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Fatigue Evaluation of Welded Steel Bridge Girders at FAST

Duane Otter, Brian Doe, and MaryClara Jones

Summary

With regular monitoring and inspections, the steel bridge at Facility for Accelerated Service Testing (FAST) continues in service, having accumulated over 1,600 million gross tons (MGT) of heavy axle load traffic and more than 10 million load cycles. Crack repair and remediation measures have proven effective. In addition, the bridge has accumulated over 1,500 MGT and over 9.5 million load cycles of 39-ton axle load traffic on a significant crack in a tension flange.

Transportation Technology Center, Inc. conducts full inspections at 25 to 30 MGT intervals, supplemented by more frequent monitoring of selected areas as conditions warrant. Appropriate safety measures are in place for continued train operations.

Results from the ongoing fatigue test are intended to help railroads extend the safe service life of their steel bridges. Also, the monitoring tools and repair techniques evaluated in this test will be valuable in helping railroads to better prioritize bridge maintenance and renewal budgets and economically extend bridge life.

Interim Conclusions

- Crack repair and remedies to reduce the stress state have resulted in the extension of life of a welded bridge by 1,000 MGT at FAST.
- Effective inspection, maintenance, and safety methods including ongoing stress and deflection measurements have successfully extended the service life of the steel bridge at FAST.
- Stop-hole drilling retrofits and bolted splice repairs are both performing well to date, with tonnage accumulations over 1,000 MGT in some cases.
- Removal of rail joints on the bridge slowed the initiation rate of cracks and the growth of existing cracks. For the critical flange crack, the removal of the rail joints reduced the stress ranges to below the apparent crack growth threshold.
- Measurements of typical maximum deflections, maximum stresses, and cyclic stress ranges indicate the new aluminum car FAST train has essentially the same effects on the bridge as did the old steel car FAST train.
- Ultrasonic measurements are performed approximately every 15 MGT on the tension flange crack to check for crack growth. Negligible growth has been found since the crack was initially discovered. This confirms previous findings using electrochemical fatigue sensors and acoustic emissions.

This study is being conducted as part of the program at FAST, which is funded by the Association of American Railroads.

Please contact **Duane Otter (719) 584-0594** with questions or concerns regarding this *Technology Digest.* E-mail: duane_otter@ttci.aar.com.

INTRODUCTION

The steel bridge at FAST has been in service since 1997. While fatigue testing was not part of the original test plan for this bridge, development of cracks within the first few months of service prompted additional monitoring and recording of crack activity for safety purposes.

The ongoing full-scale steel bridge test at FAST continues to provide fatigue results for crack initiation and growth in a safe and controlled railroad environment. Also, this bridge test provides evaluation of various repair methods and evaluation of potential technologies for enhanced inspection and condition monitoring.

Numerous cracks in the steel bridge at FAST became visible during the early period of service. Cracks have continued to initiate, often in different areas of the bridge. The one common factor is that all of the cracks appear to have initiated at or near a welded connection. This *Technology Digest* provides an update to a series of previous progress reports on the fatigue cracks in this bridge.[1,2,3,4,5]

Crack Types and Suspected Causes

Most of the early cracks developed in the tension zone near the ends of welded stiffeners. These are commonly referred to as web-gap cracks. Web-gap cracks have been observed in welded girders in both railway and highway service.[6] Cracks of this type are generally caused by out-of-plane distortion of the girder web in the area between the bottom of a stiffener and the bottom (tension) flange of a girder. The girders at FAST are early examples of welded girders in the railway industry (i.e., 1957 and 1968). In the years since then, American Railway Engineering and Maintenance of Way Association (AREMA) Chapter 15 recommendations have changed to reduce the likelihood of this type of cracking.[7] The current recommendations call for a clear distance of six times the girder web thickness between the end of the welded stiffener and the tension flange. In comparison, the spans at FAST have a clear distance of about one to two times the girder web thickness. And in the case of the 65-foot span, the web-to-stiffener welds wrap around the ends of the stiffeners, sometimes touching the web-to-flange weld.

