducted at a 0.010 in/min loading rate (ASTM D1761) and connection specimen assembly immediately prior to test evaluation. Evaluations for both primary and secondary load orientations test series include thirty independent specimen observations. Cyclic loading test evaluations were limited to only five test replications.

Deck-to-girder specimens for exposure to repetitive shear displacements were evaluated in a cyclic test apparatus. The apparatus includes three principal components bottom stationary support frame for restraint of the girder, top slide displacement frame to supply shear action displacement to the deck portion of connection specimen, and motor-operated slider drive mechanism (Figure 7). Machine frame design provided for simultaneous evaluation of five deck-to-girder specimens. Slider drive mechanism with an equipped eccentric cam system permitted control over the magnitude of lateral displacement. To conduct the cyclic test series the cam offset was calibrated based on monotonic data to achieve an approximate NDS connection design load. Load resistance measurements were taken to monitor joint degradation (connection fatigue) as a function of number of cyclic shear displacements (1, 10, l00, 1000, 10,000, 100,000, 300,000, 600,000 and 10^6 cycles). Cyclic loading rate was 6.26 Hertz. This cycling speed closely replicates the natural frequency for a glulam timber bridge (Abendroth, 1989). After exposure to the 10^6 displacement cycles the lateral resistance specimens were tested under monotonic load conditions to identify residual connection performance.

Withdrawal resistance tests to characterize deck-to-girder load-slip under single force application were conducted with the Ametek universal test machine. Two linear potentiometers were again used to measure joint deformation at 1/2 second intervals. Testing force was applied through a spreader bar to the girder main member at equidistant position along the member length on opposite sides of the supported deck. Test evaluations (0.010 in/min loading rate) were conducted to a maximum 0.20-in joint deformation limit as opposed to ultimate load. Some deck-clip joint connections failed catastrophically prior to this 0.20-in deformation limit. After test evaluation withdrawal specimens were examined for connector or wood (compression perpendicular-to-grain) failure and the lateral resistance test series inspected to assess connection yield mode (Johansen, 1949). Lag bolt connections under axial loading were strongly influenced by wood fiber compaction under the lag connector washer. For lateral resistance, dismantled lag bolted 5.125-in. deck-to-girder specimens exhibited predominately yield mode IV failure (e.g. two plastic hinge points per shear plane). Thinner 3.125-in. deck with the 9-in. lag bolt connections tended to be more evenly split between yield modes IV and III, (e.g. bearing-dominated wood fiber yield failure).

EXPERIMENTAL RESULTS

Load-Deformation Data Analysis

European yield model (EYM) is now standard practice for lateral resistance connection design with the NDS (1991 ed). Yield strength is typically taken as a 5% offset load value by offsetting initial slope of the load-deformation curve by a deformation equal to 5% of the bolt diameter (Wilkinson, 1993). Load-deformation response of deck-to-girder connections provided limited linearity, especially for deck clip evaluations. Researchers who have conducted similar evaluations can appreciate the often erratic behavior of connection tests. Instead of the standard 5% offset method, a linear regression approach was utilized to determine 5% offset load for valuation of yield strength. Comparison of regression to EYM 5% offset with analysis of random load response curves showed reasonable agreement between methods. On average primary lateral resistance values agreed within three and two percent for yield load and yield displacement, respectively. Secondary loading orientation showed slightly less agreement with 4% and 12% differences between methods. Test results reported are load at yield, deflection at yield, and elastic slope (stiffness, K1) to qualify connection behavior at the 5% offset value.

Lateral Resistance Results - Monotonic Loading

Tables 1 and 2 collectively provide summary for all the various monotonic test series (Figure 1) for hardwood glulam deck-to-girder connection behavior at estimated EYM 5% offset.

Results (Table 1 and 2) show deck clips consistently provided greater stiffness but not necessarily higher load at yield resistance. Lag bolt connections tend to provide higher load at yield at least in the primary test orientation. Average 5% offset loads for the 9-in. and 12-in. lag bolt connector test series were compared to design performance limit as predicted by yield theory equations (NDS, 1991). Comparisons indicate that experimentally derived yield loads after safety and normal duration adjustment matched well the theoretical NDS design limits within most instances a plus or minus 10% difference. The largest difference (-20.l%) occurred for the combination 2x4/2x6 girder series with secondary test orientation.

