

Fatigue Strength of Solid Sawn Timber Railroad Bridge Stringers

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ABSTRACT

In 1998, Transportation Technology Center, Inc. (TTCI), a subsidiary of the Association of American Railroads, collaborated with Texas A&M University on a program of testing timber railroad bridge stringers as part of the AAR's Bridge Life Extension program. Included in this effort were static and dynamic tests on southern pine; Douglas fir, and glued-laminated stringers.

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

Although other components can also determine load capacity of a timber bridge, stringers are the main elements that carry bending loads. Field observations are indicating that some older timber stringers are showing signs of distress under heavy axle loading.

From 1998 to 2000, tests on new, creosote-treated, solid sawn stringers were conducted. These involved 21 southern pine and 24 Douglas fir stringers. The objective of the study was to generate fatigue data on the stringers for use in assessing the effects of heavy axle loads on the performance and reliability of existing bridges. Test results indicated that the minimum horizontal shear stresses at failure are considerably higher than the those currently specified and

allowable in the American Railway Engineering and Maintenance of Way Association

(AREMA) *Manual for Railway Engineering* for southern pine and Douglas fir species.

Therefore, railroad engineers may want to consider higher allowable horizontal shear strength values in rating the existing bridges to realize additional load capacity. More specifically, the following observations were made. 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.

- The smallest mid-depth monotonic shear stresses at failure were 231 psi for southern pine and 190 psi for Douglas fir stringers.
- The smallest mid-depth pulsating shear stress that caused shear failure of a stringer was 165 psi for southern pine and 155 psi for Douglas fir.
- The pulsating load caused incremental growth of pre-existing checks to form shakes and, ultimately, a mid-depth horizontal shear failure for specimens of both species.
- There was very little difference in fatigue strength between the southern pine and Douglas fir stringers. 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 also 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 the existing timber railroad bridge routes.

INTRODUCTION

Despite the current trend of replacing timber bridges with steel, concrete or culvert and fill, timber bridges still comprise about one-third the inventory of Class 1 railroads. On average, they

are more than 40 years old, and many are currently subjected to heavy axle load operation. Replacement of these bridges is gradual, with various measures being employed to extend their useful service lives.

Although caps and piles are included in determining 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. Figure 1 shows a typical timber railroad bridge and Figure 2 shows timber bridge stringers. Field observations are indicating that some older timber stringers are showing signs of distress under heavy-axle load operations.(1)

As part of the Association of American Railroads' (AAR) Bridge Life Extension Program, Transportation Technology Center, Inc. (a wholly-owned subsidiary of the AAR) embarked on a program of testing timber railroad bridge stringers in collaboration with Texas A&M University (TAMU). This program involved static and dynamic tests on southern pine, Douglas fir, and glued-laminated stringers.

In the first phase of the program (1998-99), tests on 21 solid sawn, creosote-treated, southern pine stringers (8 3/4" x 16" x 14') were completed.(2) During the second phase in 2000, 24 solid-sawn, creosote-treated Douglas fir stringers (6 3/4" x 16" x 14') were completed. The stringers were supported simply and subjected to 4-point bending. The purpose of this study was to generate fatigue data on stringers for use in assessing the effects of heavy axle load operations on the performance and reliability of existing bridges. Findings 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.

TEST PROCEDURES

The stringer specimens for both species were new in that they had never been subjected to any load in a bridge structure. Each stringer specimen was numbered, measured, and weighed. The southern pine stringers were visually graded by a Southern Pine Inspection Bureau (SPIB) inspector. The visual grading of these stringers varied from select structural to below No. 3 with majority being No. 2 dense with moisture content ranging from 14 to 40 percent. The Douglas fir stringers were visually graded as a lot by an inspector from the West Coast Lumber Inspection Bureau (WCLIB). The visual grading of these stringers was at least No. 1 with moisture content of below 19 percent. 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 elastic modulus, the dynamic modulus data was used to divide the populations of 21 southern pine and 24 Douglas fir stringers into two sample groups. Each group was of similar strength distribution: a group of 5 and a group of 16 for southern pine, and a group of 6 and a group of 18 for Douglas fir; respectively. A trial-and-error process was used to form these groups whereby the mean modulus and standard deviation of modulus were matched as closely as possible of each species, and the original populations formed these groups. The 5- and 6-specimen groups were tested statically to failure to establish the strength distribution of the populations. The remaining 16 and 18 specimen groups were tested under pulsating load to fatigue failure. 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.

