INITIAL RESULTS OF CONCRETE BRIDGE TESTING AT FAST

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ABSTRACT

Two new precast, prestressed concrete bridges were installed at the Facility for Accelerated Service Testing (FAST) at the Transportation Technology Center (TTC) in Pueblo, Colorado, USA, in December 2003. A variety of tests are being conducted under 39-ton axle load traffic. One bridge features three state-of-the-art (SOA) spans. The second bridge features two conventional spans. Tests underway include measurements of strain and impact in the spans and foundations, force distribution issues, and the effects of different tie types on both impact and track transition issues. Long-term performance evaluations include performance of the spans under heavy axle loads, field repairs to spans, and ballast puncture and abrasion resistance of waterproofing materials.

The paper describes the two FAST ballasted deck concrete bridges, the test layouts and objectives, and results to date. Comparisons to AREMA guidelines are made where appropriate. Tonnage accumulation on the bridges at FAST as of June 2005 is over 200 million gross tons (MGT).
INTRODUCTION

In December 2003, trains began rolling over two new precast, prestressed concrete test bridges on the FAST High Tonnage Loop at TTC. The bridges were constructed in order to conduct a variety of tests under the heavy axle load (HAL) train. These tests are jointly sponsored by the Association of American Railroads (AAR) and the Federal Railroad Administration (FRA).

A brief summary of current test topics follows:

- Accelerated service testing of conventional and state of the art (SOA) prestressed concrete spans
- Performance of spans under 315-kip gross rail load traffic
- Effects of different tie types on track maintenance and bridge performance
- Dynamic load increase (impact) in concrete spans and foundations
- Performance of concrete repair techniques
- Abrasion and puncture resistance of deck waterproofing materials
- Bridge approach and track geometry issues

DESIGN OF TEST BRIDGES

A team of North American railroad industry bridge experts designed the layout for the new concrete bridges at FAST. The team included bridge engineers from each major North American railroad as well as representatives from the American Railway Engineering and Maintenance of Way Association (AREMA) structures committees. Two separate bridges were constructed in order to double the number of end spans for testing. Experience suggests that end spans
encounter the highest impacts due to the effects from the transition between the approach and the bridge span – known as the “bump at the end of the bridge.”

The first bridge is a three-span bridge and is referred to as the SOA bridge (Figure 1). The SOA bridge spans reflect the latest in North American concrete railroad bridge designs in short, medium, and long span lengths. This bridge features a 42-foot high-performance concrete (HPC) double-cell box span as the center span. CN designed this center span for Cooper’s E-90 loading. The 9000 psi concrete mix used for the HPC span includes microsilica to enhance durability. The flanking spans are a 30-foot double-cell box span, and a 15-foot slab span. Both flanking spans are designed to the new Union Pacific Railroad (UP)-BNSF Railway (BNSF) joint standard designs and were designed for Cooper’s E-80 loading as per the 2003 AREMA manual (AREMA, 2003).

The second bridge is a two-span conventional concrete bridge (Figure 2) and is more representative of the existing North American railroad concrete bridge inventory. The 24-foot and 32-foot spans are typical short and long double-cell boxes – originally fabricated for BNSF in 2001. These spans were designed for Cooper’s E-80 loading. The abutments for the conventional bridge were built to allow installation of a deeper 56-foot single span at a future date. The concrete ties on this bridge are a BNSF design.

The HAL experiment at FAST is currently operating with 315,000 pound cars – heavier than the 286,000 pound maximum for interchange service. In light of the long-term industry trend of increasing car loadings, the foundations for both bridges were designed to handle Cooper’s E-100 loading, which is higher than the current AREMA bridge design load of E-80. The HPC span in the SOA bridge was designed to accommodate Cooper’s E-90 loading. Should
the industry decide in the future to conduct research on heavier car loadings, the bridge foundations will be suitable for evaluation of stronger concrete spans. The same design loading (E-100) was used for the foundations of the FAST steel bridge installed in 1997.

The bridge foundations are constructed of typical materials for concrete bridges in the western United States. Driven steel H-piles (HP 14 x 89) support precast concrete caps. The abutment backwalls are standard UP-BNSF bolt-on designs. The spans rest on either neoprene or elastomeric bearing pads, as supplied with the spans.

Both concrete bridges are installed on a 5-degree curve with 4 inches of superelevation – about 500 feet from the steel bridge. The curving forces will provide an additional element of accelerated service testing on these bridges. The approach tracks to each bridge are constructed of continuous welded rail (CWR) on BNSF-designed concrete ties and granite ballast. Figure 3 shows the concrete bridge test location on the FAST test loop.

