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Measurement of Load Environment and Performance of Insulated Joints at Western Mega Site

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Summary

Since July 2004, Transportation Technology Center, Inc. (TTCI) and the Union Pacific Railroad (UP) have been taking measurements in a revenue service track known as the “western mega site” to quantify the load environment and long-term performance of bonded insulated joints (IJs). The site, located near Ogallala, Nebraska, is on a UP heavy haul coal line and has been subjected to 220 MGT annually. The eight IJs under test are all located on tangent track with concrete ties. Observations and results from the measurements thus far have shown:

- Seven of the bonded IJs under test that are supported on a tie with a 3-tie plate have accumulated more than 470 MGT with acceptable performance, as of September 2006.
- One bonded IJ suspended between two ties without a 3-tie plate failed at 330 MGT due to a broken joint bar (fatigue crack).
- For the IJ suspended between two ties, the bottom of a joint bar was subjected to the highest tensile stress in the winter (sum of the live bending stress due to dynamic wheel loading and the longitudinal rail stress), consistent with where the crack initiated (bottom) and when it happened (December 2005) for the failed IJ.
- For an IJ supported on a tie with a 3-tie plate, the bottom of a joint bar was subjected to compressive bending stress due to dynamic wheel loading, which would cancel some longitudinal tensile stress in the winter.
- Because IJs are often installed at neutral rail temperatures above 100°F, the magnitude of total tensile stress in the winter is significantly higher than the magnitude of total compressive stress in the summer, therefore more critical to IJ mechanical performance.
- Maximum longitudinal tensile force was recorded as 310 kips. Maximum dynamic wheel forces were measured at least twice as high as the static wheel loads. Under normal conditions, the total maximum tensile stress was estimated to be 45 ksi, lower than the nominal yield strength of a joint bar (70 ksi). Fatigue damage, however, could result due to repeated stress applications, occasional large impact forces, possible quality issue, or stress concentration in a joint bar.
- To reduce the maximum tensile stress, IJ design and maintenance should be improved to reduce vertical impact wheel loads, to reduce vertical deflection of joints, and to limit the “pull” force used to install an IJ plug that can create a very high neutral rail temperature above 120°F.

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INTRODUCTION

As part of the ongoing “mega site” research program, measurements were taken at the western mega site located near Ogallala, Nebraska, to determine load environment and long-term performance of bonded IJs. Testing began in the summer of 2004, when eight IJs were instrumented and installed in tangent track between MP36 and MP54. The objectives of this test include:

- Define the actual IJ load environment in revenue service under heavy axle loads (HAL) for developing improved IJ designs and maintenance practices
- Monitor and measure long-term performance of bonded IJs with two different foundation configurations
- Define failure modes, when any of the IJs under test fails

The IJs have accumulated 470 MGT as of September 2006. One failed at 330 MGT due to a broken joint bar (fatigue crack), but the remaining seven are still in service and have performed acceptably. As a comparison, the medium life for a group of 150 IJs previously tested by TTCI was 172 MGT and the average service life of IJs based on railroad surveys is 280 MGT for tangent track (TD04-006). In general, however, the western mega site is subjected to heavier and denser axle loads as well as higher operating speeds than those IJ sites reported in the earlier study.

TEST IJs AT WESTERN MEGA SITE

The western mega site is in UP’s South Morrill Subdivision, Nebraska. This mega site was established to consolidate various revenue service experiments intended to quantify the effects of HALs on track infrastructure and to test new technologies, improved track design, and maintenance practices (TD05-026). Tonnage is high, approximately 220 MGT per year, of which 80 percent comes from unit coal trains running eastbound at 50 mph.

Eight IJ (Allegheny design) plugs (rail section with preinstalled IJ) were instrumented and installed at four different locations between MP 36 and MP 54, all on tangent track with concrete ties. Among them, six are used on 141 RE rails with 8-hole joint bars (48 inches), and two are used on 133 RE rails with 6-hole joint bars (36 inches). Seven IJs have a supported foundation (e.g., the length of the IJ rests on a plate over three ties, with a tie directly under the end post), and one is on a suspended foundation (i.e., the end post is suspended over the ballast crib and there is no multi-tie plate). Figure 1 shows a supported IJ (141 RE rail) and a suspended IJ (133 RE rail).

