TECHOLOGY DIGEST

Timely Technology Transfer — 02-012

Fatigue Testing of Douglas Fir, Glued-laminated, Timber Railroad Bridges

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Recent tests show that glued-laminated Douglas fir timber bridge stringers offer a 30 and 40 percent gain in performance over the solid-sawn southern pine and Douglas fir stringers. Early indications in the test program suggest that using wood products such as glued-laminated stringers might attain very favorable performance under heavy axle loads.

Transportation Technology Center, Inc., (TTCI) in collaboration with Texas A&M University, began testing glued-laminated stringers to determine their capacity to extend the service life of railroad timber bridges. Timber stringers are the main flexural elements in a timber railroad bridge. They carry the load of a train from the deck of a bridge (the portion of a bridge that provides direct support for traffic) to the bents (the caps and columns). Testing began in 2001 on 20 new 6 3/4″×18″×15′ long, glued-laminated, creosote-treated, Douglas fir railroad bridge stringers. The tests were conducted in four-point bending to generate critical data for use in assessing the effects of heavy axle load operations on the performance and reliability of the existing timber bridges.

Main findings from this laboratory investigation include:

- All of the static test failures** were horizontal shear ruptures at mid-depth in shear span. The smallest mid-depth monotonic shear stress that caused a shear failure was 446 psi. The average monotonic shear strength of the stringers was 517 psi with a standard deviation of 47 psi.
- Nine of the twelve stringers that failed under pulsating load, failed in horizontal shear. The smallest mid-depth pulsating shear stress that caused shear failure of a stringer was 214 psi.
- The three remaining stringers that failed under pulsating load, failed in tension.
- Observations during the fatigue tests suggest that pulsating load causes incremental growth of pre-existing checks and ultimately a mid-depth horizontal shear failure.
- The glued-laminated Douglas fir specimens have shown substantial gain in performance over the solid-sawn Douglas fir and solid-sawn southern pine stringers tested previously.[1, 2]

The results of these tests are being shared with AREMA Committee 7-Timber Structures for purposes of affecting changes in the shear design value used for timber railroad bridges. The S-N curves developed will be used in TTCI's modeling software Railroad Timber Bridge Stringer Model™ to assess the fatigue life of glued-laminated stringers in existing timber bridges.

More research is needed to determine the reliability of the available designs of glued-laminated stringers as well as other wood products intended for use in timber railroad bridges.

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** The term "failure," as used in this document when referring to a single stringer, does not imply that the stringers are no longer able to provide load resistance as part of a bridge structure

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INTRODUCTION AND CONCLUSIONS

In earlier tests performed on solid-sawn stringers by TTCI, results showed that railroad bridges could withstand higher stresses than previously thought.[1,2] Use of higher stresses for rating existing bridges will allow railroads to realize additional capacity for carrying heavy axle loads and extending service life. Further, TTCI, in collaboration with Texas A&M University, began testing glued-laminated stringers to determine their capacity to extend the service life of railroad timber bridges. Timber stringers are the main flexural elements in a timber railroad bridge (Figure 1). They carry the load of a train from the deck of a bridge (the portion of a bridge that provides direct support for traffic) to the bents (the caps and columns).

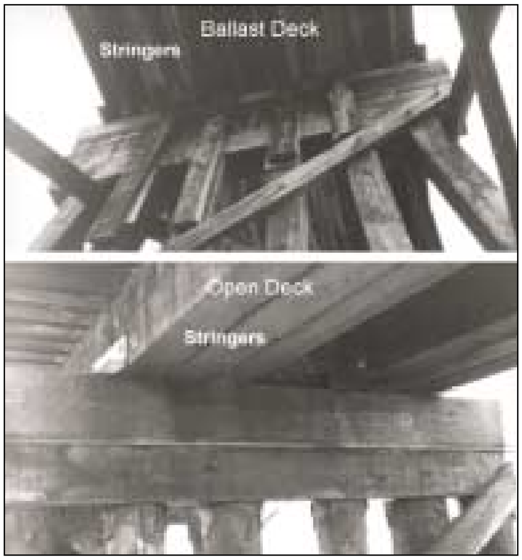

Figure 1. Timber Bridge Stringers

Last year, testing began on 20 new 6 3/4″×18″×15′ long, glued-laminated, creosote-treated, Douglas fir railroad bridge stringers. The tests were conducted in four-point bending to generate critical data for use in assessing the effects of heavy axle load operations on the performance and reliability of the existing timber bridges.

