TECHNOLOGY DIGEST

Timely Technology Transfer — 01-006

Fatigue Strength of Treated Douglas Fir Timber Railroad Bridge Stringers

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Summary

Transportation Technology Center, Inc. in collaboration with Texas A&M University conducted fatigue tests in 2000 to generate data for assessing the effects of heavy axle loads on the performance and reliability of existing bridges with Douglas fir stringers. The test results listed below indicate the minimal horizontal shear stresses at failure for Douglas fir specie are considerably higher than the currently specified allowable horizontal shear stress values in the American Railway Engineering and Maintenance of Way Association manual. From these results, railroads may want to consider higher horizontal shear values in rating the existing bridges to realize additional load capacity.

Tests were conducted as the second phase of the Association of American Railroad's Bridge Life Extension Program. The tests were conducted on 24 new 6 3/4-inch by 16-inch by 14-foot-long, solid-sawn, creosote-treated, Douglas fir railroad bridge stringers. These stringers were visually graded as a lot to be at least No. 1 with moisture content less than 19 percent.

The following observations were made:

- The average monotonic (static) shear strength of the stringers was 360 psi. The smallest mid-depth monotonic shear stress that caused a shear failure was 190 psi.
- The smallest mid-depth pulsating shear stress that caused shear failure of a stringer was 155 psi at 305,000 cycles.
- The pulsating load caused incremental growth of pre-existing checks to form shakes and ultimately a mid-depth horizontal shear failure.
- There was very little difference between the performance of Douglas fir and previously tested southern pine species. The Douglas fir had a slightly larger variance than the southern pine and demonstrated a bit more sensitivity to pulsating load.

The results of these tests are being used to develop a fatigue damage assessment model for stringers and to investigate the economic impact of the operation of heavy axle loads on existing timber railroad bridges.

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Suggested Distribution:
☐ Maintenance of Way
☐ Planning & Analysis
☐ Bridges & Structures
☐ Safety

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INTRODUCTION AND RESULTS

Despite the current trend of replacing timber bridges with steel, concrete, or culvert and fill, timber bridges still comprise about one-third of the bridge inventory of Class 1 railroads. On average, these bridges are more than 40 years old and are subjected to heavy axle loads. As their replacement is gradual, various measures are being employed to extend their useful service lives.

Although caps and/or piles can also determine load capacity of a timber bridge, stringers are the main elements that carry bending loads. They are placed side by side in two or more element chords beneath each rail. Exhibit 1 shows timber bridge stringers. Field observations are indicating that some timber stringers are showing signs of distress under heavy axle load operations.[1]

As part of the bridge life extension program, the Association of American Railroads, in collaboration with Texas A&M University, started a program of testing timber railroad bridge stringers. The program involved static and dynamic tests on southern pine, Douglas fir, and glue laminated stringers. In its first phase, tests on 21 southern pine stringers were completed during 1998-99.[2] During 2000, under the second phase of the program, 24 new 6 3/4-inch by 16-inch by 14-foot-long, solid-sawn, creosote-treated, Douglas fir railroad bridge stringers were tested in four point bending. The purpose of the investigation was to generate critical data for use in assessing the effects of heavy axle load operations on the performance and reliability of existing Douglas fir bridges. Results will be used to make estimates of remaining service life, to guide field inspections, to determine the economics of stringer life extension techniques, and to assess the increase in maintenance cost of operating heavy axle load traffic on a given route segment. The results of the tests are summarized as follows:

