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Characterization of a Vintage Riveted Steel Deck Plate Girder Bridge Span at FAST

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Summary

In an effort to extend the life of railroad bridges and to develop recommended practices for life extension maintenance and cost effective repair procedures, Transportation Technology Center, Inc. (TTCI), Pueblo, Colorado, is evaluating a vintage riveted steel span from 1912. The span, which is in place on the steel bridge at the Facility for Accelerated Service Testing (FAST), was donated by Norfolk Southern (NS) Railway. The vintage span replaced a similar length welded steel span that was provided by Conrail when the FAST steel bridge was originally constructed.

Prior to installation at FAST, TTCI crews instrumented this bridge span in revenue service on the NS. Comparisons between the vintage riveted span performance at FAST and in revenue service, as well as between the vintage span and the previous welded steel span, are made based on measurements to date. Comparisons are also made to values calculated based on theoretical models. Observations include:

- The 315,000-pound heavy axle load environment to which the vintage riveted span is subjected at FAST is considerably more severe than the axle load environment this span experienced in revenue service. The stresses and deflections in the vintage span at FAST are likewise almost twice as large as those measured in revenue service.
- Measured stresses in the vintage riveted span are similar to the measured stresses in the previous welded steel span; however, the stresses in the vintage span are 20 percent higher as a fraction of the steel strength, thereby reducing the live-load capacity.
- Measured deflections in the vintage riveted span are somewhat less than those measured in the previous welded steel span; this reduction is expected given that the vintage span is 15 percent deeper than the welded span. Deflections are well within American Railway Engineering and Maintenance-of-Way Association recommendations.
- For both the vintage riveted span and the welded steel span, theoretical models predict stresses about 10 percent higher than measured but deflections about 20 percent lower than measured.
- Conversion of the span from a ballasted deck in revenue service to an open deck at FAST resulted in an increase in live-load capacity of nearly 50 percent. The conversion also increased the importance of bracing members, as the floor pans provided considerable lateral stiffness and redundancy.

This study was conducted by TTCI and is funded through the Association of American Railroads' Strategic Research Initiatives Program.

INTRODUCTION

TTCI is investigating efforts to extend the safe service life of existing railroad bridges. NS donated the 1912 vintage riveted steel bridge span to TTCI. The span was installed in the steel bridge at FAST in December 2009 for testing under 315,000-pound heavy axle load (HAL) traffic. The span was originally constructed for the Wabash Railroad and was in service over Wildcat Creek in Lafayette, Indiana. Testing of this span will be used to develop and evaluate effective life extension, retrofit, and repair strategies for similar bridges.

The 55-foot 5-inch span is a typical example of a riveted steel deck plate girder span, similar to many of the steel bridges still in revenue service today. Figure 1 shows the steel span in revenue service.

Figure 1. Vintage Riveted Steel Span in Revenue Service on NS

TRAFFIC HISTORY

Prior to installation at FAST, the vintage riveted span carried very little HAL traffic when compared to HAL traffic at FAST. Approximately 75 percent of the traffic at FAST is heavier than any traffic measured on the vintage riveted span while it was in revenue service. Figure 2 displays the axle loads at FAST compared to revenue service. Figure 2 also shows the axle loads the 55-foot 6-inch welded steel span was carrying before it was removed.