Statistical Comparison of Lateral Resistance Results

Testing subsets of the experimental design were paired into four studies cases for statistical comparisons between solid lumber to combination 2x4/2x6 girder type and connector type with respect to the three different glulam wood species. Comparisons (t-tests at $\alpha = 0.05$) to evaluate performance differences are presented (Table 3 and 4) for these study cases with respect to primary and secondary orientation lateral resistance results. Tables 3 and 4 indicate that most test subsets compared (Study Case 1-4) for 5% offset load and elastic stiffness are statistically different at $\alpha = 0.05$ significance level.

Lateral Resistance Results - Cyclic Exposure

Force resistance with induced displacement under cyclic loading for lag bolt and deck clip test series are presented in Table 5.

Values shown (Table 5) represent averaged force resistance measurements normalized to 1.6 NDS connection design load (the 1.6 factor is for adjustment to 10-minute load duration). Normalized values indicate that force resistance of the deck-to-girder connections tended to exceed the predicted NDS design load for four of the six test series.

CM9Z (combination 2x4/2x6 girder with 9-in. lag bolt connection) test series on averge exhibited the greatest departure from predicted NDS lateral resistance. This departure may related to greater edge distance of the installed lag bolt connector compared with narrower solid lamination test girder assemblies. As a trend it is observed that connection resistance declined below NDS design load after exposure betwen 10^3 to 10^5 number of cycles. Table 6 presents the data on cyclic exposure specimens subsequently tested under monotonic load conditions to 0.20-in. deformation limit to evaluate residual yield strength and stiffness (K1) values.

Withdrawal Resistance Results

Descriptive statistics for withdrawal resistance data for the deck-to-girder test series are presented in Table 7. Withdrawal results (Table 7) are interesting specific to the unexpectedly high stiffness for combination 2x4/2x6 girder with 9-in. lag connection (CM9W) yet & lower yield load compared with (M9W) solid girder performance. Some uncertainty existed over this mean test observation. Re-examination of the CM9W data files indicate data reduction analyses may have not completely excluded initial nonlinear settling deformations. Also it was questioned whether a significant size effect (8-in. 2x4/2x6 combination width versus 5.125-in. solid girder width) contributed to observed withdrawal performance. An additional ten CM9W 5.125-in. specimens have since been tested with resultant load-slip properties load at ‘yield’ (5362 lb), deflection at yield (0.042 in.), and elastic slope K1 (152719 lb/in). These values more closely match the observed trend for the other test series. It is believed that the larger 2x4/2x6 girder contributed significantly to influence initial test results. With these findings new statistical are appropriate before comparisons are made on withdrawal performance.

Summary

To summarize, the experimental results for monotonic loading indicate that both lag bolt and WEYCO deck clip type device with hardwood glulam provide lateral resistance that met with theoretical NDS design limits. The deck clip connection appears to be a viable option for update of BLC-560M. Overall deck clip installations provided higher average joint connection stiffness (K1) for both primary and secondary test orientation. However, primary test orientation data show lag bolt connectors provide better performance in terms of higher 5% offset (load at yield). Observed differences in connector performance data (K1 and load at ‘yield’) were found in most instances to be statistical significant (α at 0.05). Of special interest the 2x4/2x6 red maple combination girder proved to provide lateral resistance consistent (no real difference $\rho = 0.16$) at least in terms of yield strength with that for the red maple solid lamination type glulam girder. Experimental results under cyclic shear displacement conditions showed lateral resistance decline below NDS design load after exposure between 10^3 and 10^5 cycles. Witmer, 1996 provides detailed analysis to describe this connection degradation or fatigue behavior for hardwood glulam deck-to-girder connections.

Table 1. Summary of 5% offset load-slip properties with respect to primary (z) test orientation.

	Load at 'Yield' (lbs)			Deflection at 'Yield' (in)			Elastic Slope (K1) (lbs/in)		
Test Series	Mean	Std. Dev.	COV (%)	Mean	Std. Dev.	COV (%)	Mean	Std. Dev.	COV (%)
CM9Z[1]	4,739	447	9.4	0.183	0.061	33.8	27,667	6,739	24.4
M9Z[2]	4,572	453	9.9	0.140	0.036	25.7	34,122	8,103	23.7
M12Z[3]	5,884	744	12.6	0.211	0.073	34.8	32,146	11,815	36.3
P12Z[4]	3,674	388	10.6	0.184	0.045	24.8	22,101	6,022	27.2
R12Z[5]	5,431	418	7.7	0.131	0.036	27.5	46,075	10,746	23.3
M5Z[6]	2,564	921	35.9	0.019	0.022	116	217,270	101,150	46.6
P5Z[7]	2,413	592	24.5	0.021	0.020	97.4	166,203	67,269	40.5
R5Z[8]	2,715	759	28.8	0.021	0.020	94.6	208,358	120,264	57.7

[1] Red maple 3.125" deck with 9-in. lag screw connected to combination (2x4/2x6 lumber) 8-in. wide girder.

