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Preliminary Impact Load Assessment of Ballast Deck Prestressed Concrete Bridges

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Summary

Two bridges located on curved track at the Transportation Technology Center's Facility for Accelerated Service Testing (FAST) in Pueblo, Colorado, and one bridge located on tangent track on the BNSF Railway in Piñon, Colorado, were tested. The test at FAST aims at assessing the initial stress-state of the prestressed concrete bridges. The objective of the BNSF bridge test was to evaluate the difference in behavior of intermediate and end spans under dynamic loads. The distribution of vertical loads across the widths of the spans was also measured.

Results summaries from this study include:

- Wheels on bridge spans with standard bolted rail joints installed are capable of producing high dynamic impacts that may exceed the design impact load.
- Removing standard bolted joints and flat wheels reduces the dynamically induced stress-state.
- Bridge end spans are experiencing higher impact loads than intermediate spans on tangent track.
- The girders of the bridges located on both curved and tangent track show non-uniform load distribution across the width of the spans.
- The American Railway Engineering and Maintenance of Way Association 2005 guideline's recommended design impact and centrifugal force values appear to be adequate for bridges without bolted rail joints.

Railroads will benefit in terms of reduced impact loads through lower maintenance costs and extended service lives of concrete bridges, according to a study under way by Transportation Technology Center, Inc.

The railroad industry spends about half of their bridge capital on concrete bridge construction, now comprising up to 20 percent of the total railroad bridge inventory. These investment levels make it especially important to evaluate short- and long-term performance of concrete bridges under heavy axle load traffic.

INTRODUCTION AND CONCLUSIONS

Concrete bridges at FAST provide a unique opportunity to study the dynamic behavior of bridges when subjected to heavy axle load (HAL) traffic. Improved dynamic behavior will result in reduced maintenance and extended service life of concrete bridges. Due to low cost and rapid construction, concrete bridges are a convenient alternative to timber trestles. Concrete bridges make up more than 20 percent of the railroad bridge inventory based on length, and current construction accounts for about half of railroad bridge capital investment. This makes it especially important to assess the performance of concrete bridges under HAL conditions.

The results of tests show that end spans on tangent tracks are subjected to higher impacts than the intermediate spans. As well, the stress distribution across the width is not uniform in the spans of bridges both on tangent and curved track.

An important aspect of a bridge is its service lifespan, which greatly depends on its stress-state. Bolted joints create higher impacts that may exceed design impact loads. In addition, flat wheels induce higher impacts in bridge spans than normal wheels. Removing these factors will reduce the stress-state, resulting in increased service life and reduced maintenance.

The stress-state in bridges also depends in part on vehicle suspension systems, wheel maintenance practices and track induced vehicle dynamics. Controlling these factors is the subject of other industry initiatives. But, stress introduced by these factors may also be decreased by reducing bridge stiffness and increasing damping of the track structure on the bridge.

The purpose of the FAST bridge research program is to study the dynamic behavior of bridge spans caused by impact loads. The stress-state in girders will be studied by changing the ballast depth, tie types and installing pads of different damping materials under ties. Installing a ballast mat is also a possibility. These techniques should reduce support stiffness, increase damping, and improve overall dynamic performance of bridges. The current test assesses the initial dynamic behavior of the FAST bridges and is the basis of comparison for further testing.

BRIDGE DESCRIPTIONS

The high tonnage loop at FAST has two ballasted deck concrete bridges. The first bridge has 24- and 32-foot double-cell-box spans and is usually called a “conventional bridge.” The second bridge is known as a “state-of-the-art” bridge. The intermediate span is 42 feet and has double-cell-box type girders and is made of high-performance concrete. The flanking spans are a 30-foot double-cell-box and a 15-foot slab span. Construction of both of the bridges was completed in late 2003. The bridges are subjected to mostly 315-kips loaded cars. Both of the bridges have standard concrete ties.

Designs of all but the 42-foot spans are based on Cooper E-80 loadings and follow AREMA chapter 8 design guidelines and BNSF/Union Pacific Railroad (UP) design practices. The 42-foot span was designed by CN based on E-90 loading. Foundations of both the bridges are based on E-100 design. The girders are supported on precast pile caps laid over H-piles. The bridges are on a 5-degree curve and have a ballast depth of 16 inches under the high rail of the curve and 12 inches under the low rail of the curve.