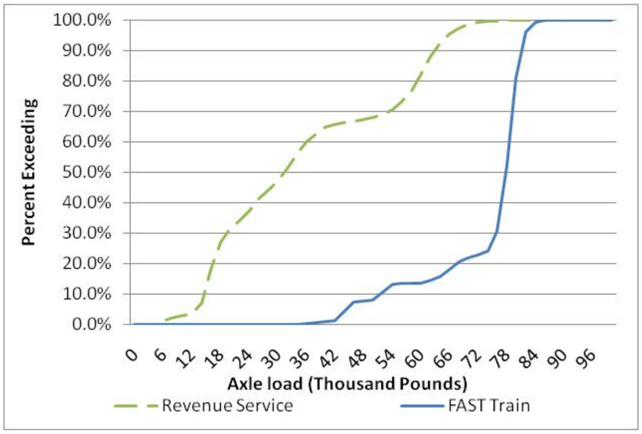

Figure 2. Comparison of Cumulative Distribution of Axle Loads

SPAN RATINGS

When installed in revenue service, the vintage riveted span had concrete floor pans and a ballasted deck, as Figure 3 shows. The live load with this deck was rated at Cooper's E-42, following AREMA Chapter 15 recommended practice.[1] When the span was installed at FAST, it was installed as an open-deck span, with ties directly supported by the steel girders, as Figure 5 shows. With the open deck, the live load rating increased almost 50 percent to Cooper's E-61, including a 10 percent reduction for corrosion. For comparison, the previous welded steel span at FAST rates at Cooper's E-89. The loading of the HAL train is equivalent to Cooper's E-62. Figure 4 compares the ratings with the HAL train loading. Currently, the HAL train at FAST is running near the limit of calculated span capacity.

Figure 3. 1912 Vintage Riveted Span with Ballasted Deck on NS

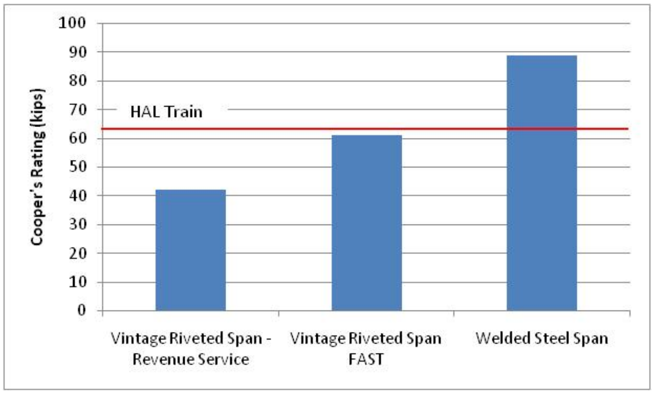

Figure 4: Ratings for Vintage Riveted Span and Welded Steel Span Compared to Cooper Equivalent Loading for HAL Train

INSTRUMENTATION

Strain gages and displacement transducers were installed on the vintage riveted span while it was still in place in revenue service at Lafayette. This was done so that a full comparison could be made with the data collected at FAST. The original welded steel span at FAST, which was replaced, had similar instrumentation to provide data for comparison.

Mid-span deflections were measured using string potentiometers attached to the bottom of the span. Strain gages were attached near mid-span at the top and at the bottom of both girders to determine peak stresses. Also, strain gages were placed near ¼-, ½-, and ¾-heights on the web of the span to determine the effects the conversion from ballasted deck to open deck had on bending stress distribution.

Figure 5 displays the vintage riveted span installed at FAST and the location of the instrumentation.

Figure 5. Vintage Riveted Span at FAST

STRESS MEASUREMENTS

Figure 6 compares the average peak stresses in the vintage riveted span measured at FAST and in revenue service. As expected, because of the higher axle loads at FAST, the corresponding stress is higher. The typical peak live load stresses experienced at FAST are about 80 to 90 percent greater than those in revenue service.

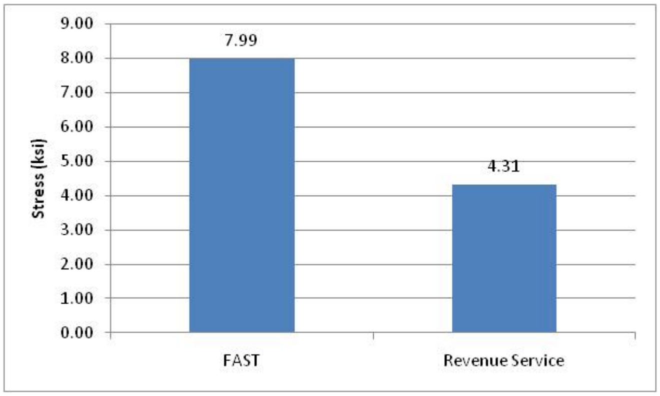

Figure 6. Comparison of Average Peak Live Load Stresses for Vintage Riveted Span

Theoretical stress values were calculated using conventional bending beam models. Because the test train at FAST has no flat wheels, no rail joints on the span, and the bridge approaches were smooth, no impact was included in the theoretical calculations. Figure 7 compares the measured stresses in the vintage riveted span and the previous welded steel span to theoretical values. Note that stresses were measured over a limited time period, and over the life span of the bridge, higher impacts and stresses can be expected.