Instrumentation was installed on the rails and joint bars to measure the following responses, which are the critical load parameters needed for the development of improved IJ design and maintenance practice:

- Longitudinal rail force and rail temperature
- Vertical impact force
- Joint bar bending stress

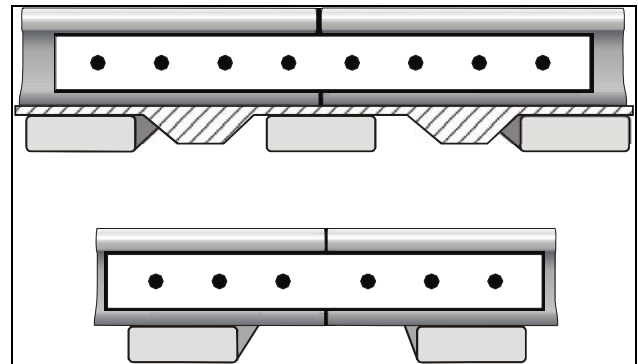


Figure 1. Supported IJ (top) vs. Suspended IJ (bottom)

Longitudinal Rail Force

For each of the eight IJs, longitudinal rail force and rail temperature were recorded every half hour on both rails connected by the IJ since installation. The total force included (1) the thermal force component due to temperature change and (2) the initial force used to install (pull) an IJ plug.

Figure 2 shows longitudinal rail force in an IJ rail and rail temperature measured from July 2004 to Dec. 2005. As illustrated, the rail was generally in tension (negative), with the maximum tensile force recorded at the coldest rail temperature. At this IJ location, the maximum tensile force was approximately 300 kips. For all eight IJs tested, the maximum force was recorded as approximately 310 kips at -10°F.

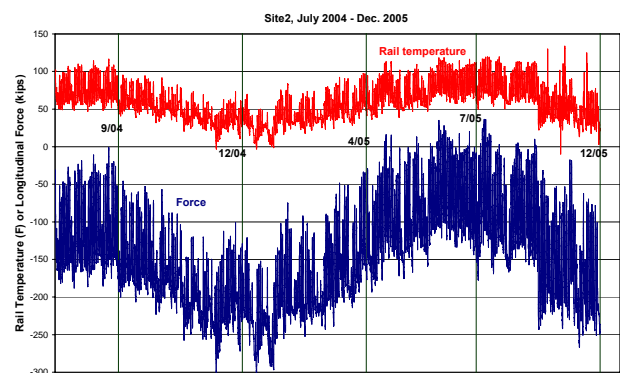


Figure 2. Rail Temperature and Longitudinal Force

The relationship between longitudinal rail force and rail temperature can be seen in Figure 3, in which the force measurements are plotted against rail temperature. As shown, longitudinal rail force is essentially proportional to rail temperature change.

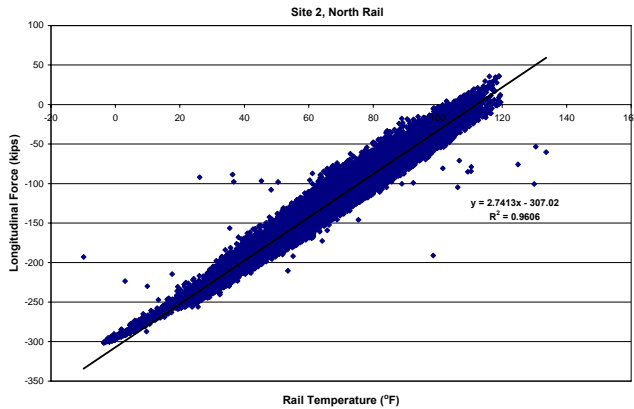


Figure 3. Longitudinal Force vs. Rail Temperature

The rail neutral temperature is defined as the temperatures when the longitudinal force is equal to zero. As Figure 3 shows, this IJ had neutral rail temperature varying between 100° and 120°F.

