TECHNOLOGY DIGEST
TD-05-004
©MARCH 2005
TIMELY TECHNOLOGY TRANSFER

The work described in this document was performed by Transportation Technology Center, Inc.,
a wholly owned subsidiary of the Association of American Railroads.

# Performance Evaluation of Bonded Insulated Joints

### by Muhammad N. Akhtar, David D. Davis and Dave Read

## Summary

Significant progress has been made to understand the effects of heavy axle load environment on bonded insulated joints (IJ). The causes of IJ problems were analyzed and documented by Transportation Technology Center, Inc. (TTCI) in *Technology Digest* TD-04-006, April 2004. Having identified the parameters responsible for IJ problems, TTCI is now assisting the industry in developing economical and long-lived designs. The improved IJs are expected to reduce significant direct and indirect costs involved in maintaining railroad track and signal systems.

This digest describes problems with current designs and presents a recommendation for potential design solutions. It also evaluates the response of IJ components to varied loading, foundation, and environmental conditions. For this purpose, real time stress-strain data was collected, destructive IJ inspection was done, and finite element analysis was performed.

Findings:

- Current installation and longitudinal stress management practices result in high neutral temperatures for IJs.
- The running surface created by the insulated “end post” in the gap at the joint generates higher dynamic forces. These impacts accelerate ballast degradation requiring frequent maintenance of IJ foundations.
- Cracked and broken bars and bolts are observed during early IJ service life even when epoxy and insulation are still intact.
- Transition of IJs from “slip critical” to “bearing type” is a possible cause of cracked thimbles, bolts, bars, and metal flow in bolt holes.*
- Finite element analysis predicts that the strength of IJ components is generally adequate under fair foundation conditions.

This study is being conducted as part of the AAR’s Strategic Research Initiative Program on performance of insulated joints.

---

* “Slip-critical” joints transfer load due to joint bar contact pressure only. “Bearing-type” joints transfer load partially due to bearing of bolts also.

Please contact **Muhammad Akhtar (719) 584-0515** with questions or concerns regarding this *Technology Digest.* E-mail: Muhammad_Akhtar@ttci.aar.com.

## INTRODUCTION

Having identified the parameters responsible for IJ problems, TTCI is assisting the industry in developing economical and long-lived designs. The improved IJs are expected to reduce significant direct and indirect costs involved in maintaining railroad track and signal systems.

## INSPECTION OF PROBLEM IJS

A database of 133 problem IJs removed from revenue service was collected and analyzed by TTCI. While some IJs have ceased to insulate without any visual indications, the predominant mode for loss of electrical insulation starts from the epoxy unzipping and debonding at the end post. Other causes of not electrically insulating or losing structural strength are bar cracking, bolt cracking, and end post battering. As Figure 1 shows, the mode of occurrences leading to replacement is the same for all the suppliers. However, there is a significant difference in the life of IJs of different suppliers. This is due to redundancy in some designs. The joints are installed in pairs, and the signal system can run even if one IJ does not continue to insulate. Many insulated joints remain in track long after insulation failure and are removed only for structural reasons. Thus, the service life reported for insulated joints is somewhat higher than the actual life over which the insulation of an IJ is effective.

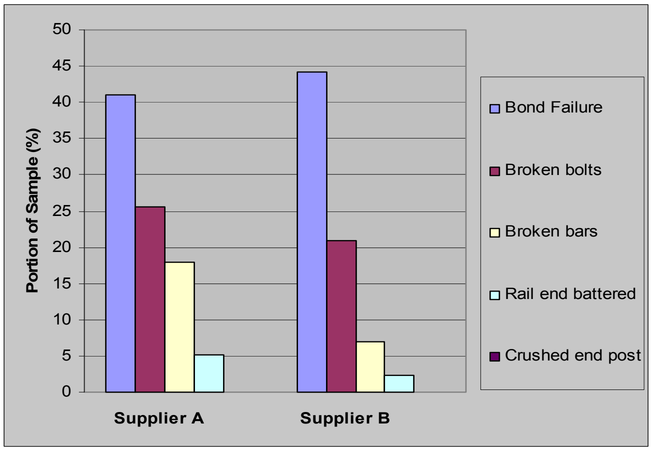


**Figure 1. Different IJ Defects Found in Bonded IJ's Removed form HAL Service Modes for Major Suppliers**

Twenty-five IJs were destructively disassembled and examined. Mostly the epoxy was degraded and only the bolts held up the joint. However, some joints were electrically good and structurally sound. Metal flow and chipping at the end post is a likely reason for their removal.

