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## Dynamic Load and Track Response: Bridge Approach Test at the Western Mega Site

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### Summary

One of the revenue service experiments at the western mega site located near Ogallala, Nebraska, is the bridge approach test conducted by the Transportation Technology Center, Inc. and Union Pacific (UP). Test results show that the dynamic load environment and track response for the bridge and its approaches are severe under the as-is track condition. More specifically:

- A large number of high impact wheel loads, at least twice as high in magnitude as static wheel loads, were generated in the approach track and the track on the bridge. Furthermore, the number of high impact wheel loads was even greater on the bridge than in the approach, because the track on the bridge is a lot stiffer and has less damping than the bridge approaches.
- One-year after the start of this experiment, concrete ties began to crack and mud pumping from ballast breakdown occurred as a result of repeated impact wheel loads on the approaches and the bridge (note that existing ties with cracks were replaced and dirty ballast was cleaned prior to the test). One and half years later, a rail also broke in a mud pumping hole, likely due to repeated large wheel impact loads and poor support condition in muddy ballast.
- Also, as a result of large impact wheel loads and ballast breakdown forming mud pumping holes, ballast support of concrete ties varied greatly; in some cases leading to increased center binding and in other cases leading to unstable tie support.
- Significant vibrations (acceleration) were recorded from the rails into the ties in the test area, again indicating a severe wheel load environment for the as-is track condition.

The as-is track condition is a 12-inch ballast deck concrete bridge with concrete ties, representing the base case test condition. The underlying causes for the poor load environment and track response are differential track settlement, high track stiffness on the bridge, and rapid track stiffness and damping changes between bridge and their approaches. An improved condition (Phase 2) will employ improved track resilience and track damping on the bridge, leading to reduced impact wheel loads and better track geometry retention.

The western mega site is located near Ogallala, Nebraska, on UP's coal route with predominately 286,000-pound heavy axle load (HAL) traffic. Various revenue service experiments are conducted at the western mega site to quantify HAL effects on track infrastructure; and to test new technologies, improved track designs and maintenance practices intended to mitigate the effects of HALs on the track structure. The mega site testing program is funded by the Association of American Railroads and Federal Railroad Administration.

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**INTRODUCTION**

One of the revenue service experiments conducted at the western mega site, located near Ogallala, Nebraska, is the bridge approach test. This experiment was started in September 2005, with the objective to quantify dynamic load environment, track response, and long-term track performance for a ballast deck concrete bridge with the following conditions:

- Phase 1: As-is condition, i.e., 12-inch ballast deck concrete bridge with concrete ties. This test has been completed and the test results are summarized in this *Technology Digest*.
- Phase 2: Ties on the bridge will have rubber pads fitted on the bottom surface. In addition, drainage in ballast will be improved to help prevent mud pumping.

Ballast mat between the ballast layer and the bridge deck will be used in a future phase. These methods have been implemented at FAST and proven effective.

Phase 2 is intended to improve track resiliency and damping for the track on the bridge, which will reduce dynamic vehicle track interaction for both the bridge and approach areas. Reduced wheel impact forces and improved track drainage will reduce ballast breakdown, mud hole development, and differential track settlement.

At this mega site, unit coal trains run at 50 miles per hour, and the total annual tonnage is 230 million gross tons (MGT) per year. Bridges at this site are ballast deck concrete bridges with concrete ties. With the current as-is condition, most of these bridges and their approaches require frequent tamping and other maintenance, due to rough track geometry, mud pumping, cracked ties, and broken rails caused by high-impact loads. The underlying causes are differential track settlement, high track stiffness on the bridge, and rapid-track stiffness and damping changes between bridges and their approaches.<sup>1,2</sup>

**TEST SITE AND INSTRUMENTATION**

One of the bridges and its approach track was instrumented in September 2005. The bridge is a 10-foot short span on tangent track. Prior to instrumentation, existing concrete ties with cracks were replaced with new ties and dirty ballast was undercut and replaced. Figure 1 shows the test site.