Also early on in the test period, a tension flange crack developed. The source of this crack appears to be constraint-induced-fracture, as described by Conner et al.[8] The welded connection detail at the gusset plate for bracing connections on the inside of the girder is very similar to one in the reference. There are welds in three directions that constrain the steel from deforming or yielding under load. Because of this constraint in all directions, the steel is prone to rupture or fracture instead. The resulting crack in the 65-foot span at FAST is very similar to one shown in reference 8 for the US 422 bridge near Pottstown, Pennsylvania. However, in the case of the FAST steel bridge, the tension flange is much larger and did not fracture completely. Recent changes to AREMA Chapter 15 recommendations address this sort of connection, providing details to prevent inducing a fracture failure mode. For details of this type in existing bridges, reference 8 suggests a preventive retrofit.

Since the early test period, numerous other cracks have developed in the steel bridge, many in less likely locations, or of less documented types and causes. Figures 1 and 2 show the various cracks and the accumulated tonnage at which they were first noted. Figure 1 is for the 65-foot span. Figure 2 is for the 55.5-foot span. Although the 65-foot span has a greater number cracks, more of the 55.5-foot span cracks have propagated into the web of the girder.

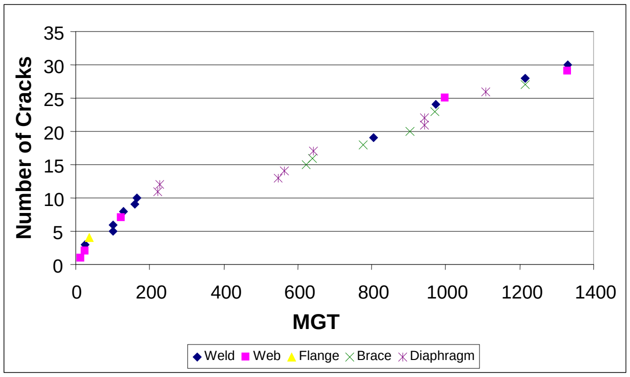

Figure 1. History of Cracks Noted in 65-foot Welded Girder Span

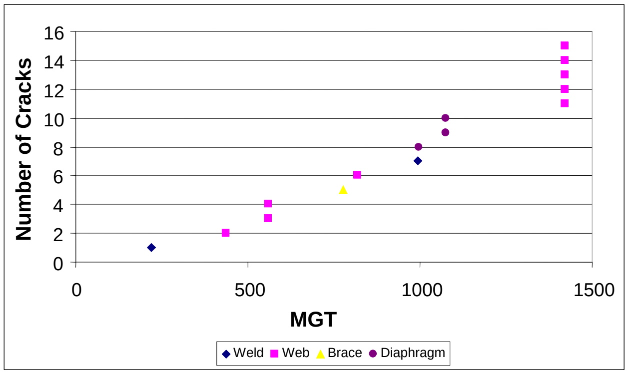

Figure 2. History of Cracks Noted in 55.5-foot Welded Girder Span

The most recent cracks noted are in the webs of the 55.5-foot girders, at the bottom lateral bracing connections. A total of five of these cracks, which are 4 to 5 inches long, were noted – four in the south girder and one in the north girder. Figures 3 and 4 show one of the cracks.

Figure 3. Crack in Web near Bottom Lateral Brace Connection, Inside of 55.5-foot Welded Girder

Figure 4. Crack in Web near Bottom Lateral Brace Connection, Outside of 55.5-foot Welded Girder

Performance of Repairs

Thus far, all repairs installed have performed successfully. Stop holes have been drilled in three web-gap crack locations in the 65-foot welded girder. In each case, no further crack propagation has been noticed. Tonnage accumulated on the drilled stop holes is over 1,600 MGT for all three holes.

