

The work described in this document was performed by Transportation Technology Center, Inc., a wholly owned subsidiary of the Association of American Railroads.

Key Findings:

- The current AREMA recommendation of Fatigue Design Impact in combination with net sections provides a conservative stress estimate. A comparison of measured vs calculated stresses shows calculated stresses are 30-40% higher than the measured stresses.
- The proposed Fatigue Rating Impact with net section and alpha factor provides more accurate stress estimation than Fatigue Design Impact with no alpha factor. The Fatigue Rating Impact can be effectively used for railroad bridge fatigue evaluation.
- A convenient method to calculate bending stresses using gross section and zero impact provides similar values as using the proposed Fatigue Rating Impact and alpha factor for tested girder and beam spans.
- The bending stresses calculated using distance between bearing faces for the span length more closely match the measured stresses. This is especially evident for shorter spans; while for longer spans, the assumption about span length is less noticeable.

Calculated versus Measured Stresses for Typical Steel Girder Railway Bridges

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[Transportation Technology Center, Inc. \(TTCI\)](#) is testing riveted steel girder railway bridge spans for fatigue and safe service life performance. These tests are being conducted at the Facility for Accelerated Service Testing (FAST) in Pueblo, CO. The bridges at FAST carry approximately 150 million gross tons (MGT) per year of heavy axle load (HAL) traffic. The spans are being loaded at or above their normal rated capacity by the FAST train. In addition, TTCI is performing tests in revenue service on steel railway bridges to obtain loading data under different train types on different span lengths.

TTCI is using this research to investigate life extension and service life estimates for common steel spans as part of the [Association of American Railroads'](#) (AAR) Strategic Research Initiatives (SRI) program.

This *Technology Digest* presents bending stress estimation using different assumptions about section properties, span length, and dynamic impact factor. Comparisons include gross versus net sections and effective span length (center-to-center of bearings, length between bearing faces, and overall span length). Stresses calculated using a proposed new Fatigue Rating Impact with alpha factor were compared to stresses calculated using Fatigue Design Impact. Finally, these various calculations were compared to field measurements.

BACKGROUND

Existing bridge fatigue life evaluation procedures are often conservative. Currently, the American Railway Engineering and Maintenance-of-Way Association (AREMA) recommends using many of the same criteria for railroad bridge design and capacity ratings of existing structures. Based on TTCI experience in field measurements of stresses on railroad bridges at FAST and in revenue service, as well as other observations,¹ it is evident that the design stresses are too conservative for fatigue evaluation of existing structures. Recently, the new proposed Fatigue Rating Impact with combination of alpha factor was proposed by Sweeney.¹ Therefore, TTCI performed a study to compare measured stresses with calculated stresses using current AREMA recommendations and the proposed Fatigue Rating Impact combined with an alpha factor.

DYNAMIC IMPACT

The dynamic effect on a railway bridge is a complex issue that has various sources. Parameters affecting the dynamic behavior of a steel railway bridges are:

- Dynamic characteristics of the live load (mass, vehicle suspension stiffness, natural frequencies, and damping).
- Train speed (can be a significant parameter).
- Train handling (causing pitching acceleration).
- Dynamic characteristics of the bridge (mass, stiffness, natural frequencies, and damping).
- Span length (increasing impact due to higher natural frequencies of short-span bridges).
- Deck and track geometry irregularities on the bridge (surface roughness).
- Track geometry irregularities on the bridge or bridge approach.
- Differences in track stiffness between bridge and approach.
- Rail surface conditions, including corrugations or rolling contact fatigue.
- Rail joints (a significant parameter, of particular importance for short spans).
- Flat or out-of-round wheel conditions.
- Bridge supports (alignment and elevation).
- Bridge layout (member arrangement, skew, and curvature).
- Probability of attaining the maximum dynamic effect concurrently with maximum load.

According to AREMA 2018,² the impact load due to the sum of vertical effects and rocking effect created by passage of locomotives and trainloads, shall be determined by taking a percentage of the live load and shall be applied vertically at top of each rail.

This full design impact represents a rare event. Therefore, for fatigue design and rating stresses, AREMA provides Fatigue Design Impact, which is 35 percent of full design impact for girders.² Recently, the new proposed Fatigue Rating Impact with combination of alpha factor was proposed by Sweeney.¹

The proposed Fatigue Rating Impact for fatigue evaluation of existing structures (stringers, beams, girders, and floor beams) is 15 percent of Full Design Impact, combined with the AREMA speed reduction. The Fatigue Rating Impact represents the average ratio of measured impact to calculated design impact values. For a bridge with smooth continuous welded rail and well-maintained approaches, and trains with well-maintained wheels, the average impact can be near zero at typical freight train operating speeds.

The alpha factor values proposed for various structural components are as follows:

- Stringers, beams, girders, and floor beams use a static load multiplier ratio, alpha, of 85 percent.
- Truss members other than hangers use a static load multiplier ratio, alpha, of 87 percent.
- Truss hangers use a static load multiplier ratio, alpha, of 115 percent.