Each specimen was inspected thoroughly to assess pre-test condition and paint chalk was used to highlight all pre-existing cracks. This allowed observing the mechanism of failure and crack propagation path relative to the pre-existing, naturally occurring imperfections (Figure 2).

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 consists of two sub-assemblies with identical dimensions and capacities with an ultimate design load of 110 kips. Test specimens were supported simply and subjected to 4-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. These loads produced theoretical shear stress values that ranged between 100 and 500 psi. Figure 3 shows the loading frame for fatigue tests.

A central computer controlled the tests and recorded the output of the load cells and displacement transducers. There were three displacement transducers for each specimen? one placed at midspan and one at each of the two load points. This arrangement of displacement measurements 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

The results of the tests are presented in Figures 4 through 7 and Tables 1 and 2. For southern pine, 13 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 failure load. Two of these were visually graded as No. 2 dense and one as No. 3. Two of them had pre-test cracks. The three remaining fatigue tests were terminated after stringers survived 30 million

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 \pm 73 psi standard deviation. All 10 specimens 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 (at 4,488,900 cycles).

For Douglas fir, 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 \pm 124 psi standard deviation. Of the 14 stringers that failed under pulsating load, 13 failed in horizontal shear. Of these, one stringer 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 (at 305,000 cycles).

Observations during the fatigue tests suggested that 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 many tens of short, shallow checks distributed uniformly on all faces of a stringer.

Tables 1 and 2 list all documented shear failures during full-scale testing of new, creosote treated, southern pine and Douglas fir railroad bridge stringers. Relevant results from a similar previous investigation (3) are combined with the results from the present study.

Figure 5 is a plot of pulsating shear stress amplitude versus pulsating load cycles from the tests on southern pine stringers.(2) 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 and substantial variability in timber fatigue strength is readily noticeable.

Figure 6 is a plot of pulsating shear stress amplitude versus pulsating load cycles from the tests on Douglas fir stringers. As in Table 2, 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 again readily noticeable in this plot.

Figure 7 is a plot comparing the strength characteristics between southern pine and Douglas fir stringers. There is very little difference in fatigue strength apparent between the two species. However, the Douglas fir has 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.

CONCLUSIONS

The conclusions drawn from this study can be summarized as follows. Note: 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.

Southern Pine Stringers:

- Thirteen of the sixteen fatigue tests resulted in failure of specimens. Three fatigue specimens failed during the first loading cycle before reaching the target failure load. The three remaining fatigue tests were terminated after stringers survived 30 million cycles of loading. Thus, 18 of the 21 tests resulted in specimen failure; that is, 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 was 231 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.
- 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 indicate no correlation between shear strength and moisture content.
- 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.

Douglas Fir Stringers

- 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; that is, 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.
- Thirteen of the fourteen 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.
- As 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 and shear strength and moisture content could be made.

Both Southern Pine and Douglas Fir Stringers

- 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.
- There was very little difference apparent between the Douglas fir and southern pine species. However, the Douglas fir had a slightly larger variance than the southern pine and demonstrates a bit more sensitivity to pulsating load.
- The smallest stresses for both the monotonic failure and the fatigue failure were greater than the currently specified allowable stress values in the *AREMA Manual for Railway*

Engineering for southern pine. Therefore, railroads engineers may want to consider higher values of shear stress for rating existing bridges for additional load carrying capacity.

