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PENNDOT

CYCLIC LOAD TESTING OF WELDABLE SHEAR CONNECTORS FOR GLULAM DECKS ON BRIDGE GIRDERS

University-Based Research, Education, and Technology Transfer Program

AGREEMENT NO. 359704, WORK ORDER 113

FINAL REPORT

July 2002

By H. B. Manbeck, J. J. Janowiak, and A. Olorunisola

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16. Abstract

The overall objective of the research reported was to determine the residual shear strength and stiffness of a weldable shear stud-epoxy grout connector system for attaching glulam decks to steel bridge girders after long term (15M cycles) cyclic shear loading. Specific objectives were to determine the load-slip characteristics of the connector system after 15M load cycles and to prepare an appropriate addendum to the Pennsylvania Department of Transportation's BLC-560M, Standard Plans for Hardwood Glulam Highway Bridges, based on the measured residual strength and stiffness after 15 M load cycles. Ten test specimens, five with load parallel to the wood grain and five with load perpendicular to the wood grain, were loaded cyclically to 2,200 pounds of shear load. Shear strength and stiffness were measured after one and 15 M cycles of load from static tests on a Universal Testing Machine. Secondary measures of shear stiffness were measured after 1000, 10,000, 100,000, 400,000, 1M, 2M, 4M, 6M, 8M, 10M, 12M, 14M and 15M load cycles. One specimen failed prematurely after approximately 6.9 M load cycles. The failure mode for this specimen was combined bending and shear failure of the steel stud due to faulty specimen mounting in the test jig. All other specimens were still sound after 15 M load cycles. The failure mode for each of the nine specimens, when loaded to failure in static tests, was plastic hinge development at the interface between the shear stud and the attached steel plate. There was no evidence of wood failure in any of the specimens at ultimate strength. The residual strength of the connector system after 15 M load cycles of fatigue loading to 2,200 pounds was 92.8 percent and 87.7 percent, respectively, of the original strength for loading parallel and perpendicular to the grain. The normalized average shear stiffness (Ratio of stiffness after 15 M load cycles to the stiffness after one load cycle) of the parallel and perpendicular to grain specimens was 0.48 and 0.74, respectively. These results indicate that the addendum sheet submitted in the final report for Work Order 97 of Prime Agreement No. 359704 in December, 2001 for the weldable shear stud-epoxy grout connector system for the BLC-560M, Standard Plans for Hardwood Glulam is still appropriate, without change, for bridges with a 100 year life cycle at 400 ADTT.

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CYCLIC LOAD TESTING OF WELDABLE SHEAR CONNECTORS FOR GLULAM DECKS ON BRIDGE GIRDERS

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FINAL REPORT

Prepared for

Commonwealth of Pennsylvania
Department of Transportation

By

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and
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1.0 INTRODUCTION

Two previous project reports, submitted to the Pennsylvania Department of Transportation (PENNDOT)[1], between July 1, 1999 and December 7, 2001, have documented the steps taken to develop and conduct performance tests on a novel weldable shear connector for glulam decks on existing bridge girders developed at The Pennsylvania State University (figure 1.1). The reports presented results of the following performance tests that were successfully conducted on the weldable epoxy shear stud connection:

(i) Static testing, involving loading the connection in three independent directions: parallel to the grain, perpendicular to the grain, and in direct withdrawal; and

(ii) The residual load-slip characteristics of the welded shear stud epoxy grout (WSSEG) connection after a design life of 50 years with an average daily truck traffic (ADTT) volume of 200 trucks per day, i.e., 3.7 million cycles of loading.

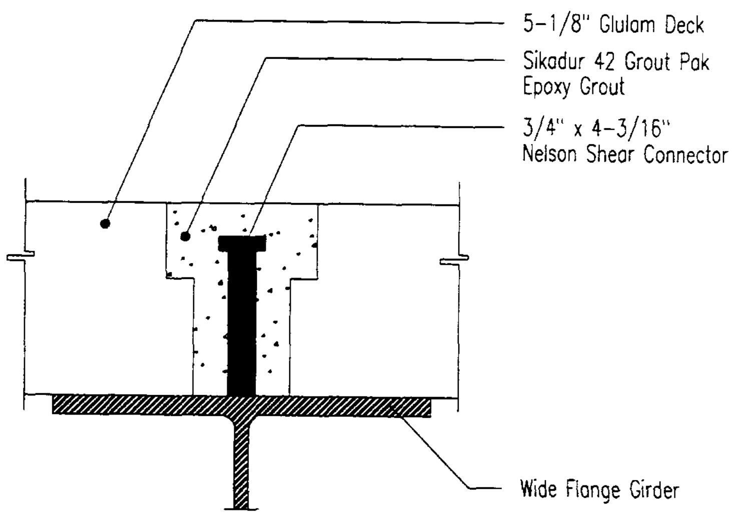

Figure 1.1. The WSSEG Connection Detail for Glulam Deck Installation.

The data obtained in all three static tests (shear parallel to the grain, shear perpendicular to the grain, and withdrawal) showed that WSSEG is superior in terms of strength and stiffness to the BLC-560M offset shoe connection currently used by PENNDOT for fastening glulam timber decks to steel girders for use either in new construction or the rehabilitation of steel girder bridges. The test protocol employed demonstrated a high degree of reliability as measured by a relatively low coefficient of variation (COV) for

[1]The reports based on PDA Contract No. ME 449269 and PENNDOT Prime Agreement No. 359704 Work Order 97, respectively.

the test data. The load slip performance tests showed that WSSEG retained more than 93 percent of its original connection strength (96.4 percent and 93.5 percent, respectively, for loading parallel and perpendicular to the wood grain directions) at the end of the 3.7 million cycles of fatigue loading subjecting the WSSEG connection to a repetitive 2,100-lbs shear force.

The goal of this study was to establish connection strength and the residual shear stiffness of WSSEG after 15 million cycles of repetitive loading. This report presents the procedures, results and conclusions of this project. Supplementary materials such as laboratory data are presented in a compact disc attached as an appendix.

2.0 WSSEG LABORATORY EVALUATIONS

2.1 SCOPE OF LABORATORY EVALUATIONS

Ten WSSEG connection assemblies were investigated for evaluation of their load fatigue characteristics when subjected to 15 million cycles of loading to approximately 2,200 ± 100-lbs. Five of the specimens were randomly selected and loaded in shear in the parallel to wood grain direction, and five for loading in the perpendicular to wood grain direction to collect nondestructive test data to characterize initial stiffness measures for the assembled WSSEG specimens. Load-deformation data were collected with an in-situ load cell and dial indicators at 14 logarithmic intervals to monitor specimen connection status and to obtain a qualitative measure of connector shear stiffness during the cyclic test protocol. Connector shear stiffness after one and after 15 million cycles of loading were obtained from static tests on a universal testing machine. In addition to evaluation of residual stiffness, WSSEG specimens were subjected to destructive testing to examine characteristic residual joint connection strength after 15 million cycles of loading. Strength refers to the five percent offset load (5% P) of the static load-deflection response curve recorded for each specimen. This value is consistent with the application of European Yield Theory to establish dowel connector design limit performance of wood dowel connectors. Data collection from this current laboratory activity has been compiled with previous PENNDOT sponsored research data collection on the WSSEG connection system to identify, on a comparative basis, relative trends for reductions in observed connector performance with number of load cycles.

