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## Steel Bridge Life Extension for Riveted Steel Girder Spans at FAST

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### Summary

Transportation Technology Center, Inc. (TTCI) has used a number of techniques to safely extend the service life of two steel bridge spans at the Facility for Accelerated Service Testing (FAST). A 103 year-old riveted deck plate girder span had been removed from revenue service due to low load rating, but with modifications and repairs has been serving at FAST under 39-ton axle loads for over 800 MGT. A second riveted deck plate girder span with a low load rating has been serving at FAST for nearly 300 MGT with no defects noted to date. These spans are being used in conjunction with alternative service life estimation methodologies to develop improved estimates of service duration for riveted steel spans.

Overall keys for extending service life of these bridge spans at FAST:

- Stress state reduction: Smooth rail surface and good track geometry are maintained on bridge and approaches.
- Inspections: Regular overall inspections and frequent cursory inspections.
- Repairs: Simple and effective bolted repairs to bracing systems.
- Monitoring systems: Installation of simple deflection indicator devices, automated monitoring of basic bridge responses, and periodic targeted monitoring of critical performance parameters.

Performance of the spans to date appears to indicate that implementing refined methodologies for steel bridge life estimation might be promising, and may result in extended service life in many cases.

Cracks in the 55.5-foot span appear to have initiated in areas of significant corrosion. To date, no cracks have been noted in the 65-foot span.

The FAST train loading on the 55.5-foot span is 100 percent of its normal rated capacity. On the 65-foot span, it is 125 percent of the normal rated capacity. The spans are helping evaluate refined life estimating methodologies for riveted steel girder spans, which comprise much of the steel bridge inventory for North American railroads.

Many of these life extension techniques can be employed in revenue service in one form or another to extend the safe service life of bridges. Stress state reduction, inspection, and targeted monitoring techniques can be employed to extend the service life of concrete and timber bridges in addition to steel bridges.

This work has been conducted under the AAR Strategic Research Initiative on Bridge Life Extension, as well as the FAST Program.



## INTRODUCTION AND CONCLUSIONS

The steel bridge at FAST has two riveted steel deck plate girder spans with lengths of 65 feet and 55.5 feet. Both spans have carried considerable amounts of heavy axle load (HAL) traffic at FAST with the use of several bridge life extension techniques. Successful methods include:

- Stress state reduction
- Inspections
- Repairs
- Monitoring systems
- Capacity enhancement
- Improved life assessment techniques

These life extension methods and monitoring techniques allowed years of continuing train operations over the spans in spite of conditions that may not be up to current recommended practice. A previous *Technology Digest* discussed the efforts for a 65-foot welded steel girder span.<sup>1</sup> In late 2013, HAL train operations began on a riveted 65-foot span of lighter design. The 55.5-foot riveted deck plate girder span, installed in late 2009, has significant corrosion, particularly in horizontal elements of the bracing system. It is also being loaded to 100 percent of its normal rated capacity by the HAL traffic at FAST. In nearly five years of service, it has developed broken bracing members. The two spans of the FAST steel bridge are shown in Figure 1.



Figure 1. FAST Steel Bridge with 65-foot and 55.5-foot Riveted Deck Plate Girder Spans

### 55.5-Foot Riveted Span

The 55.5-foot span is a riveted steel span fabricated in 1912 for the Wabash Railway and served on a main line in Indiana. It is typical of steel deck plate girders constructed in that era, which used plates and angle sections to build up the cross section. In 2009, the span was removed from revenue service by Norfolk Southern (NS) and installed at FAST. The span was removed as part of a bridge upgrade that included replacement of three spans with low ratings, and replacement of the entire bridge deck. At the time, this bridge had a concrete floor and ballast deck, as shown in Figure 2. The concrete floor and ballast deck were removed from the span prior to installation at FAST.