The bridge on BNSF at Piñon consists of four spans of 14-feet long and is located on tangent track. Each span has two 14-inch deep slab-type girders. Carrying southbound traffic, the bridge is subjected to loaded coal as well as mixed freight trains. One end span and two intermediate spans were tested. The strain gages were only installed at midspan locations on each span.

METHODOLOGY

Strain gages were installed on the concrete bridges at FAST to measure the bending strains at midspans, shear strains at end of spans, and the axial strains in piles. See Figure 1a for strain gage locations. A test train passed at 2 mph in each direction, and then the speed was increased at 5 mph increments starting with 5 mph and ending at 45 mph. The test train had two 4-axle locomotives on both ends. The train had two 263-kip, two 286-kip, and twelve 315-kip cars.

Strain gages were also installed on three BNSF bridge spans at Piñon, Colorado, to measure midspan bending strains, Figure 1b. Seven coal and mixed freight trains passed southbound over the bridge. This bridge is on tangent track and train speed varied.

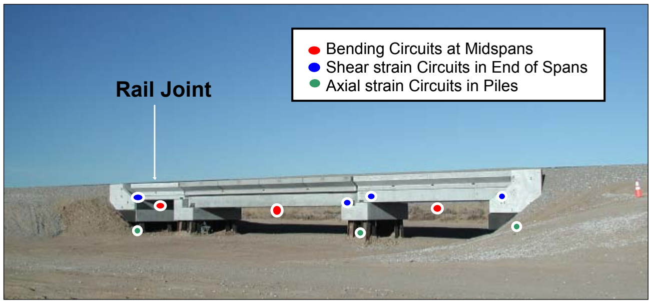

Figure 1a. Concrete Bridge at FAST

Figure 1b. Bridge on BNSF at, Piñon, Colorado

MEASUREMENTS

The measured data from bending, shear and axial strain circuits were used to determine the statistical distribution of impacts and centrifugal forces, as well as to investigate the effects of span length and train speed on bridge dynamic behavior. Impact was calculated as the ratio of peak strain at a particular train speed to the corresponding peak strain for the 2-mph run at FAST. Most bridge members experienced about one load per cycle per group of four closely spaced axles of the test train. So each pass generated 21 distinct load cycles per train for most members for the test train used.

IMPACT LOADS

Centrifugal force effects were removed from individual channels by quadratic regression curve-fitting to calculate the impacts. Figure 2 shows the measured impact data plotted as a function of span length. Negative impact indicates dynamic wheel loads are less than static wheel loads. As the plot indicates, impacts reduce with increasing span length. Longer spans support more axles, so the effect of impacts from a single axle is reduced. The measured impact values follow the trend of AREMA 2005 recommended values for smooth continuously welded rail (CWR).[1]

Figure 3 illustrates that 95.5 percentile impacts show a trend of increasing with speed. This increase in impact at higher speeds is likely caused by vehicle dynamics effects.

