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Premium and Next Generation Insulated Joints in Heavy Axle Load Revenue Service

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Summary

Nearly a decade ago, the average service life expected from a conventional epoxy insulated joint (IJ) in heavy axle load (HAL) service was estimated to be between 150 and 300 million gross tons (MGT). Since then, significant improvements in quality control and implementation of new designs and materials have brought the expected average service life for these products to about 500 MGT. New improvements continue to be made to individual components as well as enhancements to the traditional IJ design that are pushing the service life of IJs well beyond 500 MGT. This *Technology Digest* reports on the latest results of the premium and next generation IJ testing in the western mega site, including their life expectancy based upon current results from revenue service testing.

In August 2011, 42 IJs of premium and next generation designs were installed within the western mega site in Nebraska. To date, five failures have been recorded between 391 and 654 MGT, and the remaining in-service IJs are preforming acceptably after more than 750 MGT. Testing involves regular inspections of the IJs in revenue service, noting any failed components, unusual maintenance requirements, and service life in track.

By monitoring long-term performance of premium and next generation IJs in the HAL revenue service environment, common failure modes among these products can be defined when failures occur, providing valuable feedback to both railroads and suppliers. The dominant failure modes observed within the western mega site are metal flow and rail-end chipping for IJs with a butt-joint configuration. Rolling contact fatigue, in the form of head checks and spalling, has been a prevalent issue for IJs with an angled cut design.

In addition to the western mega site, performance of premium and next generation IJs are being actively monitored at multiple revenue service locations in order to provide in-track service life for life expectancy estimations. Weibull survival analyses have been utilized to provide estimates for the various premium and next generation designs currently available, though additional data is required to improve the accuracy of these estimates.

This investigation is being undertaken by the Transportation Technology Center, Inc. under the sponsorship of the Association of American Railroads and Federal Railroad Administration.

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INTRODUCTION

IJs are used extensively in the railroad's train control system as a means for dividing the mainline into smaller electrically isolated signaling blocks. Movement between these blocks is governed by a series of traffic control signals on each end of the block, which communicate the occupancy or obstruction of the adjacent blocks to the locomotive engineer. IJs prevent unintentional shunting of the track circuit between adjacent blocks.

Research results from 2004 indicate the average service life of a conventional IJ to be approximately 150–300 MGT.[1] Improvements in quality control have brought the service life expected for IJs to about 500 MGT.[2] Continued improvements to individual components as well as new designs are pushing the service life of IJs beyond 500 MGT.

In August 2011, 42 IJs of premium and advanced (i.e., next generation) designs were installed within the western mega site. The primary objectives of this study are as follows:

- Monitor and measure long-term performance of premium and next generation IJs in the HAL revenue service environment
- Define the failure modes associated with the designs involved when such a circumstance occurs

Field testing involves regular inspections of the IJs in revenue service, noting any failed components, unusual maintenance requirements, and service life in track. These test IJs were installed on the major heavy haul coal route through western Nebraska, near Northport and North Platte. These mainline tracks receive approximately 200–250 MGT/year and 120–150 MGT/year respectively from predominantly 286-kip gross rail loads operating at speeds between 40 and 50 mph. All of the test IJs within the western mega site reside (most supported) on standard concrete ties.

CURRENT PREMIUM IJ DESIGNS

The premium IJs currently available feature improvements in the strength of individual components by means of either larger components (e.g., longer bars) or components manufactured from new, more durable, materials (e.g., ceramic end posts), thus increasing the load capacity of the IJs as well as their resistance to fatigue and weathering. Premium IJ designs installed in the western mega site include the following:

- IJs with ceramic end posts (i.e., end posts featuring ceramic disks embedded in the electrically insulating material)
- IJs with high-modulus bars, which allow the vertical stiffness of the IJ to be more comparable to that of the adjacent rail
- IJs with improved epoxy
- Center-supported IJs, which feature a high-strength insulating material that increases the stiffness of the joint through mechanical wedging action between the bars and the rail
- IJs with 48-inch, 8-hole bars

To date, one IJ, featuring a 48-inch, 8-hole bar with Kevlar® insulation and fiberglass end post, was removed after 391 MGT due to epoxy failure and severe rail-end batter. Due to identical reasons, a 48-inch, 8-hole bar with a ceramic end post was removed after 443 MGT. The IJs remaining in service have accumulated approximately 753 MGT as of December 1, 2014, and have performed acceptably.

If not properly addressed by joint slotting, metal flow can develop over the end post, as Figure 1 shows. Aside from the obvious fact that this may lead to the electrical failure of the IJ, deflections under wheel loads will cause this metal flow to chip out or batter, resulting in the situation shown in Figure 2. As other component- and foundation-related issues have been resolved, metal flow issues are becoming the primary failure modes associated with the premium IJs in revenue service.