Bolted splices have been installed to repair four broken top lateral bracing members in the 65-foot span. Two of the splice repairs have accumulated over 1,000 MGT, and the other two have accumulated 750 and 880 MGT, all with no problems. Figure 5 shows a typical bolted splice repair.

Figure 5. Typical Bolted Splice Repair of Broken Top Lateral Brace in 65-foot Welded Girder

An experimental partial weld repair of a stiffener[2] is performing well with nearly 700 MGT of tonnage accumulated.

Ultrasonic measurements are performed approximately every 15 MGT on the tension flange crack to check for crack growth. Negligible growth has been found since the crack was initially discovered.

Many cracks seem to have become dormant after initially appearing. This might be due to stress redistribution, release of residual tensile stresses, or reduced stress state by removing rail joints from the bridge.

Safety measures in place include bridge deflection monitoring systems and cribbing to limit movement in case of excessive girder deflection.

Performance Comparison for Old and New FAST Trains

Beginning in September 2009, operations at FAST were conducted using a new train of about 115 aluminum body “bathtub” gondola 39-ton axle load coal cars, pulled by three 6-axle SD70 locomotives. The old train was typically about 75 cars, primarily steel body high-side gondola coal cars, pulled by four 4-axle GP40 locomotives.

Bridge measurements under both the old and new train show little difference in terms of the effect of the trains on the bridges. This is expected because the axle loads and axle spacings for the cars are the same for each train. Measurements of typical maximum deflections, typical maximum stresses, and cyclic stress ranges are similar between the old and new trains. Thus, the introduction of the new train at FAST should not have a significant effect on the ongoing tests.

Figure 6 compares the typical maximum measured deflections under each train and the theoretical deflection for both the 65-foot and 55-foot welded girder spans. The differences between the old and new trains are insignificant. For the theoretical deflections, the nominal 39-ton axle load freight cars and axle spacings, and center-to-center of bearings span lengths were used. No impact was included in the theoretical calculations, because the data was taken from time periods with no joints on the bridge, and the FAST train rarely has any impact-producing wheels. Note that the measured deflections are referenced to ground, so deflections due to compression in foundations, bearings and bearing pads, and shear deformations in the girders are included. The theoretical deflections are calculated for girder bending only; therefore, it is not surprising that they are somewhat less than the measured values.

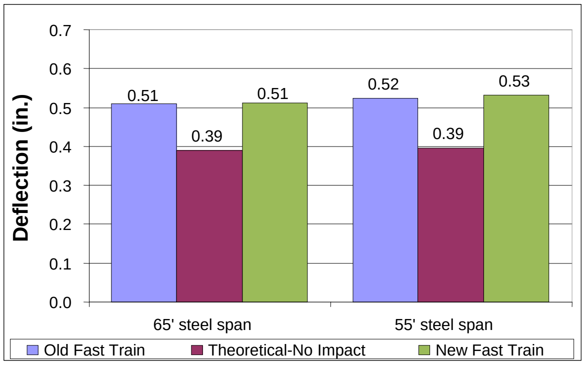

Figure 6. Comparison of Typical Maximum Deflections for FAST Train

Figure 7 compares the typical maximum measured stresses under each train, as well as the theoretical stresses for both the 65-foot and 55-foot welded girder spans. As with the measured deflections, the differences in the stresses between the old train and the new train are not significant. For the theoretical stresses, the nominal 39-ton axle load freight car and axle spacings, and center-to-center of bearings span lengths were used. No impact was included in the theoretical calculation, because the data was taken from time periods with no joints on the bridge, and the FAST train rarely has any impact-producing wheels. Note that the measured stresses are somewhat lower than the theoretical stresses for each span, but more for the 55-foot span. This trend has been observed in previous field studies of railroad bridges.[9,10]