These tests show that the glued-laminated Douglas fir stringers offer a 30 and 40 percent gain in the performance over the solid-sawn southern pine and Douglas fir stringers. However, more research is needed to determine the reliability of the available designs of glued-laminated stringers as well as other wood products intended for use in timber railroad bridges. Nevertheless, early indications in the test program suggest that using wood products such as glued-laminated stringers might attain very favorable performance under heavy axle loads.

EXPERIMENTAL PROCEDURES

The stringer specimens tested in this study were new; that is, they had never been subjected to load in a bridge structure. Upon delivery, each stringer specimen was assigned a nominal identification number, measured, and weighed. The average cross-sectional area, moment of inertia, section modulus, volume, and specimen density were determined for each specimen.

Originally, there were 20 specimens: 7 for monotonic (static) testing and 13 for fatigue testing. However, one of the specimens for fatigue testing failed prematurely, leaving 19 specimens for further testing. Each specimen was inspected thoroughly to assess pre-test condition. All pre-existing cracks were highlighted to allow for observation of the mechanism of failure and crack propagation paths relative to pre-existing, naturally occurring imperfections.

A two-level loading frame (Figure 2) was designed and fabricated for this study, which allowed four stringers to be tested simultaneously at a maximum loading frequency of 3 Hz. Test specimens are supported simply and subjected to four-point bending.

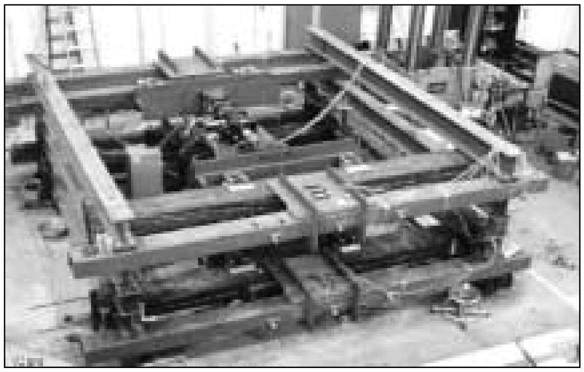

Figure 2. Fatigue Loading Frame

A central computer controlled the test loads and recorded the output of the load cells and displacement transducers. Three displacement transducers were used for each specimen: one each placed at mid-span and the two load points. This arrangement of displacement measurement allowed for determining bending deflection and flexural stiffness in the constant moment region of the specimen independent of shear deformations in the remainder of the beam.

Experimental Results

Results from previously conducted fatigue tests showed minimum horizontal shear stress at which a solid-sawn southern pine stringer failed at 165 psi and a solid-sawn Douglas fir stringer failed at 155 psi.[1, 2] Because these stress values were considerably higher than those currently recommended for design by

American Railway Engineering and Maintenance of Way Association (AREMA) guidelines (85-100 psi and 75 psi, respectively), an opportunity was created to raise the rating stress values for additional capacity on existing timber railroad bridges.

The present program involved 20 glued-laminated Douglas fir stringers. Of these, 13 were subjected to a dynamic test and 7 to a monotonic (static) test. All 13 attempted fatigue tests resulted in failure of the specimen (Table 1 and Figure 5). One of the 13 fatigue specimens failed during the first loading cycle before reaching the target load; another specimen is still under test and to date has accumulated over 2 million cycles of loading.