Broken bolts, broken bars, and cracks in holes have been detected by the detector cars and visual inspection during relatively early IJ service life. Apparently these factors could be related to the quality of the material and the assembling process.

## CHARACTERIZATION OF LOAD ENVIRONMENT

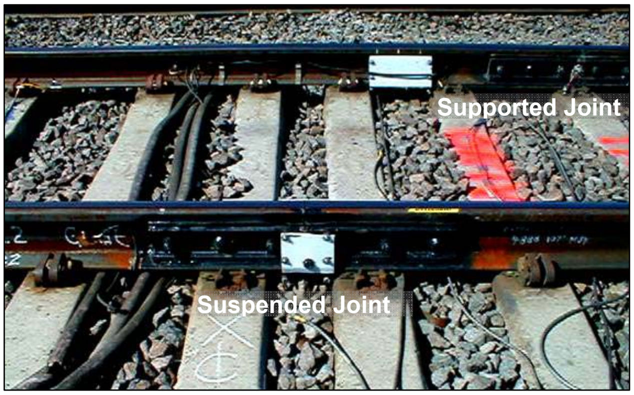
Four pairs of instrumented IJs were installed at the testing site in revenue service to measure real time longitudinal thermal strains. Longitudinal strains in the rails are being recorded by data loggers and downloaded by TTCI every four to six weeks. Longitudinal force data is being collected until the joints fail.

Out of eight joints, two are also instrumented with bending and vertical force circuits. One is supported on a concrete tie and 3-tie plate. The other one is suspended between a 24-inch center-to-center concrete tie. These IJs have the capability to capture vertical force and bending strains when subjected to dynamic loads.

## STRAIN MEASUREMENTS

Figure 2 shows supported and suspended IJs with bending, longitudinal, and vertical strain circuits. A test train passed over the IJs at 40, 50 and 60 mph. Bending strains and vertical impacts were measured using a dynamic data acquisition system. Longitudinal strain data was collected with automatic data loggers. The measured data was used to determine the statistical distribution of forces.

The projected data in Figure 3 shows that longitudinal thermal tensile force in the rail could be about 500 kip at 0°F provided there is no physical change in the track. Temperatures less than 0°F will cause even higher forces.



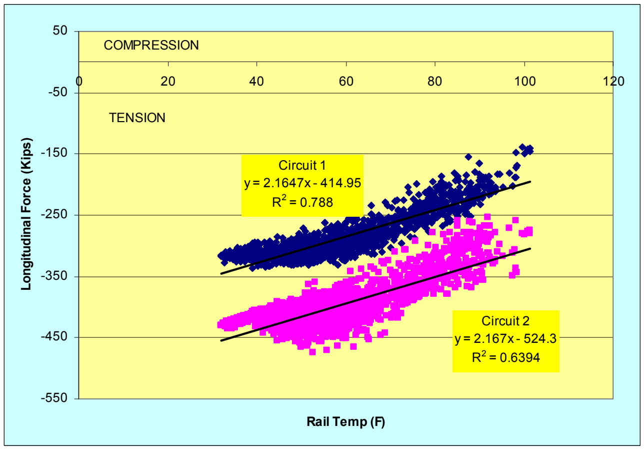


**Figure 2. One Pair of Instrumented Joints with Supported and Suspended Foundations**

**Figure 3. Rail Temperature and Longitudinal Force**

Figure 4 (top) shows the peak tensile bending stresses measured in the bottom of suspended joint bars when the wheel was on the center of the crib. Figure 4 (bottom) shows compressive bending stresses in the bottom of supported joint bars, when the wheel was on the center of the crib next to the end post. Since peak stresses are only 10 percent of the general strength, the bar bending strength seems adequate.

