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Effects of Ballast Depth and Degradation on Stresses in Concrete Bridges

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Summary

As part of evaluating stress-state reduction in concrete bridges, Transportation Technology Center Inc. (TTCI) studied the effects of ballast depth and fouling on impact loads imparted on two concrete bridges at the Facility for Accelerated Service Testing (FAST), Pueblo, Colorado.

The effect of ballast fouling was studied on the state-of-the-art (SOA) concrete bridge at FAST, and the effect of ballast depth is being studied on the conventional concrete bridge at FAST.

Test results from this study include:

- When ballast depth was decreased from 12 inches to 8 inches, the conventional concrete bridge at FAST experienced impact loads approximately 30 percent higher.
- Maximum impact load increases with train speed, confirming previous studies.
- Maximum impact load decreases with span length, confirming previous studies.
- Based on 400 MGT of tonnage accumulation, ballast fouling appears to be causing increased impact loads on the SOA bridge at FAST.

Impact loads measured during both tests remained within the American Railway Engineering and Maintenance-of-Way Association design impact load guidelines for concrete bridges.[1]

Previous tests at FAST have demonstrated methods that have successfully reduced impact loads on concrete bridges using a variety of softening or cushioning techniques.[2,3.4]

Results of these studies will be used to recommend minimum ballast depth and corresponding maintenance intervals.

Future tests will quantity the effect of ballast fouling on impact loads and track geometry degradation on the bridge using sieve analyses.

This study was conducted by TTCI as part of the Association of American Railroads' Strategic Research Initiatives Program on railroad bridges.

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BACKGROUND AND INTRODUCTION

At FAST, TTCI has conducted various tests to reduce stress-state in concrete bridges.[2,3,4] Dynamic stresses in concrete bridges can be attenuated by sufficient ballast depth, and cushioning or softening materials. Recent tests at FAST compared impact loads on concrete bridges using different tie and softening materials.

Softening materials, which included under-tie pads and a ballast mat, proved to decrease the stress-state in concrete bridges. This was also true for plastic and timber ties.[4] This digest focuses on the importance of ballast in reducing impact loads in concrete bridges.

New ballast contains void space between aggregate particles. Properly functioning ballast will transmit and distribute the load of the track and railroad rolling equipment to the underlying surface. It will also maintain proper track cross level, surface, and alignment. Good ballast provides resiliency and energy absorption for the track, which in turn reduces the impact stresses on the bridge.

With time and tonnage, ballast deteriorates and becomes fouled. Fouled ballast occurs when fine-grained material fills the void spaces.

Adequate void space and depth help achieve optimal performance of ballast.

BRIDGE DESCRIPTIONS

The High Tonnage Loop at FAST has two ballasted deck concrete bridges: the conventional concrete bridge and the SOA concrete bridge. Construction of both bridges was completed in late 2003. To date, these bridges have been subjected to approximately 910 MGT of mostly 315,000-pound gross rail load cars.

The conventional concrete bridge has 24- and 32-foot double-cell-box spans. The bridge currently has timber ties and Air Boss fasteners.

The center span of the SOA bridge is 42 feet long with double-cell-box type girders and is made of high-performance concrete. The flanking spans are a 30-foot double-cell-box girder and a 15-foot slab span. Because the 30-foot girder was temporarily removed from service for testing of a hybrid composite beam span, the data for this span was taken out of the results. The SOA bridge is equipped with a Getzner ballast mat and standard concrete ties. Figure 1 shows the ballast mat on the SOA bridge.

Designs of all but the 42-foot span are based on Cooper E-80 loadings and follow the American Railway Engineering and Maintenance-of-Way Association (AREMA) design guidelines and BNSF Railway and Union Pacific Railroad joint common standard design practices. The 42-foot span was designed by Canadian National Railway based on E-90 loading. Foundations of both the bridges are based on E-100 design loading. The girders are supported on precast pile caps set on H-piles.

The bridges are on a 5-degree curve and have a ballast depth of 16 inches below the ties under the high rail of the curve and 12 inches below the ties under the low rail of the curve.

Figure 1. Getzner Ballast Mat on SOA Bridge

METHODOLOGY AND MEASUREMENTS

Strain gages were installed to measure the bending strains at mid-spans on the concrete bridges at FAST. This data was used to determine impacts as well as to investigate the effects of span length and train speed on bridge dynamic behavior.

A test train passed at 2 miles per hour (mph) in each direction. The speed was then increased at 5-mph increments starting with 5 mph and ending at 45 mph.

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.

Effects of ballast were evaluated on both concrete bridges at FAST. Ballast fouling was studied on the SOA bridge, and the influence of ballast depth was studied on the conventional concrete bridge.

IMPACT LOADS

Impact loads decrease with span length. Figure 2 shows the correlation of span length and impact.

The maximum measured impact loads were well below the recommended AREMA 2010 design values.[1] This is not unexpected, as the impact loads experienced at FAST were mainly low-frequency impacts as there were no rail joints on the bridge, and the train at FAST typically does not have any flat wheels.