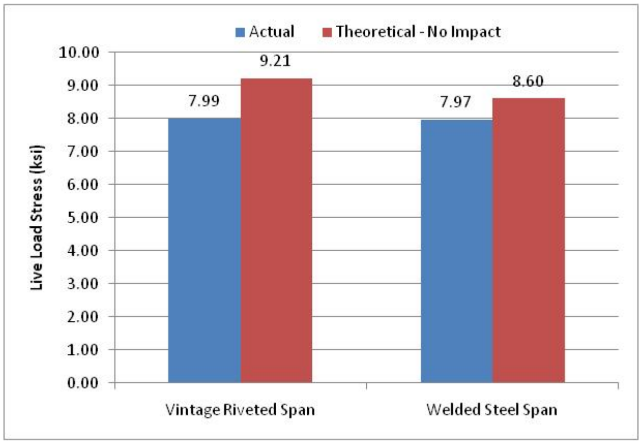

Figure 7. Comparison of Typical Peak Stresses of Vintage Riveted Span and Welded Steel Span at FAST

The measured stress values are about 7 to 15 percent less than the theoretical calculated stress values for both the vintage riveted span and the previous welded steel span. Similar results have been reported by Sweeney et al.[2] Some possible contributing factors include partial fixity of the bridge bearings and distribution of wheel loads by the rails.

Information provided by NS and Conrail indicates that the yield strength of the steel in the vintage span is 30 ksi and in the welded span is 36 ksi. So while the live load stresses in each span at FAST are similar, they are 20 percent higher in the vintage riveted span as a fraction of the yield strength.

MID-SPAN DEFLECTION MEASUREMENTS

Comparison of the mid-span live load deflections at FAST to revenue service indicates the span had smaller deflections in revenue service than at FAST, as expected. This is due primarily to the heavier axle loads operated at FAST. It might also be due in part to additional span stiffness from the concrete floor pans supporting the ballasted deck. In revenue service, the span experienced many lighter weight and empty train cars. Figure 8 displays the typical measured peak deflection and calculated deflection for the vintage riveted span. The mid-span deflection of the vintage span at FAST is approximately 50 percent greater than the deflection of the span in revenue service.

Theoretical values were calculated for the vintage riveted span and the previous welded steel span at FAST. A theoretical value was not calculated for the span in revenue service (see Figure 9). The typical peak deflection measured for the vintage span at FAST is less than that for the previous welded steel span. This result is also predicted in the theoretical models. The primary reason for the lower deflections is that the vintage riveted span is 15 percent deeper than the previous welded span.

