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CWR/Bridge Thermal Interaction: Testing at the Eastern Mega Site

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Summary

The Transportation Technology Center, Inc., (TTCI) has completed testing of an open-deck steel bridge in the Eastern Mega Site on the Norfolk Southern's Virginia Division. This test was intended to further characterize the thermal interaction between continuous welded rail (CWR) and open-deck steel bridges.

Testing was comprised of two components: A long-term investigation into the thermal performance of CWR on the bridge and a short-term dynamic test to measure CWR/bridge interaction under heavy-axle load (HAL) train traffic.[1] The long-term investigation was initiated in November 2010 to monitor thermal interaction between the track and bridge. Instrumentation was installed on three spans of different lengths at the east end of the bridge. Data was collected automatically and periodically downloaded between November 2010 and September 2012.

Current AREMA Chapter 15 recommendations are based on the assumption that rail neutral temperature is constant. In addition, calculations assume that span movements are realized at the bridge expansion bearings. However, test observations show otherwise. The following are conclusions from the test results:

- Movement of the bridge, likely resulting in noticeable changes in rail longitudinal force, was observed. Movement is likely due to curve movement as well as bridge tower flexure.
- Multiple changes in rail neutral temperature on the bridge were observed over the course of the experiment, likely due to a combination of repair of broken rails, rail changes, as well as movement of the bridge, and rail movement under train traffic.
- Measured displacements between the intermediate spans and between the easternmost span and the backwall differed from the predicted values, potentially due to factors not considered in traditional analysis including movement of the steel towers combined with locked bearings. Elastic rail fasteners allow limited rail longitudinal movement while continuing to provide constant longitudinal resistance (friction) without gouging deck ties.
- No damage to deck ties was observed during the course of testing. Elastic fasteners are used over the entire length of the bridge.

This investigation was undertaken by TTCI under the HAL revenue service program co-sponsored by the Association of American Railroads and Federal Railroad Administration.

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INTRODUCTION

Rail longitudinal forces are caused by thermal expansion and contraction and are restrained by the combined resistance of the rail-tie fastening and ballast. Additional longitudinal forces are applied by passing train traffic. Open deck steel bridges, which also expand and contract due to thermal effects, can, depending on the stiffness of the track-to-bridge attachment, contribute further to the longitudinal forces experienced by the rail and the bridge.

Previous tests have begun to characterize this track-to-bridge longitudinal stiffness.[2] However, in some cases, the forces predicted are more severe than observed evidence seems to support.

Between November 2010 and September 2012, TTCI conducted tests on an open-deck steel bridge that crosses the Roanoke River at mile post (MP) V257.5 in the eastern mega site.[3] This test was intended to further characterize the interaction between CWR and open-deck steel bridges. It was comprised of two components: (1) a long-term investigation to measure thermal performance and (2) a short-term dynamic test to measure CWR/bridge interaction under HAL train traffic. This report describes the long-term investigation. The results of the short-term dynamic testing including details of train operations were published in 2011.[1]

New elastic fasteners were installed over the length of this span in 2010. Elastic fasteners provide longitudinal restraint (through friction) but will allow relative rail-to-superstructure movement if longitudinal rail force exceeds the fastener clamping force. No damage to deck ties was observed during the course of testing.

TEST BRIDGE DESCRIPTION

The 100-year old open-deck steel bridge selected for this investigation is located on Norfolk Southern's Virginia Division near Roanoke, Virginia. The site sees approximately 40 MGT of traffic annually, comprised mainly of eastbound loaded coal and grain trains with some mixed freight trains.

Figure 1. Test Bridge over the Roanoke River at MP V257.5

Figure 1 shows the test bridge looking west from the east approach. The bridge is 525 feet in length and lies entirely within a 6-degree curve. Eleven spans of different lengths comprise the full length of the bridge, though Spans 8-11 were of specific interest with regard to the long-term testing. The bridge sits on riveted steel towers ranging from 16 to 45 feet in height. Figure 2 is a diagram of the spans concerned.