With the concrete floor and ballast deck, the span had a normal live load rating of Cooper E-42 per AREMA recommended practice.<sup>1</sup> The use of an open deck at FAST in place of the concrete floor and ballast deck resulted in a significant reduction in the weight of the span. This weight reduction allows for a train load capacity enhancement. The normal live load rating as installed at FAST is Cooper E-61

including a reduction for corroded members. This is a 45 percent increase in the normal live load rating. Not all ballast deck to open deck conversions will be able to provide as much of a capacity increase. The reinforced concrete floor on this bridge is likely heavier than most timber floors that are commonly used.

The FAST test train loading on this span is equivalent to Cooper E-61, so the span is being loaded to 100 percent of its normal rated capacity at FAST.



Figure 2. 55.5-foot Riveted Span (second span from camera) in Prior Service with Concrete Floor and Ballast Deck

### 65-Foot Riveted Span

The 65-foot riveted girder span was fabricated in 1954 for the Southern Railway and served on a lightly used line in Alabama. Like the 55.5-foot span, it is typical of steel deck plate girders constructed in that era, using plates and angle sections to build up the cross section. Service over the span ended in 1988 due to a reroute of traffic. The span has a normal live load rating of Cooper E-45.5 with an open deck, as installed at FAST. The FAST test train loading on this span is equivalent to Cooper E-57, so the span is being loaded to 125 percent of its normal rated live load capacity at FAST.

### Stress State Reduction

Rail joints have been eliminated from the bridge as much as practical, to limit impact forces from vehicles, thus reducing the live load stresses in the bridge. While a flat wheel on a car might introduce an impact force once every wheel revolution across the bridge, a bolted rail joint introduces an impact force for every axle passing over the bridge. And these repeated impact forces are applied at the same location, which can quickly lead to excessive demands on the structure at a particular location. In addition, keeping a smooth running rail, free of corrugations and surface defects also minimizes the impact forces.<sup>2,3</sup>

Maintenance of good track geometry on the bridge and bridge approaches minimize vehicle dynamic forces, which could also contribute to an increase in the stress state. The approaches to the FAST steel bridge are constructed of compacted, well-draining backfill material with broad slopes. The approach track has historically required minimal geometry maintenance.

By maintaining smooth rail and smooth track geometry on the bridge approaches, the dynamic vertical wheel load affects measured on the FAST steel bridge are considerably less than

those predicted using AREMA recommended practice.<sup>4</sup> AREMA design impact values are 47 percent for the 55.5-foot span and 48 percent for the 65-foot span. For fatigue, the AREMA mean impact values are about 17 percent for each span. Typical values measured at FAST with the maintenance conditions described are less than 10 percent.

**Monitoring Systems**

In order to quantify changes in bridge performance as tonnage accumulates, three separate monitoring systems are installed near mid-span on the 55.5-foot riveted span:

- An automated mid-span deflection and strain monitoring system, which provides warnings when levels are reached
- Resettable “fish scale” maximum deflection devices to provide indication to test controller of maximum girder deflections
- A lateral deflection system, which is used on a scheduled basis to monitor lateral movements of the girders at both top and bottom flanges.

Similar systems are in place on the 65-foot span, with the exception of the lateral deflection system. The lateral bracing on the 65-foot span is in good condition, so lateral deflections are not as much of a concern for this span. These monitoring systems are all very simple and provide actionable data or indications. The deflection and strain monitoring system provides data for each train pass that can be checked and monitored as desired. The fish scales are checked manually by the test controller at times during train operations. (The fish scales have been used at FAST for many years to provide an indication of rail movement in curves.) Figure 3 shows a fish scale maximum deflection indicator as well as a string potentiometer for the deflection monitoring system.

