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Stress-State Reduction in Concrete Bridges

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Summary

The Transportation Technology Center, Inc. (TTCI), Pueblo, Colorado, is currently evaluating several techniques and materials to attenuate the effects of impacts imparted to ballasted deck bridges by reducing track stiffness. Wood ties and concrete ties with rubber pads tested at the Facility for Accelerated Service Testing (FAST) at the Transportation Technology Center have successfully reduced impacts and track surfacing requirements of concrete bridges.[1,2,3] Other attenuation techniques might include rail seat pads, tie plate pads, ballast mats, tie type, and increased ballast depth.

Plastic ties were installed on the state-of-the-art (SOA) concrete bridge at FAST. Later, a combination of a ballast mat and conventional concrete ties were installed and tested on the same bridge. Impact data was collected from strain gages installed at the midspans, while a test train passed over both the SOA and conventional concrete bridge spans at different speeds. Test results were in-line with previous tests and are summarized below:

- Plastic ties reduced the Vertical Track Modulus (VTM) by 30 percent, as compared to standard concrete ties.
- The impacts at midspans were reduced by about 30 to 40 percent after concrete ties were replaced with plastic ties on the SOA bridge.
- As compared to the original installation with standard concrete ties, use of plastic ties has reduced the track surfacing requirements of the bridge by a factor of five.
- Ballast mat and standard concrete tie combinations reduced the VTM by about 55 percent.
- The impacts at the midspan were reduced by about 30 to 40 percent, with the combination of a ballast mat and standard concrete ties on the SOA bridge.
- Additional tonnage is accumulating on the ballast mat to determine track surfacing requirements. Performance to date indicates a significant improvement compared to standard concrete ties without the ballast mat.
- In both cases, the impacts attained through these improvements remained within the American Railway Engineering and Maintenance-of-Way Association design impact guidelines.

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INTRODUCTION

Vehicle dynamics, rocking effects, wheel defects, and geometry defects cause railcar suspension systems to induce high- and low-frequency impacts into track and bridge spans. High-frequency impacts primarily affect fasteners, ties, and ballast; whereas, low-frequency impacts primarily affect the ballast track foundations and, consequently, the bridge structure.[4]

Several techniques and materials may be used to attenuate the effects of impacts imparted to ballast deck bridges by reducing the track stiffness on concrete bridges. These may include, but are not limited to, under-tie rubber pads, rail seat pads, tie plate pads, ballast mats, tie type, and ballast depth.

TTCI investigated techniques and materials for track foundations at FAST to improve the dynamic behavior of bridges. Degradation of ballast may also be minimized, which might reduce maintenance requirements of bridge spans and approaches. A reduction in the stiffness of the track over bridge spans is also expected, which should minimize the change in the stiffness between the bridge and bridge approaches and further lower impacts.

Plastic ties were installed and data was collected from the SOA concrete bridge at FAST. Later, standard concrete ties and a ballast mat were installed on the same bridge and data was collected. Two sets of data were collected on the conventional concrete bridge with wood ties to measure the long-term effect on impacts.

Impact data was collected using a test train, and results were compared with data from a previous test on the SOA bridge with standard concrete ties.[1] Tamping cycles were logged to quantify degradation of the track surface, cross level, and alignment under the heavy axle load (HAL) test train.

Since the installation of wood ties, plastic ties, and the ballast mat on concrete bridges, there has been a reduction in track maintenance demands on the bridges compared to previous conditions, when standard concrete ties were used. VTM was reduced to a value comparable to the bridge approaches. Also, 30 to 40 percent reductions in impacts were measured. The results from previously installed standard concrete ties with rubber pads are in line with current test results.