FIELD MEASUREMENTS

Five riveted steel girder railway bridges located at FAST carry approximately 150 MGT per year of heavy axle load (HAL) traffic. The east steel bridge contains a 55 ft., 5-in. span and a 65-ft. span and is located on tangent track. The west steel bridge has two shorter spans: 24 ft. and 32 ft. and is located on 5-degree curve with 4 in. of superelevation. The newest addition to FAST is a 30-ft. span located on the state-of-the-art bridge that is also located on 5-degree curve with 4 in. of superelevation. East and west steel bridges have automated data collection so TTCI has records of thousands of train passes over these spans. The data is collected periodically from the 30-ft. span. Data has been collected for train traffic in both directions during 2018.

TTCI previously tested three open-deck bridge spans on Norfolk Southern Railway (NS) to obtain loading history data under different train types on different span lengths. Riveted steel DPG spans of 30, 64, and 80 ft., in approximate overall lengths, were tested at the eastern mega site between Roanoke, VA and Bluefield, WV.³ Data was obtained under normal revenue traffic at quarter points and mid-span on all three bridge spans. Traffic included unit coal, unit grain, automotive, articulated double stack, and general merchandise for all bridges combined.

TTCI also collected data from BNSF Railway (BNSF) Bridge 617 on the Pueblo Subdivision over the Fountain River.⁴ This bridge has five ballasted deck spans with north girders of 113 ft., 10 in. overall length and 111 ft., 6 in. between bearing centers and south girders of 115 ft. overall length and 112 ft., 8 in. between bearing centers. Measurements were taken under revenue service Union Pacific Railroad and BNSF trains. Data was collected for loaded coal trains, as well as other loaded unit trains (grain, tank).

For bridges at FAST, the typical train consists of 53-ft. railcars, loaded to 315,000 lbs. For revenue service bridges the measurements used were only for coal trains with the assumption of 53-ft. railcars loaded to 286,000 lbs. This load was used to predict bending stresses at mid-span.

CALCULATED STRESSES

For purposes of fatigue life estimation, AREMA Chapter 15 currently recommends the use of Fatigue Design Impact in combination with net section. This provides a conservative stress estimate. For all spans mentioned in the previous section, the comparison of measured vs. calculated stresses is presented in Figure 1, showing that calculated stresses are 30-40 percent higher than the measured stresses. The highest calculated stress is around 14.5 ksi while the highest measured is only around 10 ksi.

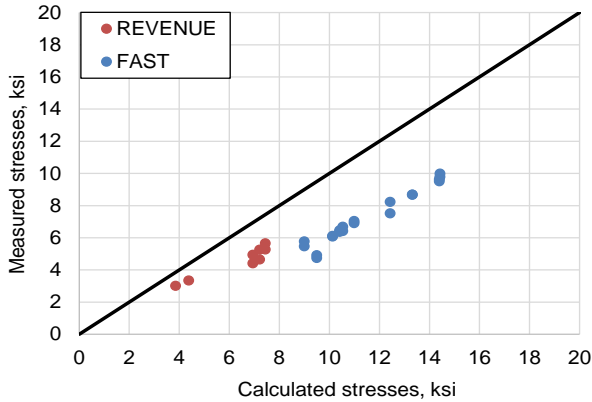


Figure 1. Bending stresses, measured vs. calculated, net section and fatigue design impact (current AREMA recommended practice)

A convenient way to calculate predicted bending stresses is using gross section and zero impact. Calculations were performed with various assumptions of span length: effective span length (center-to-center of bearings), length between bearing edges, and total span length.

Figure 2 presents a comparison of measured stresses with calculated stresses using gross section and zero impact.

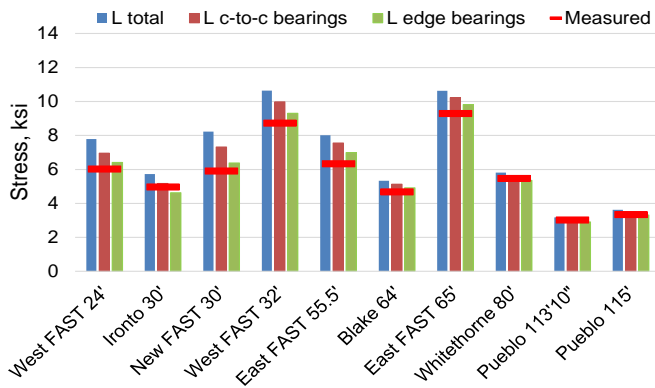


Figure 2. Bending stresses, measured vs. calculated, gross section and zero impact

The closest match is reached when the span length is taken as the distance between inside bearing edges. It is especially

evident for shorter spans, while for longer spans, the assumption of the span length is less noticeable.

COMPARISON OF IMPACT FACTORS

Based on previous findings, the length between inside bearing edges provides the closest match to measured stresses; however, the more common approach is to use effective span length based on center-to-center distance between bearings. Therefore, further investigation is presented using this effective span length. Figure 3 presents various combinations of impact and section properties. It is visible that the calculations with net sections are too conservative, unless the Fatigue Rating Impact and alpha factor are used.