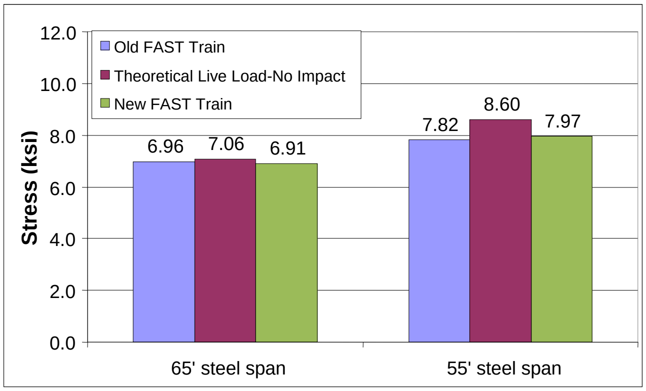

Figure 7. Comparison of Typical Maximum Stresses for FAST Train

Fatigue performance of steel spans is normally linked to the cyclic stress ranges experienced by the spans. Figures 8 and 9 show the cyclic stress ranges for the 65-foot and 55.5-foot welded girders respectively, for both the old and new trains at FAST. Again, the differences are insignificant. The tails in the distributions, shown in Figures 8 and 9, are likely due to vehicle dynamics. The cyclic stress ranges were counted using the rainflow cycle counting algorithm typically recommended for steel fatigue studies.[6]

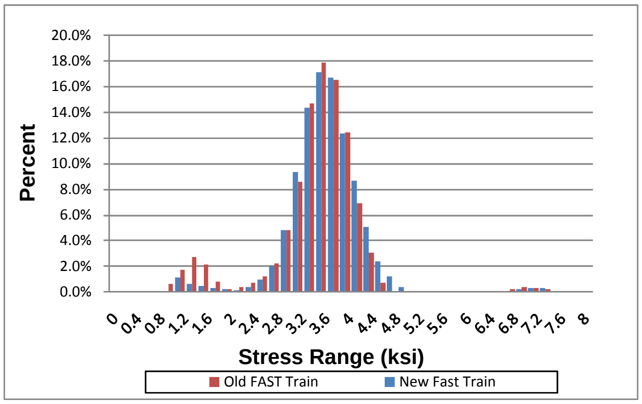

Figure 8. 65-foot Welded Girder – Cyclic Stress Range Histogram

Background

The welded deck plate girder spans in the FAST steel bridge were donated by Conrail in 1997. The spans were originally designed by the Pennsylvania Railroad to a Cooper E-72 design load with diesel impact. The 65-foot span was fabricated in 1957. The 55.5-foot span was fabricated in 1968. Both spans have open timber decks.

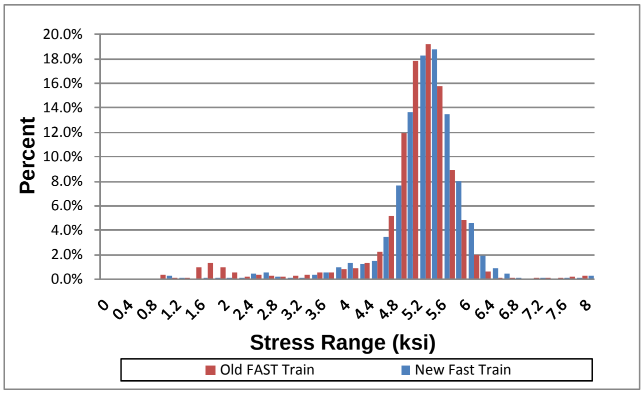

Figure 9. 55.5-foot Welded Girder – Cyclic Stress Range Histogram

Future Work

TTCI recently installed a 1912 vintage riveted deck plate girder span in place of the original 55.5-foot welded deck plate girder span from Conrail. This span will be used to evaluate the effects of 39-ton axle load traffic on a typical span of that vintage. There are thousands of similar spans in the North American railroad bridge inventory. This span will also allow for testing of repairs to corroded members.

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