Table 1. Available Shear Failure Data: Unused, Creosote-Treated, Glued-Laminated, Douglas Fir, Railroad Bridge Stringers

Specimen No.[†]	Shear Stress (psi)	2,180,279 Cycles	Shear
TAMU-1	216	Test in Progress	Test in Progress
TAMU-2	576	0.5	Shear (mono.)
TAMU-3	529	0.5	Shear (mono.)
TAMU-4	214	142,211	Shear
TAMU-5	307	110,507	Shear
TAMU-6	371	2,907	Tension
TAMU-7	494	0.5	Shear (mono.)
TAMU-8	520	1,593	Shear
TAMU-9	517	1,221	Shear
TAMU-10	563	0.5	Shear (mono.)
TAMU-11	477	0.5	Shear (mono.)
TAMU-12	520	24	Tension
TAMU-13	427	2,688	Shear
TAMU-14	446	0.5	Shear (mono.)
TAMU-15	401	14,789	Shear
TAMU-16	533	0.5	Shear (mono.)
TAMU-17	370	15,885	Shear
TAMU-18	308	374,656	Shear
TAMU-19	399	1401	Tension
TAMU-20	432	1950	Shear

[†] The "TAMU" prefix refers to specimens from the present study at Texas A&M University.

All seven of the monotonic failures were horizontal shear ruptures at mid-depth in a shear span. The smallest mid-depth monotonic shear stress that caused a shear failure was 446 psi. The average monotonic shear strength of the stringers was 517 psi with a standard deviation of 47 psi. Nine of the 12 stringers that failed under pulsating load failed in horizontal shear; the other three stringers failed in tension. The smallest mid-depth pulsating shear stress that caused shear failure of a stringer was 214 psi. The design value recommended by the current AREMA guidelines is 125 psi, which shows that higher values could be used for rating existing bridges to realize additional capacity.

Observations during the fatigue tests suggest that pulsating load causes incremental growth of pre-existing checks and ultimately a mid-depth horizontal shear failure. Two or three dominant pre-existing checks (i.e., long and/or deep checks) at mid-depth of a stringer appeared to be more deleterious than many short, shallow checks distributed uniformly on all faces of a stringer.

Table 1 lists shear failures during full-scale testing of 6 3/4″×18″ unused, creosote-treated, Douglas fir, glued-laminated railroad bridge stringers.

Figure 3 is a plot of pulsating shear stress amplitude versus pulsating load cycles from previous tests of solid-sawn southern pine stringers. Both axes of the plot are drawn to a logarithmic scale. A mean regression line is indicated on the plot. This line was determined through a least-squares-fit procedure whereby the error of estimating stress was minimized for observed cycles to failure; run-out tests (i.e., tests without a failure) were not included in the regression calculations. The lower 95-percent confidence limit is also indicated on the plot. Substantial variability in timber fatigue strength is readily observed in this plot.

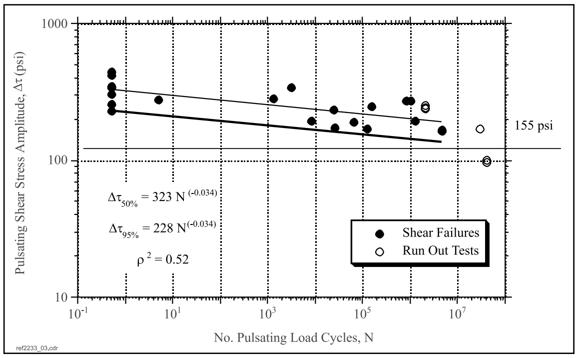

Figure 3. Data from Tests of Solid-Sawn Southern Pine Stringers; Plot of Pulsating Shear Stress Amplitude vs. Pulsating Load Cycles

Figure 4 is a similar plot of pulsating shear stress amplitude versus pulsating load cycles from the previous tests of solid-sawn Douglas fir stringers. The lower 95-percent confidence limit is also indicated on the plot. Substantial variability in timber fatigue strength is readily observed in this plot.

Figure 5 is a plot of pulsating shear stress amplitude versus pulsating load cycles from the present tests of glued-laminated Douglas fir stringers. As in Figure 4, both axes of the plot are drawn to a logarithmic scale. The lower 95-percent confidence limit is also indicated on the plot. Substantial variability in timber fatigue strength is readily observed in this plot.

