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Effects of Lengths and Cross Sections of Joint Bars on Rail Joint Forces

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Summary

This *Technology Digest* discusses on-going research regarding the rail and rail seat interaction forces due to the abrupt stiffness changes caused by rail joints. These stiffness changes are affected by lengths and cross sections of joint bars. Different joint bar lengths and cross sections were modeled using beam on elastic foundation and finite element analysis techniques. The results were further validated under quasi-static conditions with experiments performed at the Facility for Accelerated Service Testing under the Association of American Railroads' Strategic Research Initiatives Program. Findings from the study are presented below.

- For non-insulated, bolted mechanical rail joints:

Rail seats under joints with 36-inch bars experience 20 percent higher loads than rail seats under continuous rail. The increase in static load likely contributes to increased ballast degradation under joints. Joints with 48-inch bars experience 10 percent lower rail seat loads than 36-inch joint bars, and thus, are expected to reduce ballast degradation under joints. Besides improved load distribution, 48-inch joint bars also increase bending and longitudinal strength of joints.

- For insulated, bonded rail joints:

Insulated rail joints behave similar to continuous welded rail because of the adhesive. The current cross-sectional area of the joint bars appears to be satisfactory for transmitting load to the cross-ties. That is, the resulting rail seat load from joints is similar to that produced by the same loads over continuous loads. A significant increase in joint bar cross-sectional area may increase the difference in stiffness between the continuous rail and insulated joints. This condition may create similar problems to those seen in track at bridges/bridge approach transitions.



INTRODUCTION

Rail joints, both non-insulated and bonded insulated, are discontinuities in the running surface of the track. While they may not be as big a discontinuity as a turnout or crossing diamond, they still have the potential to create high dynamic loading, resulting in increased maintenance and reduced service life. This *Technology Digest* (TD) evaluates the effects of joint bar lengths, cross sections, and joint types on the forces transmitted by the rail joint to the supporting crossties and ballast.

BACKGROUND

At the rail end gap of a rail joint, both the cross-sectional area and moment of inertia are minimums for the joint assembly. The current trend in the industry is to increase the lengths and cross sections of joint bars. Larger cross sections and longer lengths are believed to increase joint resistance to bending and longitudinal loads respectively. However, a sudden increase or decrease in stiffness over a small length can alter the load distribution and how it is transferred from joints to ties. This TD discusses, analytically and experimentally, the effects of these two parameters on joint and foundation loading, and recommends optimum lengths and cross sections.

Analytical modeling shows that the wheel load path of bonded insulated joints (IJs) and non-insulated joints are different. In the case of an IJ, wheel load induced in track changes in a step function at the joint assembly ends where there is a change (i.e. an increase) in stiffness. This is due to the assumption that the joint bars are fully bonded to the rail along their entire length. The magnitude of load change is proportional to the difference in the magnitude of bending stiffness of the joint assembly and the rail. Load on each uniformly spaced crosstie in track increases when a wheel moves from the rail to the joint. Obviously, the joint bars must be sized appropriately to carry the expected thermal, bending, and shear loading. Within this requirement, use of smaller bars will reduce the additional loading on crossties and ballast from the joint. Increasing joint bar length may have some other benefits like higher resistance to longitudinal load and spreading impact load over a greater distance along the rail, but the analytical model, using the input described in this paper, does not indicate differences in the load transfer mechanisms in track.

A wheel load tends to concentrate tie loading directly under the non-insulated joint. Thus, in current installation and maintenance practices, using higher cross section joint bars for non-insulated joints is beneficial. Also, longer joint bars are expected to distribute load to a larger area, reducing the unit tie load and the ballast degradation rate.

Experience has shown that joint stiffness affects load distribution, increases metal flow at rail ends, and increases railhead chipping.

ANALYTICAL MODELING

Moment of inertia of joint assembly increases by about 33 percent where the joint bars are attached to the rail and reduces by about 66 percent where there is a gap in the rail and only joint bars are holding the rails. Moment of inertia of joint assembly can be calculated by adding the moment of inertia of each component, such as joint bars and rail. Because IJ components are bonded as well as being fastened, moment of inertia of IJ assembly may be similar to calculated moment of inertia of joint assembly.