Impact loads are also affected by train speed. Figure 3 shows that impact generally increases with train speed.

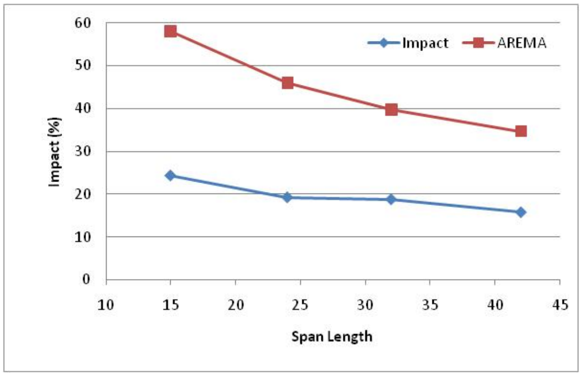

Figure 2. Effect of Span Length on Impact Loads

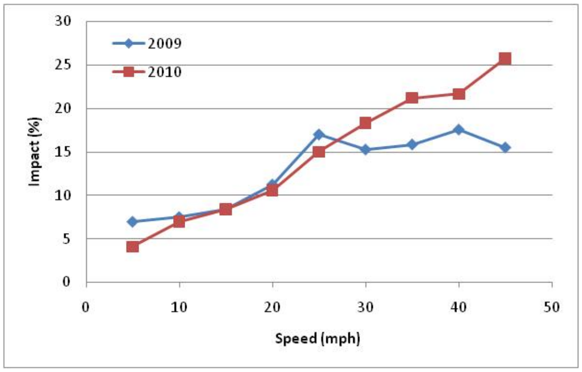

Figure 3. Effect of Train Speed on Impact Loads

BALLAST FOULING

The SOA bridge at FAST has a ballast mat that was installed in 2007. Since then, the bridge has accumulated over 450 MGT. As seen in Figure 4, impact loads increase with tonnage.

This increase in impact seems to be caused by ballast fouling. As tonnage has accumulated on the bridge, some ballast has deteriorated and small material has filled the void spaces that were present with the new ballast. When these void spaces fill up, the effect ballast has on attenuating stress-state on the bridge is reduced. Figure 5 shows the results from a sieve analysis performed on the 42-foot span. Results show that the new ballast (at zero MGT) had significantly fewer fines than the ballast after 457 MGT.

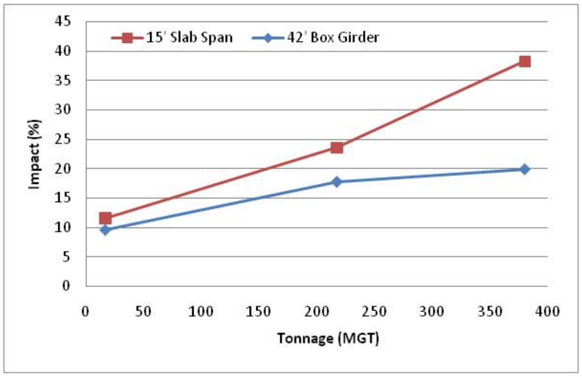

Figure 4. Impact versus Tonnage on SOA Bridge

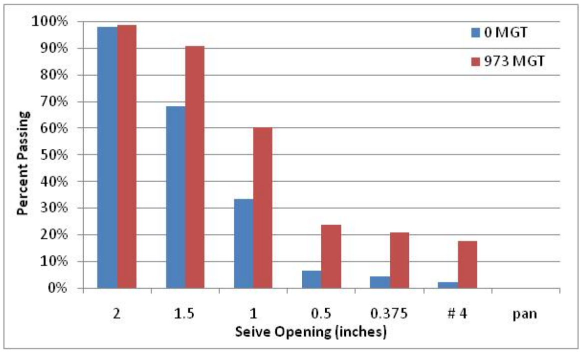

Figure 5. Results from Sieve Analysis

It is evident from the results that the SOA concrete bridge at FAST is experiencing fouled ballast. Verification of fouled ballast can be seen in Figures 6 and 7.

Figure 6 shows a pile of fine material that has fallen through between the two girders on the 15-foot span of the SOA bridge. Seepage is also evidence of fouled ballast. Figure 7 shows the west abutment of the SOA bridge with seepage stains from fouled ballast.

Figure 6. Evidence of Fouled Ballast

Figure 7. Evidence of Fouled Ballast

BALLAST DEPTH

After 882 MGT, both spans on the conventional concrete bridge were raised 4 inches, reducing ballast depth by 4 inches. This was done to test the effect of ballast depth on impact. Figure 8 shows the results of this experiment.

Figure 8 shows that both spans of the conventional concrete bridge experienced approximately 30 percent more impact with 8 inches of ballast than with 12 inches of ballast (under low rail). Adding ballast to a bridge appears to be an effective means of reducing impact. However, the effects of the additional dead load also need to be considered, particularly on bridges that are operated near their rated live load capacity.