[2] Red maple 3.125" deck with 9-in. lag screw connected to solid lamination 5.125-in. wide girder.

[3] Red maple 5.125" deck with 12-in. lag screw connected to solid lamination 5.125-in. wide girder.

[4] Yellow poplar 5.125" deck with 12-in. lag screw connected to solid lamination 5.125-in. wide girder.

[5] Red oak 5.125" deck with 12-in. lag screw connected to solid lamination 5.125-in. wide girder.

[6] Red maple 5.125" deck with WEYCO deck clip (5-in. attaching lag screws) connected to solid lamination 5.125-in. wide girder.

[7] Yellow poplar 5.125" deck with WEYCO deck clip (5-in. attaching lag screws) connected to solid lamination 5.125-in. wide girder.

[8] Red oak 5.125" deck with WEYCO deck clip (5-in. attaching lag screws) connected to solid lamination 5.125-in. wide girder.

Table 2. Summary of 5% offset load-slip properties with respect to secondary (y) test orientation.

	Load at 'Yield' (lbs)			Deflection at 'Yield' (in)			Elastic Slope (K1) (lbs/in)		
Test Series	Mean	Std. Dev.	COV (%)	Mean	Std. Dev.	COV (%)	Mean	Std. Dev.	COV (%)
CM9Y[1]	4,314	1,199	27.8	0.167	0.084	53.7	29,124	9,512	32.8
M9Y[2]	4,992	779	15.8	0.222	0.073	32.9	24,250	5,676	23.4
M12Y[3]	5,936	645	10.9	0.279	0.104	37.3	23,954	7,863	32.8
P12Y[4]	4,086	313	7.7	0.218	0.041	19.2	20,130	4,817	23.9
R12Y[5]	5,511	507	9.2	0.209	0.052	25.0	41,981	10,648	25.4
M5Y[6]	8,732	1,963	22.5	0.132	0.095	72.2	91,695	46,963	51.2
P5Y[7]	5,326	2,168	40.7	0.062	0.051	85.2	124,400	61,475	49.4
R5Y[8]	5,485	2,125	38.7	0.034	0.016	46.7	151,610	70,879	46.7

[1,2,3,4,5,6,7and 8] See Table 1 for Footnotes

Table 3. Statistical comparisons for four study cases with primary load test orientation results.

Study Case	Test Subsets Compared	Probability (ρ-value) 5% offset load	Probability (ρ-value) elastic stiffness, K1
1	M9Z vs. CM9Z[1]	0.16	0.0018
2	R12Z vs. R5Z[2]	0.0000	0.0000
3	P12Z vs. P5Z[3]	0.0000	0.0000
4	M12Z vs. M5Z[4]	0.0000	0.0000

[1,2,3 and 4] See Table 1 for Footnotes, Z denotes Primary Test Load Orientation

Table 4. Statistical comparisons for four study cases with secondary load test orientation results.

Study Case	Test Subsets Compared	Probability (p-value) 5% offset load	Probability (p-value) elastic stiffness, K1
1	M9Y vs. CM9Y[1]	0.021	0.0021
2	R12Y vs. R5Y[2]	0.95	0.0000
3	P12Y vs. P5Y[3]	0.031	0.0000
4	M12Y vs. M5Y[4]	0.0000	0.0000

[1,2,3 and 4] See Table 1 for Footnotes, Y denotes Secondary Test Load Orientation

Table 5. Force resistance under cyclic loading conditions normalized to NDS design loads.