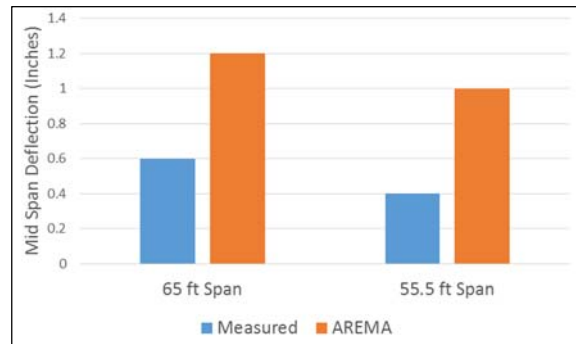


**Figure 3. Fish Scale Vertical Deflection Indicator (right) and String Potentiometer (left) for Deflection Monitoring**

Typical deflections for these spans under the FAST train is about 0.4 inch for the 55.5-foot span and 0.6 inch for the 65-foot span. The maximum deflections recommended by AREMA are about 1.0 inch for the 55.5-foot span and 1.2 inches for the 65-foot span. Lateral movements of the girders on the 55.5-foot span are monitored on a periodic basis. Measurements are taken for both the top and bottom flanges near mid-span. The lateral movements are monitored to determine the performance of the lateral bracing system in relation to the applied loads. Most of the corrosion has been in the lateral bracing system, and some has intentionally been left in place without repair, hence the desire for periodic

monitoring. Lateral deflection results have been reported previously<sup>5</sup> and no increases have been noted since then.

Figure 4 shows typical mid-span deflections under the HAL train at FAST. For comparison, the AREMA recommended maximum values are also shown. Note that the measured deflections are no more than half the recommended maximum.



**Figure 4. Typical Mid-Span Deflections under HAL Train**

Over 5 years of service at FAST, the 55.5-foot riveted span has accumulated 840 MGT and 5.3 million load cycles of HAL traffic. In one year of service at FAST, the 65-foot riveted span has accumulated 281 MGT and 1.8 million load cycles of HAL traffic. Complete bridge inspections are conducted about every 30 MGT or about every 200,000 load cycles. In addition, the bridge is the subject of frequent cursory inspections, being at eye level in a location frequented by numerous track workers, instrumentation specialists, and engineers. Deflections and strain readings from the tension flanges are monitored on a regular basis.

**Maintenance 55.5-Foot Riveted Span**

During the 5 years that the 55.5-foot riveted span has been in service at FAST, cracks have developed in seven bracing members and two gusset plates. Each of the cracks initiated at an area where there was significant corrosion. For bracing members, typically the horizontal leg of an angle was almost fully corroded. In one case, the bracing member was so corroded that it was replaced with a new angle. In the other six cases, simple bolted splice repairs were used, as have been used in previous spans at FAST.<sup>1</sup> Three of these repairs have accumulated more than 700 MGT of HAL traffic and are still performing well. These simple splice repairs are much easier to make than a full member replacement, and they do not require the track to be taken out of service.

The two top lateral gusset plates that have cracked have not yet been repaired. Repairs to these members typically require removing some of the deck ties and track out-of-service time to do so. At the request of industry bridge engineers, these gussets are currently being left unrepaired, and lateral deflections are being monitored. There has been discussion of attempting an alternative repair from below track level that does not require removal of deck ties at some point in the future.

**Span Performance and Live Load Stresses**

Typical maximum live load stresses near mid-span during FAST train operations are about 7 ksi for the 55.5-foot span

and about 10 ksi for the 65-foot span. Figures 5 and 6 show typical time histories for the 55.5-foot span and 65-foot span, respectively. Although the peak live load stresses are noticeably higher in the 65-foot span, the cyclic stress ranges for the traversing train are closer to each other in magnitude. The primary live load stress cycles occur once per car for each span. The primary cycle is due to the group of four axles from adjacent trucks of coupled cars. The effective stress range computed using rainflow cycle counting and the root-mean-cube method<sup>4</sup> are about 5.3 ksi for the 65-foot span and about 4.4 ksi for the 55.5-foot span. In each case, the effective stress range is considerably less than the peak measured live load stress. The reason for this lies in the ratio of the car length to the span length,<sup>6</sup> and the fact that the spans do not unload completely between cars. The cars in the FAST train are 53-foot rotary dump gondolas typical of coal service in North America.