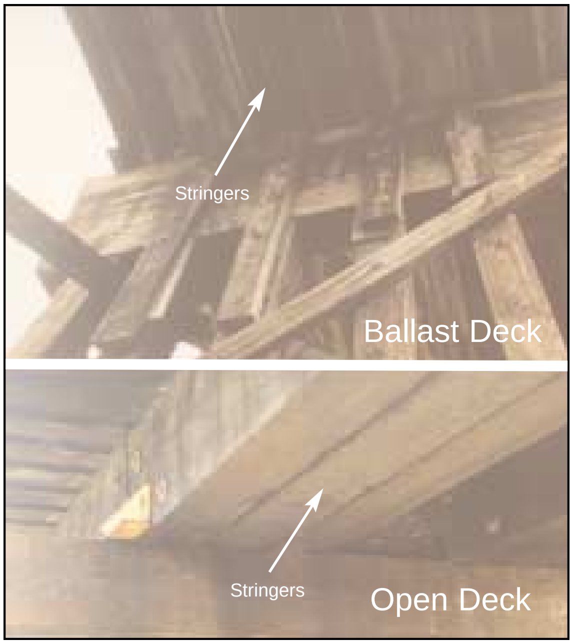

Exhibit 1. Timber Bridge Stringers

- All 18 attempted fatigue tests resulted in failure of the specimen. (The word "failure" as used here does not imply that the stringer had no remaining strength or that, as part of a bridge structure, it would have rendered the bridge unsafe). Four fatigue specimens, however, failed during the first loading cycle before reaching the target fatigue load. Thus, 24 of the 24 tests resulted in specimen failures: 10 monotonic and 14 fatigue failures.
- Nine of the monotonic failures were horizontal shear ruptures at mid-depth in a shear span; one was a tension failure. The smallest mid-depth monotonic shear stress that caused a shear failure was 190 psi. The average monotonic shear strength of the stringers was 360 psi, with a standard deviation of ±124 psi.
- Thirteen of the 14 stringers that failed under pulsating load failed in horizontal shear; one developed a compression bearing failure under a load point. The smallest mid-depth pulsating shear stress that caused shear failure of a stringer was 155 psi.
- Both the smallest pulsating load failure and the monotonic failure values are greater than the currently specified allowable stress values in the American Railway Engineering and Maintenance of Way Association manual for Douglas fir.
- Since the Douglas fir stringers were visually graded as a lot to be at least No. 1 grade with moisture content below 19 percent, no correlation between shear strength and visual grade, on shear strength and moisture content, could be made.
- The pulsating load caused incremental growth of pre-existing checks to form shakes (separation of grains between annual rings of wood) 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 numerous short, shallow checks distributed uniformly on all faces of a stringer.
- There is very little apparent difference between the

performance of Douglas fir and southern pine species. However, the Douglas fir has a slightly larger variance than the southern pine and demonstrates a bit more sensitivity to pulsating load.

TEST PROCEDURES

The stringer specimens were new in that they had never been subjected to any load in a bridge structure. Each stringer specimen was numbered, graded visually as a lot by a certified inspector from the West Coast Lumber Inspection Bureau, measured, and weighed. The average cross-sectional area, moment of inertia, section modulus, volume, and density were determined for each specimen.

A longitudinal stress-wave analysis was used to determine an estimate of the elastic modulus of each specimen. Based upon an empirical correlation between wood strength properties and wood modulus, the dynamic modulus data was used to divide the population of 24 stringers into two groups: a group of six and a group of 18. A trial-and-error process was performed, whereby the mean modulus and standard deviation of modulus were matched as closely as possible among the two groups. The six-specimen group was tested statically to failure to establish the strength distribution of the population. The remaining specimens were tested in fatigue.

A two-level loading frame was designed and fabricated to allow four stringers to be tested simultaneously at a maximum loading frequency of 3 Hz. The frame consists of two subassemblies with identical dimensions and capacities with an ultimate design load of 110 kip. Test specimens were supported simply and subjected to four-point bending. The initial levels of pulsating load were determined based upon the monotonic test results. Subsequent fatigue load amplitudes were selected based upon cumulative fatigue test data. Exhibit 2 shows the loading frame for fatigue tests.

Exhibit 2. Loading Frame Used for Fatigue Tests

TEST RESULTS

The results of the tests are presented as Exhibits 3 through 5. All 18 attempted fatigue tests resulted in failure of the specimen. Four fatigue specimens, however, failed during the first loading cycle before reaching the target fatigue load. Thus, 24 of the 24 tests resulted in specimen failures: 10 monotonic failures and 14 fatigue failures.

Nine of the monotonic failures were horizontal shear ruptures at mid-depth in a shear span; one was a tension failure. The smallest mid-depth monotonic shear stress that caused a shear failure was 190 psi. The average monotonic shear strength of the stringers was 360 psi, with a standard deviation of ±124 psi. Thirteen of the 14 stringers that failed under pulsating load failed in horizontal shear; one developed a compression bearing failure under a load point. The smallest mid-depth pulsating shear stress that caused shear failure of a stringer was 155 psi.

The equation of the mean regression line for pulsating shear stress amplitude on cycles to failure is given as Equation 1:

$$\Delta\tau_{50\%} = 344\,N^{(-0.040)};r^2 = 0.44$$

The equation of the 95 percent lower confidence limit for pulsating shear stress amplitude on cycles to failure is given as Equation 2:

$$\Delta\tau_{95\%} = 212\,N^{(-0.040)}$$

Observations during the fatigue tests suggest that pulsating load causes incremental growth of pre-existing checks to form shakes 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 tens of short, shallow checks distributed uniformly on all faces of a stringer.