Test	Log (Cycles)								
Series	10^0	10^1	10^2	10^3	10^4	10^5	$3x10^5$	$6x10^5$	10^6
M9Z[1]	1.26	1.18	1.18	0.90	0.88	0.70	0.71	0.69	0.69
M12Z[2]	1.18	1.09	1.01	1.03	0.96	0.80	0.58	0.79	0.69
CM9M[3]	1.65	1.57	1.18	1.09	1.08	0.98	0.88	0.92	0.81
M9Y[1]	0.89	0.86	0.86	0.81	0.68	0.50	0.29	0.34	0.24
M12Y[2]	1.14	1.07	1.02	0.76	0.72	0.52	0.48	0.45	0.43
CM9Y[3]	0.89	0.85	0.77	0.84	0.63	0.42	0.29	0.25	0.27

[1,2and 3] See Table 1 for Footnotes, Z and Y denote primary versus secondary test orientations

Table 6. Summary of residual 5% offset load-slip properties of cyclic test specimens

	Load at 'Yield' (lbs)			Deflection at 'Yield' (in)			Elastic Slope, K1 (lbs/in)		
Test Series	Mean	Std. Dev.	COV (%)	Mean	Std. Dev.	COV (%)	Mean	Std. Dev.	COV (%)
M9Z[1]	3963	771	19.4	0.075	0.018	23.8	60839	20271	33.3
CM9Z[2]	3728	689	18.5	0.072	0.020	27.8	57620	19268	33.4
M12Z[3]	5359	1645	30.7	0.096	0.051	53.0	67444	33421	49.6
M9Y[1]	4235	946	22.3	0.103	0.031	30.4	44303	9162	20.7
CM9Y[2]	4012	273	6.8	0.168	0.092	54.5	28954	11867	41.0
M12Y[3]	3559	609	17.1	0.130	0.077	59.2	37987	19806	52.1

[1,2 and 3] See Table 1 for Footnotes, Z and Y denote primary versus secondary test orientations

Table 7. Summary of withdrawal 5% offset load-slip properties under monotonic test conditions.

	Load at 'Yield' (lbs)			Deflection at 'Yield' (in)			Elastic Slope (K1) (lbs/in)		
Test Series	Mean	Std. Dev.	COV (%)	Mean	Std. Dev.	COV (%)	Mean	Std. Dev.	COV (%)
CM9W[1]	3,925	1,030	26.2	0.007	0.004	58.7	641,681	239,689	37.4
M9W[2]	5,300	893	16.9	0.025	0.015	58.7	184,986	73,558	39.8
M12W[3]	6,260	1,017	16.2	0.016	0.009	52.4	259,736	108,776	41.9
P12W[4]	4,074	788	19.4	0.017	0.008	47.7	230,218	60,447	26.3
R12W[5]	8,615	1,031	12.0	0.017	0.005	27.4	445,923	106,862	24.0
M5W[6]	3,535	1,104	31.2	0.013	0.006	44.9	309,877	103,438	33.4
P5W[7]	3,387	526	15.5	0.017	0.005	33.3	223,436	83,949	37.6
R5W[8]	3,646	1,105	30.3	0.018	0.013	70.9	291,238	183,639	63.3

[1,2,3,4,5,6,7, and 8] See Table 1 for Footnotes, W denotes direct withdrawal testing

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Acknowledgments

This research was funded through the Pennsylvania Department of Transportation Research Project SS25-043 and the Pennsylvania Agricultural Experiment Station. The authors wish to acknowledge the services and efforts provided by Mr Jeffrey Kimmel to this experimental study.

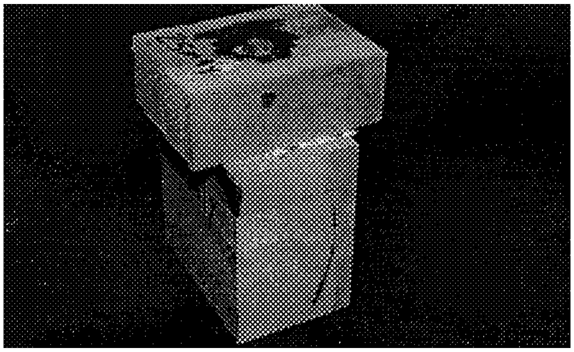

Figure 2. Lag bolt (9-in.) connection for 3.125-in. thick deck with solid lamination girder (5.125-in. width).