Figure 1. Bridge Approach Test Site

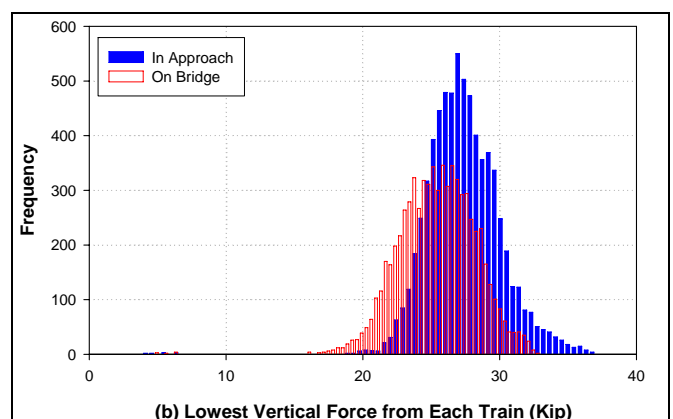
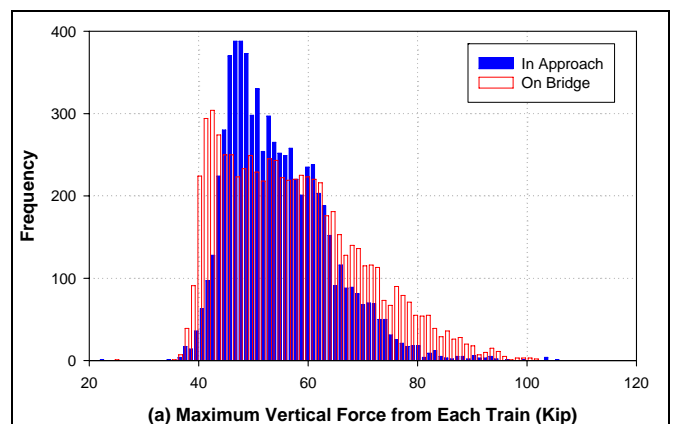
Instrumentation was designed and installed to measure dynamic load and track response in one approach track and the track on the bridge. The following is the list of measurements:

- Dynamic vertical wheel load
- Tie bending strain (top surface at tie center)
- Rail and tie vertical vibration (acceleration)

The sampling rate was 10,000 hertz (Hz) with a low-pass filter of 1,000 Hz for the load and bending strain measurements and was 4,096 Hz with a filter of 360 Hz for the vibration measurement. In addition to the above measurements, track maintenance activities were recorded.

**WHEEL IMPACT LOADS**

Wheel loads were recorded under each passing train for both the track on the bridge and the track in the approach. Figures 2a and 2b show the load environment results recorded. These two plots provide a summary of dynamic vertical wheel loads from about 8,000 trains that have passed through the test site. Figure 2a illustrates that a large number of high-impact wheel loads, at least twice as high in magnitude as the static wheel loads of 36,000 pounds, were measured on one approach track as well as on the bridge. Furthermore, the number of high-impact wheel loads measured on the bridge was greater than that in the approach, because the track on the bridge is a lot stiffer and has less damping than the track in the approaches.



Figures 2a and 2b. Maximum and Minimum Wheel Loads Generated on the Approach and Bridge

Figure 2b shows the minimum wheel loads recorded from each train. Again, the track on the bridge recorded lower minimum wheel loads than the track in the approach, also indicating greater dynamic vehicle/track interaction on the bridge. Nevertheless, as Figures 2a and 2b show, the load environment for both the approach track and the track on the bridge is severe for the as-is track condition. This load environment data will also be used as the baseline results for comparison with those to be measured under Phase 2 conditions.

As a result of the large number of impact wheel loads, 1 year after the start of this experiment, the concrete ties on the bridge started to crack and mud pumping from ballast breakdown under impact wheel loads appeared in the approaches as well as on the bridge. Figure 3 shows mud pumping holes present in one of the approaches.