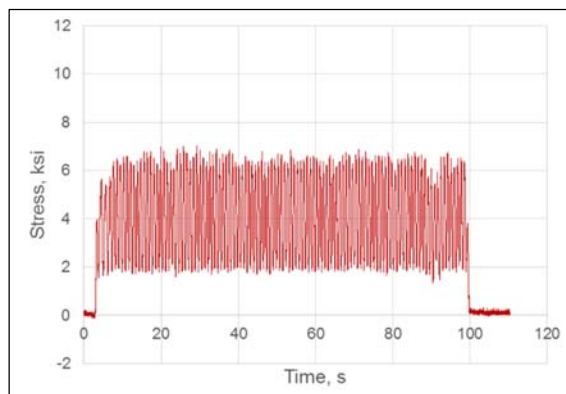


Figure 4. Typical Stress Time History for 55.5-foot Span under the FAST/HAL Train

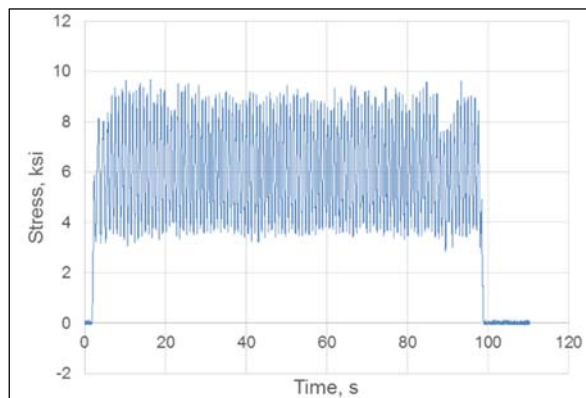


Figure 5. Typical Stress Time History for 65-foot Span under the FAST/HAL Train

The live load stress information can be used to help estimate remaining life of steel bridge spans. TTCI is investigating the use of refined life assessment techniques used in the aircraft and pipeline industries, and also for highway bridges as well as for railway bridges in Europe.

Additional testing of these spans at FAST will help determine whether some of these refined methods may be appropriate for use with riveted steel girders in the North American railway bridge industry.

The 65-foot span likely had a minimal amount of traffic in revenue service, so the tonnage accumulated at FAST is a good estimate for the total fatigue accumulation on the span. The 55.5-foot span was subjected to 98 years of revenue service on a mainline track carrying more than 50 MGT annually when the span was removed. The traffic included a variety of manifest freight, automotive, grain, and intermodal traffic. An estimate for the fatigue life consumption in revenue service has not yet been performed. The rapid tonnage accumulation on the riveted steel spans at FAST will help with evaluation of refined life estimation methods, but it is too early to make any conclusive statements.

## Conclusions

Two riveted steel girder spans are performing well after 6 years (840 MGT) and 2 years (281 MGT) of HAL service at FAST. One span previously had low rating and the other has a low rating. Keys to extending the span service life at FAST include:

- Stress state reductions: (1) maintain a smooth rail surface (eliminate rail joints, grind rail surface defects and corrugations), and (2) maintain good track geometry on bridge and approaches to minimize vehicle dynamics.
- Capacity increase (for the 55.5-foot span): (1) remove concrete floor pans and ballast deck to reduce dead load, and (2) repair or replace broken or missing braces and gusset plates prior to installation.
- Inspections: (1) regular overall inspections, and (2) frequent cursory inspections.
- Repairs: (1) simple and effective bolted splice repairs for bracing, and (2) no failures in over 700 MGT.
- Monitoring Systems: (1) simple bridge safety detection system (fish scale), (2) automated monitoring of basic strains and deflections, and (3) periodic measurement of lateral displacements (because of broken lateral gussets).

Cracks in the 55.5-foot span appear to have initiated in areas of significant corrosion. To date, no cracks have been noted in the 65-foot span. The FAST train loading on the 55.5-foot span is 100 percent of its normal rated capacity. On the 65-foot span, it is 125 percent of the normal rated capacity. The spans are helping evaluate refined life estimating methodologies for riveted steel girder spans, which comprise much of the steel bridge inventory for North American railroads.

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