TECHNOLOGY DIGEST

Timely Technology Transfer — 00-019

Fatigue Strength of Treated Southern Pine Timber Railroad Bridge Stringers

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Summary

During 1998-99, as part of the Association of American Railroad's Bridge Life Extension Program, the Transportation Technology Center, Inc. in collaboration with Texas A&M University conducted fatigue tests on 21 new 8"×16"×15' solid-sawn, creosote-treated, southern-pine railroad bridge stringers. The visual grading of the stringers varied from select structural to below No. 3 with majority being No. 2 dense. These tests were performed to generate fatigue data for use in assessing the effects of heavy axle loads on the performance and reliability of existing bridges with southern pine stringers. The test results indicate that the minimal horizontal shear stresses at failure are considerably higher than the currently specified allowable horizontal shear stress values in the AREMA manual for southern pine specie. Therefore, railroads may want to consider higher values of horizontal shear values in rating existing bridges to realize additional load capacity. More specifically, the following observations were made.

- The smallest mid-depth monotonic shear stress at failure was 231 psi and the smallest mid-depth pulsating shear stress that caused failure of a stringer was 165 psi.
- The pulsating load caused incremental growth of pre-existing checks to form shakes and ultimately a mid-depth horizontal shear failure.
- The moisture content and the visual grading had little correlation with the shear strength of the stringers.

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

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Suggested Distribution:
☐ Maintenance of Way
☐ Planning & Analysis
☐ Track Maintenance
☐ Safety

Work performed by TTCI Transportation Technology Center, Inc.
a subsidiary of the Association of American Railroads
November 2000

INTRODUCTION AND RESULTS

Despite the current trend of replacing timber bridges with steel or concrete structures, timber bridges still comprise about one-third the bridge inventory of Class 1 railroads. On average, they are more than 40 years old, and are now being subjected to heavy axle loads although in some cases not as heavy as steam locomotive axle loads in the past. As their replacement is gradual, various measures are being employed to extend their useful service lives.

Although caps and/or pile can also determine load capacity of a timber railroad 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 starting to show signs of distress under heavy axle load operations.[1]

During 1998-1999, the Association of American Railroads, in collaboration with Texas A&M University, tested 21 8"×16"×15' long, solid-sawn, creosote-treated, southern-pine railroad bridge stringers in four-point bending. The purpose of the study was to generate fatigue data for use in assessing the effects of heavy axle loads on the performance and reliability of existing bridges with southern pine stringers. 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 determine 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:

- Thirteen of the 16 fatigue tests resulted in failure of specimens. (The word “failure” as used in this article 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). Three fatigue specimens failed during the first loading cycle before reaching the target fatigue load. The three remaining fatigue tests were terminated after the stringers survived 30,000,000 cycles of loading. Thus, 18 of the 21 tests resulted in specimen failures — eight monotonic failures and 10 fatigue failures.
- All eight monotonic failures were horizontal shear ruptures at mid-depth in a shear span. The smallest mid-depth monotonic shear stress at failure was 231 psi.
- All 10 stringers that failed under pulsating load failed in horizontal shear.
- The smallest mid-depth monotonic shear stress at failure was 231 psi and the smallest mid-depth pulsating shear stress that caused failure of a stringer was 165 psi. Both values are greater than the currently specified allowable stress values in the the AREMA manual for southern pines. Therefore, railroads may want to consider higher values of shear stress for rating existing bridges for additional load capacity.
- The moisture contents among all specimens ranged between a low of 16 percent and a high of 40 percent. The monotonic and fatigue test results indicated no correlation between shear strength and moisture content.
- The visual grades among all specimens, as determined by the Southern Pine Inspection Bureau (SPIB), ranged between No. 3 and Select Structural. The monotonic and fatigue test results indicated negligible correlation between shear strength and visual grade.
- The pulsating load caused 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 numerous short, shallow checks distributed uniformly on all faces of a stringer.

Exhibit 1. Timber Bridge Stringers

TEST PROCEDURES

The stringer specimens used were new in that they had never been subjected to any loads in a bridge structure. Each stringer specimen was numbered, graded visually by a SPIB inspector, measured, and weighed. The visual grading of the stringers varied from select structural to below No. 3 with majority being No. 2 dense. The moisture content, 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 stiffness of each specimen. Based upon an empirical correlation between wood strength properties and wood stiffness, the dynamic stiffness data was used to divide the population of 21 stringers into two sample groups of similar strength distribution: a group of five and a group of 16. These groups were formed by a trial-and-error process, whereby the mean stiffness and standard deviation of stiffness were matched as closely as possible among the two groups and the original population. The five-specimen group was tested statically to failure to establish the strength distribution of the population. The remaining 16 specimens were tested in fatigue.