CONSTRUCTION OF TEST BRIDGES

The concept of a concrete test bridge at FAST has been the vision of many North American railroad bridge engineers since the beginning of the FAST program in 1976. That vision became a reality through tremendous support and contributions of many railroads and suppliers.

UP crews performed all the pile driving work for the foundations. UP also provided 2 spans for the SOA bridge as well as some concrete ties, steel piles, and miscellaneous materials.

Local crews from BNSF performed most of the general construction for both bridges. BNSF provided steel piles, handrails, and miscellaneous materials. BNSF also provided transportation for several carloads of bridge materials.
Rinker Materials contributed both of the spans for the conventional bridge as well as all the precast foundation pieces. CN furnished the HPC span that is the centerpiece of the SOA bridge. Figure 4 shows installation of the HPC span.

Canadian Pacific Railway (CP) bridge designers took the bridge concepts from the advisory group and turned them into detailed drawings for fabrication and construction of the two bridges. CP, CSX, and Norfolk Southern furnished the majority of the steel piles for the foundations.

MEASUREMENTS

TTCI staff installed strain gages at the middle of each span on both bridges (Figure 5). Figure 6 shows the strain gage locations on a typical cross section of the bridge. The strain gages are installed beneath the webs of the double-cell box girders. Strain gages have also been installed to measure end-of-span shear, and axial forces in the piles. In addition, survey measurements are used to quantify track settlement and vertical track modulus.

TEST TRAIN OPERATIONS

The FAST test train normally consists of four four-axle locomotives and approximately 80 cars, each weighing 315,000 pounds. The train normally operates at a speed of 40 mph. The resulting load spectrum on the bridges is heavier than would typically be experienced in revenue service. However, any effects due to variations in train speed, variations in car length, or variations in car weights might not be experienced. Also, the wheels of the FAST train tend to generate fewer high-impact loads than do those in revenue service. This is primarily due to stringent wheel maintenance practices and the limited amount of train braking at FAST. These operating conditions should be considered when interpreting results from FAST testing.
EXPERIMENT RESULTS

While the bridges have only been in service for less than two years, over 200 MGT of HAL traffic has been accumulated. Preliminary test results indicate several opportunities to reduce the stress-state on concrete railroad bridges.

Effects of a Bolted Rail Joint on Bridge Spans

A bolted rail joint was intentionally installed on one of the bridge spans to accelerate the degradation of the concrete ties, granite ballast, and concrete span. After 10 MGT of HAL train traffic, the track in the area of the joint required tamping on a daily basis. Rate of superelevation loss and surface loss was about 0.7 inch per MGT. The joint was maintained in track until 19 MGT in order to complete a preliminary round of measurements. The degradation was primarily in the form of ballast breakdown. One cracked concrete tie was noted near the joint. No damage to the span was noted.

To create the bolted joint, the rail was cut then bolted together with conventional joint bars. There was no railhead mismatch – as is often found when a plug rail is bolted into track. In the case of a railhead mismatch, the maintenance requirements and dynamic impact forces (see below) are likely to be even greater. Figure 4 shows the location of the rail joint on the SOA bridge, as well as the locations of the mid-span strain gage circuits. Figure 5 shows where the impact strains were measured on the 15-foot slab span with the bolted joint. Figure 7 shows the effects of the bolted rail joint as the train speed increased from 20 mph to 40 mph (64 km/h). The joint resulted in an increase in strain around 50 percent. It is likely that the range of maximum value impact forces would be even greater over a larger range of train speeds. The amount of impact is similar to that measured in a concrete bridge under flat wheels (Sharma,
This amount of impact is higher than that recommended in the 2003 AREMA guidelines for design (35 percent for a 15-foot span) (AREMA, 2003). Modeling and further discussion of impacts are covered by Fryba (Fryba, 1996).

Because the impacts over the same speed range were significantly lower on spans without rail joints (Figure 7), removing unnecessary bolted rail joints from ballast deck or open deck bridges should be one of the first priorities for reducing the stress-state on railroad bridges. Without rail joints, the amount of impact measured was less than that recommended by AREMA for design.

Removing a bolted rail joint located on a bridge is typically not more difficult than removing a joint in open track or on ballast deck bridges. Extra procedures may be required due to tie spacing and rail anchoring concerns on open deck bridges. Note: Extra precautions may be required to prevent fire on bridge timbers during welding operations.