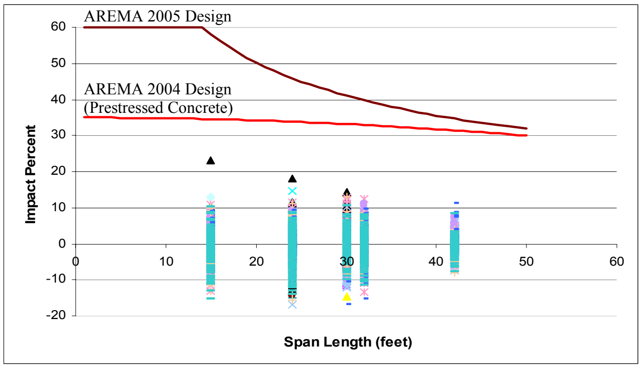

Figure 2. Impacts as Function of Span Length Without Centrifugal Force Effect

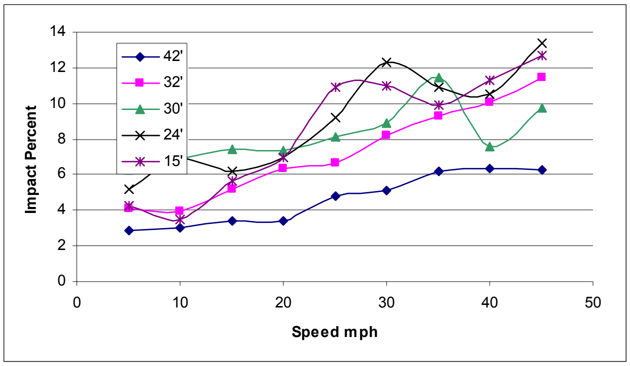

Figure 3. 99.5 Percentile Values of Impacts in Spans Related to Speed

A standard bolted rail joint was installed on the 15-foot concrete bridge span to study the effects of the impact created due to discontinuity in longitudinal rail profiles. The train passed at 20, 30, and 40 mph. Impact percentages were calculated on the basis of 20 mph. The rail joint was removed later and the span was tested again. As shown in Figure 4, a comparison of the data indicates that the 15-foot girder experienced more than 70 percent (augment above 20-mph curve) impacts while the rail joint was installed. It is likely that the magnitude of impact forces would have been greater over a larger range of train speeds.

As Figure 5 shows, the average strains in the end span of the BNSF bridge were higher than intermediate spans. These higher values in the end span are possibly due to the bridge end span having relatively higher stiffness than the bridge approach.

Figure 6 shows the impacts recorded on the end of spans as function of speed.

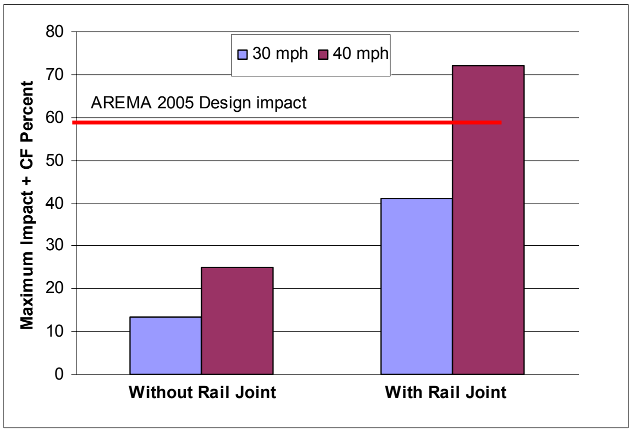

Figure 4. Comparison of Impact with and Without Rail Joint on 15-foot Span at FAST

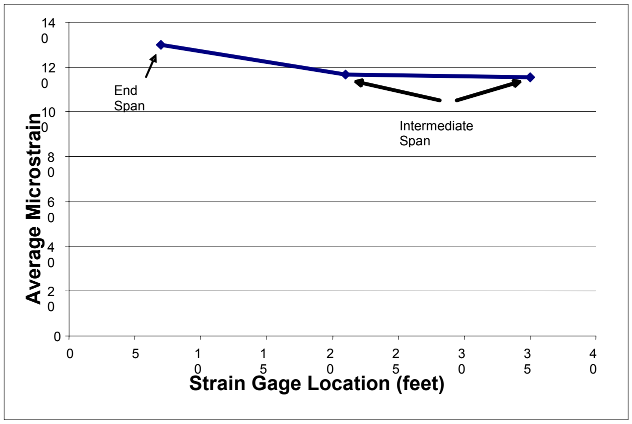

Figure 5. Average Microstrains in Midspans of BNSF Bridge

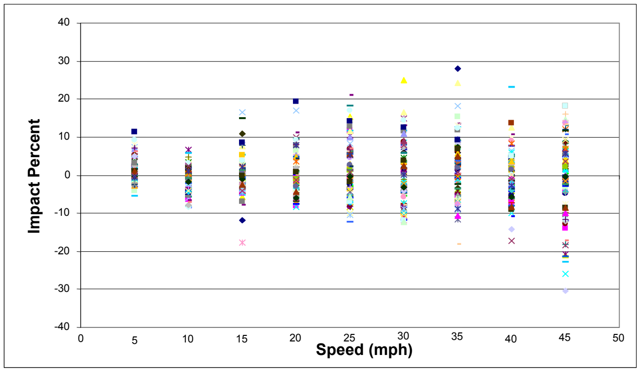

Figure 6. Impacts Due to Shear in End of Spans

CENTRIFUGAL FORCE EFFECTS

Figure 7 shows a plot of measured centrifugal force as a function of speed. As predicted, the centrifugal force effect increases with increases in speed. Some spans experienced higher centrifugal force effects. Possible causes of differences in centrifugal force are vehicle dynamics, inconsistencies in the vertical rail profile, and lateral track location on the spans.