In non-insulated joints, all components do not act as a solid assembly. Bolt torque in joints reduces over time. The practice of using four bolts instead of six bolts further complicates calculation of actual moment of inertia of the joint. Thus, the assumed compression joint may become a pin connected joint. In this way, the actual moment of inertia of the non-insulated joint may be significantly lower than the assumed moment of inertia of the joint assembly. Estimation of moment of inertia of a typical non-insulated joint is a matter of engineering judgement. Figure 1 shows the estimated moment of inertia used in the current analytical model.

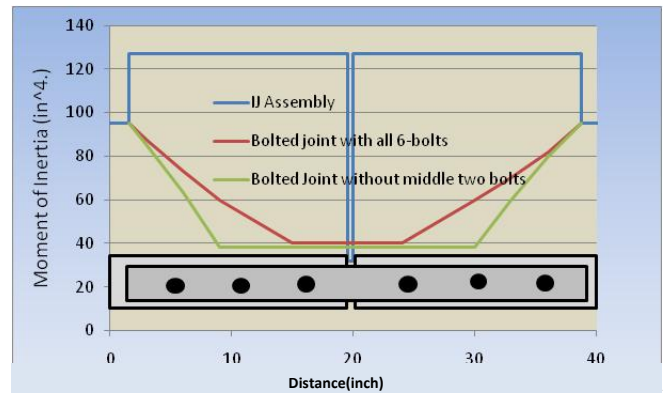


Figure 1. Moment of inertia along rail joint assembly

An equation that assumes that track is a beam (rail) with closely spaced springs (crossties) was used to analyze the effects of changes in rail stiffness. The model was developed by Winkler, modified by Schwedler and tested by Kerr.¹

$$P(x) = \frac{P\beta}{2} e^{-\beta|x|} [\cos \beta |x| - \sin \beta |x|], \quad \beta = \sqrt[4]{\frac{k}{4EI}}$$

Where,

P = 31,000 pounds, difference between loaded and unloaded condition

P(x) = Pressure along any point on track

k = Vertical track modulus, 4,000 psi

E = Modulus of Elasticity of rail, 30E6 psi

I = Moment of Inertia of rail or joints, varies from 36-195 in⁴.

Pressure (at rail seat/top of crosstie) was calculated using moment of inertia of IJ assembly (195 in⁴) for the length of the joint and moment of inertia of (95 in⁴) of rail was used

before and after the rail. Pressure on the continuous beam was converted to force, as Figure 2 shows.

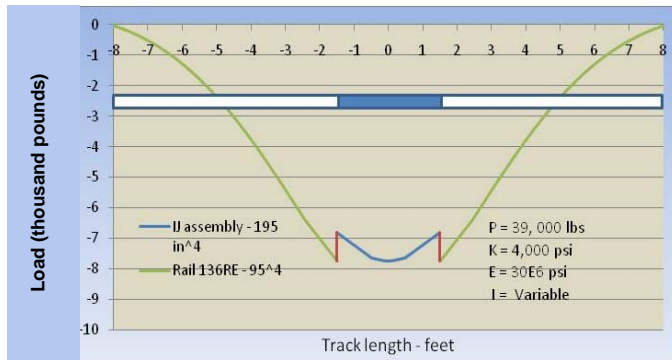


Figure 2. Variation of wheel load induced from IJ and rail to substructure

Figure 2 shows that there is a step change in force as the wheel moves from lower stiffness track (rail) to higher stiffness track (joint assembly). The step change is proportional to the change in stiffness. Due to this force change, IJ assembly is likely to experience a higher rate of ballast degradation. This is manifested as degradation at the ends of joints. A 36-inch joint is supported on two ties with the end post at the center of crib. The ends of the joint overhang 4 inches in the cribs beyond the tie. Thus, a change in force due to stiffness at the IJ end is likely to cause ballast deterioration around and under the tie supporting the joint.

The stiffness of a non-insulated joint is dependent on the number of bolts and their torque and is generally lower than the rail. The portion of joint assembly between the inner two bolts may have actual stiffness equal only to that of the joint bars. The analysis shows that crossties under a non-insulated joint experience higher loads than the crossties under continuous rail. This is due to the lower estimated stiffness of the joint.