Note that the test IJs were not actually installed at the rail temperature above 100°F. In fact, they were installed at a range of rail temperatures between 60° and 90°F. The rail “pull” forces used to install the IJ plugs created neutral rail temperature above 100°F.

Because neutral rail temperature is above 100°F, an IJ is rarely in compression. As such, compressive stress is not as critical to IJ performance as tensile stress.

An excessive pull force, which causes a high neutral rail temperature, should be avoided when installing IJ plug. For example, when neutral rail temperature is at 120°F, the tensile force can be as high as 340 kips at -10°F.

Dynamic Wheel Loads

One pair of IJs (133 RE rail) was instrumented to measure vertical impact wheel loads at the rail joints. For each IJ, strain gages were installed on both sides of the joints to measure vertical wheel loads under train passes. During the measurements conducted June through July 2005, the data was recorded at a sampling rate of 8192 Hz, with a low-pass filter of 650 Hz.

Figure 4 shows an example of recorded vertical wheel loads under one train running at 50 mph. As shown, the average dynamic wheel load for all wheels was roughly 40 kips, higher than its nominal static wheel load of 36 kips. More importantly, however, several wheels under this train alone produced impact loads as high as 80 kips — more than twice its static wheel loads.

Figure 5 shows a comparison of load distributions obtained under two trains, one running at 15 mph due to slow order and the other running at 50 mph. As shown, higher operating speed caused higher wheel-rail forces.

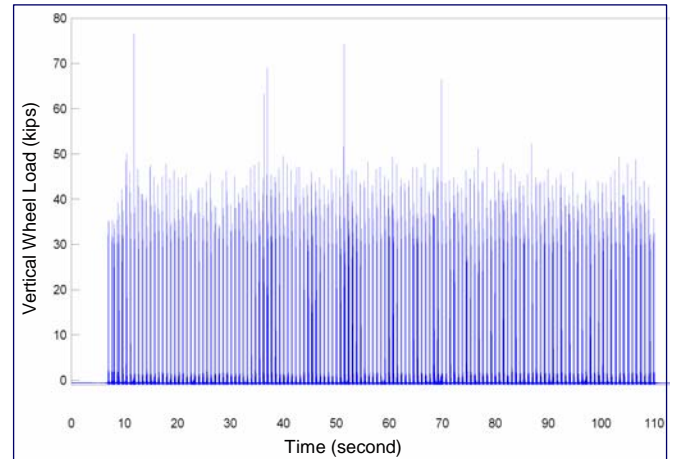


Figure 4. Dynamic Wheel Loads under a Train

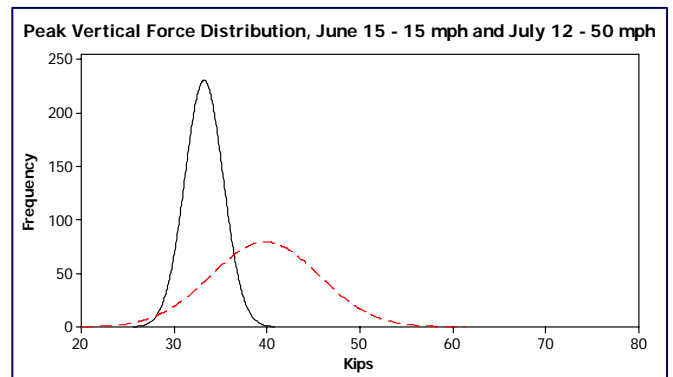


Figure 5. Distributions of Wheel Loads at Two Speeds

Joint Bar Bending Stress

The two IJs installed for 133 RE rail have different joint supports. One is supported on a concrete tie with a three-tie plate, and the other one is suspended without the multi-tie plate (see Figure 1). Strain gages were installed on the joint bars (gage and field sides) to measure actual bending strains under dynamic wheel loads. Due to the space limitation, strain gages were installed only 1 inch from the neutral axis of the joint bars (compared to 2.5 inches to the bottom of the bar).