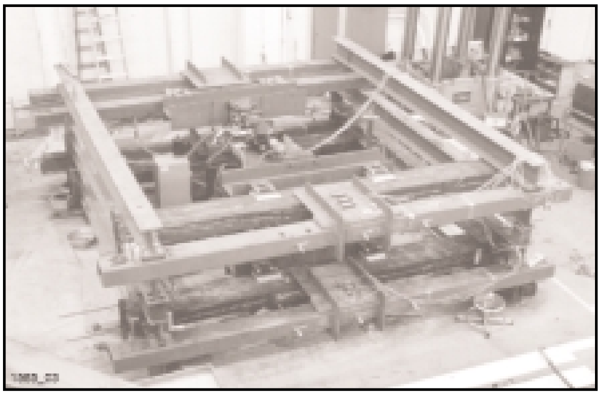

Exhibit 2. Loading Frame Used for Fatigue Tests

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 was adjustable for specimens with spans of 12 to 15 feet, widths up to 9 inches, and depths up to 20 inches. The frame consisted of two subassemblies with identical dimensions and capacities with an ultimate design load of 110 kips. Test specimens were supported simply and subjected to four-point bending. Exhibit 2 shows the loading frame used for fatigue tests.

TEST RESULTS

The results of the tests are presented as Exhibits 3 through 6. Thirteen of the 16 attempted fatigue tests resulted in failure of a specimen. Three fatigue specimens, however, failed during the first loading cycle before reaching the target fatigue load. Two of these were visually graded as No. 2 dense and one as No. 3 and two of them had pretest cracks. The three remaining fatigue tests were terminated after the stringers survived 30,000,000 cycles of loading. Thus, 18 of the 21 tests resulted in specimen failures: 8 monotonic failures and 10 fatigue failures. All eight monotonic failures were horizontal shear ruptures at mid-depth in a shear span. The smallest mid-depth monotonic shear stress at failure was 231 psi. The average monotonic shear strength of the stringers was 340 psi ± 73 psi. All 10 stringers that failed under pulsating load failed in horizontal shear. The smallest mid-depth pulsating shear stress that caused failure of a stringer was 165 psi. Coincidentally, 165 psi is also the value of the horizontal shear stress being recommended by the Southern Pine Inspection Bureau Supplement No.1, effective January 1, 2000, for different grades of southern pine (2.5" and thicker) with moisture content over 19 percent (the SPIB value is based on tests on small size clear wood specimens). This suggests that the allowable horizontal shear stress value should be closer to this value.

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 several short, shallow checks distributed uniformly on all faces of a stringer.

Exhibit 3 is a plot of pulsating shear stress amplitude versus pulsating load cycles. This includes data from these and previous tests. 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 that are stopped before specimen fails) was not included in the regression calculations. The equation of the mean regression line for pulsating shear stress amplitude on cycles to failure is given as:

$$\Delta\tau_{50\%} = 323N^{(-0.034)};\ r^2 = 0.52$$

Substantial variability in timber fatigue strength is readily observed in this plot. The equation of the 95 percent lower confidence limit for pulsating shear stress amplitude on cycles to failure is given as:

$$\Delta\tau_{95\%} = 228N^{(-0.034)}$$

Exhibit 4 is a plot of pulsating load cycles versus pulsating shear stress amplitude. Both axes of the plot are drawn to a logarithmic scale.

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

$$N_{50\%} = 6.31 \times 10^{39}\ \Delta\tau^{(-15.3)};\ r^2 = 0.52$$

A regression line was determined similar to one for Exhibit 3. The line indicated in this plot is appropriate for use in fatigue analyses where damage accumulation rules, such as Miner's rule, are employed to compute service life under variable amplitude loading conditions.