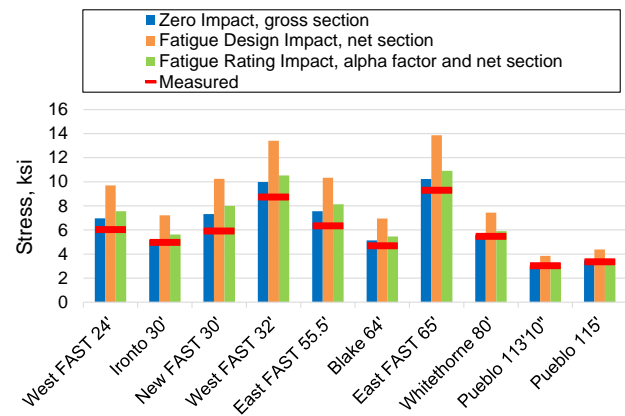


Figure 3. Bending stresses calculated using various impact and measured stresses

The comparison above revealed that two of three configurations presented on Figure 3 were close to each other. The zero impact with gross section and Fatigue Rating Impact with net section and alpha factor produce similar bending stresses that also most closely match the measured stresses.

Figures 4 and 5 present comparisons of measured vs. calculated stresses using zero impact with gross section and Fatigue Rating Impact with net section and alpha factor, respectively.

The Fatigue Rating Impact that corresponds to 15 percent of Full Design Impact with reduction factor due to speed is minimal (around 5 percent); thus is close to the assumption of zero impact. The ratio of net-to-gross section for the subject bridges ranges from 83.4 percent to 85.9 percent. The alpha factor of 0.85 is nearly the same. Therefore, calculating stresses using gross section and zero impact yields similar results as the Fatigue Rating Impact with alpha factor and net section.

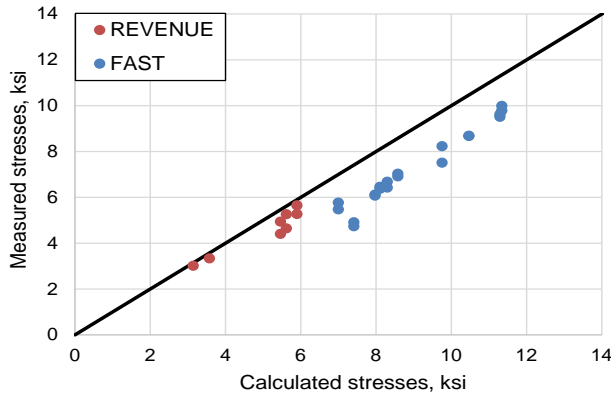


Figure 4. Comparison of measured stresses vs. calculated stresses using proposed factors

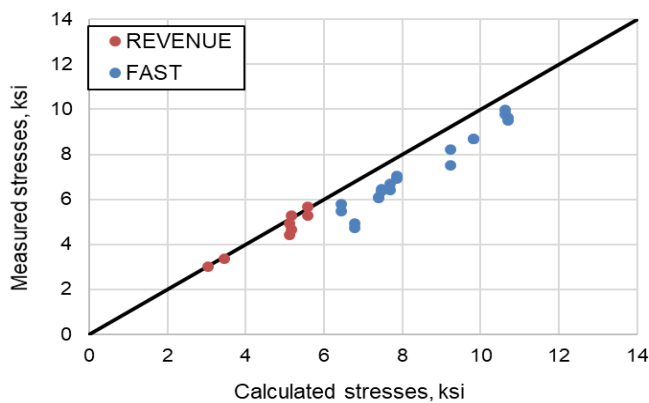


Figure 5. Comparison of measured stresses vs. calculated stresses using gross section and zero impact

LIMITATIONS

The live load stress data from FAST provide several data points beyond the stress levels typically found in revenue service. FAST spans intentionally have higher live load stresses than spans from revenue service because the cars in the FAST train are about 10 percent heavier than those in revenue service.

The data supports use of the proposed stress estimation methods for measured stress values up to 10 ksi. The calculated values using the proposed impact and alpha factors are nearly 12 ksi. Note that the use of the current AREMA fatigue stress calculations give values of over 14 ksi for this data. (Figure 1.)

Previous studies provide some insight into behavior of riveted steel girders. Tests at UI had determined a static frictional resistance of riveted connections of about 10 ksi (1911) and a typical clamping stress of about 30 ksi in riveted connections (hot driven shop type) (1930).^{5,6} This clamping stress multiplied by the steel-to-steel coefficient of friction of 0.4 (dry sliding friction) is around 12 ksi. This might explain why the use of gross section calculations matches the measured data so well. Above this

stress level, behavior might change. Further research into this behavior is recommended.

CONCLUSION

The proposed Fatigue Rating Impact with net section and alpha factor provides accurate stress range estimation that can be implemented for railroad bridge fatigue evaluation. A convenient way to calculate bending stresses using gross section and zero impact provides similar values as using the proposed factors. Further research is recommended into riveted girder behavior at various stress ranges.

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