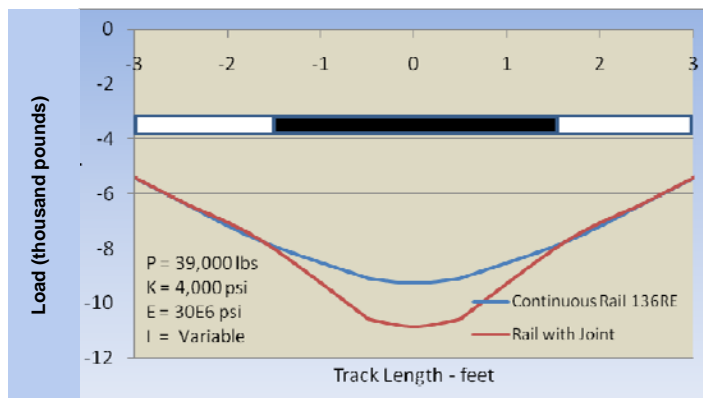


Figure 3. Wheel load induced from non-insulated joints to substructure

The effects of a change in stiffness due to 36- or 48-inch joint bars were also analyzed using finite element analysis. The effects of rail gap and ties were also included, which are typically not possible in the beam on elastic foundation model. Beam elements were used for rail and joint bars. Spring elements were used for ties. A track modulus of 4,000 pounds/inch/inch was used to calculate the equivalent stiffness of the spring elements. Using the moment of inertia, shown in Figure 1, loads induced in ties under joints were calculated. Loads in ties under joints increased by 5 percent as compared to continuous rail. The difference in loads under joints with 36- and 48-inch joint bars was lower.

In both the analyses, the only variable was the moment of inertia of the rail joint assembly. Since the actual moment of inertia is a matter of engineering judgment and actual joint condition, the results are deemed reliable for policy analysis.

EXPERIMENT SETUP

A test was set up to measure the effects of larger cross sections and longer lengths of joint bars in track. Existing tie plates were replaced with strain gaged tie plates. Four strain gages installed on a tie plate measured the wheel forces transferred from the rail. A 20-foot rail plug (Plug A in Table 1) was installed with non-insulated joints on both ends. These non-insulated joints were installed to minimize the effects of thermal force. The rail plug was the control case. When a small train consist moved in clockwise and counterclockwise directions at 2 mph, three types of data were collected: (1) vertical deflections at the center, (2) vertical forces induced into the tie plates from the rail, and (3) bending strains on the joint bars (only for non-insulated joints). The train had one locomotive, one 315,000-pound car, and one 67,000-pound car. The 20-foot rail plug was then replaced with joint plugs (non-insulated cases B-E, bonded IJ cases F-J in Table 1) and data was collected from each plug. On some joints, force in ties from joints was also measured when the train operated at 40 mph.

Table 1. Joints Tested

Plug ID	Joint Type	Area in ²	M.I – in ⁴	Torque ft-lb
	Bolted			
A	Rail – Control	--	--	--
B	36" Joint bars, no gap	5.89	16.14	600
C	48" Joint bars, no gap, 1" bolt	5.64	14.04	600
D	48" Joint bars, no gap, 1 1/16" bolt	5.64	14.04	800
E	48" Joint bars, 1/4" gap, 1" bolt	5.64	14.04	600
	Bonded Insulated			
F	36" Joint bars, 1" bolts	6.22	12.20	
G	48" Joint bars, 1" bolts	6.22	12.20	
H	Lap Joint			No gap in rail
I	High modulus joint	17.50	34.70	
J	Wraparound	13.22	50.92	

DISCUSSION AND RESULTS

Figure 4 shows the load transferred to Ties 1 through 6 from rail and non-insulated joints when the wheel was at the center of Ties 6 and 7 (at the gap). Tie 6 was closest to the wheel and experienced the highest load. The control rail and the 36-inch joint transferred the lowest and highest loads respectively in Tie 6. The magnitude of load from the 48-inch joint was in between that of the rail and the 36-inch joint. The joints tended to concentrate load in the ties directly under the joint. A non-insulated joint with the same cross section but a longer length bar, 48 inches in this case, tended to induce load in the tie that was higher than the rail, but lower than with the 36-inch joint.