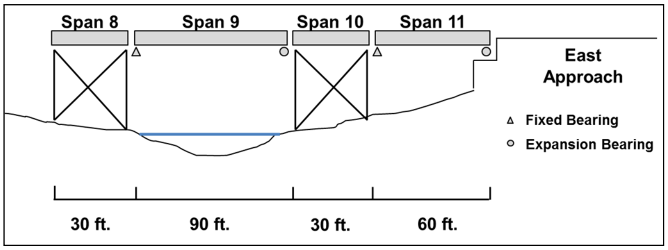

Figure 2. The Long-term Bridge Test Zone

Elastic fasteners are utilized throughout the length of the bridge. Eastbound traffic travels downhill on a 0.66 percent grade across the bridge.

Expansion bearings are located at the east backwall as well as between Spans 9 and 10 (see Figure 2). Alternating spans have either smooth or riveted surfaces interfacing with the bottom of the timber ties. In the test zone, Spans 9 and 11 have an interface with protruding rivet heads, and Spans 8 and 10 have a smooth interface.

MEASUREMENTS

Measurements in the test zone included:

- Longitudinal rail force at mid-span, at the interface between spans, and at the east backwall. Because absolute rail force at the time of strain gage installation was unknown, only changes in force can be reported.
- Relative displacements between the spans and rail, broken down between rail-to-tie and tie-to-span measurements
- Relative displacement between Spans 8 and 9; Spans 9 and 10; Spans 10 and 11; and between Span 11 and the east backwall
- Rail and girder temperature at mid-span
- Survey measurements of bridge position

RESULTS

Results from this long-term study have shown that multiple factors can contribute to the changes in longitudinal rail force. Figure 3 shows the predicted changes in rail force as a result of rail heating and cooling compared to the rail forces measured at the interface between Span 11 and the east backwall. The data displayed is for the time between March and April 2011. The observed rail force increases with temperature at a rate approximately 20 percent less than predicted from rail thermal effects.

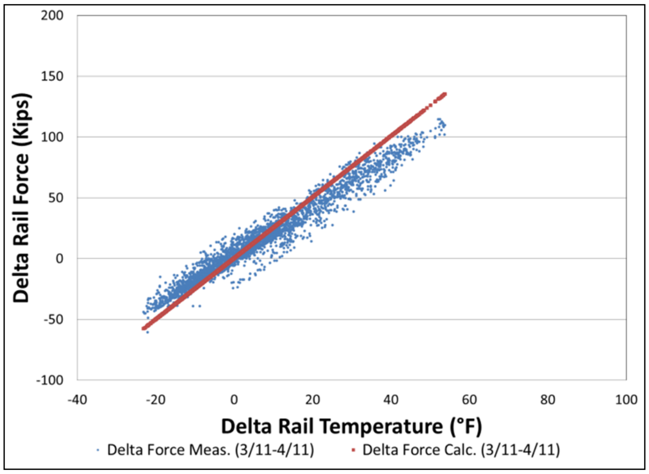

Figure 3. Rail Forces vs. Rail Temperature at the East Backwall

Figure 4 presents similar data for the other instrumented locations on the south rail over several time periods between February 2011 and September 2012. The difference between theoretical and measured rail force remains fairly consistent along the bridge.

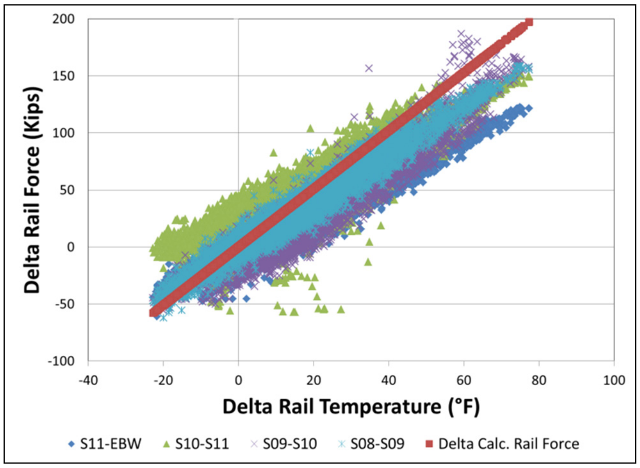

Figure 4. Rail Forces vs. Rail Temperature at Multiple Spans

One explanation for the difference between the measured and theoretical data would be the effect of forces imparted by thermal expansion and contraction of the bridge spans. However, the change in slope is generally opposite to what would be expected from this effect. Other potential explanations include:

- The curved bridge moving laterally (radial to the curve) relieving accumulated rail force
- Changes in rail neutral temperature (RNT) from longitudinal rail running
- Longitudinal movement within the bridge itself due to tower flexing or play between components

In order to identify potential movement of the bridge spans, a series of static survey measurements were conducted between February and September 2012. Lateral displacements of over 1 inch were recorded. Figure 5 shows lateral displacements measured on the north girder corrected to display radial displacement. The movement was likely due to curve movement and tower flexure. Differential heating and cooling of the bridge girders and towers may also have played a part, because the south girders had good exposure to the sun and the north girders had none.

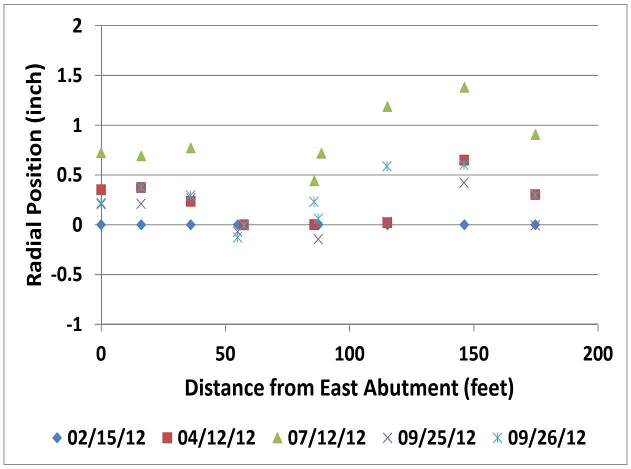

Figure 5. Static Position Measurements from North Girder Correct to Display Radial Displacement

Ideally, longitudinal rail force has a direct relationship to rail temperature. Therefore, for a given RNT, the measured data should fall along a line of constant slope.

Figure 6 shows six distinct areas of constant slope, signifying six distinct periods of constant RNT over the course of testing, shifting over a range of nearly 40°F. Two of these shifts can easily be explained by track maintenance. In July 2011, a rail plug was installed, which correlates to the shift from red to purple. A second plug was installed September 2011, which correlates to the shift from purple to green. The causes of other shifts were not as obvious, but could be due to movement of bridge as a result of curve movement and/or tower flexure. Previous studies in open track have also shown similar results for RNT shifts.[4] For this bridge, it is likely that changes in RNT were caused by a combination of repair of broken rails, rail changes, track curve movement, the effects of train traffic, and tower flexure.

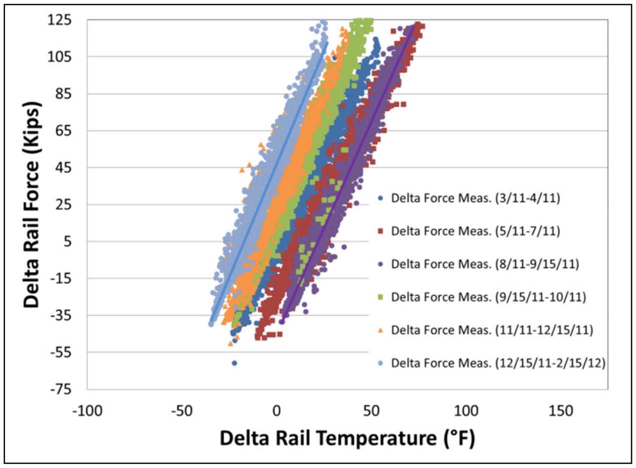

Figure 6. Notable Shifts in RNT located at the East Backwall

Figure 7 compares the measured displacement to the predicted displacement due to thermal expansion at the expansion bearing at the east end of the 90-foot span (between Spans 9 and 10).