ACKNOWLEDGEMENT

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2. Uppal, A. S., Otter, D.E., Fry, G.T., and Comardo, A.F., "Fatigue Strength of Treated Southern Pine Timber Railroad Stringers," Research Report R-939, Association of American Railroads, Pueblo, Colorado, November 2000.
3. "Laboratory Investigation to Determine Static and Repeated Load Strength of Full-Size Douglas Fir Solid Sawn Stringers," Report No. ER-70, Association of American Railroads Research Department, Chicago, Illinois, 1967.

- **Figure 1. Typical Railroad Timber Bridge**
- **Figure 2. Timber Bridge Stringers**
- **Figure 3. Loading Frame Used for Fatigue Tests**
- **Figure 4. Schematic of Test Frame and Gage Locations**
- **Figure 5. Plot of Pulsating Shear Stress Amplitude versus Pulsating Load Cycles – Southern Pine Stringers.**
- **Figure 6. Plot of Pulsating Shear Stress Amplitude versus Pulsating Load Cycles – Douglas Fir Stringers**
- **Figure 7. Plot Illustrating Comparison of Strength Characteristics between Southern Pine and Douglas Fir Solid Sawn Stringers**
- **TABLE 1. Shear Failure Data: 8" x 16" New, Creosote-Treated, Solid-Sawn, Southern-Pine, Railroad Bridge Stringers**
- **TABLE 2. Shear Failure Data: 6 3/4" x 16" New, Creosote-Treated, Solid-Sawn, Douglas Fir, Railroad Bridge Stringers**



Figure 1.



a.



b.

Figure 2.



Figure 3.

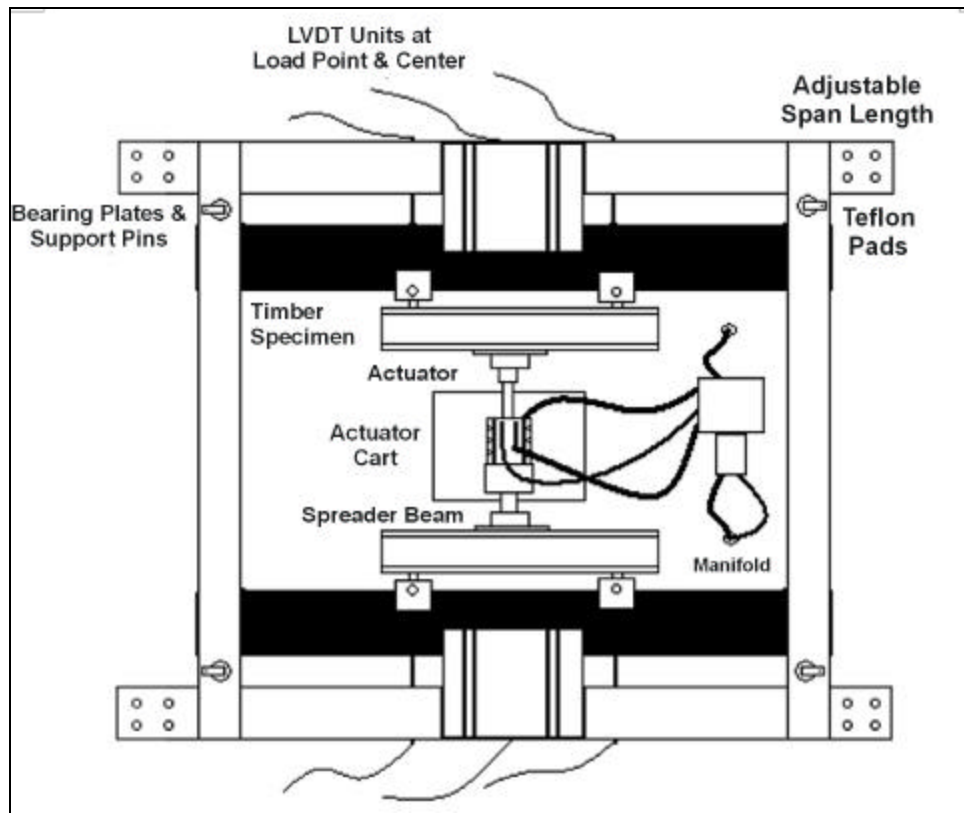


Figure 4.