2.2 TEST METHODOLOGY

The ten WSSEG connection specimens were fabricated for the cyclic testing protocol, using glulam fabricated from red maple (*Acer rubrum*). All red maple glued-laminated timber for test evaluation were identical to prior loading research. Materials in terms of glulam construction composed visual rated No. 2 or better 2x6 lumber. Five of the specimens were fabricated with the grain parallel, while the other five were fabricated with the grain perpendicular to the direction of loading. The parallel to the grain specimens were 24-in x 14-in x 5.125-in glulam pieces attached to an A36 steel plate using the WSSEG connection similar to that used in previous tests. The perpendicular to the grain specimens were 26-in x 18-in x 5.125-in glulam pieces attached to an A36 steel plate applying the Nelson stud of the WSSEG connection (figures 2.1 and 2.2). The specimen dimensions were based on the minimum recommended edge and end distances required for the development of the full connection strength following NDS (1997)[2].

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[2] "National Design Specification for Wood Construction, (NDS), 1997 ed.", published by the American Forest and Paper Association.

To assure a lack of bias between prior and current evaluation or a disparity for similarity in the red maple glulam; material density of test specimen lumber was checked through use of the following empirical relation published in NDS (1997):

$$Density = 62.4[G / 1+ G(0.009)(m.c)][1+m.c./100]$$

where

G = specific gravity of wood, and
m.c. = percent moisture content of wood

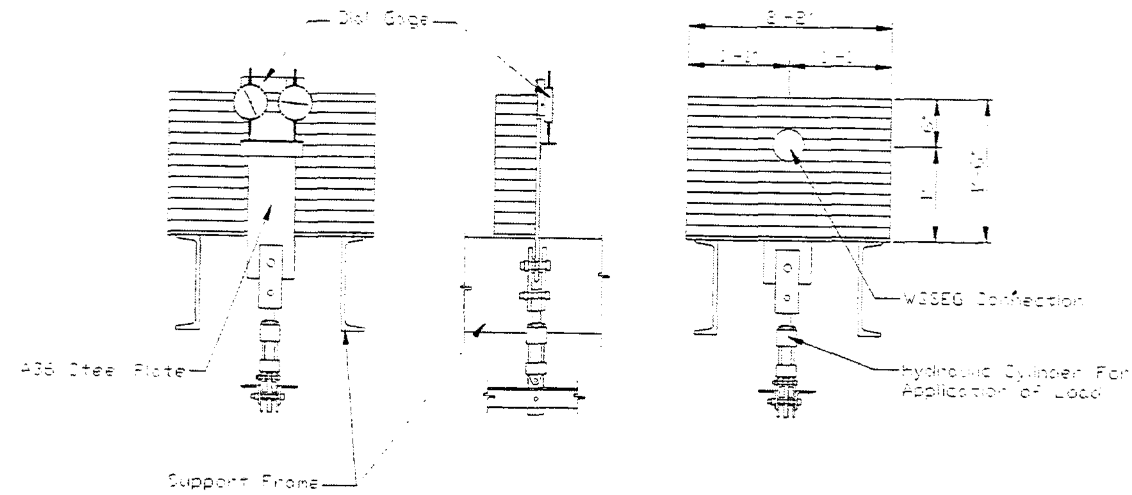
The moisture content was also determined using a Delmhorst electric resistance type moisture meter. Average moisture content for both parallel and perpendicular test materials was 9.1 ± 1 percent. Adjusted material density was 38-lb/ft^3. This density is in close agreement to the red maple used within previous laboratory WSSEG test trials (Witmer, 2002)[3].

Prior to the cyclic loading test, each of the ten specimens was loaded in a monotonically increasing static test configuration identical to that used and reported in the previous reports submitted to PENNDOT. For clarification, all static test trials involved the use of a Instron-Satec Model 100UD fully-calibrated 100 kip capacity electro-mechanical universal testing machine (UTM)[4] with integrated data acquisition system for specimen test measurement of load related displacements via LVDT (linear variable displacement transducers) analog devices. This UTM is housed in the Forest Resources Laboratory at Penn State University (University Park, PA). In contrast, the cyclic loading trials were performed in the Wood Engineering Laboratory associated with the Agricultural and Biological Department. The static tests, as noted above, were used to quantify the initial stiffness of assembled WSSEG connection specimens. Thereafter, the ten specimens were mounted in a loading frame, securing the glulam portion of each specimen in a stationary position, and attaching the steel plate to a hydraulic loading ram for exposure to repetitive loading (figures 2.3 and 2.4). This loading frame for the PENNDOT sponsored research was specially built to conduct this type of cyclic exposure testing trials to accommodate the assembled glulam with WSSEG connection specimen.

The loading ram designed to act in fatigue on the connection was then cycled between 200-lbs and 2,200-lbs at an applied rate of 5.6 cycles per second (5.6 Hz). The displacements of the connections under full load were manually measured periodically throughout the test procedure using two Starrett dial gages with least reading of 0.0001-in. Data on connection displacements were collected at approximately logarithmic intervals (N = 1, 1E3, 1E4, 1E5, 4E5, 1E6, 2E6, 4E6, 6E6, 8E6, 10E6, 12E6, 14E6, and 15E6 cycles). At each interval, connector displacement for each specimen was measured at 400-lbs increments between zero and 2,000 lbs. These measurements were taken primarily to assure that no systematic difficulties arose in the test frame or test specimens