At FAST, flat wheels and mechanical joints are largely absent. Thus, the impacts created are mostly low frequency. These are mainly caused by vehicle dynamics, from the effects of car bouncing and car rocking. However, in addition to these factors, concrete bridges in revenue service are also subjected to high-frequency wheel impacts. Typically, 315,000-pound cars generate up to 25 percent impacts on ballasted deck concrete bridges at FAST.[1] In revenue service, impacts up to 50 percent have been measured from 286,000-pound cars.[5] These impacts might effectively be reduced by using plastic ties, concrete ties with rubber pads, or a ballast mat.

METHODOLOGY

Strain gages (Figures 1a and 1b) were installed to measure the bending strains at midspans on the concrete bridges at FAST. 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. The test train had two 4-axle locomotives on both ends, one 286,000-pound car and fifteen 315,000-pound cars.

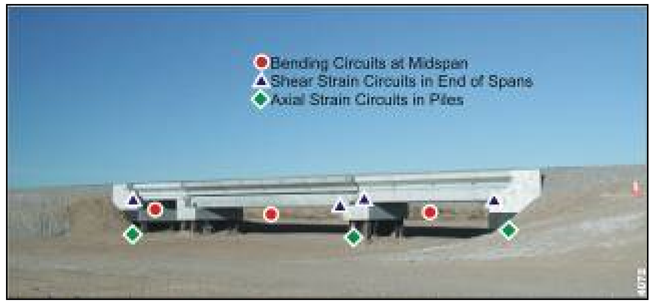

Figure 1a. SOA Concrete Bridge at FAST

Figure 1b. Conventional Concrete Bridge at FAST

Figure 2a shows the high-density polyethylene ties manufactured by Tie-Tek. Figure 2b shows the ballast mat, which is manufactured by Getzner for North American HAL environment. The mat is 3/4 inch thick and has a two-layer system. The top layer distributes the load to a larger area and the bottom layer elastically attenuates the vibrations and impacts.

Figure 2a. Plastic Ties on the SOA Bridge at FAST

Figure 2b. Ballast Mat during Installation on the SOA Bridge at FAST

Wood ties on the conventional bridge have been in service for 373 million gross tons (MGT). Three sets of data were collected to measure the long-term performance of wood ties.

Measurements

The measured data from bending strain circuits was used to determine the statistical distribution of impacts, 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 cycle per group of four closely spaced axles of the test train. Each 20-vehicle test train pass generated 21 distinct load cycles per train for most members.

Vertical Track Modulus

VTM for the SOA bridge spans was measured using the Track Loading Vehicle. Figure 3 shows the average VTM for the spans with a ballast mat reduced to approximately half of the control value. The reduced VTM is comparable to the value on bridge approaches or open track.

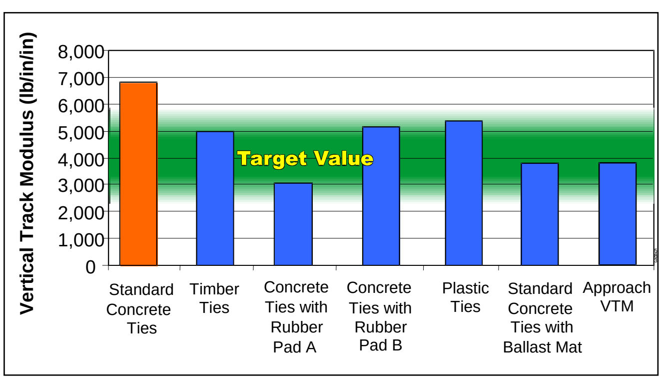

Figure 3. Average VTM of the Test Spans at FAST with Plastic Ties and Concrete Ties with a Ballast Mat (VTM from previous tests are also shown)

The measured VTM for the SOA bridge spans, with standard concrete ties, was almost double the value on open track. This difference contributed to the impacts on the bridge, which increased the wear causing ballast degradation. The methods of reducing VTM on the bridge by using plastic ties or by using concrete ties with a ballast mat appeared capable of addressing this issue.

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 640 MGT of mostly 315,000-pound loaded cars.