TABLE 1.

Specimen Number[†]	Visual Grade (SPIB)	Moisture Content (%)	Shear Stress (psi)	Cycles to Failure	Comments / Failure Mode
AAR-6	N/A	N/A	196	1,266,000	Shear
AAR-7	N/A	N/A	249	154,100	Shear
AAR-11	N/A	N/A	255	2,003,000	Run-Out
AAR-13	N/A	N/A	272	801,400	Shear
AAR-16	N/A	N/A	240	2,000,600	Run-Out
AAR-18	N/A	N/A	245	2,000,000	Run-Out
AAR-22	N/A	N/A	275	1,033,100	Shear
TAMU-1	No. 2	22	165	4,488,900	Shear & Tension
TAMU-2	Below No. 3	23	171	120,000	Shear
TAMU-3	No. 2	27	420	0.5	Shear (mono.)
TAMU-5	No. 3	17	449	0.5	Shear (mono.)
TAMU-6	No. 2 Dense	15	237	23,843	Shear
TAMU-7	No. 2 Dense	19	347	0.5	Shear (mono.)
TAMU-8	No. 1	18	171	29,050,000	Run-Out
TAMU-10	Below No. 3	14	101	40,000,000	Run-Out
TAMU-13	No. 3	22	259	0.5	Shear (mono.)
TAMU-14	No. 2 Dense	25	277	5	Shear
TAMU-15	No. 2 Dense	33	190	62,667	Shear
TAMU-17	No. 2	16	196	8054	Shear
TAMU-21	No. 2 Dense	19	97	40,000,000	Run-Out
TAMU-22	No. 3	19	286	1,300	Shear
TAMU-23	No. 2 Dense	28	341	0.5	Shear (mono.)
TAMU-24	Sel. Structural	25	167	4,580,500	Shear
TAMU-25	No. 2 Dense	19	231	0.5	Shear (mono.)
TAMU-26	Sel. Structural	35	309	0.5	Shear (mono.)
TAMU-28	No. 3	40	352	0.5	Shear (mono.)
TAMU-29	No. 2 Dense	18	174	24,953	Shear
TAMU-30	No. 3	24	342	3,000	Shear

TABLE 2.

Specimen Number[†]	Visual Grade (WCLIB)	Moisture Content (%)	Shear Stress (psi)	Cycles to Failure	Comments / Failure Mode
AAR-2	N/A	N/A	155	1,331,560	Shear
AAR-3	N/A	N/A	186	2,083,000	Run-Out
AAR-5	N/A	N/A	173	2,110,802	Run-Out
AAR-6	N/A	N/A	221	2,128,200	Run-Out
AAR-7	N/A	N/A	237	147,770	Shear
AAR-8	N/A	N/A	242	227,300	Shear
TAMU-1	At least No.1	Below 19%	220	1,887,126	Shear
TAMU-2	At least No.1	Below 19%	283	3,303	Shear
TAMU-3	At least No.1	Below 19%	231	42,006	Shear
TAMU-4	At least No.1	Below 19%	489	0.5	Shear (mono.)
TAMU-5	At least No.1	Below 19%	282	0.5	Shear (mono.)
TAMU-6	At least No.1	Below 19%	155	305,000	Shear
TAMU-7	At least No.1	Below 19%	301	66,700	Shear
TAMU-8	At least No.1	Below 19%	206	1,634,388	Shear
TAMU-9	At least No.1	Below 19%	524	0.5	Shear (mono.)
TAMU-10	At least No.1	Below 19%	410	0.5	Shear (mono.)
TAMU-11	At least No.1	Below 19%	501	0.5	Tension (mono.)
TAMU-12	At least No.1	Below 19%	208	0.5	Shear (mono.)
TAMU-13	At least No.1	Below 19%	359	0.5	Shear (mono.)
TAMU-14	At least No.1	Below 19%	302	680	Shear
TAMU-15	At least No.1	Below 19%	371	4,432	Shear
TAMU-17	At least No.1	Below 19%	156	24,900,000	Shear
TAMU-18	At least No.1	Below 19%	381	768	Shear
TAMU-19	At least No.1	Below 19%	155	550,000	Shear
TAMU-20	At least No.1	Below 19%	294	0.5	Shear (mono.)
TAMU-21	At least No.1	Below 19%	482	0.5	Shear (mono.)
TAMU-22	At least No.1	Below 19%	156	63,000	Shear
TAMU-23	At least No.1	Below 19%	189	4,200	Shear
TAMU-24	At least No.1	Below 19%	190	0.5	Shear (mono.)
TAMU-25	At least No.1	Below 19%	199	2,300,800	Bearing