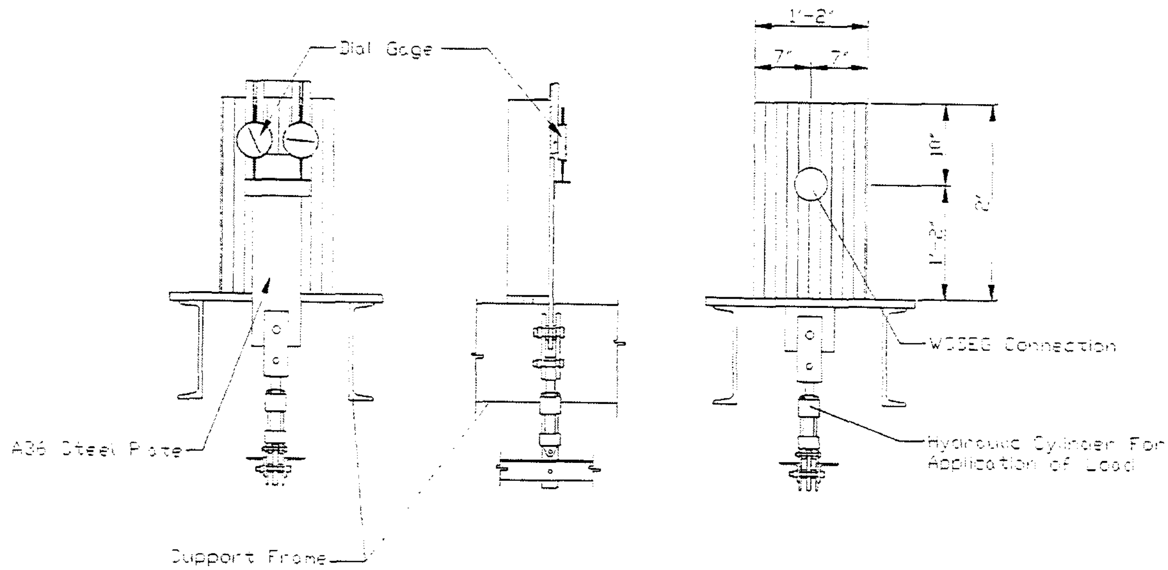
[3] A research report in the Department of Agricultural and Biological Engineering, The Pennsylvania State University, University Park, PA 16802
[4] The specimens were loaded up to 5,000-lbs on the UTM and up to only 2,000-lbs on the cyclic load test rig (due to equipment limitations). The stiffness values obtained from the UTM were, however, subsequently normalized to 2,000-lbs.

during the cyclic load phase of the test protocol, and to allow estimation of the connector stiffness reduction trend with number of cycles.



(a) (b) (c)

Figure 2.1. Schematic Illustrations of WSSEG Perpendicular to Grain Specimen Test Arrangement, Front (a), Side (b), and Back (c) Views.



(a) (b) (c)

Figure 2.2. Schematic Illustrations of WSSEG Parallel to Grain Specimen Test Arrangement, Front (a), Side (b), and Back (c) Views.

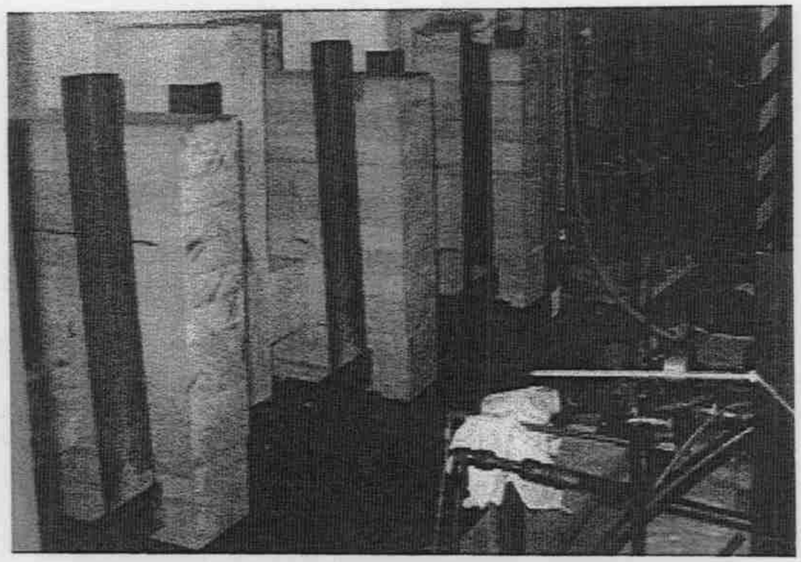


Figure 2.3. WSSEG Specimens for Exposure to Cyclic Loading Trial.

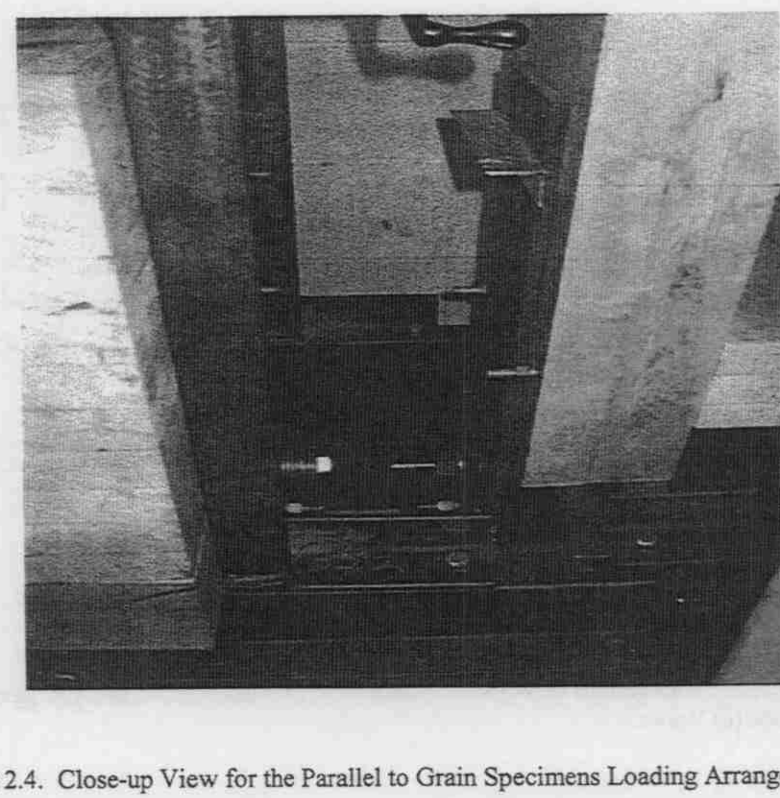


Figure 2.4. Close-up View for the Parallel to Grain Specimens Loading Arrangement.

The connection in specimen 8 (parallel specimen) failed at about 6.9 million cycles of loading. Specimen failure was identified as a combined tension plus shear failure due to a flaw in the interface between the test jig and the test specimen. Subsequent data analyses for the parallel to grain specimens therefore involved only four specimens (specimens 2, 4, 6, and 10).

At the completion of the 15E6 loading cycles, the specimens were removed and loaded to failure in a monotonically increasing static test configuration using the identified Satec UTM. This static test was used to quantify the connector residual shear stiffness after 15E6 loading cycles by comparing the outcomes to the initial test values obtained. Residual connection strength after 15E6 cycles was also measured in these tests and was compared to initial connector strength cited in the PENNDOT/PTI Work Order 97, Final Report.

3.0 LABORATORY DATA RESULTS

3.1 FIVE PERCENT OFFSET STRENGTH

The laboratory data for the cyclic tests and the initial and final static tests using UTM are included in the compact disc (CD) attached as the appendix. Table 3.1 shows the five percent offset strength values of the test specimens after 15E6 load cycles. Figures 3.1 and 3.2 show sample plots of the load-deformation behavior observed in the static test after 15E6 load cycles including the plot of connection stiffness and offset load for the perpendicular and parallel to the grain specimens. Table 3.2 compares the connection strength after 3.7E6 and 15E6 cycles with the cycle 1 test data originally reported in the final report for PDA Contract ME 449-269, appended to the final report for PENNDOT/PTI Work Order 97.

