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Stress-State Reduction in Concrete Bridges Using Under-Tie Rubber Pads

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Summary

Transportation Technology Center, Inc. (TTCI) is studying materials and techniques to improve the dynamic behavior of concrete bridges. The objective is to attenuate impacts induced in bridge components by optimizing damping of the track structure. Reducing the difference in stiffness between the bridge and bridge approaches is also expected to lower impacts into bridges.

The options being investigated for additional damping of track structure over the bridges are under-tie rubber pads, under-tie-plate pads, different tie types, ballast mats, and variation in ballast thickness. In the current test, the ballasted deck concrete bridge with under-tie rubber pads was tested and impact results were compared with a standard concrete-tie ballasted deck bridge. While the long-term performance of under-tie rubber pads is not known, preliminary results have lead to the following conclusions:

- Under-tie rubber pads significantly reduced vertical track modulus on the bridge to a value comparable to bridge approaches at the Facility for Accelerated Testing (FAST).
- Under-tie rubber pads minimally reduced the maximum impacts induced in the midspans by 2 to 10 percent.
- Track surfacing requirements of the bridges have been noticeably reduced with under-tie pads compared to a bridge with standard concrete ties.
- The above ground portion of the bridge foundation experienced impacts as high as those at midspans.
- The maximum impacts measured in end of spans and midspans remained well below the design impacts, under smooth rail conditions (no joints), a train with no flat wheels, and ties both with and without under-tie pads.

This study is being conducted as part of the AAR's Strategic Research Initiative on railroad bridges, and the FAST Program, which is funded in part by the Federal Railroad Administration.

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INTRODUCTION AND CONCLUSIONS

Vehicle dynamics, rocking effects, and railcar suspension systems induce high- and low-frequency impacts into track and bridge spans. The high-frequency impacts affect fasteners, ties, and ballast, whereas low-frequency impacts affect the track foundations and consequently the bridge structure.

Several techniques and materials may be used to attenuate the effects of impacts by increasing the damping of bridges. These include under-tie-rubber pads, rail seat pads, tie plate pads, ballast mats, tie type, and ballast thickness.[1]

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

In this test, concrete ties equipped with under-tie rubber pads were installed on the concrete bridges at FAST. The impact data was collected using a test train, and results were compared with data from a previous test with standard concrete ties (without rubber pads).[2] In addition, survey measurements were used to quantify settlement and vertical track modulus (VTM) of the track over the bridge. The analysis showed that the VTM with under-tie rubber pads was reduced by half on the bridge approaches.

A small reduction in impacts is achieved as the pads cushion the bridge structure. Since the installation of the ties with rubber pads, the track maintenance demand of the bridge as compared to the other bridge with standard concrete ties also seems to be reduced.

At FAST, flat wheels and mechanical joints are absent. Thus, the impacts created are of low frequency. These are mainly caused by vehicle dynamics such as car bouncing and rocking effects. In addition to these factors, concrete bridges in revenue service are also subjected to high-frequency wheel impacts. The effects of the impact on a bridge could be 50 percent of the static wheel load effect.[3] These impacts might effectively be reduced by using under-tie rubber pads.

BRIDGE DESCRIPTIONS

The High Tonnage Loop at FAST has two ballasted deck concrete bridges. One has 24- and 32-foot double-cell-box spans, normally called a "conventional" concrete bridge. The other bridge is known as the "state-of-the-art" concrete bridge. The intermediate span 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. Construction of both of the bridges was completed in late 2003. To date, the bridges have been subjected to 216 MGT of mostly 315-kips loaded cars.

Designs of all but the 42-foot span are based on Cooper E-80 loadings and follow AREMA design guidelines and BNSF Railway and Union Pacific 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 low rail of the curve.

METHODOLOGY

Strain gages (Figure 1) 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. 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.

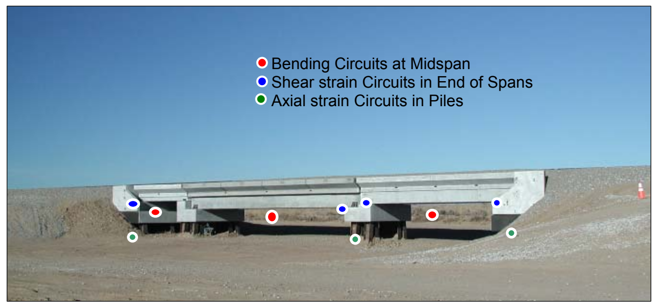

Figure 1. Concrete Bridge at FAST

The standard concrete ties on the state-of-the-art bridge were replaced with Union Pacific style concrete ties with rubber pads. Using a modified ASTM test, the stiffness and damping characteristics of rubber pads were evaluated as 105 lbs/in and 3 lbs/in/sec at 200 MHz respectively. Figure 2 shows concrete ties with rubber pads.