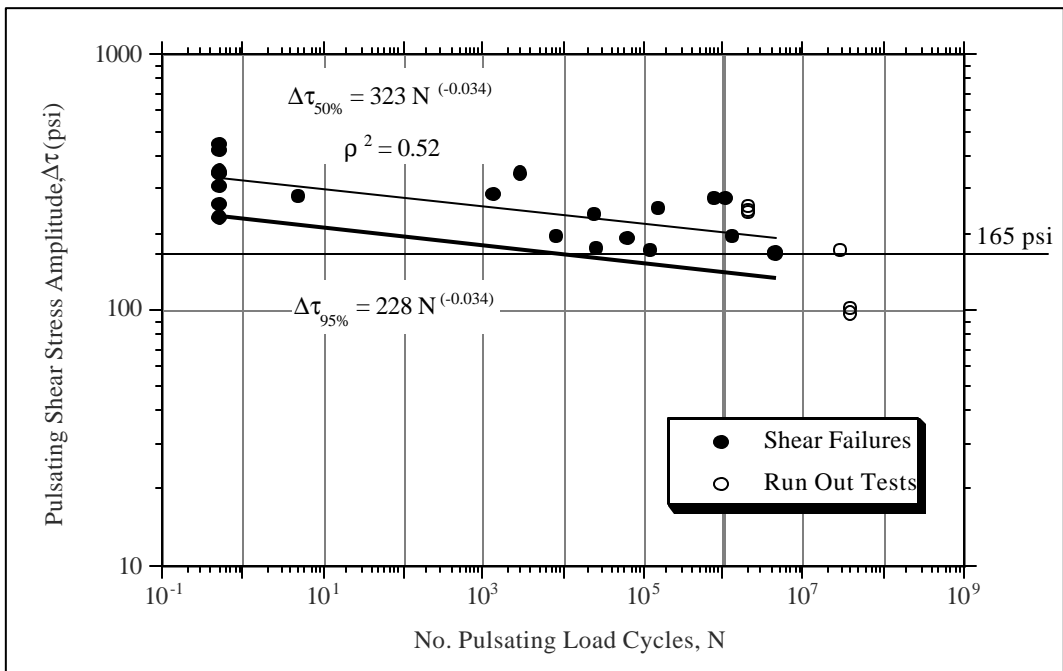


Figure 5.