The average five percent offset strengths of the parallel and the perpendicular to grain connection after 15E6 load cycles were 20,128-lbs and 14,896-lbs respectively. The corresponding COV's were 2.59 percent and 12.12 percent. These five percent offset strengths compare favorably with those reported in PDA Contract ME 449-269 Final Report (appendix 2A), (table 3.2), for similar specimens after 1 cycle of loading (i.e., 21,690-lbs and 16,980-lbs, respectively, for parallel and perpendicular to grain loading), and after 3.7E6 load cycles, (i.e., 20,910-lbs and 15,880-lbs, respectively, for the parallel to grain and the perpendicular to grain connections). The percentage loss in connection strength after 3.7E6 cycles was only 3.6 percent of the original connection strength when loaded parallel to grain and 6.5 percent when loaded perpendicular to grain. The overall percentage loss in connection strength after 15E6 cycles was only 7.3 percent of the original connection strength when loaded parallel to grain and 12.3 percent when loaded perpendicular to grain. These small reductions in connection strength indicate that the number of WSSEG connectors based on original strength is satisfactory. That is, the number of WSSEG connectors, as reported in the January 19, 2001 Penn State submission to PENNDOT, are still satisfactory after 15 million load cycles to 2,200-lbs.

Table 3.1. Five Percent Offset Shear Strength Values of the Specimens After Completion of 15E6 Load Cycles.

Test Orientation/ Actual Specimen Number	Observed 5% Offset Load Values (lbs)	Test Orientation/ Actual Specimen Number	Observed 5% Offset Load Values (lbs)
Perpendicular to Grain Load		**Parallel to Grain Load**	
(1)	16,500	(2)	19,740
(3)	16,500	(4)	20,620
(5)	15,530	(6)	20,530
(7)	12,750	(8)	N/A[1]
(9)	13,200	(10)	19,620
Average	**14896**	**Average**	**20128**
Std. dev.	**1804.8**	**Std. dev.**	**520.3**
COV (%)	**12.12**	**COV (%)**	**2.59**

[1] Parallel Specimen No. 8 failed prematurely at 6.9E+06 load cycles due to combined bending and shear stresses due to improper test jig/specimen assembly.

Table 3.2. Comparison of Five Percent Offset Shear Strength Values After 1, 3.7E6 and 15E6 Load Cycles.

Load Cycles	**Parallel Specimens**		**Perpendicular Specimens**	
	5% Offset Load (lbs)	**Percent Difference (%)[1]**	**5% Offset Load (lbs)**	**Percent Difference (%)[1]**
1 Cycle[2]	21,690		16,980	
3.7E6 cycles[3]	20,910	3.6	15,880	6.5
15E6 cycles[4]	20,128	7.3	14,896	12.3

[1] Percentage difference in strength at N cycles and strength after 1 cycle.
[2] From PDA Contract ME 449-269 (appendix 2A).
[3] From Draft Final Project Report of October 8, 2001 (page 8).
[4] From current study, using four parallel and five perpendicular specimens respectively.

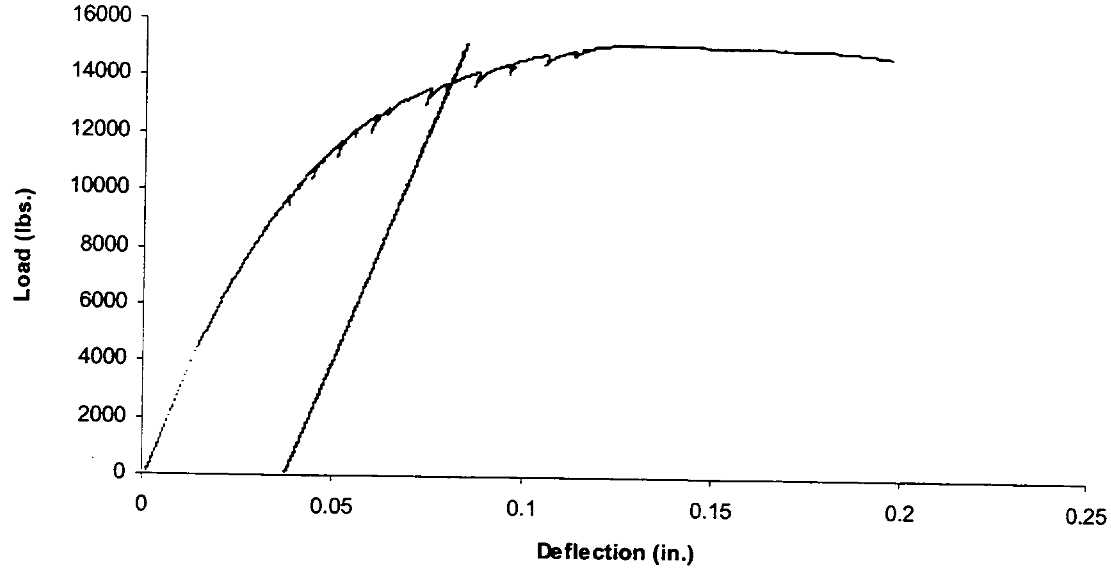


Figure 3.1. Static Load-Deflection Response of Specimen Loaded Perpendicular to Grain (Specimen 9) Obtained with UTM after 15E6 Load Cycles.

Note: Yellow line denotes regressed line to define stiffness, while magenta line denotes five percent offset strength line.