Figure 3. Mud Pumping Holes in the Approach

At mud pumping holes, the track becomes weak when saturated with water, and large cyclic deflections often occur under HAL train operations. When dry, the track becomes stiff (particularly concrete tie track), generating larger impact wheel forces due to rough track geometry. Either condition leads to poor track performance. In March 2007, as a result of the impact wheel loads and poor track condition, one rail broke in an approach track at a mud pumping hole. Figure 4 shows the broken rail that occurred at this test site.



Figure 4. Broken Rail that Occurred in a Mud Pumping Hole

TIE BENDING

Measurements were taken to quantify responses of concrete ties as well as tie support conditions. Eight ties (four on the bridge and the other four in the approach) were instrumented with strain gages on the top surface at the center of each tie to measure bending strain under train passes. Figure 5 shows a comparison of tie bending strain test results on two different ties that had developed two different support conditions over time. Statistical values (maximum, minimum, average, and 98<sup>th</sup> percentile) obtained under each train were plotted sequentially for 8,000 train passes over these two ties.

Figure 5a shows a tie in the approach with stable support, as indicated by the consistent tie bending strain results throughout 8,000 train passes. Conversely, Figure 5b shows a tie with increased center binding (on the bridge), indicated by increased magnitudes of the measured tensile strain. Center binding is a condition in which the tie is supported primarily at the center as opposed to being supported under rail seats – considered to be one of the main reasons for causing concrete ties to crack. This condition can occur when ballast breaks down under the rail seats or due to inadequate or improper ballast tamping.

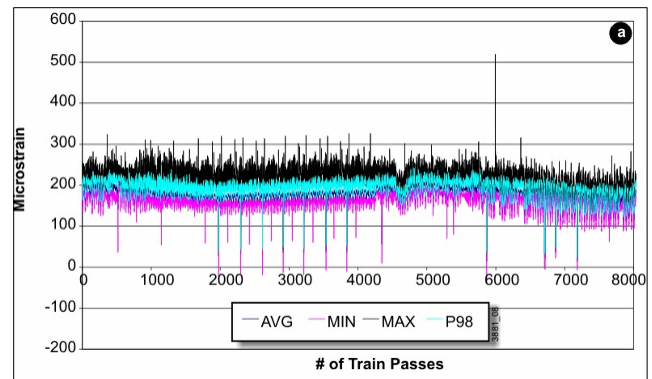


Figure 5a. Tie Bending Strain Results with Stable Support

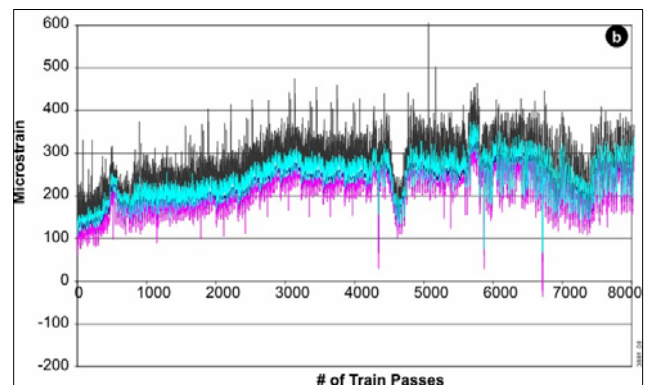


Figure 5b. Tie Bending Strain Results with Center-bound Bridge Tie

A concrete tie will crack on the tension surface when bending levels exceed both the concrete precompression (imparted by the prestress tendons) and the available concrete tensile strength. For the concrete ties installed at this site, the allowable tensile strain capacity was estimated to be between 470 and 650 microstrains, although individual tie calibration was not performed.

For the two ties shown in Figure 5, the tie support condition shown in Figure 5a was better than the one shown in Figure 5b, although magnitudes of tensile strain recorded under those 8,000 train passes for both ties were below the allowable capacity (with few exceptions).

