TECHNOLOGY DIGEST
TD-07-020
©JULY 2007
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.

Evaluation of Improved Designs for Bonded Insulated Joints in HAL Service

David D. Davis, Muhammad N. Akhtar, John Bosshart*, Ed Kohake,** and Tom O'Connor***

SUMMARY

Prototype testing of insulated joints (IJs) for heavy axle load (HAL) freight service is being conducted on some of the busiest coal routes in the world. Transportation Technology Center, Inc. is assisting BNSF Railway and Union Pacific in evaluating the performance of IJs in HAL coal service. Preliminary results from field evaluation of many prototypes are presented here.

IJ performance in HAL freight service is improving with a combination of better designs and foundations. Many of the improved designs are performing well in HAL coal lines, with expected service lives of 600 million gross tons or more. This is two to three times the life of a standard IJ in the same service.

Improvement of IJ performance in HAL freight service is a primary strategic objective for North American railroads to eliminate or reduce the adverse impacts of IJ failures on network service reliability.

While testing is ongoing, several approaches for service life improvements look promising:

Foundations

Supported joints will lower deflection and epoxy shear stress significantly. Direct support with a crosstie and an insulated plate are the best configurations. Multi-tie plates alone are less effective, but still provide benefits. Less effective yet, but still providing benefits are configurations that use smaller tie spacing or larger ties on conventional spacing.

Components

For reasons still not fully understood, tougher insulators between rail and joint bars provide service life benefits. IJs with Kevlar™ insulators between rail and joint bars are providing longer service lives than similar joints with conventional fiberglass insulators.

Methods of better sealing the rail-epoxy interface such as sealants and liner gaskets around joint bar ends are providing some benefit in reducing early failures. The ingress of water into the joint is still likely to happen after some IJ wear and deformation. Thus, additional work in developing more weather resistant epoxies is needed.

Advanced Designs

Angle-cut IJ designs address the major failure modes of the current designs: dynamic loads and high epoxy shear stresses. These designs have been effective in reducing deflections, IJ caused dynamic loads, and epoxy shear stresses. Running surface profile and rail material durability become more important issues with these improved designs.

*** Director, Track Standards & Procedures, BNSF**
**** Sr. Manager, Methods & Research, Union Pacific**
***** Asst. Manager, Track Standards, BNSF**

Please contact **David Davis (719) 584-0754** with questions or concerns regarding this *Technology Digest.* E-mail: david_davis@ttci.aar.com.

TTCI
Transportation Technology Center, Inc.

INTRODUCTION

Field testing of innovations for bonded IJs is being conducted on some of the most severe service environment tracks in North America. Prototypes are evaluated on the Powder River Basin coal lines of BNSF Railway (BNSF) and Union Pacific (UP). These routes carry 200 to 400 million gross tons (MGT) per year on two to four tracks. The typical train is a loaded coal train with 286,000-pound gross rail load cars. Figure 1 shows a schematic map of the coal lines with prototype IJ tests.

Figure 1. Western Coal Route IJ Test Locations

FIELD TEST LIMITATIONS

Field testing is the ultimate proof test of any design. In that regard, it offers the opportunity for rapid prototype evaluation and further development. For this reason and the strategic need for better IJ performance, field testing has been used extensively for IJ research and development.

There are limitations to the use of revenue service field testing for prototypes. Among these are the effects of uncontrolled variables. Compared to a test environment like, for example, the High Tonnage Loop of the Facility for Accelerated Service Testing at the Transportation Technology Center (TTC), Pueblo, Colorado, revenue service has more uncontrolled variables that may affect the outcome of the tests. Among these are:

- Train speeds
- Track support conditions
- Rail longitudinal stress
- Tonnage rates
- Lack of appropriate control cases

These variables can have a significant effect on results of small sample tests. The typical IJ test consists of a relative handful of samples. In many cases, there is one or a pair of IJs of a given design in test. A companion *Technology Digest*, TD-07-14, describes the results of controlled tests at FAST used to help develop the prototype.[1]

FIELD TEST RESULTS

The usual field test consists of observing the performance of the test IJ in service, noting any failed components, unusual maintenance required, and service life in track. As the determination of service life is somewhat arbitrary, this can make objective comparisons (remembering the potential effects of uncontrolled variables) somewhat difficult. However, the goal of IJ research and development is to significantly improve the performance of IJs in HAL service. Thus, the tests are designed to be relatively insensitive to small improvements. The risk of the revenue service testing approach is that a good idea may be lost due to random chance, such as an early failure of a single prototype or the selection of an inappropriate test site.