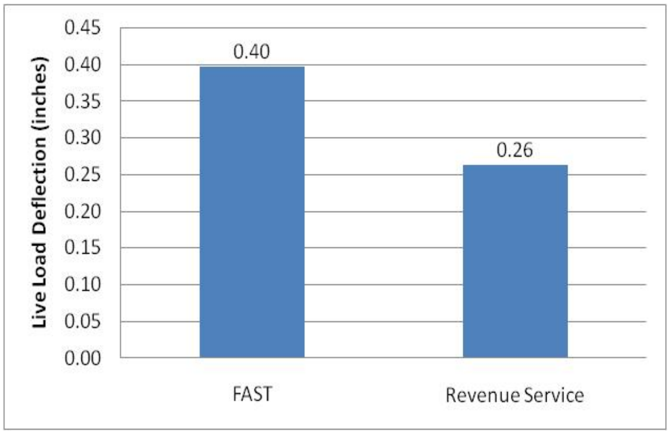

Figure 8. Comparison of Mid-Span Live Load Deflections for Vintage Riveted Span

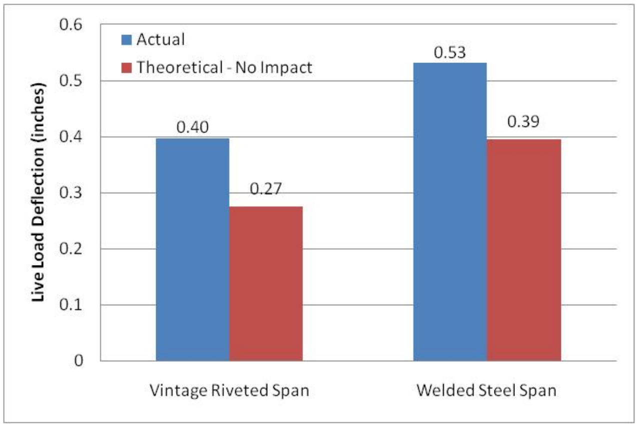

Figure 9. Comparison of Live Load Deflections of Vintage Riveted Span and Welded Steel Span

Note that the theoretical deflection values are less than the measured values. There are several possible contributing factors that might explain this. First, the theoretical deflection model considers only beam bending. It does not include shear deformations. Nor does the theoretical model at this point consider displacements in the bearings, bearing pads, or foundations.

OPEN DECK CONVERSION EFFECTS

When the vintage span was in service on the NS, five strain gages were attached to each girder near mid span. These gages were placed on the bottom angle, near ¼ height, near ½ height, near ¾ height, and on the top angle. Figure 10 shows the results from these strain gages from the bottom of the girder to the top. Note that the neutral axis (location of zero bending stress) is lower in the span at FAST than it was in revenue service. This is most likely due to composite action of the concrete floor pans while the span was in revenue service. With the concrete floor pans removed for service at FAST, the resulting neutral axis shifted lower. Because more of the steel is in compression without the floor pans, bracing becomes more important to provide stability to the span. The presence of the concrete floor pans in revenue service provided redundancy in the case of corroded or missing bracing.

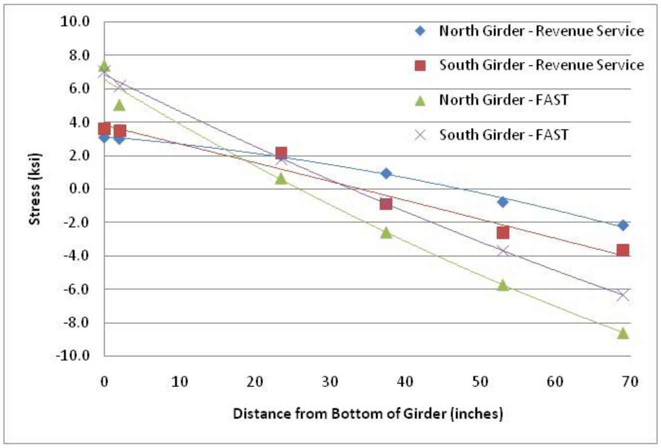

Figure 10. Stresses at Mid-Span of Vintage Riveted Span

CONCLUSIONS

The vintage span has carried more than 200 MGT of HAL traffic since installation at FAST. The span has performed acceptably, only requiring repairs to corroded bracing elements.

FUTURE WORK

Future work planned includes testing of various life-extension and repair techniques, as well as fatigue investigations.

ACKNOWLEDGEMENT

NS donated the vintage riveted span and assisted with field testing. In particular, this work would not have been possible without the support of James N. Carter, Jr., Chief Engineer – Bridges and Structures, and Howard C. Swanson, Assistant Chief Engineer – Bridges.

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2. Robert A.P. Sweeney, George Oommen, and Hoat Le, May 1996. “A Summary of Seven Years of Railway Bridge Testing on Canadian National Railway,” Bulletin No. 756, Proceedings Volume 97, American Railway Engineering Association. pp. 333-347.