Note that Figure 5 also indicates a period of slow orders between train passes 4,500 and 4,700. As shown, slow orders had a greater effect on the tie with the center binding condition (Figure 5b) than on the tie with the stable tie support (Figure 5a).

For the eight instrumented ties, four showed stable or improved tie support over time; whereas, the other four ties exhibited either increased center binding or an unstable ballast support condition due to fouled ballast and mud pumping (showing hairline or severe crack). The poor tie support condition was another reason why, 1 year following the start of this experiment, some ties started to crack. In places where ties showed cracks, there was mud or fouled ballast present. Toward the end of Phase 1, a few ties at this test site cracked severely. Figure 6 shows an example of severely cracked concrete ties.



Figure 6. Severely Cracked Concrete Tie

**RAIL AND TIE VIBRATION**

Toward the end of Phase 1 (March 2007), eight accelerometers were installed on the rails and ties to measure the vibration environment of the test site. Four accelerometers were used in one approach track and the other four were used on the bridge. Rail and tie vibration responses were obtained under several coal trains running at 50 mph. These results will also be used as the baseline results for comparison with those to be obtained for the Phase 2 track design.

Figure 7 shows examples of rail and tie acceleration results obtained under two passing trains. The range of rail vibration was from -50 to 50 g, while the range of tie vibration was from -30 to 30 g. Consistent with wheel load results, shown in Figure 2, vibration on the bridge also appeared to be higher than vibration on the approach for the same reason previously mentioned.

**PHASE 2, FUTURE WORK**

Phase 1 testing of the as-is track condition concluded in the summer of 2007. In Phase 2, the track will undergo a ballast undercutting and replacement, and the ties on the bridge will

be replaced with ties with rubber pads preinstalled on the bottom surface. In addition, the ties in the approaches will be replaced with regular concrete ties. Drainage will be improved to prevent mud hole development. The same measurements will be repeated to quantify if the load environment changes and how track performance may improve as a result of improved track resilience, damping, and track geometry.

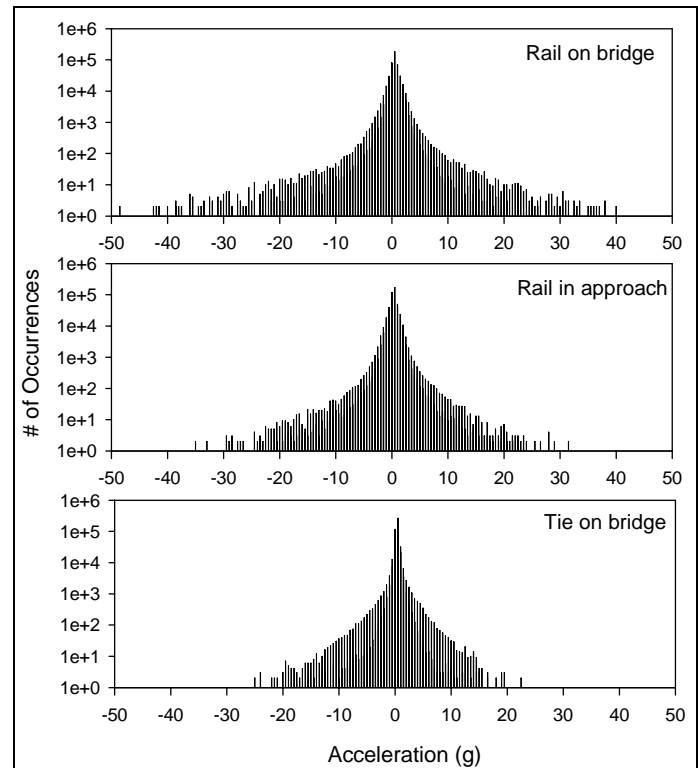


Figure 7. Rail and Tie Vibration Results

**Acknowledgments**

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