Exhibit 4 is a plot of pulsating shear stress amplitude versus pulsating load cycles from the previous tests on southern pine stringers. As in Exhibit 3, both axes of the plot are drawn to a logarithmic scale. A mean regression 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 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.

Exhibit 5 is a plot comparing the strength characteristics between southern pine and Douglas fir stringers. There is very little difference apparent between the two species. However, the Douglas fir has

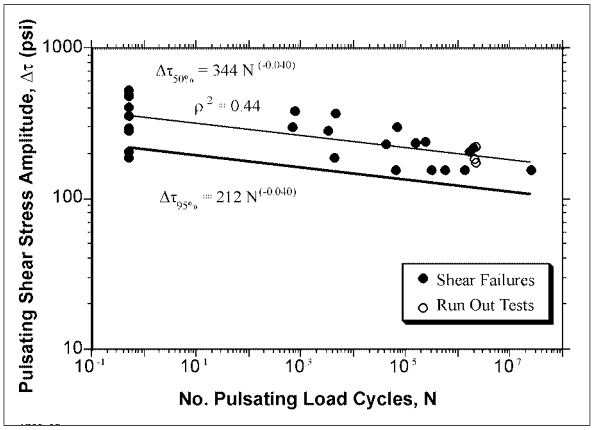

Exhibit 3. Plot of Pulsating Shear Stress Amplitude Versus Pulsating Load Cycles – Douglas Fir Stringers.

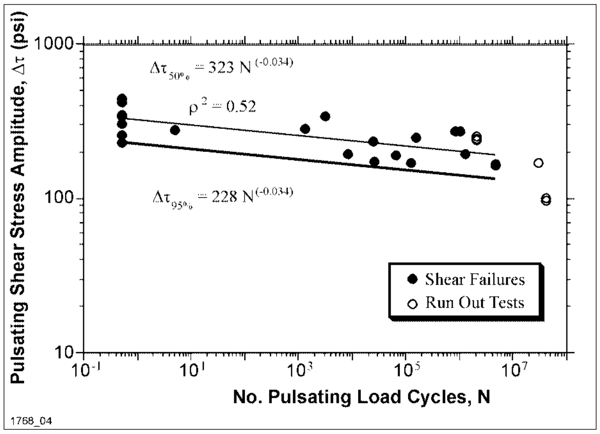

Exhibit 4. Plot of Pulsating Shear Stress Amplitude Versus Pulsating Load Cycles – Southern Pine Stringers.

a slightly larger variance than the southern pine and demonstrates a bit more sensitivity to pulsating load. As a result, even though the Douglas fir obtains a 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.

The smallest monotonic and pulsating load failure values are considerably higher than the currently specified allowable stress values in the AREMA manual for both the southern pine (85 to 100 psi) and Douglas fir (75 psi) stringers.

ACKNOWLEDGMENT

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REFERENCES

1. Uppal, A. S., and Otter, D.E. ,“Methodologies for Strengthening and Extending Life of Timber Railroad Bridges.” AAR, TTC, Report No. R-922, Pueblo, CO., November 1998.
2. Uppal, A. S., Otter, D.E., Fry, G.T., and Comardo, A.F., “Fatigue Strength of Treated Southern Pine Timber Railroad Stringers” AAR, TTC, Report No. R-939, Pueblo, CO., November 2000.

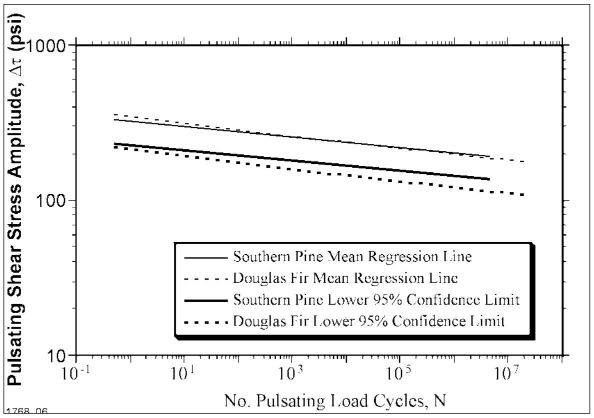

Exhibit 5. Plot Illustrating Comparison of Strength Characteristics between Southern Pine and Douglas Fir Solid Sawn Stringers

3. AAR “Laboratory Investigation to Determine Static and Repeated Load Strength of Full-Size Douglas Fir Solid Sawn Stringers.” AAR Research Dept. Report No. ER-70, Chicago, Ill., 1967

Note: Please contact Shakoor Uppal at (719) 584-0749 with questions or comments about this document.

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