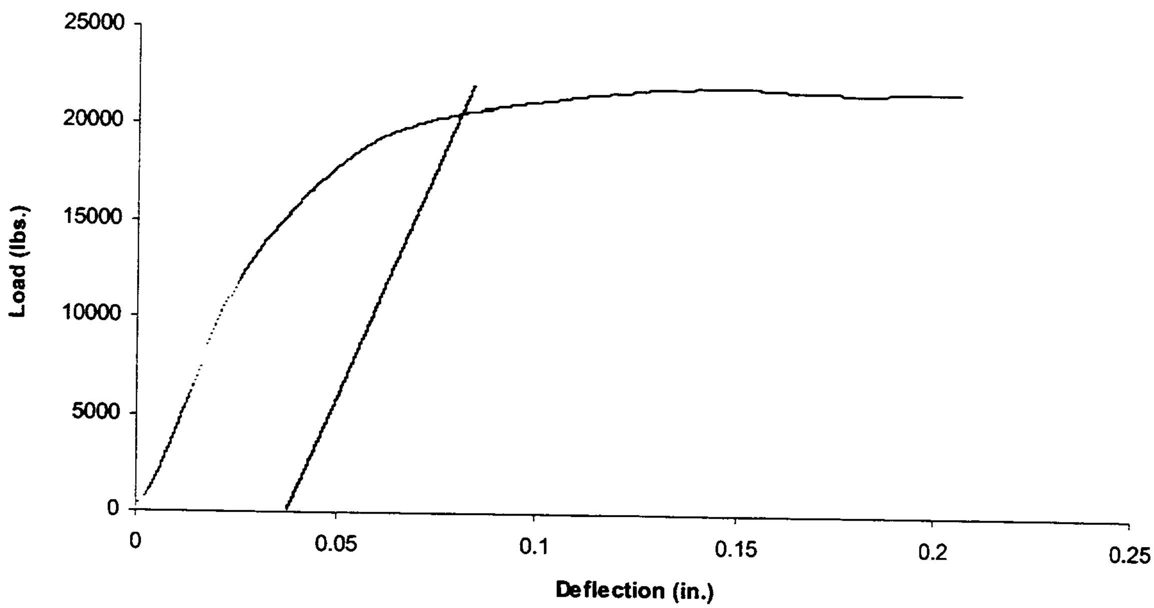


Figure 3.2. Static Load-Deflection Response of Specimen Loaded Parallel to Grain (Specimen 6) Obtained with UTM after 15E6 Load Cycles.

Note: Yellow line denotes regressed line to define stiffness, while magenta line denotes five percent offset strength line.

3.2 RESIDUAL STIFFNESS

Table 3.3 compares the initial shear stiffness values (slope of the load-deflection curve at P = 2k) after one load cycle for all the parallel and the perpendicular specimens, with the residual initial stiffness values after 15E6 cyclic loading for the four parallel and the five perpendicular specimens using the UTM. Figures 3.3 and 3.4, respectively, illustrate the shear deflection behaviors for the four parallel and five perpendicular test specimens after the 15 million cycles of loading.

Table 3.3. Shear Stiffness Values of the Connector Specimens After One and After 15E6 Cycles of Repetitive Loading at P = 2k From UTM Tests.

Test Orientation/Actual Specimen Number	Observed Shear Stiffness After 1 Cycle (lb/in) [1]	Observed Shear Stiffness After 15E6 Cycles (lb/in) [1]
Perpendicular to Grain Load		
(1)	4.09E+05	3.14E+05
(3)	5.94E+05	5.01E+05
(5)	3.19E+05	3.27E+05
(7)	4.90E+05	2.12E+05
(9)	4.49E+05	3.38E+05
Mean	**4.52E+05**	**3.38E+05**
SD	**1.01E+05**	**1.04E+05**
COV (%)	**22.4**	**30.7**
Parallel to Grain Load		
(2)	7.0E+05	3.13E+05
(4)	4.39E+05	4.70E+05
(6)	7.99E+05	3.42E+05
(8) [2]	1.22E+06	N/A
(10)	7.13E+05	3.54E+05
Mean	**7.74E+05**	**3.69E+05**
SD	**2.84E+05**	**6.9E+04**
COV (%)	**36.6**	**18.6**

[1] Test results obtained at 2,000-lbs loading using the UTM.
[2] Parallel Specimen No. 8 failed prematurely at 6.9E+06 load cycles due to combined bending and shear stresses due to improper test jig/specimen assembly.

The average residual shear stiffness values after 15E6 load cycles for the four parallel and the five perpendicular to grain connections were 3.69E+05 and 3.38E+05 lb/in, respectively, (the corresponding COV's being 18.6 percent and 30.7 percent); corresponding average shear stiffness values after one load cycle were 7.74E+05 lb/in and 4.52E+05 lb/in, (respective COV's being 36.6 percent and 22.4 percent).

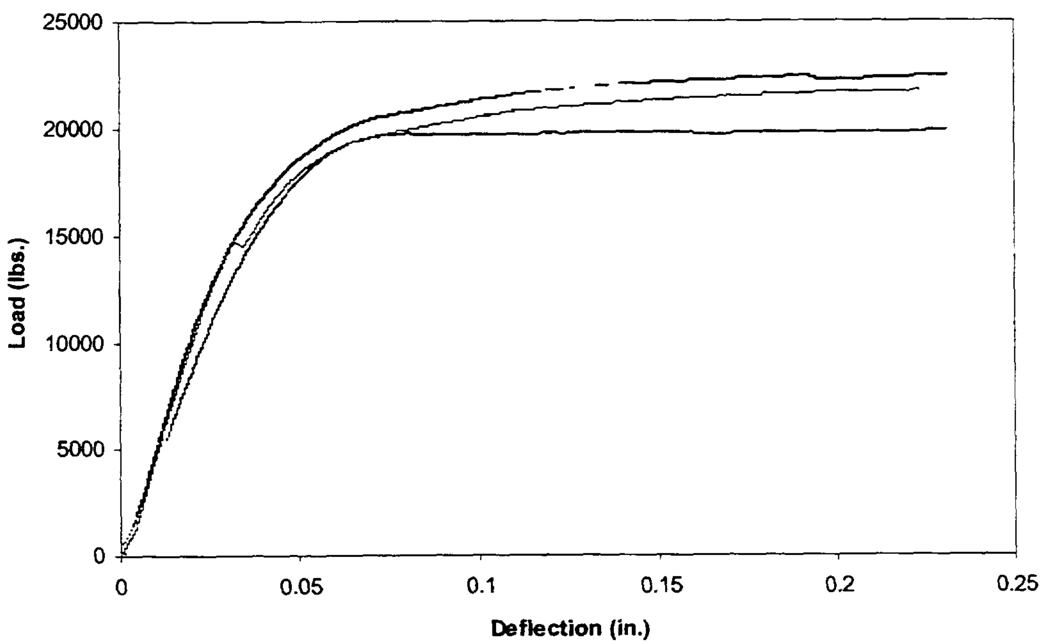


Figure 3.3. Loading Behavior of the Four Parallel Specimens (2, 4, 6, and 10) After 15E6 Cycles.