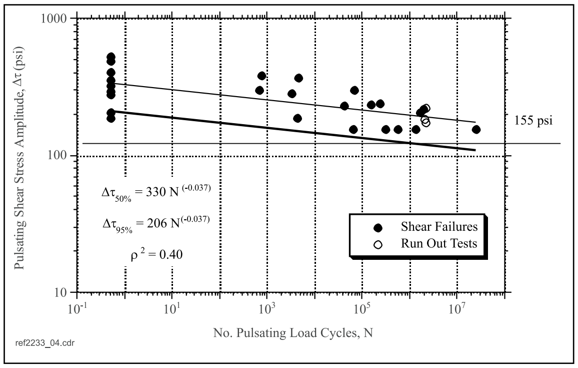

Figure 4. Data from Tests of Solid-Sawn Douglas Fir Stringers, Plot of Pulsating Shear Stress Amplitude vs. Pulsating Load Cycles

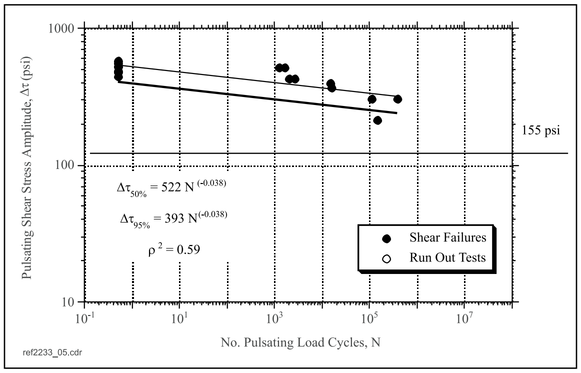

Figure 5. Data from Tests of Glued-Laminated Douglas Fir Stringers; Plot of Pulsating Shear Stress Amplitude vs. Pulsating Load Cycles

DISCUSSION

Figure 6 compares the strength characteristics among solid-sawn southern pine, solid-sawn Douglas fir, and glued-laminated Douglas fir stringers. There is very little difference apparent between the two groups of solid-sawn specimens. The mean regression lines for these two groups are nearly identical. However, the Douglas fir stringer has a slightly larger variance than the southern pine stringer and demonstrates a bit more sensitivity to pulsating load. As a result, even though the Douglas fir stringer obtains a slightly larger mean static strength than the southern pine, the lower 95-percent confidence limit is less favorable for the Douglas fir than for the southern pine.

Figure 6 also shows a substantial gain in performance by the glued-laminated Douglas fir specimens. For the lamination design used in the specimens tested, the lower 95-percent confidence limit for the glued-laminated specimens is 30 and 40 percent higher than the mean regression curves for both solid-sawn species tested. But, again, further research is needed to determine the reliability of the available designs of glued-laminated stringers as well as other wood products intended for use in timber railroad bridges.

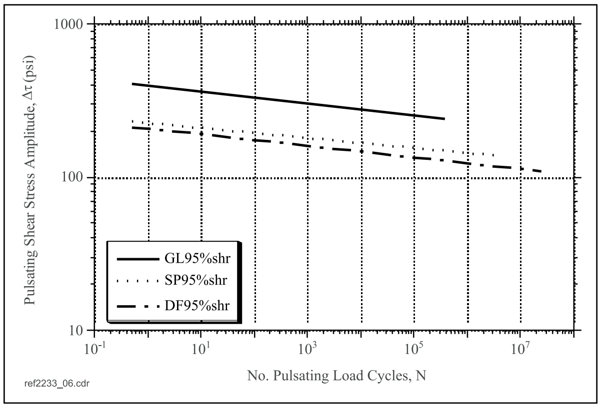

Figure 6. Comparison of Strength Characteristics among Solid-Sawn Southern Pine (SP), Solid-Sawn Douglas Fir (DF), and Glued-Laminated Douglas Fir (GL) Stringers

References

1. Uppal.A. Shakoor., G.T. Fry, M. R. Manigot and P.J. Sculley. “Fatigue Strength of Southern Pine Railroad Bridge Stringers,” R-945, Association of American Railroads, Washington, D.C., March 2001.
2. Uppal, A. Shakoor, G.T. Fry, P.M. Sculley, and B.C. Bartell. “Fatigue Strength of Douglas Fir Railroad Bridge Stringers,” R-953, Association of American Railroads, Washington, D.C., December 2001.

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