**Reducing the Stress-State through Impact Reduction**

One of the most commonly cited causes for undesirable vehicle dynamics at bridge ends is the change in vertical track modulus between the embankment and the bridge deck. Typically the bridge deck is much stiffer than the approach. To address this issue, various types of ties are being installed on these concrete bridges in an effort to evaluate and reduce the amount of impact force transmitted to the concrete spans.

In theory, some of these various ties should benefit the bridge in two ways: (1) Reduce the amount of impact force transmitted from rail to bridge span, and (2) Reduce vehicle dynamics due to a more uniform track stiffness between bridge and approaches.
The testing at FAST intends to quantify these reductions in stress-state. Numerous strain gages on the spans and foundations at FAST are being used to evaluate and compare the impact forces with each type of tie.

After completing a series of measurements with the standard concrete ties, a set of concrete ties with rubber pads was installed on the SOA bridge (Figure 8). The pads are designed to reduce the track modulus to a value comparable to that on the approach track. See Figure 9 for a comparison of vertical track modulus with standard concrete ties and concrete ties with rubber pads. The concrete ties with rubber pads resulted in a significant reduction in the vertical track modulus on the bridge.

The resulting maximum recorded impacts are shown in Figure 10. These impacts were calculated using a 2 mph low speed reference train pass. A small reduction in impacts is achieved as the pads cushion the bridge structure to some extent. No rail joints were on the bridge in either case. Since the installation of the ties with rubber pads, the track tamping demand on this bridge seems to have been reduced compared to the other bridge with conventional concrete ties. An exact comparison is not possible due to differences in rail surface conditions and other factors.

The concrete ties with rubber pads were removed from the SOA bridge after 130 MGT of service. On some ties, the glue was no longer holding the pads to the ties. However, the rubber pads showed no signs of deterioration. These ties were replaced with second generation concrete ties cast with integral rubber pads.

At the same time, timber ties with Pandrol® fasteners were installed on the conventional concrete bridge, in place of the standard BNSF concrete ties that had been in service for 182 MGT.
Plans for future testing include similar evaluations using plastic ties, as well as the possibility of evaluating the use of a ballast mat on the bridge deck.

**Reducing the Stress-State through Better Load Distribution**

Figure 6 shows a typical cross section of a FAST concrete bridge span, including locations of strain gages. Figure 11 shows a typical strain distribution laterally across the bottom width of the span. Note that the greatest strain is about 35 percent higher than the lowest strain. Variations in the strain distribution across the width of the span can be caused by several things, such as placement of track on the span, fit between spans and caps, bearing properties, and cross section design, and of course, train operating speed on curved track.

Future research plans by TTCI call for investigating techniques at FAST to make the load distribution more uniform. By doing so, the peak stresses in the span will be reduced, hopefully prolonging the useful service life of the span.

**Puncture and Abrasion Resistance of Deck Waterproofing Materials**

A test of cold liquid applied (CLA) waterproofing membrane materials, both with and without protection layers, is being conducted on the conventional concrete bridge. The primary objective of this test is to evaluate the puncture and abrasion resistance of the various materials under ballasted railroad track with heavy traffic. The test includes CLA products from three different vendors and protection layer products from two vendors. The test plan was developed with the help of experts from AREMA Committee 8, Subcommittee 3, in charge of bridge deck waterproofing protection. Figure 12 shows part of the test installation during bridge construction. Granite ballast is used on both bridges. At this early stage of testing, there are no results to report for this long-term durability test.
In the dry climate near Pueblo, Colorado, the actual waterproofing capabilities of the materials will not be severely tested because of the low humidity and low annual rainfall.

**CONCLUSIONS AND FUTURE WORK**

To accommodate increasing weight demands on railroad bridges, testing of one three-span SOA bridge and one two-span conventional concrete bridge are being performed at FAST.

Testing indicates that under heavier (315,000 pound cars) traffic, these bridges are performing well to date.

Testing of a bolted rail joint on one of the spans showed impact loads greater than 50 percent. Removal of bolted rail joints on bridges is an effective way to reduce the stress-state.

For bridges with bolted rail joints, a temporary speed restriction (slow order), will also reduce the stress-state, until the joint can be removed.

Impact reduction testing shows that concrete ties with rubber pads on the bottom, resulted in a significant decrease in vertical track modulus and a slight impact reduction. Future testing includes the use of timber and plastic ties and possibly a ballast mat on the bridge deck.

Strain gage testing results show that variations in the strain distribution across the width of the span vary widely (35 percent) calling for future investigations to make the load distribution more uniform.
ACKNOWLEDGMENTS

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Strain Gauges

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Bolted Rail Joint on a 15-Foot (4.57 meter) Span

Spans without Rail Joints

Span Length

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<td>42 feet</td>
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