Load Environment

Characterization of the load environment has been an important part of the IJ Strategic Research Initiative. IJs have shown the same sensitivity to wheel load as other special trackwork, such as crossing diamonds, turnouts, and rail joints on bridges. Significant reductions in service life have been documented (up to 90 percent) from nominal 33 to 40 kip wheel loads.[2]

Quantifying, documenting, and understanding the effects of wheel load increases, and the true service load environment is needed to improve the performance of IJs in HAL service. Thus, a brief update on the measured service environment will be presented in terms of its effect on design decisions.

Vertical Dynamic Loads

Vertical dynamic loads come from two sources: (1) vehicle caused and (2) track caused. Table 1 lists the dynamic load environment for HAL IJs. IJ design cannot affect vehicle caused dynamic loads, but IJ design can affect the track caused dynamic loads. A smooth transition is needed at IJs. These abrupt changes lead to discontinuities that result in high dynamic forces. Track stiffness and the rail running surface must change more gradually than they do with current designs.

Table 1. Dynamic Load Environment for HAL IJs

Load	Source	Maximum Value	Effect on Design
Vertical Dynamic	Train caused (e.g., wheel surface)	180 kips (5 x static) Most of fleet < 1.2	Emphasize impact resistant materials
Vertical Dynamic	Track caused (e.g., IJ endpost gap)	100 kips (3 x static) Most IJs ~2.0	Requires smooth running surface and stiffer IJs
Longitudinal	Weather, rail stress management policy	500 kips	Supported IJ configurations preferred

Longitudinal Loads

Changes in temperature of rail result in thermal forces that affect IJ performance. For typical mainline rail sections used, about 2.5 kips of force change per degree Fahrenheit (°F) of temperature change can be expected. Thus, a range of longitudinal forces of about 300 to 500 kips is expected in places with 120 to 200 degree rail temperature changes over the year.

Of importance to note is the effect of foundation/tie support on the interaction of the longitudinal and vertical loads on IJ epoxy shear stresses. For conventional suspended IJs (where the endpost of the joint is over a ballast crib), the shear stresses from longitudinal tensile forces and vertical loading are additive at the endpost. However, when the IJ is supported (i.e., there is a tie or plate under the endpost), the resulting shear stresses are of opposite sign. The maximum shear stress moves away from the endpost. The maximum is generally lower, as well.[2]

PERFORMANCE RESULTS BY CATEGORY

Reflecting the importance of the problem to the industry, many prototypes are in test on western coal routes. The results, often still preliminary, are presented by category of design/problems addressed. The categories are:

- Bigger components: to produce IJs with more load capacity
- Better foundations: to reduce IJ deflection overall and bar-to-rail movement
- New materials: more durable components to withstand fatigue and environmental degradation
- Better designs: to reduce (or mitigate the effects of) dynamic loads

BIGGER COMPONENTS

A series of prototypes were built that have bigger components. The general idea is to make the IJ rail components properties (i.e., vertical stiffness) match the surrounding rail.

High Modulus Bars

These were designed to match the IJ to the rail vertical stiffness. Stress analysis suggests that the epoxy shear stresses will still be high relative to the ultimate strength of the epoxy. The expected failure mode is epoxy unzipping. Performance in track to date has been good, with average service of 210 MGT to date and performing well.

Wrap-Around Bars

Wrap-around bar joints were designed to exceed the vertical stiffness of the rail. The design has bars that wrap around the base of the rail, essentially creating an integral bearing plate for the rail base, as Figure 2 shows. The expected failure mode for this design has not been determined. To date, their performance has averaged 186 MGT in track.

Figure 2. Wrap-Around Bars in Revenue Service Testing

Thick-Web Rail

The thick-web rail IJ is intended to reduce deflections and maximum epoxy shear stresses. The design may also require a supported foundation to be successful. The expected failure modes are running surface fatigue and epoxy failure. Thick-web rail joints have been in track for 385 MGT to date and are performing well.

BETTER FOUNDATIONS

The design of a practical foundation of IJs, frogs, and switches is an age-old problem. Currently used bonded IJ designs are vertically weaker than the parent rail. Thus, the IJ has more deflection under load than the surrounding track. Another approach to remedy this problem, other than the stiffer IJ rail components described above, is to improve the foundation under the IJ. This approach has the advantages of being a semi-permanent installation that would allow continued use of the existing IJ steel design.

Three-Tie Plate, 8-Hole Bars

The combination of a longer joint and an improved foundation is providing service life benefits. The supported foundation provides benefits by reducing epoxy shear stresses as described above. While no comprehensive records exist (although there are now many in service), the expert opinion is that these IJs are providing a longer service life, perhaps 300 to 400 MGT versus 200 MGT. The effects of longer bars versus direct support cannot be separated in these tests. However, the effects of the foundation should be greater, based on analytical work. The failure modes are similar to the unsupported joints, in that the epoxy still fails. Additional development work is needed to reduce fatigue failure of the multi-tie plates. Figure 3 shows the three-tie plate, direct support foundation used by UP.