Also, the load transfer zone away from the point of application was narrower in the case of joints and wider in the case of rail.

Higher loads under ties from non-insulated joints were due to lower stiffness than rail. Thus, the experimental results were similar to the analytical findings. Higher cross sections that match the properties of rail may mitigate the problem of stiffness difference.

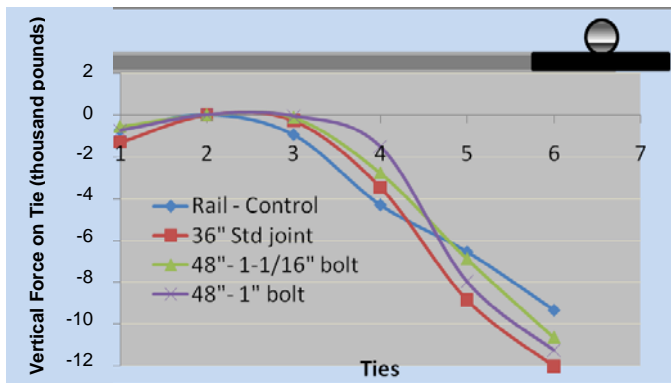


Figure 4. Load transferred to ties through non-insulated joint

As Figure 5 shows, the difference in normalized load of joints and typical rail was less than 5 percent except for the wraparound IJ, which was 15 percent higher. It may be concluded that the load transfer pattern of new standard IJs is similar to the rail. A high modulus joint bar has most of its mass located in the middle. It may be concluded that the mass being at the center of the crib does not change the pattern of load transfer. Similarly, the wraparound joint bar has about twice the stiffness of the rail, which likely increases the load on the tie directly under the joint.

Careful study of causes and effects as stated above is recommended before increasing the joint bar cross sections.

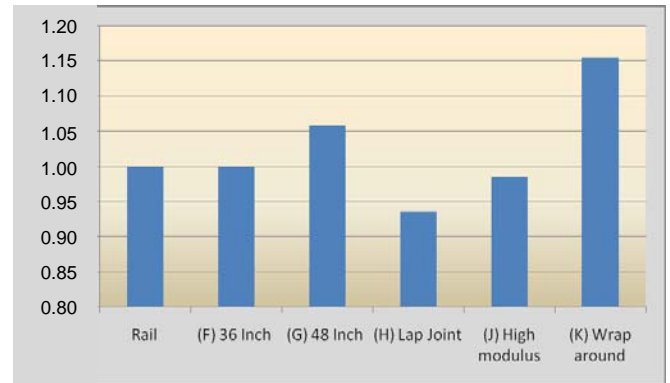


Figure 5. Rail seat loads from IJs normalized to rail

Tie rail seat load under IJs was also measured at 40 mph train speeds. However, the data is inconclusive, because of other joints in the vicinity of the test. It appears that a dip or cusp as far as 50 feet away from the joint may have affected the maximum forces in ties under the joint.

Bending strains under non-insulated joints were measured at 2 mph. The data shows no significant difference in strains between different types of 48-inch non-insulated joints and 36-inch non-insulated standard joint bars. Data collected under a different project funded by Office of Research and Safety of Federal Railroad Administration shows that 48-inch joint bars have lower bending stresses than 36-inch joint bars at 40 mph.²

FUTURE WORK

Analytical modeling and experimental data advocates use of a larger cross section in the middle of joint bars for non-insulated joints. For the next test phase, manufacturing of a new joint bar design with more mass in the center of the joint is planned. Experimental test data will be collected and compared with the data presented in this TD. Also, dynamic performance evaluation of joint bars with longer lengths and larger cross sections is planned.

REFERENCES

1. Kerr, A. D. 2004. *Fundamentals of Railway Track Engineering*. Omaha: Simmons-Boardman Books, Inc.
2. Akhtar, M. et al. 2010. "Effects of Track Parameters on Rail Joint Bar Stiffness and Crack Growth." *AREMA Annual Conference and Exposition*, Orlando, Florida.