Figure 6 shows the comparison of the bending strain test results (minimum, average, and maximum peak responses under a passing train) between the joints supported and suspended. The results correspond to a joint bar location 1 inch below the neutral axis. As shown, under dynamic wheel loads, the bar area below the neutral axis is in tension (positive) with the suspended joint, whereas the bar area is in compression (negative) with the supported joint.

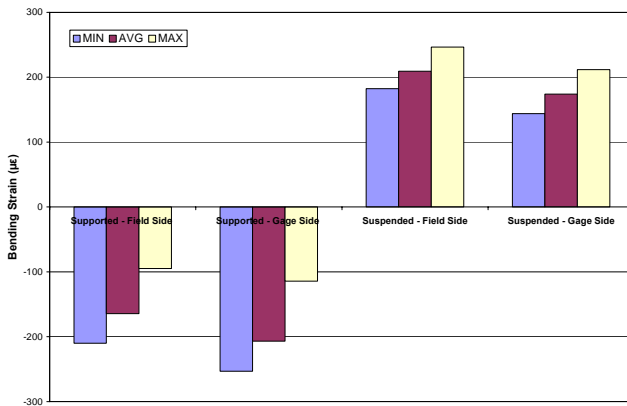


Figure 6. Bending Strains in Joint Bars

Total Stress in Joint Bar

In a joint bar, the total stress is the sum of longitudinal stress and live bending stress due to wheel loading. From the early discussion, a joint bar is usually in tension in terms of longitudinal force. Under dynamic wheel loading, however, a joint bar may have the maximum tensile or compressive stress at its bottom or top, depending on joint support condition. If a joint is suspended, the maximum stress should be tensile and occurs at the bottom of the bar. If a joint is supported, the maximum tensile stress should occur at the top of the bar.

Based on Figure 6, the maximum tensile stress can be estimated to be 19 ksi at the bottom of the joint bar (strain times Young’s modulus, multiplied by 2.5 to get the stress at the bottom). Assuming a maximum longitudinal tensile force of 300 kips at -10°F, the corresponding tensile stress in a joint bar would be 26 ksi (force divided by the total cross section area of two bars). Therefore, the maximum total tensile stress at the bottom of the bar would be 45 ksi, below the nominal yield strength of the joint bar at about 70 ksi (TD05-004).

Broken Joint Bar

As mentioned earlier, the suspended IJ failed in December 2005 because the joint bar on the field side broke. The failed IJ section was brought back for laboratory examination, which indicated no issue of de-bonding of the epoxy between the bars and the rail. The other components, such as bolts, were also in good conditions. The failure occurred because of the fatigue crack growth, which initiated at the bottom corner of the joint bar (see Figure 7, which also shows the location of the crack).

In December, under normal conditions, the total maximum tensile stress at the bottom of the bar was about 45 ksi. Fatigue damage, however, could result due to repeated stress applications, occasional large impact forces, possible quality issues, or stress concentration in a joint bar.

To increase this factor of safety in fatigue design, the current IJ design and maintenance practices should be improved in the following areas to reduce the maximum tensile stress generated in an IJ (TD06-012):

- Improve IJ and foundation design to reduce wheel impact forces and vertical deflection of joint bar
- Limit the maximum rail pull force used to install an IJ plug creating a high neutral rail temperature above 120°F



Figure 7. Broken Joint Bar due to Fatigue Crack

OTHER OBSERVATIONS

- For the suspended IJ pair used on 133 RE rails, six ties were replaced in June 2005 with new ones that have rubber pads underneath. These ties experienced more deflections under dynamic wheel loads, due in part to inadequate ballast consolidation, which might have contributed to the joint bar failure at this location, although the other joint bar supported on a tie is still in service.
- Two 3-tie plates used to support the IJs cracked at approximately 450 MGT, but there was no safety issue, therefore, the plates were not replaced.
- Improvements can be made to the practice of slotting to remove rail surface plastic flow over the end post. Currently, this practice leaves a short dip over the joint, which may increase wheel impact forces.

Performance monitoring of the IJs at the mega site is ongoing.

ACKNOWLEDGEMENTS

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