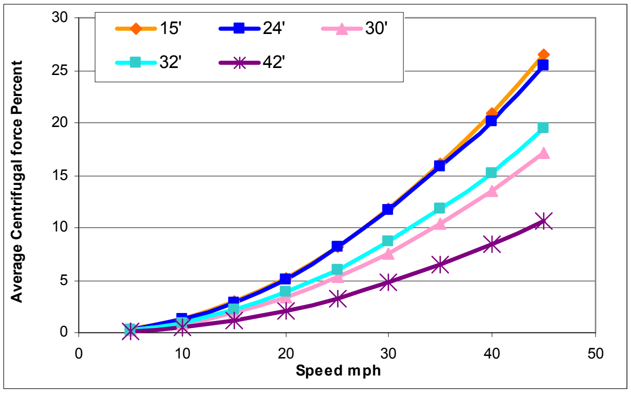

Figure 7. Average Measured Vertical Effect of Centrifugal Force in Spans at FAST

SPAN WIDTH VERTICAL LOAD DISTRIBUTION

Figure 8a shows the distribution of vertical load across the width of the spans on the BNSF bridge. The strain is higher in the middle gages and reduces gradually at the edge gages. The load distribution is nonlinear and fairly symmetrical. Slight asymmetry in strains in the West girder (end span) may be attributed to track geometry, ballast conditions, vertical rail profiles and support conditions.

Figure 8b shows the distribution of vertical load along the width of the bridge spans on the 5-degree curve at FAST. The gages on the outer high rail side edge and lower inner edge tend to experience the highest and lowest strains. This is expected. Centrifugal force from trains operating faster than the balanced speed will result in higher vertical forces in outer girders and lower vertical forces in inner girders.

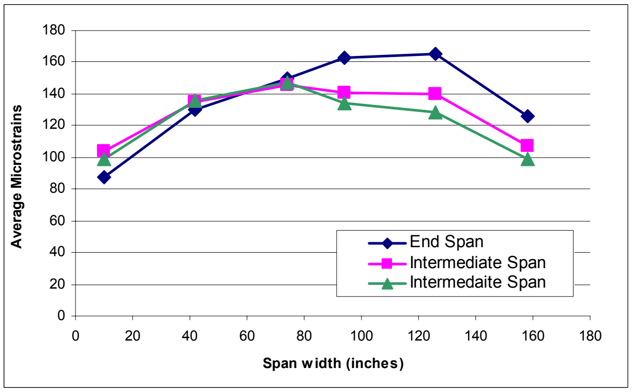

Figure 8a. BNSF Bridge on Tangent Track

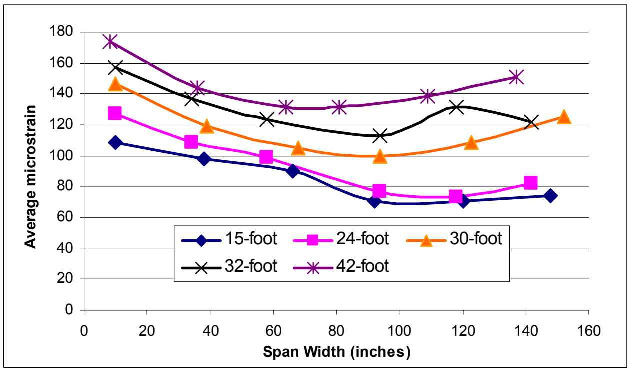

Figure 8b. Bridge at FAST on Curved Track

FUTURE WORK

Impact assessment of the bridges at FAST using standard concrete ties is completed. In the next phase of testing the bridges at FAST will be tested with a different tie configuration. A set of concrete ties with commercially available noise and vibration pads has been installed on the bridge. The configuration of ties and pads has helped reduce the stiffness of the bridge at FAST to a value comparable to that of the approach track. A reduction in impact induced in bridge spans and more uniform lateral load distribution is expected. Using ballast mats and further testing is planned with timber ties, plastic ties, and different ballast depths.

REFERENCES

1. Manual for Railway Engineering, American Railway Engineering and Maintenance of Way Association, Landover, Maryland. 2005.