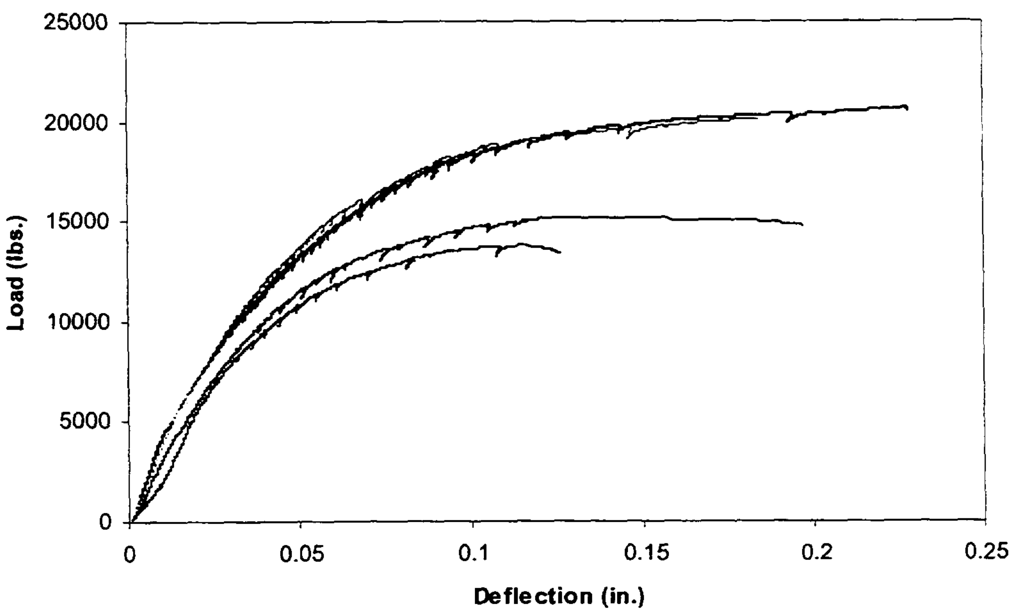


Figure 3.4. Loading Behavior of the Five Perpendicular Specimens (1, 3, 5, 7, and 9) After 15E6 Cycles.

The percentage loss in connection stiffness after 15E6 load cycles was 52.5 percent of original connection shear stiffness when loaded parallel to the wood grain and 25.2 percent when loaded perpendicular to the wood grain.

To estimate, by deduction, the trend in loss of connection shear stiffness with the loading cycle, the displacements of the connections under incremental static loading (i.e., loading at 400-lbs increments between zero and 2000-lbs loads), were manually obtained with the two Starrett dial gages at approximately logarithmic intervals (N = 1, 1E3, 1E4, 1E5, 4E5, 1E6, 2E6, 4E6, 6E6, 8E6, 10E6, 12E6, 14E6, and 15E6 cycles). Three connection specimens each, out of the five perpendicular and the four remaining parallel specimens, gave the most consistent dial gage data throughout the cyclic test protocol. These were parallel specimens (2), (4), and (6) and perpendicular specimens (1), (5), and (9). Normalized average shear stiffness (k_N/k_0 = stiffness at N / stiffness at N = 1) versus the logarithm of load cycles curves obtained from these representative sample specimens are shown in figures 3.5 and 3.6. The normalized average shear stiffness values for the specimens from the UTM tests were also plotted with a special symbol at the N = 15E6.

Table 3.4 compares the average normalized shear stiffness values after 15E6 cycles for these representative parallel and perpendicular to grain specimens, obtained using mounted dial gages, with the stiffness values, obtained for the four parallel and the five perpendicular specimens, using the UTM. Results obtained using the mounted dial gages gave consistently higher average residual stiffness values than the results obtained from the UTM. However, as shown in table 3.4, the order of magnitude of differences in the values obtained using both methods were fairly consistent, being in the range of 0.67 to 0.86 for both loading orientations.

Table 3.4. Comparison of Average Normalized (k_{15}/k_0) Shear Stiffness After 15E6 Load Cycles of Connection Specimens from Dial Gage and UTM Test Data.

Specimen Load Orientation	Normalized Residual Shear Stiffness Obtained with Dial gage indicator [1]	Normalized Residual Shear Stiffness Obtained with UTM [2]	Multiplier[3]
Parallel	0.72	0.48	0.67
Perpendicular	0.86	0.74	0.86

[1] Residual Values obtained using the relationship: K_{15M}/K_0 for three representative specimens each.
[2] Values obtained using the relationship: K_{15M}/K_0 for four parallel and 5 perpendicular specimens.
[3] The multipliers were obtained using the relation: $(K_{UTM}) / (K_{dial\ gage})$.

The multipliers indicated in table 3.4 were used to generate estimated values of the residual stiffness of the connection specimens at the different load cycles, (i.e., at the previously indicated logarithmic intervals), based on the average residual stiffness values obtained using the mounted dial gages. That is, the estimated stiffness ratio after N cycles

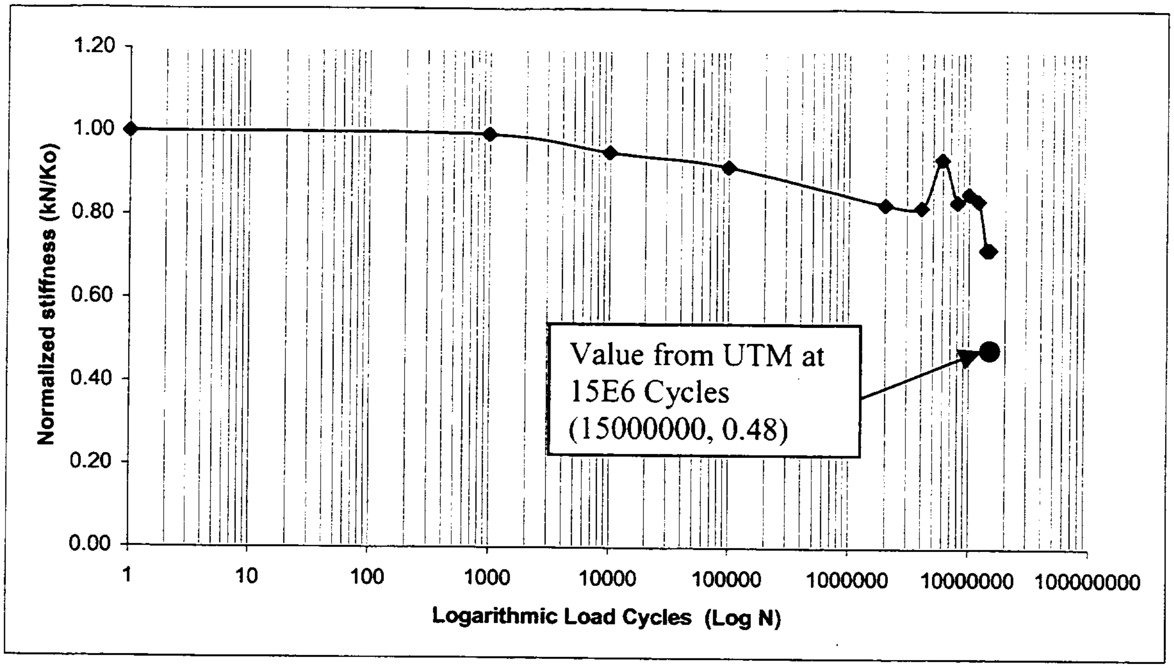


Figure 3.5. Normalized Average Stiffness vs. Log. of Load Cycles for Parallel Specimens (2), (4), and (6) from Dial Gage Data.