Measured displacements at the fixed bearing end of the 90-foot span were approximately ±0.1 inch. These values are expected to be near zero. The measured displacements at the expansion bearing end of the 90-foot span were less than predicted, approximately the same as the fixed bearing end.

The predicted displacement assumed no tower movement, but it is possible that the span expansion is being accommodated through flexure of the towers rather than through expansion at the bearings.

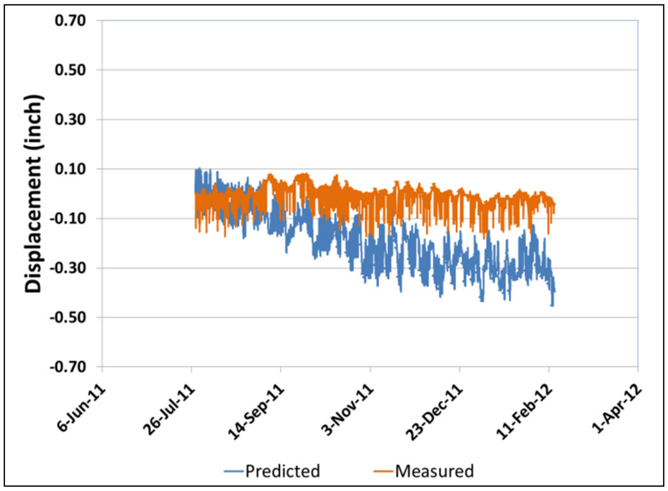

Figure 7. Longitudinal Displacement between Spans 9 and 10 (Expansion Bearing)

Figure 8 compares the measured longitudinal displacement to the predicted at the east end of the 60-foot span (between Span 11 and the east backwall).

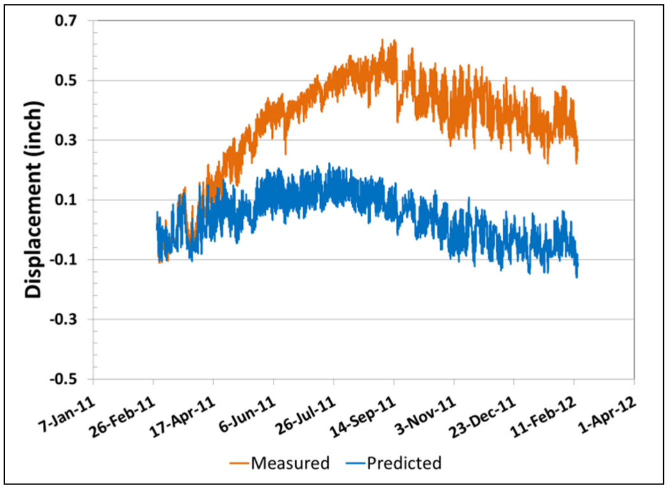

Figure 8. Displacement between Span 11 and the Backwall (Expansion Bearing)

Measured short-term and seasonal displacements were significantly larger than predicted. Since the girder displacement was less than predicted at the intermediate spans and greater than expected at the backwall, it is possible that the expansion of the intermediate girders was taken up in the towers rather than in the expansion bearing at the east end of the 90-foot span (Span 9). The greater-than-expected displacement seen in Figure 8 may have been a result of accumulated displacement from tower flexure at the intermediate spans.

In spite of the various movements, no damage to deck ties was observed during the course of testing. This is likely due in part to the use of elastic rail fasteners rather than rail anchors on the bridges.

CONCLUSIONS

Measurements indicate that the forces in this bridge due to thermal interaction with the CWR were less than predicted by traditional theory. The inconsistencies in the measured forces are likely due to factors not considered including lateral shift of the bridge radial to the curve, resulting in changes in rail force, changes in RNT, longitudinal movement due to tower flexure and potentially locked bearings at Span 9.

If longitudinal rail force exceeds elastic fastener force, elastic rail fasteners allow limited rail longitudinal movement while continuing to provide constant longitudinal resistance (through friction) without gouging deck ties.

ACKNOWLEDGEMENTS

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