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

By Muhammad N. Akhtar, Duane Otter, and Brian Doe

Summary

Transportation Technology Center, Inc. (TTCI) is investigating techniques and materials for track foundations 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, a reduction in the stiffness of the track over bridge spans is expected, which should minimize the change in stiffness between bridge and bridge approaches, further lowering the impacts.

Several techniques and materials may be used to attenuate the effects of impacts by increasing the damping of 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 thickness.

In the current test, standard concrete ties with second-generation rubber pads were installed over the recently constructed state-of-the-art concrete bridge at the Facility for Accelerated Service Testing (FAST). Also, standard concrete ties over the conventional ballasted deck concrete bridge were replaced with standard wood ties and elastic fasteners. Impact data was collected from strain gages installed at midspans, when a test train passed over the bridges at different speeds. A comparison of the current results with the previous test results has led to the following conclusions:

- As compared to standard concrete ties, use of wood ties and concrete ties with rubber pads has reduced the track surfacing requirements of both bridges by at least 30 percent.
- Wood ties and concrete ties with rubber pads can reduce the vertical track modulus of bridges to a value comparable to bridge approaches with concrete tie track.
- The impacts at midspans were reduced by 10 percent after concrete ties were replaced with wood ties on the conventional concrete bridge.
- Measured impacts in midspans of both bridges with concrete ties, concrete ties with rubber pads, and wood ties remained under the AREMA design impacts.

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



INTRODUCTION AND CONCLUSIONS

Vehicle dynamics, rocking effects, wheel defects, and railcar suspension systems induce high- and low-frequency impacts into track and bridge spans. The high-frequency impacts affect primarily fasteners, ties, and ballast; whereas, low-frequency impacts primarily affect the ballast track foundations and consequently the bridge structure.¹

Several techniques and materials may be used to attenuate the effects of impacts by increasing the damping of 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 thickness.

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 bridge spans and approaches. In addition, a reduction in stiffness of track over bridge spans is expected, which should minimize the change in stiffness between bridge and bridge approaches, further lowering the impacts.

In the current test, concrete ties equipped with second generation under-tie rubber pads were installed on the state-of-the-art concrete bridge at FAST. Also, the concrete ties on the conventional concrete bridge were replaced with wood ties.

Impact data was collected using a test train, and results were compared with data from a previous test on both of the bridges with standard concrete ties.² In addition, survey measurements were used to quantify settlement of the track on the bridges.

Since the installation of wood ties and concrete ties with rubber pads on conventional and state-of-the-art bridges, respectively, there has been a reduction in track maintenance demand, compared to when the bridges were installed with standard concrete ties.

At FAST, flat wheels and mechanical joints are absent. Thus, the impacts created are mostly 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. Impacts up to 50 percent have been measured on concrete bridges in revenue service.³ These impacts might effectively be reduced by using under-tie rubber pads and wood ties.

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 of the state-of-the-art 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. Construction of both bridges was completed in late 2003. To date, these bridges have been subjected to 325 MGT of mostly 315-kip 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 (UP) railroad 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 set on 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 1a and 1b) were installed on the concrete bridges at FAST to measure the bending strains at midspans, shear strains at end of spans, and axial strains in piles. A test train passed at 2 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 and two 263-, two 286-, and twelve 315-kip cars.

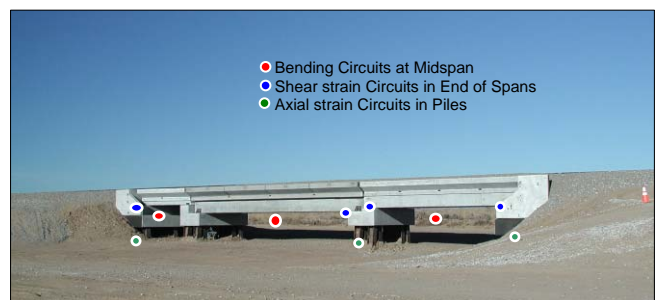


Figure 1a. State-of-the-Art Concrete Bridge at FAST



Figure 1b. Conventional Concrete Bridge

The standard concrete ties on the state-of-the-art bridge were replaced with UP style concrete ties with rubber pads.⁴ Figures 2a and 2b show these pads. Using a special test,⁵ the stiffness and damping characteristics of both iterations of rubber pads were evaluated (Table 1).



Figure 2a. Concrete Ties with Rubber Pads. Iteration 1, Pads Glued to Concrete Tie Bottoms at Site



Figure 2b. Concrete Ties with Rubber Pads. Iteration 2, Pad Grooves Bonded Into Concrete Ties at Plant

Table 1. Stiffness and Damping Values of Rubber Pads Iterations I and II

Rubber Pads Iterations	Stiffness lbs/in.	Damping lbs-sec/in.
I	105	3
II	145	1.75

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

Vertical track modulus (VTM) measurements taken with the previous generation of concrete ties with under-tie pads was reduced to approximately half the value without rubber pads.⁴ 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. Testing of VTM with these new ties is planned for 2006.