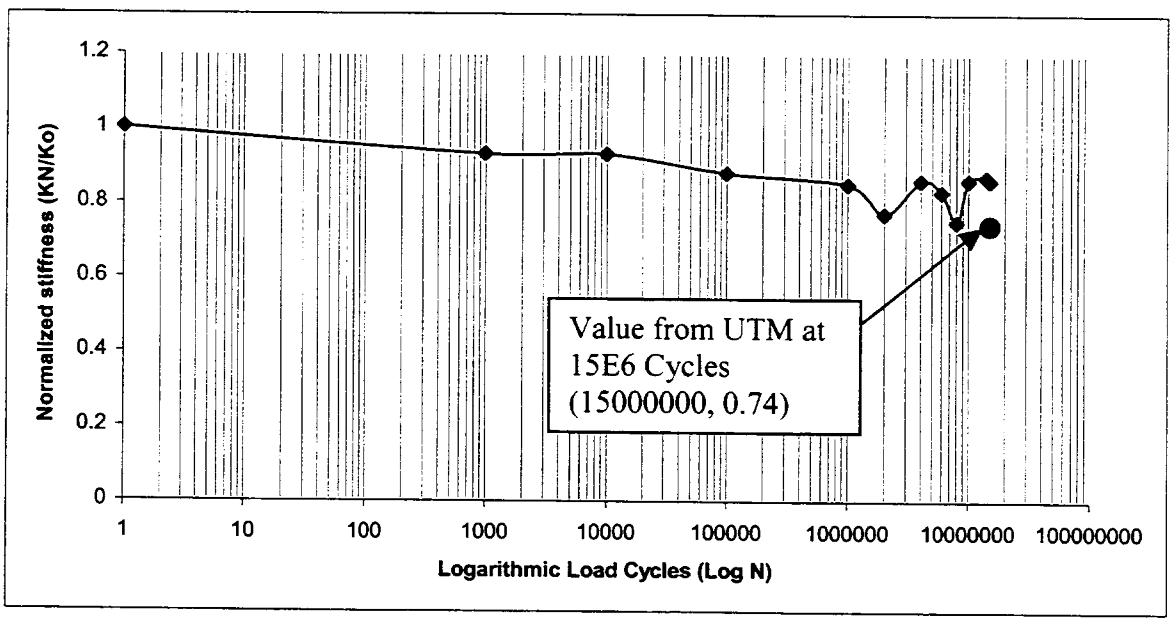


Figure 3.6: Normalized Average Stiffness vs. Log. of Load Cycles for Perpendicular Specimens (1), (5), and (9) from Dial Gage Data.

is the product of the average stiffness ratio from dial gage data and the appropriate multiplier in the last column of table 3.4. The results are presented in figure 3.7 and 3.8. Note that the data points at N = 1 and N = 15E6 cycles are from UTM tests and are the most reliable. The data points between one and 15E6 cycles were deduced from the dial gage measurements and are estimates.

The data in figures 3.7 and 3.8 suggest a nearly linearly decreasing normalized shear stiffness with log (N) for both load orientations. Closer inspection suggests the rate of decrease in normalized stiffness is actually decreasing slightly with number of cycles.

Table 3.5 compares the average normalized shear stiffness values after 3.7 E6 and 15E6 cycles for the parallel and perpendicular to grain specimens, obtained using the UTM. The normalized shear stiffness at 3.7E6 load cycles are from the load-slip data reported in the Final Report for PENNDOT Prime Agreement No. 359704, Work Order 97[1]. These data points are plotted on figures 3.7 and 3.8. The estimated stiffness for perpendicular to grain loading is almost identical to the UTM generated stiffness. The estimated stiffness is 27 percent lower than the UTM generated value for the parallel to grain loading.

Table 3.5: Comparison of Average Normalized (k_{15}/k_0) Shear Stiffness After 3.7E6 and 15E6 Load Cycles of Connection Specimens.

Specimen Load Orientation	Normalized Residual Shear Stiffness After 3.7E6 Cycles[1]	Normalized Residual Shear Stiffness After 15E6 Cycles
Parallel	0.66	0.48
Perpendicular	0.71	0.74

[1] From PDA Draft Final Project Report of October 8, 2001.

3.3 YIELD MODE

A destructive test evaluation (involving breaking the specimens apart for visual examination of the mode of connection failure) of the remaining nine WSSEG connection specimens (i.e., five perpendicular and four parallel specimens) conducted at the completion of the 15E6 loading cycles showed that in all cases, the studs were bent, and plastic hinges were formed in the fastener (figure 3.9). There was no evidence of wood failure in any of the specimens. The theoretical yield model that best approximates this behavior is Yield Mode III_m[5] as given by AF&PA (1997)[6]. This observation is similar to

[5] The WSSEG connection is best described, theoretically, as a bolted connection (since there is no withdrawal), where the stud is assumed to be the bolt, and the weld as the nut. In such a two-member connection, the main member is the thicker member, i.e., the glulam, while the side member is the steel plate. In a Mode III_m mechanism, the dowel (in this case the Nelson stud) bends and a plastic hinge occurs inside the main member.

[6] American Forest and Paper Association (AF&PA), 1997. National Design Specification for Wood Construction and Supplement, 1997 ed., AF&PA, Washington, DC.

that reported after 3.7E6 load cycles in the final report to PENNDOT for Prime Agreement 359704, Work Order 97.

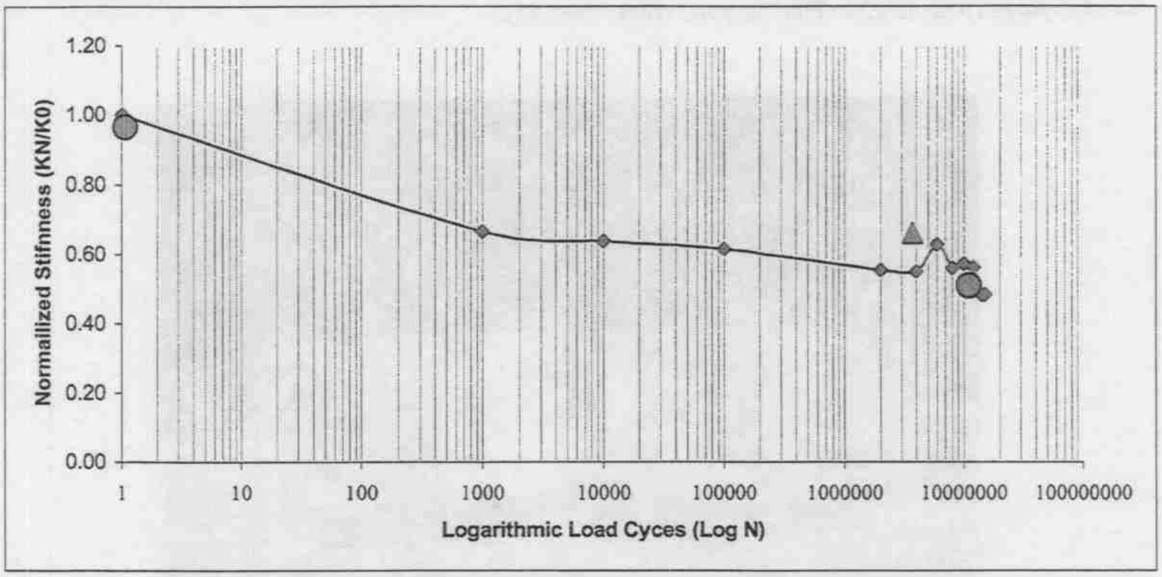


Figure 3.7. Estimated Trend for Normalized Average Stiffness vs. Log. of Load Cycles for the Parallel Specimens.