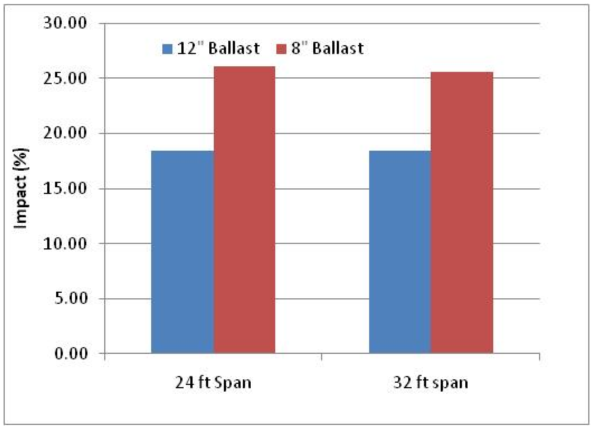

Figure 8. Effect of Ballast Depth on Impact

TRACK GEOMETRY

Mid-span displacements of the concrete spans were measured with string potentiometers during the same test runs as the impacts. Actual displacement is compared to theoretical values of deflection calculated using full-design impact factors following AREMA recommended practice.[1] Figure 9 shows the deflections of all the spans at FAST.

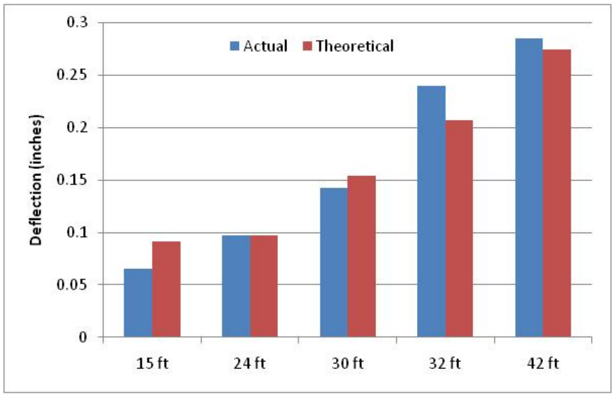

Figure 9. Bridge Deflections

It is noted that the theoretical values are for bending deflections only, while the measured values include compressing of bearing pads and foundation elements, shear deformations, and seating effects of spans that might not have perfectly uniform bearing conditions.

Track geometry measurements were taken before and after fouling (SOA bridge), and before and after changes in ballast depth (conventional). Data from 2009 refers to data collected before ballast fouling and before changes in ballast depth; 2010 data shows the data after these changes.

Standard deviations of vertical track surface on both bridges were measured and the results can be seen in Figures 10 and 11. Track surface roughness has increased in the last year because of reduced ballast depth on the conventional concrete bridge. The track surface roughness on SOA bridge has increased in the last year. This can be attributed to ballast fouling.

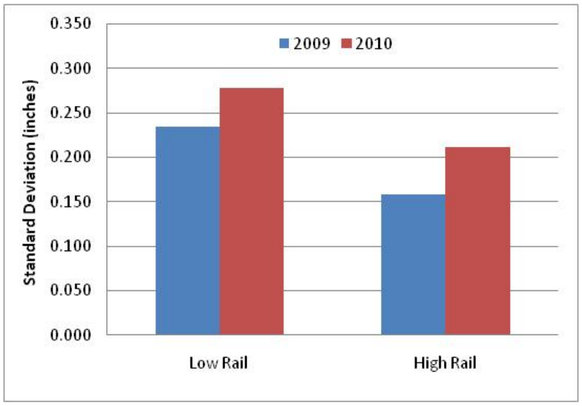

Figure 10. Vertical Track Surface of Conventional Concrete Bridge at FAST

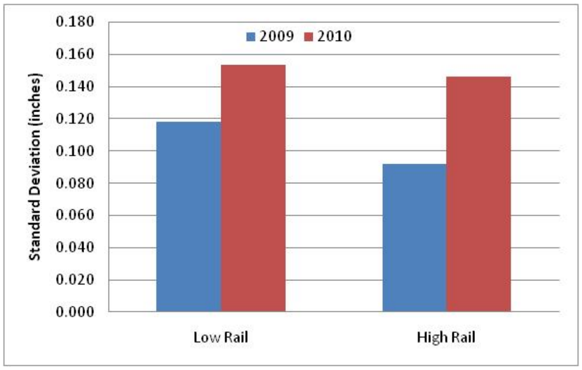

Figure11. Vertical Track Surface of SOA Bridge at FAST

FUTURE TESTING

An ongoing test at FAST includes ballast degradation measurements on the conventional concrete bridge. This test will help quantify some hypotheses raised in this digest.

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1. American Railway Engineering and Maintenance-of-Way Association. 2010. *Manual for Railway Engineering*, Ch. 8, Concrete Structures & Foundations, Lanham, MD.
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4. Akhtar, M.N., D. Otter, and B. Doe. August 2008. "Stress-State Reduction in Concrete Bridges." *Technology Digest* TD-08-032, AAR/TTCI, Pueblo, CO.