Figure 3. Three-Tie Plate, Direct Support Foundation

BNSF uses wood tie panels (in concrete tie track) for track transitions and high dynamic load segments like IJs. The panels have wider standard ties under the IJs, typically 11 inches versus 9 inches, and longer standard ties on the whole panel, 9 1/2 feet versus 9 feet. The panels provide additional track damping with a footprint similar to concrete ties. The change in tie type does create two new transition zones 20 feet away from the IJs. While no comprehensive records exist (although there are now many in service), the expert opinion is that these wood panel IJs are providing a longer service life, perhaps 300 to 400 MGT. The effects of new ties and ballast versus the material change cannot be separated in these tests.

NEW MATERIALS

Durability is a key issue for all track components, as they are required to survive for up to hundreds of millions of load cycles.

Weathering is also a potentially significant factor. The service environment is quite demanding for non-metallic components. Rail temperatures can range from -40 to +160 °F. Also, the IJ serves in what could be described as a ground contact environment, with the potential for many wet/dry cycles.

Stronger, Tougher Insulators

Stronger, tougher insulators provide benefits to IJ service life. Kevlar has been used to replace the fiberglass insulator cloth that is placed between rail and joint bars. The insulator is embedded in the epoxy layer of bonded joints and serves the functions of spacer, insulator, and epoxy reinforcement. Conventional epoxy joint lab testing of Kevlar joints shows them to be no stronger and marginally more durable than fiberglass cloth joints. However, revenue service testing shows them to provide a significantly longer service life. Combined with a direct support foundation, Kevlar joints are expected to provide a 600 MGT service life. It is speculated that Kevlar performs better in the more complex load environment of the field (where impacts and multi-planar stresses occur).

Liners and Flexible Epoxies

More flexible epoxies and rail liners that inhibit water entry into the IJ end post area are being tested. These changes have not been entirely successful in keeping water out of the joints, based on observations of rust leeching from some prototypes. However, they appear to be addressing a major cause of degradation in lower tonnage rate applications. They are likely to have a bigger performance and economic impact in these applications.

Solid epoxies are also in test. This type of epoxy is applied as a sheet and then heated to conform and bond to the steel surfaces. Their performance has not been as good as the conventional bonded IJs to date.

Ceramic Coatings

Lab shear testing of epoxies without a mesh insulator shows the joint to be stronger than those with an insulator layer. Thus, development of a strong, durable insulating rail coating will permit a stronger epoxy layer and elimination of extra parts. One pair of bonded IJs with ceramic coatings on the rail and joint bars is in test, with 310 MGT of service to date.

BETTER DESIGNS

Designs that attempt to address the issues of reducing IJ caused dynamic loads and improving the mechanical efficiency of the current IJ design are described in this section.

UP Taper-Cut IJs

The taper-cut IJ is designed to reduce maximum epoxy stresses by two thirds. This design differs from recent 45-degree joints in that it is designed to be a more efficient joint.

Recently, UP installed the first revenue service test of lapped joint or taper-cut IJs. These joints have performed well in 100 plus MGT of HAL testing at TTC. Figure 4 shows a taper-cut IJ in field testing.

Figure 4. Taper-Cut IJ in Revenue Service Testing

Reconfigured Insulation

The typical bonded IJ isolates the rails from each other, the rails from the joint bars, and the rails from each bolt. The joint bars and bolts are electrically connected. Under tensile stresses, the joint bars can move relative to the rails, causing failure of the bolt sleeve insulation at the rail/bar/bolt hole interface. To address this problem, a reconfigured design that isolates the bolts from the joint bars is in test. As the joint deteriorates or slips, resulting force exerted on each bolt's insulation is reduced twofold. The bolt is also able to be replaced. In the typical standard design, insulation fails and replacement of bolt is not possible without shunting the circuit. Figure 5 shows this design. Several joints of this design are in test with average service of 170 MGT to date.

Figure 5. Reconfigured Insulation IJ

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the technical and logistical help of Eric Olson, BNSF and Dwight Clark and Sam Atkinson, UP in the conduct of the inspections reported in this *Technology Digest.* Their expertise in track design and maintenance are the source of many of the ideas developed into the prototypes described.

REFERENCES

1. Davis, David, et al. May 2006. “Analysis of Conventional and Tapered Bonded Insulated Joints.” *Technology Digest* TD-06-014. Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.

2. Davis, David, et al. February 2002. “Results From Special Trackwork Experiments at FAST.” Research Report R-954. Association of American Railroads, Transportation Technology Center, Inc., Pueblo, Colorado.