Note: The circular-shaped symbols denote the normalized average stiffness values obtained from UTM, while the triangular-shaped symbol denotes the normalized average stiffness value at 3.7E6 cycles from UTM (Final Report, Work Order 97).

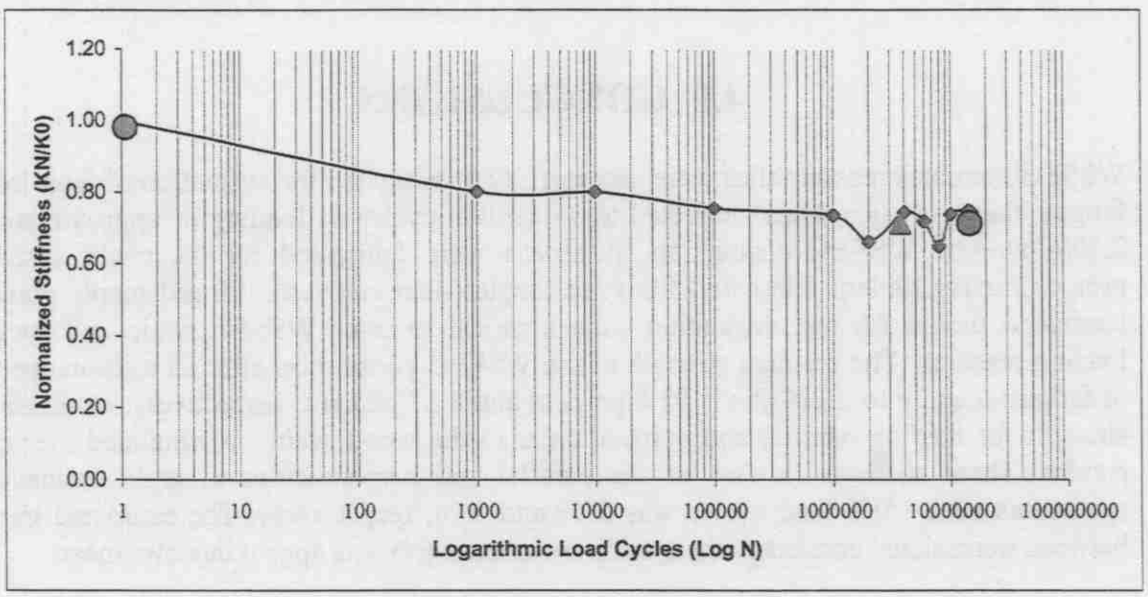


Figure 3.8. Estimated Trend for Normalized Average Stiffness vs. Log. of Load Cycles for the Perpendicular Specimens.

Note: The circular-shaped symbols denote the normalized average stiffness values obtained from UTM, while the triangular -shaped symbol denotes the normalized average stiffness value at 3.7E6 cycles from UTM (Final Report, Work Order 97).

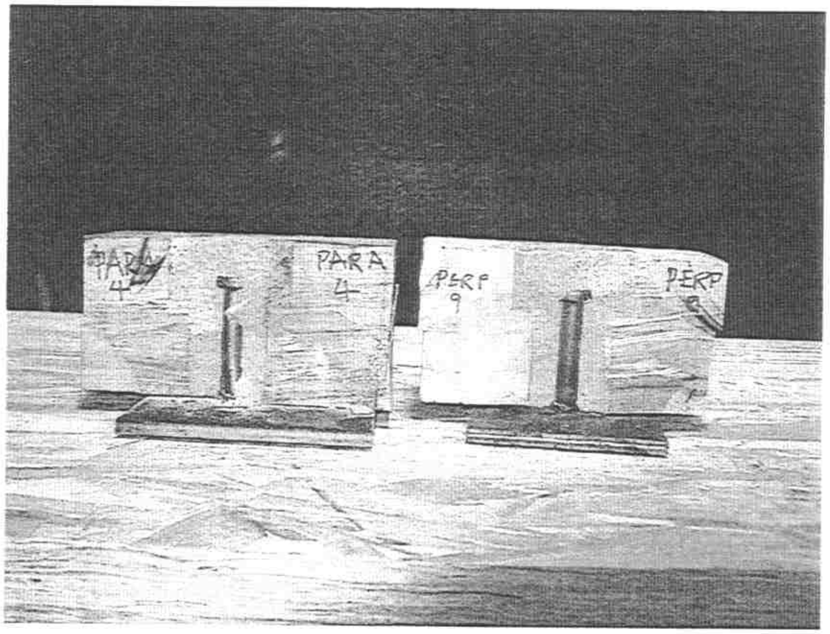


Figure 3.9. Close-up View of the Fatigued Nelson Studs in One Parallel and One Perpendicular WSSEG Connector Specimens.

4.0 CONCLUSIONS

WSSEG connection assemblies were successfully investigated for evaluation of their load fatigue characteristics when subjected to 15 million cycles of loading of approximately 2,200-lbs. The WSSEG connection specimens were fabricated for the cyclic testing protocol, using glulam fabricated from red maple (*Acer rubrum*). All red maple glued-laminated timber for test evaluation were identical to prior WSSEG static and cyclic loading research. The residual strength of the WSSEG connection after 15 million cycles of fatigue loading to 2,200-lbs is 92.8 percent and 87.7 percent, respectively, of original strength for loading parallel and perpendicular to the wood grain. Normalized average residual shear stiffness (k_{15}/k_0) of the parallel and perpendicular to grain connector specimens after 15E6 load cycles was 0.48 and 0.74, respectively. The estimated trend between normalized connector shear stiffness and log (N) was approximately linear.

The original connection strength is satisfactory for design calculations for bridge applications with up to 15 million load cycles. The loss in shear stiffness is also not a concern since the bridge girders in PENNDOT's BLC-560M standard plans for Hardwood Glued-Laminated Timber Bridges do not include composite action between the deck and girders. The loss in shear stiffness with load cycle would only tend to reduce the cyclic shear force carried by the WSSEG connector over the life of the bridge deck system. Thus, the revised detail for the WSSEG connection recommended in the Final Report for PENNDOT Prime Agreement 359704, Work Order 97 is satisfactory, without change, for a 400 ADTT application with a service life of 100 years (15E6 load cycles).