Exhibit 5 is a plot of fatigue strength ratio versus moisture content. Here the fatigue strength ratio is defined as the ratio of observed shear strength to mean regression shear strength at observed cycles to failure. The moisture contents among the 21 specimens ranged

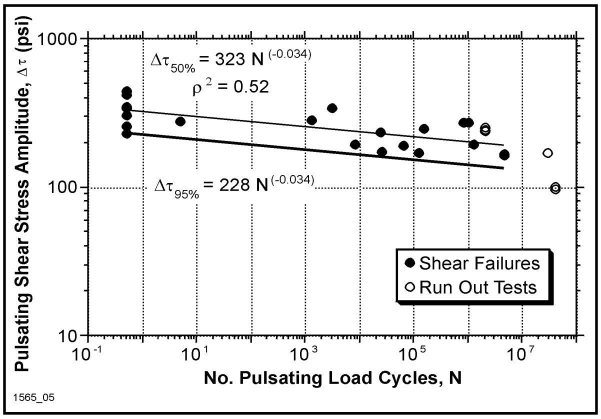

Exhibit 3. Plot of Pulsating Shear Stress Amplitude Versus Pulsating Load Cycles

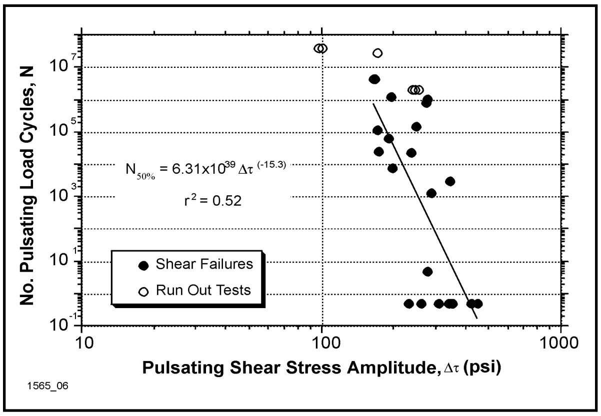

Exhibit 4. Plot of Pulsating Load Cycles Versus Pulsating Shear Stress Amplitude

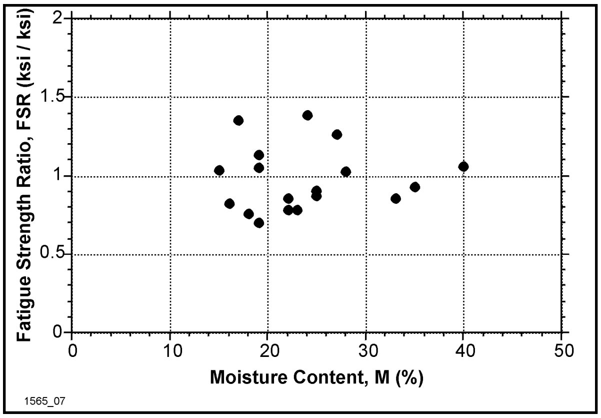

Exhibit 5. Plot of Fatigue Strength Ratio Versus Moisture Content

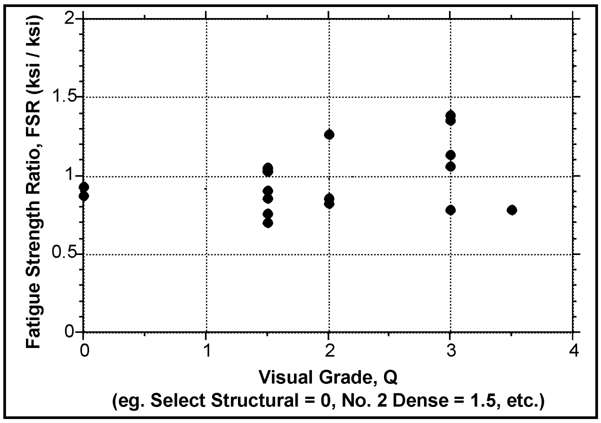

Exhibit 6. Plot of Fatigue Strength Ratio Versus Visual Grade

between a low of 16 percent and a high of 40 percent. As indicated, the monotonic and fatigue test results indicate nearly zero correlation, $r^2 = 0.00$, between shear strength and moisture content.

Exhibit 6 is a plot of fatigue strength ratio versus visual grade. Here the fatigue strength ratio is defined as the ratio of observed shear strength to mean regression shear strength at observed cycles to failure. The visual grades among the 21 specimens, as determined by a certified SPIB inspector, ranged between No. 3 and Select Structural. As indicated in Exhibit 8, negligible correlation exists, $r^2 = 0.1$, between shear strength and visual grade.

ACKNOWLEDGMENT

Authors thankfully acknowledge Messrs: C.T. Goewey and W. Benton of Norfolk Southern Corporation for the donation of the southern pine stringers for the tests.

REFERENCES

1. **Uppal, A. S., and Otter, D.E. (1998).** "Methodologies for Strengthening and Extending Life of Timber Railroad Bridges," Association of American Railroads, Transportation Technology Center, Research Report No. R-922, Pueblo, CO.

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