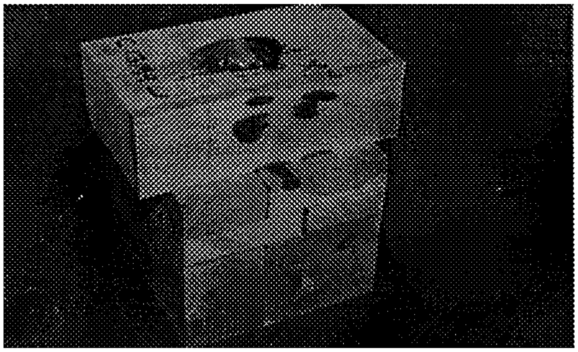

Figure 3. Lag bolt (12-in.) connection for 3.125-in. thick deck with combination 2x4/2x6 lamination girder (8-in. width).

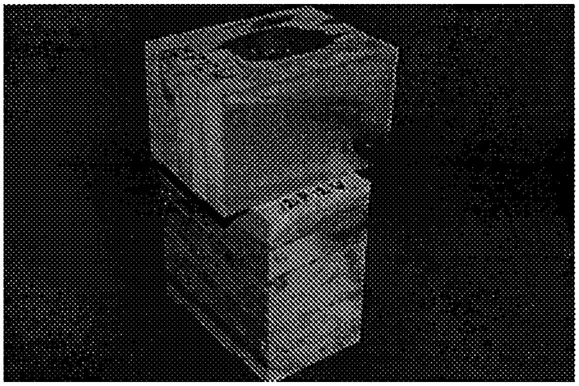

Figure 4. Lag bolt (12-in.) connection for 5.125-in. thick deck with solid lamination girder (5.125-in. width).

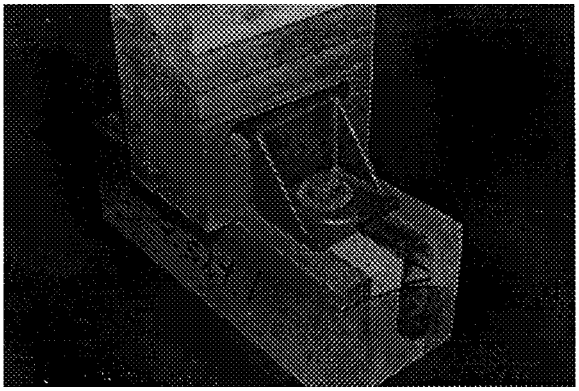

Figure 5. Deck clip (5-in. attaching lag bolts) connection for 5.125-in. thick deck with solid lamination girder (5.125-in. width).

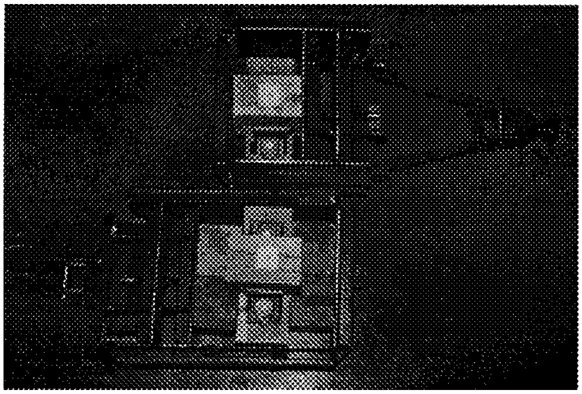

Figure 6. Lateral resistance test apparatus with open view to illustrate clamped deck clip test assembly.

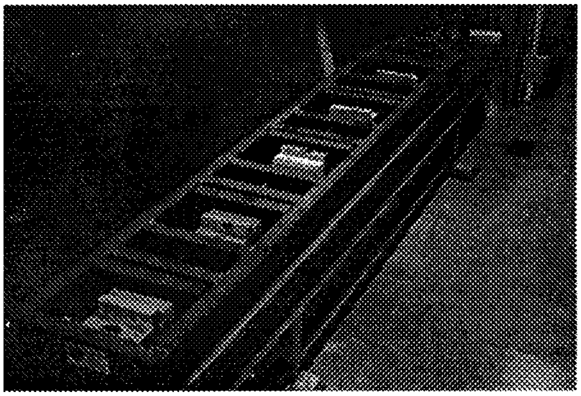

Figure 7. Cyclic loading frame machine to conduct repetitive shear displacement on assembled deck-to-girder specimens.

In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., ed(s). National conference on wood transportation structures; 1996 October 23-25; Madison, WI. Gen. Tech. Rep. FPL- GTR-94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.