Figure 2. Concrete Ties with Rubber Pads prior to Installation at FAST

Measurements

The measured data from bending, shear, and axial 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. So each pass generated 21 distinct load cycles per train for most members for the test train used.

Vertical Track Modulus (VTM)

The VTM of all bridge spans was measured using the Track Loading Vehicle (TLV). As Figure 3 shows, the average VTM of spans with under-tie pads is reduced to approximately half the value without rubber pads. The reduced VTM is comparable to the value on bridge approaches or open track.

Generally, the end spans of bridges adjacent to approaches are subjected to higher impacts. Also, the track at bridge approaches may develop "dips." Both of these factors are associated with abrupt change in track stiffness from approach to bridges. The method of reducing VTM by using under-tie rubber pads appears capable of addressing this transition issue.

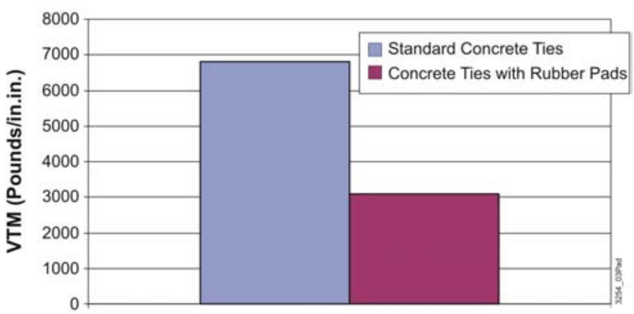

Figure 3. Rubber Pads have reduced the Vertical Track Modulus (VTM) on the Bridge

IMPACT LOADS

As Figure 4 shows, the maximum impacts induced in all the midspans were reduced to some extent when concrete ties with rubber pads were installed. Lower frequency impacts due to vehicle dynamics like car rocking are attenuated by about 2 to 10 percent in terms of midspan bending. It is likely that higher frequency impacts, such as those due to rail surface defects, are attenuated more. This is evidenced by a reduced tamping demand on the bridge when the ties with rubber bottom pads were installed.

The maximum measured impacts were below the recommended design values of AREMA 2005 (see Figure 4).[4] This is not unexpected as there were no rail joints on the bridge, and the FAST train typically does not have any flat wheels.

Figure 5 shows the comparison of impacts in foundation piles for 30- and 42-foot spans. The rubber pads seem to have marginal effect on impacts induced in pile foundations.

As shown in Figure 6a, maximum impacts for end of span shear were higher in the spans with rubber pads. However, Figure 6b shows that 99.5 percent of impacts were somewhat lower than the values measured when the bridge had standard concrete ties. The higher impacts in Figure 6a appear from wheels of only one car and might be attributed to resonance.