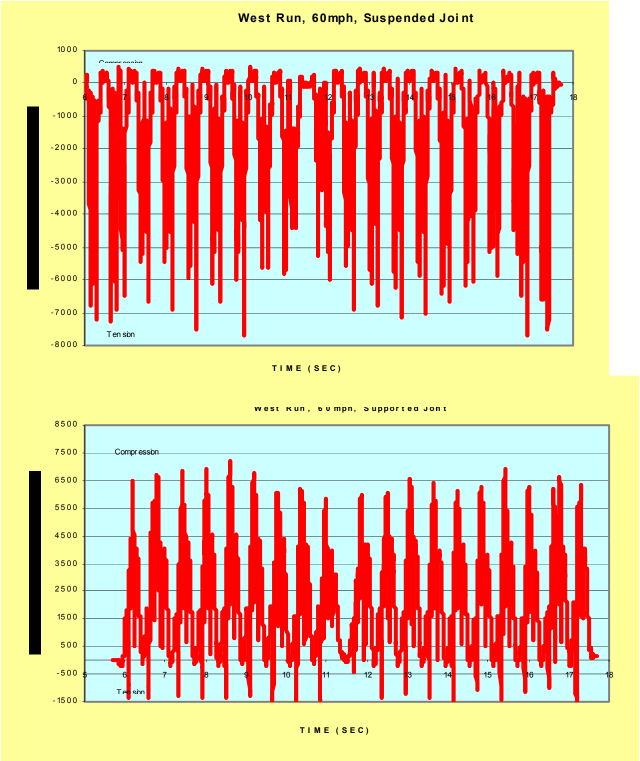


**Figure 4. Bending Stresses in Joint Bars**
**(top) Suspended (bottom) Supported**

Figure 5 shows the frequency distribution of vertical impacts caused by wheels running at various speeds. The higher impacts are probably due to flat wheels in the revenue service test train. These loads are likely the cause of metal flow at the end post, increased joint deflections, and degraded ballast.

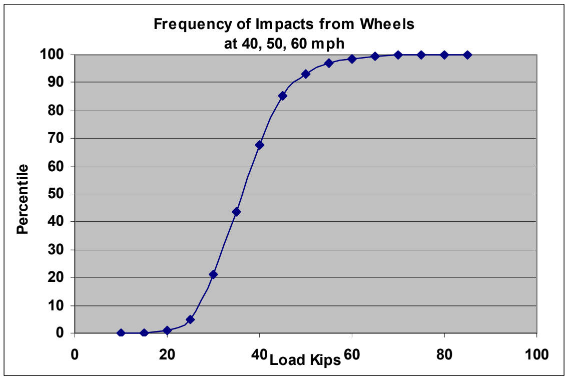


**Figure 5. Vertical Impact Force Distribution over an IJ for a Typical Run**

## FINITE ELEMENT ANALYSIS

A typical 6-bolt insulated joint of RE136 rail was modeled using ANSYS Finite Element Analysis software. The load cases were designed to simulate the most likely operational envelope of the IJ. See Figure 6 for graphical stress distribution for all cases.

### Case 1

A vertical load of 60 kip was applied at the longitudinal center of model. The wheel-rail contact position can move laterally on railheads due to car rocking effects, vehicle dynamics, wheel wear/tear, and wheel negotiation in curves. To simulate this condition, the load was applied at different lateral positions. The analysis predicts that the epoxy under the rail gage corners may be subjected to compressive stress of up to 10 ksi.

### Case 2

In addition to vertical load, a longitudinal tensile load of 300 kip was applied to simulate the thermal forces developed under winter conditions. The analysis shows that stresses in the IJ bars were well below the design yield strength of 70 ksi.

### Case 3

In addition to vertical and longitudinal loads, a differential settlement of 1 inch was applied at one support. This was to simulate the possible degraded foundation due to impacts. FEA predicts that the bars would yield under these conditions. This does not mean, however, that the bars would plastically or permanently deform on a large scale under this condition. When a ductile steel member yields in a small, localized area, the local forces are redistributed so that they are reacted by the elastic material surrounding the yielded material. This redistribution of force results in somewhat lower stress in the yielded material. Permanent distortion would occur only if the yield stress had been reached in a much larger area. As a result, it may be reasonable to assume that IJ bars have the tendency to yield under this load environment. The axial stresses due to preload in the bolts remained less than yield strength in all load cases. These stresses are about half the yield strength of high strength bolts. It can be reasonably assumed that IJ bending alone does not cause bolt failures. However, torsion caused by the location of the wheel contact on the railhead may cause higher principal stresses in the bolts.

Figure 7 shows the non-linear contact pressure distribution between the joint bars and rail. The pressure is highest close to the bolt holes and reduces away from the bolts. The epoxy failure and temperature changes are believed to further reduce the contact pressure between joint bars and rail. This can cause the IJ to change from “slip-critical” to “bearing type” joint.