Bridge Maintenance

As Figures 3a and 3b show, ballast tamping cycles were reduced by at least 30 percent after standard concrete ties were replaced with rubber padded concrete ties and wood ties on the state-of-the-art and conventional bridges, respectively. The most likely cause is due to the reduced low-frequency impacts, which increase wear and tear of ballast. This indicates that rubber pads and wood ties appear to add significant damping to the track structure, and thus may reduce the impacts induced in bridge spans.

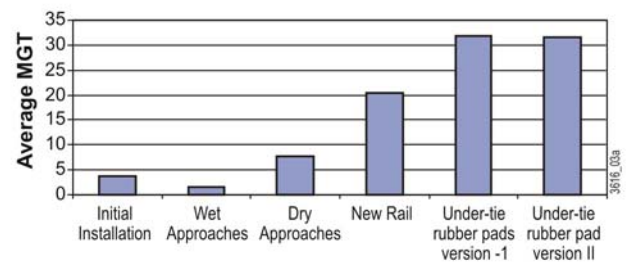


Figure 3a. Ballast Tamping Cycles on the State-of-the-Art Bridge

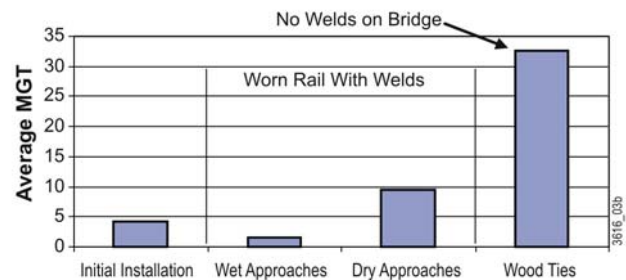


Figure 3b. Ballast Tamping Cycles on the Conventional Bridge

IMPACT LOADS

As Figure 4 shows, the maximum impacts induced into 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 pads were installed.

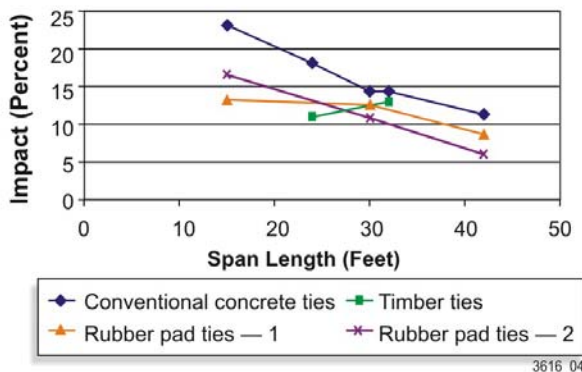


Figure 4. Maximum Impact for Mid-Span Bending

The maximum measured impacts were well below the recommended design values of AREMA 2005.⁶ This is not unexpected as there were no rail joints on the bridge, and the FAST train typically does not have any flat wheels.

The pile foundations and span ends experienced higher impacts, which are close to the AREMA recommended design impacts. The higher impacts seem not to be of serious concern because they are caused by very low strains. The range of shear strains at end of spans was 10 to 50 micro-strain as compared to midspan bending strains, which ranged from 60 to 200 micro-strain.

Distribution of Vertical Loads

Figure 5 shows a typical strain distribution across the width of spans with timber ties and concrete ties 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

TTCI is monitoring long-term performance of under-tie rubber pads. 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. Similar tests are being conducted in revenue service.

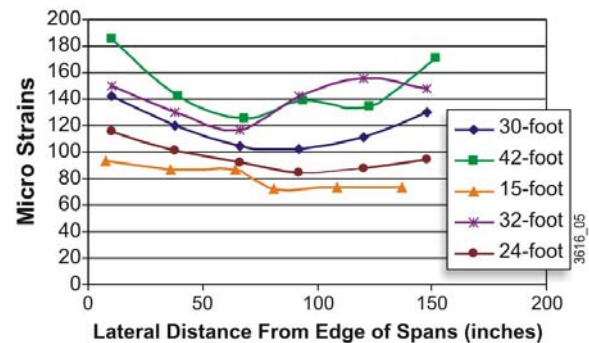


Figure 5. Strain Distribution across the Span Width

ACKNOWLEDGEMENTS

UP contributed the concrete ties with rubber pads used in this test. The Association of American Railroads (AAR) and FRA sponsored this work.

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