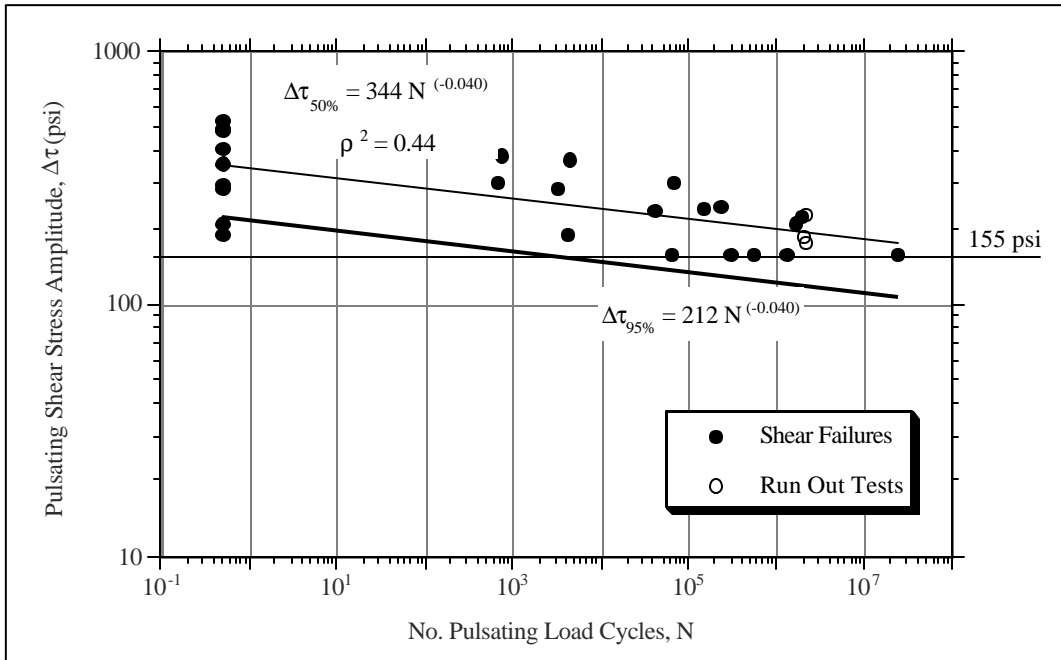


Figure 6.

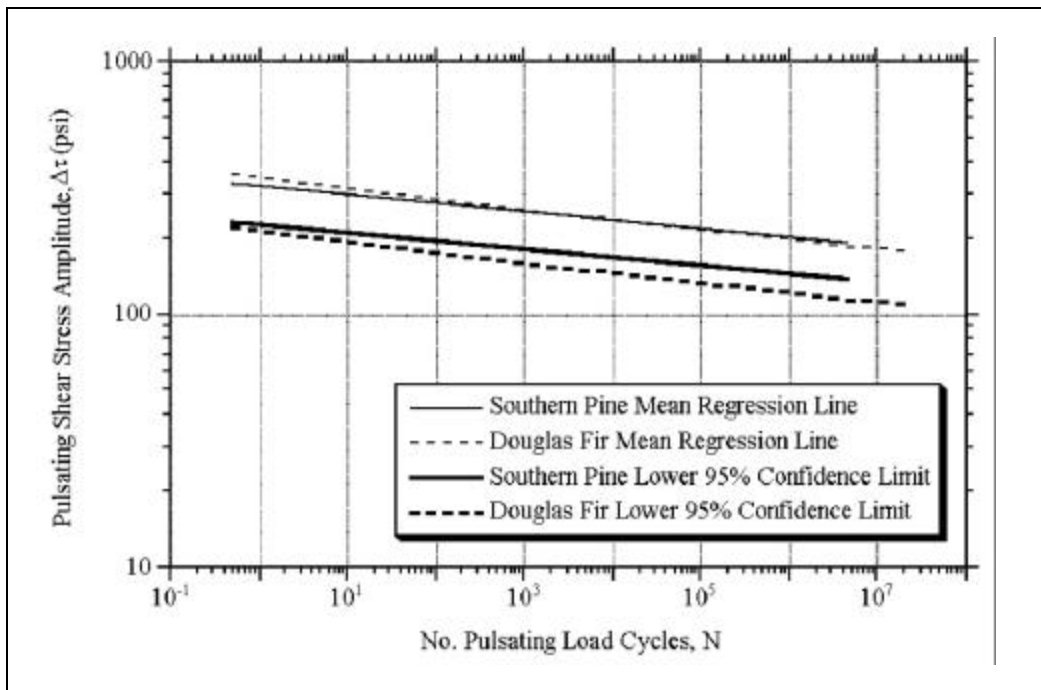


Figure 7.