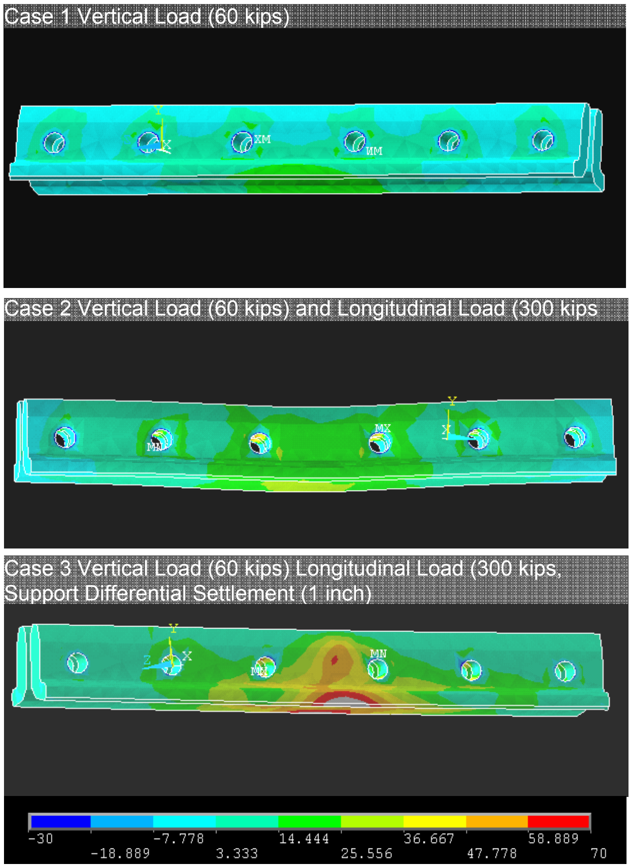


**Figure 6. Principal Stress Distribution in IJ Bars**

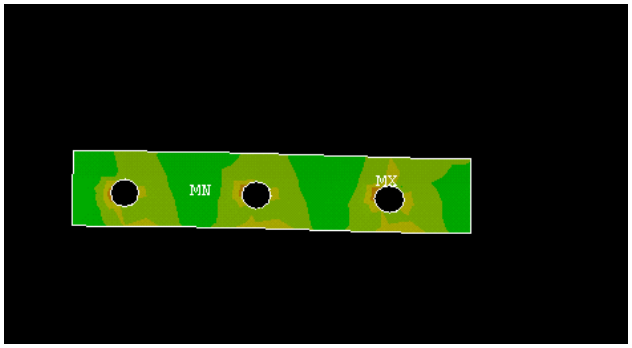


**Figure 7. Non-linear Contact Pressure Distribution between Bars and Rail**

In bearing type joints, the bolt holes are subjected to shear and contact stresses. Under assumed loading on the model, the calculated shear stresses are close to the material yield limit. These shear stresses together with residual stresses may cause localized plastic deformation of bolt holes. The contact stresses may also cause crushing of the thimbles and epoxy in the bolt holes.

The model was created using solid brick, pretension, and contact elements. The pretension elements have the ability to simulate preload in the bolts. The contact elements were used to calculate contact pressures induced in epoxy due to preload of bolts. The load from one rail to the other was transferred through bars using only contact pressure.

The model was created to simulate a 36-inch-long overhanging on 19.5 inch center-to-center supports. The model was free to move at supports in the longitudinal direction (z-axis) and restrained in the vertical (y-axis) and the lateral (x-axis) directions. The right end was restrained in the z-axis and free to move in the x and y directions. Longitudinal load was applied on the other end.

The FEA results were validated using real time load and deflection measurements.

## RECOMMENDATIONS

- Reduce deflections and relative rail-bar movement:
  - IJ deflections should be reduced by increasing tie bearing area.
  - IJ designs could be more forgiving to foundation conditions. This may be accomplished by using higher modulus joint bars and larger diameter bolts.
  - Increase number of bolts of higher diameters to allow increased preload and improved contact pressure between rail and joint bars.
- Reduce/mitigate effects of impacts:
  - Add damping to the IJ foundation.
  - Use commercially available noise and vibration rubber pads under tie-plates and ties
- Review processes and design parameters:
  - Review quality control of materials and assembling process of IJ components is recommended
  - The epoxy strength and flexibility should be improved at the end post and in the bolt holes.

## Reference

1. Davis, David D., Don Guillen and D. Collard. “Bonded Insulated Joints Performance in Mainline Track,”. *Technology Digest* TD-04-006, April 2004, Association of American Railroads, Transportation Technology Center, Inc.