Figure 1. Severe Metal Flow developing over the End Post

Figure 2. Severe Rail-End Batter at the Joint

As the improvements associated with the premium IJ designs focus on strength of individual components and do not significantly alter the design of the IJ, the running surface still features a discontinuity that causes wheel impacts by passing traffic. These impacts can increase significantly when rail batter, to the extent shown in Figure 2, is present. In a previous study, TTCI has identified high-frequency wheel impacts as a significant root cause of IJ failures,[3] resulting in increased stress on the IJ components. This is the likely reason for the failure of the two aforementioned IJs that experienced epoxy failure and rail-end batter.

NEXT GENERATION PROTOTYPE IJ DESIGNS

Advanced, or next generation, prototype IJ designs are also being monitored along with the premium IJs in the western mega site. These designs effectively improve upon the conventional IJ design by involving features that help reduce dynamic loads. The two designs currently being tested include:

- Taper cut IJs, which provide for a smooth wheel transition between the two adjoining rails through the use of an angled cut, effectively reducing impacts resulting from running surface discontinuities. The longer LAP™ joints were evaluated in this test.
- Keyed IJs, which feature keys (partially embedded in the rail and joint bars) placed at the bolt locations, allow longitudinal loads to be transferred through the keys rather than through the weaker epoxy bond.

Taper cut IJs, as well as supported IJs with 48-inch, 8-hole bars, were instrumented with strain gages with a sampling rate of 512 hertz after approximately 250 MGT in order to measure bending stresses continuously in the bar under dynamic loads. This data was compared to measurements taken on suspended IJs over hardwood ties with 48-inch, 8-hole bars under 315-kip gross rail loads at TTCI's Facility for Accelerated Service Testing. The results show a notable decrease in bending stresses for the supported situation and even larger decrease for taper cut IJs (Figure 3). The larger 12-hole bars in the taper cut joint, combined with the angled transition zone, are effective in reducing bending stresses in this IJ design.

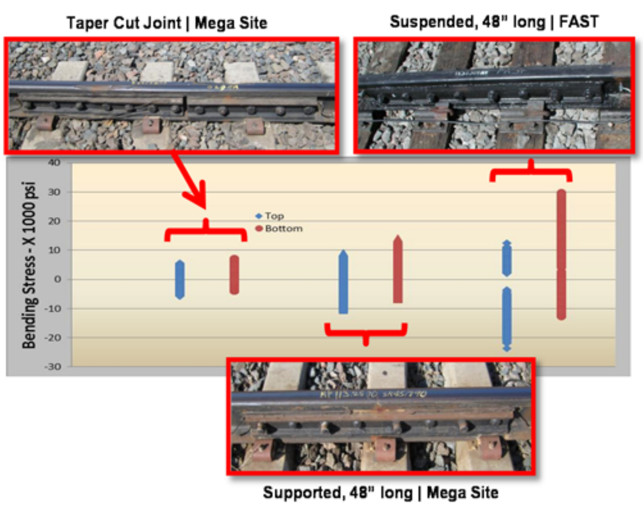

Figure 3. Bending Stresses for Taper Cut IJs and IJs with 48-inch bars in Supported and Suspended Applications

To date, however, three taper cut IJs have been removed from revenue service due to different failure modes, namely a fracture emanating from the bolt hole, a transverse rail defect, and severe spalling on the gage corner (Figure 4). These failures occurred between 515 and 654 MGT. The taper cut IJs remaining in service, with accumulated tonnages between 252 and 753 MGT, are performing acceptably. Although, rolling contact fatigue (RCF) has been a common issue among most of the taper cut IJs being tested in revenue service. RCF is related to the wheel-rail interaction during the short transition between rails.

Figure 4. Severe Spalling on the Gage Side of the Taper Cut IJ

The taper cut IJ containing the transverse defect was shipped to the Transportation Technology Center in Pueblo, Colorado, to be destructively disassembled to determine the root cause of the defect. Although efforts were unsuccessful in breaking open the defect, it was determined that the defect was located on the gage side rail, near the longitudinal center of the IJ. The defect area started from the side facing the long-angle cut and was located between 0.3 and 1 inch below the top surface, with a width of approximately 0.75 inch.

Keyed IJs, developed by TTCI, have adapted well to revenue service applications and continue to perform well under HAL traffic. Each key is capable of resisting 800-kip loads without failure and previous studies have shown that keys are not necessary at each bolt hole for the IJ to benefit from the improved strength this design provides compared to current designs relying on epoxy for load transfer.[4] Given this, the keyed IJs are very effective in resisting adverse longitudinal forces that would typically fatigue conventional epoxy IJs (Figure 5).