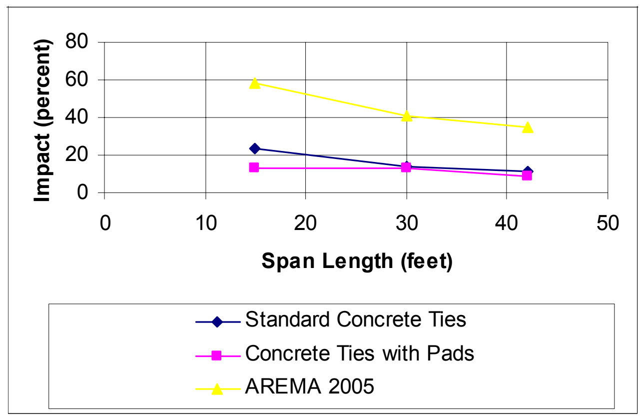

Figure 4. Maximum Impacts in Midspans

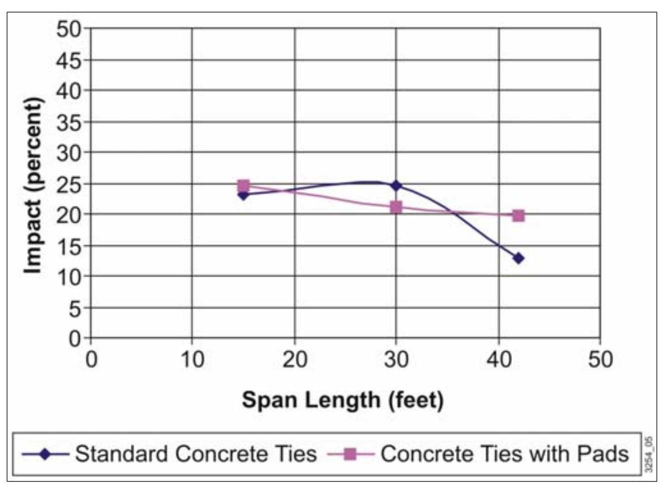

Figure 5. Maximum Impacts in Pile Foundation

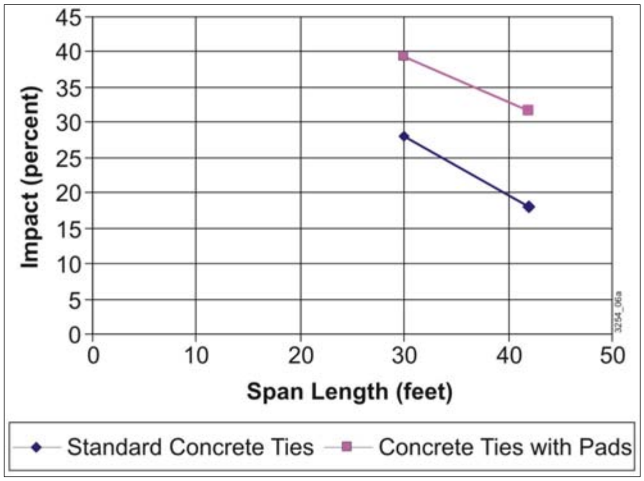

Figure 6a. Maximum Impacts in End of Span Shears

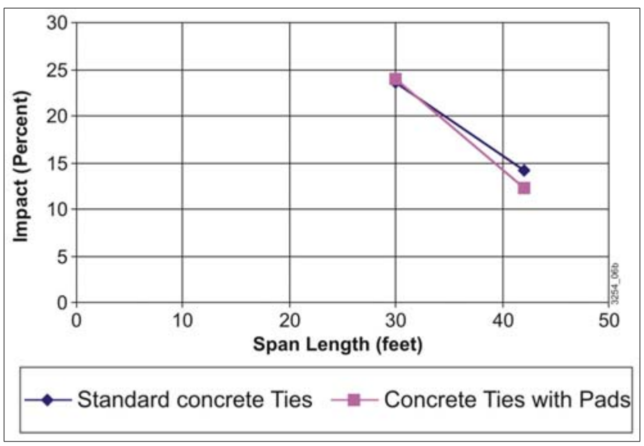

Figure 6b. 99.5 percent End of Span Shears

Lateral Distribution of Vertical Loads

Figure 7 shows a typical strain distribution across the width of spans with under-tie rubber pads. The strain values and pattern are similar to the spans with standard concrete ties.[2] Note that the largest strain is about 35 percent higher than the lowest strain. This variation in strain distribution across the width of the span can be caused by several factors, such as curvature and superelevation, placement of track on the span, fit between spans and pile caps, bearing pad properties, and cross section design. Future testing is planned to investigate ways to provide a more uniform stress distribution of vertical loads across the width of spans, thus reducing the stress state of the bridge.

FUTURE WORK

The VTM of the bridge tested with current under-tie pads is lower than the approaches. In order to optimize the dynamic response parameters of rubber pads, a similar test is being planned using concrete ties with different damping and

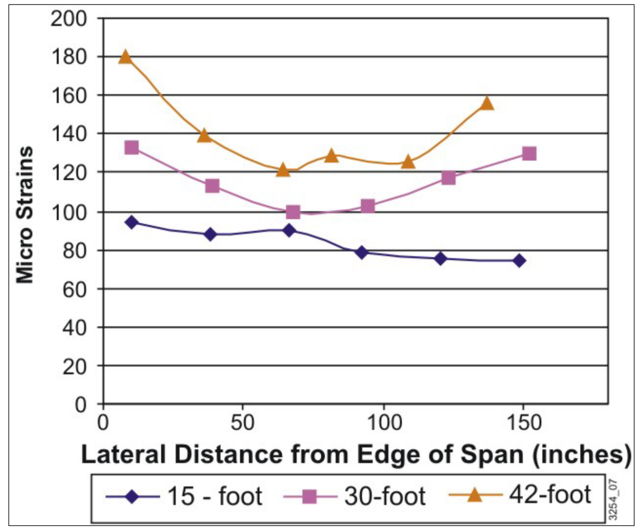

Figure 7. Strain Distribution across the Span Width

stiffness values. Similar tests are being conducted in revenue service. TTCI is monitoring long-term performance.

Further testing of the conventional and the state-of-the-art concrete bridges is also planned with timber and plastic ties, ballast mats, and different ballast depths.

Acknowledgement

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