The conventional concrete bridge has 24- and 32-foot double-cell-box spans. The intermediate 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 and a 15-foot slab span.

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 design practices. The 42-foot span was designed by Canadian National 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.

BRIDGE MAINTENANCE

A major advantage of plastic ties was a reduction in surfacing requirements. As Figure 4 shows, average ballast tamping cycles were reduced (almost by a factor of five) after standard concrete ties were replaced with plastic ties, because of a reduction of the impacts that increased ballast degradation. Concrete ties with bottom rubber pads and wood ties also reduced the impacts induced in the bridge spans, leading to reductions in track surfacing demand. Effects of the ballast mat on the maintenance cycles are currently undetermined, but performance to date indicates similar or better reduction.

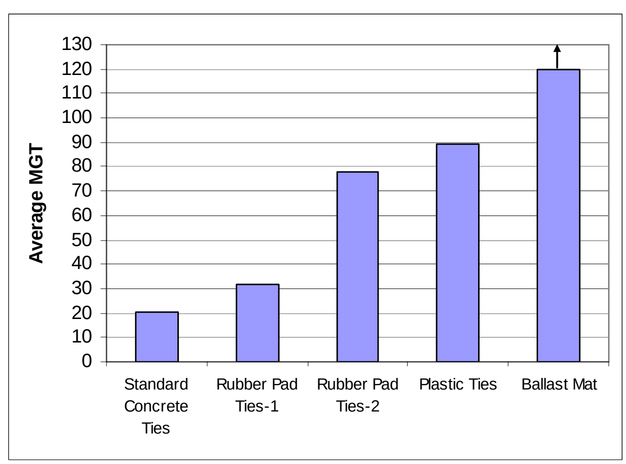

Figure 4. Ballast Tamping Cycles on the SOA Bridge

IMPACT LOADS

As Figure 5 shows, the maximum impacts induced into all the midspans were reduced when concrete ties were replaced with plastic ties, timber ties, or concrete ties with bottom rubber pads. Installation of the ballast mat with standard concrete ties also had a similar effect on impact reduction. Lower frequency impacts due to vehicle dynamics, like car rocking, are attenuated from 20 to 40 percent in the midspan bending. It is likely that higher frequency impacts, such as those due to rail surface defects, are attenuated more. This was also evident by a reduced tamping demand and VTM on bridges.

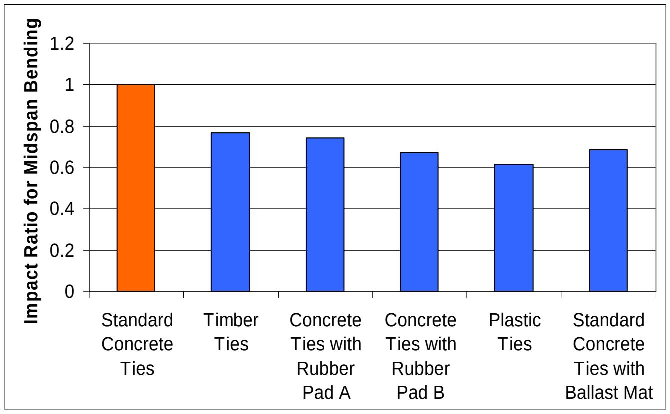

Figure 5. Maximum Impact for Midspan Bending

The maximum measured impacts were well below the recommended AREMA 2005 design values.[6] This is not unexpected, as there were no rail joints on the bridge and the train at FAST typically does not have any flat wheels.

FUTURE WORK

On the conventional concrete and SOA bridges, ballast thickness ranges from 12 inches to 16 inches. This depth, with the height of box girders, significantly reduces the head clearance. In the future, ballast depth will be reduced on the SOA bridge to determine the effectiveness of the ballast mat in such cases.

Also, the tests conducted so far are short term in nature. Long-term durability effects of ballast mat, plastic ties, wood ties, and concrete ties with rubber under-tie pads will be monitored.

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