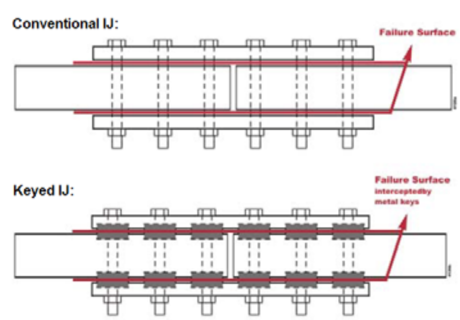

Figure 5. Comparison of Longitudinal Load Transfer

There are six keyed IJs in service within the western mega site, namely the North Platte terminal. To date, one was removed after 57 MGT for unknown reasons. The remaining keyed IJs have accumulated more than 270 MGT as of December 1, 2014, with no potential failure modes present.

Four additional keyed IJs have been installed on a major heavy-haul coal route within the eastern mega site as well, where they are performing similarly well after more than 190

MGT to date. These IJs were installed in suspension over hardwood crossties. This mainline track receives approximately 40–50 MGT/year of predominantly 286-kip gross rail loads operating at speeds between 20 and 30 mph.

LIFE EXPECTANCY ESTIMATES

In order to better compare the service lives of the various designs currently in use within revenue service, TTCI, with support from suppliers and host railroads, is actively monitoring premium and next generation designs in multiple sites around the United States for long-term performance. A sample of 100 premium and next generation IJs from revenue service, broken down between six different products (Table 1), were selected to conduct an updated Weibull survival analysis. This analysis provides life expectancy estimates for the different products listed in Table 1.

Table 1. Breakdown of the Selected IJ Sample

TYPE	Still in Service	Removed without Failure	Failure	Total by TYPE
Center Supported	13	0	5	18
Ceramic End Post	11	0	4	15
Improved Epoxy	8	0	3	11
High Modulus*	11	0	0	11
Keyed*	15	2	1	18
Taper Cut	17	2	8	27
Totals	**75**	**4**	**21**	**100**

*Insufficient number of failures to conduct Weibull analysis; Weibayes analysis utilized instead

In addition to these IJs currently being monitored in the western and eastern mega sites, identical designs being tested on a Class I railroad in the southwest region (80–100 MGT/year) were also included in this analysis. IJs that remain in service and those removed for reasons other than a failure (e.g., weld removal) are included in the analysis as censored data. Where applicable, the Weibull and logistic distribution were used to determine the survivability of the IJ designs and, in turn, provide a 95 percent confidence interval (CI) for the median tonnage to failure. In the case there was insufficient samples for a proper Weibull analysis, a Weibayes analysis was used assuming a normal life ($\beta = 1$). The results are provided in Table 2. Note that as more data is collected (both tonnage and failures) the median tonnage-to-failure estimates generally increase.

Table 2. Results of the Weibull/Weibayes Analyses

TYPE	Censored	Failure	95% CI for Median Tonnage to Failure
Center Supported	13	5	566 - 747
Ceramic End Post	11	4	399 - 804*
Improved Epoxy	8	3	295 - 1,045
High Modulus	11	0	649**
Keyed	17	1	616**
Taper Cut	19	8	343 - 1,340

* Logistic distribution ** Weibayes lower-bound estimate

Figure 6 shows the survival plot, representing three designs that could be analyzed using the Weibull survival analysis. The plot shows the number of failures in service was sufficient enough for the center-supported IJs to provide a narrow CI, providing a more reasonable estimate of the service life for this design.

Other IJ designs still require more failure to be recorded for a more accurate estimate of service life in revenue service. In the case of the taper cut IJs, a number of failures have already been observed, though the initial quality of this design has significantly improved with recent products, resulting in a much larger CI.

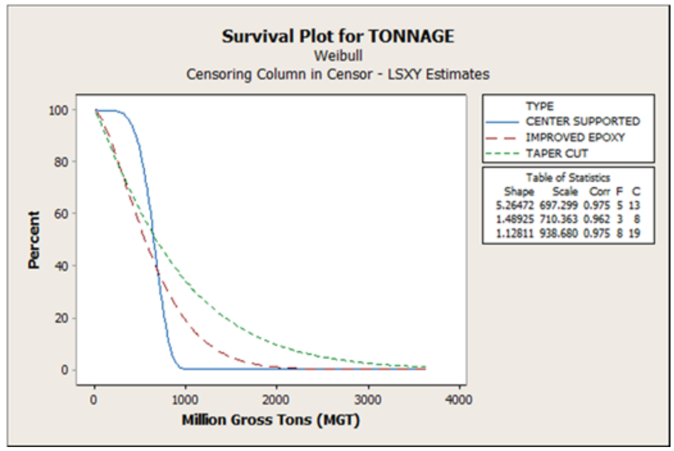

Figure 6. Survival Plot for the Results of the Weibull Analysis

FUTURE WORK

TTCI will continue to monitor the test IJs still in revenue service and provide a more refined life expectancy estimate as more failures are recorded. With these improved estimates, a cost-benefit analysis will be completed using the various designs of IJ currently available in the industry.

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