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Improved Joint Bar Profile for Heavy Axle Load Environment

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Summary

Transportation Technology Center, Inc. (TTCI) has developed a joint bar profile that is likely to increase performance of rail joints, especially in continuously welded rail. The new profile is likely to reduce three of the four most common service failure modes (i.e., cracking initiated from the top, in the center, and at the bolt holes), and the remaining service failure mode (cracking at the bottom edge) is likely to be reduced by improving the material mechanical properties.

Following are the features of the new joint bar profile:

- Larger contact with the rail web – to reduce contact stresses and metal flow
- Thicker web – to provide better support for the bolt holes, reducing bolt-hole cracking
- Higher bolt torque – to reduce rail to bar slippage, resulting in lower dynamic loads due to the minimum rail end gap
- High relief for worn wheels – to eliminate wheel flange contact with the joint bar

Results of finite element analysis of TTCI's new joint bar profile suggest these benefits are possible. Several prototypes of improved joint bars have been manufactured, and laboratory and in-track testing to evaluate the design is in progress.

The current joint bar design evolved during the 1930s when almost all track was jointed. Thus, the main feature of the joint bar design was the least contact of the joint bar with the rail fishing (i.e., web) surfaces. This feature allowed rail movements that released thermal stresses induced by rail temperature changes. However, in today's load environment, the least contact design causes higher rail-joint bar contact stresses, which cause metal flow. Most of the cracks seen in revenue service initiate from locations of metal flow.



INTRODUCTION

TTCI is investigating to increase joint bar performance by improving manufacturing methods and materials, maintenance practices, and joint bar design. The first two improvements have been addressed in two previous *Technology Digests* (TD).^{1,2} This TD discusses the possible improvements to the cross-sectional profile of joint bars.

The objective of improving the cross section of joint bars is to increase rail joint resistance to longitudinal movement due to temperature changes. This has been achieved by increasing the contact between rail and joint bar surfaces. Thus, the rail joint is likely to behave as a friction-type joint instead of a current bearing-type joint. In friction-type joints, bolts create significant clamping force resulting in enough friction between joint members to prevent slippage.

In order to keep the same level of handling effort in revenue service, the improved joint bar has a maximum weight of ~60 pounds. Bending stresses in improved joint bars are likely to be similar to the current joint bars. The ability to bend along the longitudinal axis, or joint bar “springiness,” is a good feature of the current designs, and it was maintained to some extent in the improved joint bar. The joint bar also provides higher relief for worn (i.e., tall flange) wheels.

BACKGROUND

The current joint bar profile was designed to minimize contact with the rail (allowing longitudinal movement of the rail relative to the bars). That is why the joint bar makes line contact with the head and base of the rail. This small contact area induces stress risers, which often initiate cracks.

The current design allows longitudinal movement of rail with change in temperature. In jointed rail, many times the joints are oiled to avoid joint freezing. This no-locking feature of the joint is not desirable in continuous welded rail (CWR) territory.

In CWR, temperature decreases in rail may increase the gap significantly. Impact generated due to this wide gap can increase the rate of degradation. Higher rates of degradation may cause higher deflections under the joints, requiring frequent ballast tamping or peaking. If the foundation is not maintained to acceptable deflection levels, it can cause undesirable vehicle dynamics such as higher vertical and lateral loads and excitation of various frequencies.

The rail joint is a bearing-type joint in which bolts are responsible for load transfer; i.e., bolts transfer load from the first rail to the joint bars and back to the second rail. Basically, this load transfer causes both shear and bending in the bolts. A 1-inch diameter Grade-5 (A325) bolt has allowable shear capacity of 53,400 pounds in double shear bearing-type joints.³ Thus, the bolts in the rail joints will have a design capacity of 106,800 and 160,200 pounds in four-hole and six-hole joints, respectively.

If a 1-degree temperature change below the neutral (longitudinally stress-free) temperature of the rail generates

2,000 pounds of force in the rail, then an 80-degree change below the stress-free temperature would create a stress that would exceed the shear capacity of six bolts, and a 53-degree temperature change in that range would exceed the shear capacity of four bolts. The actual temperatures at which bolts will be stressed beyond their allowable shear strength will be different due to bolt bending, bolt-hole tolerances, and the part of the load carried by friction between the joint bars and the rail.

In addition to shear, joint bar movement with respect to rail causes bending in bolts. Theoretical estimates of bending stress are complex, because moment arm and the support conditions of bolts are constantly changing during relative movement of joint bars and rail. However, broken bolts show fatigue rings, suggesting fatigue failure in bending.

At locations in the United States with daily temperature fluctuations of more than 50 degrees in the range below the temperature at which the rail has no longitudinal stress, joints in CWR track that have two bolts in each rail may be loaded above the design limit for two bolts.

Design capacity of rail joints can be increased by taking advantage of more contact area and higher diameter bolts. That will be performed experimentally later, and has not been addressed in the current document.

PERFORMANCE OF CURRENT JOINT BARS

The current joint bar shape has most material away from the neutral axis, which provides benefit in terms of higher moment of inertia for a given weight. The weight of a current joint bar is 60 pounds. The improved joint bar profile was designed not to significantly exceed this weight. Thus, moment of inertia, which is a measure of bending strength, may not be increased without a corresponding significant increase in weight of the joint bar.

Joint bars are often removed from track because of cracking or breaking. Cracks initiate largely on the bottom or top center of joint bars. Some crack initiations appear to be related to surface discontinuities or material fatigue, and these may be reduced or eliminated by improving manufacturing processes or by increasing material strength. Managing residual stresses properly is another option.⁴

However, the cracks that start at locations of very high contact stress are design related and may not be reduced or eliminated using the above mentioned approaches. At the top of the bar, if the center of the joint is suspended between two ties, the compressive bending stresses are the highest. Due to rail and joint bar contact, the contact stresses are also very high. These two types of stresses combined are responsible for metal flow and notch formation, which ultimately initiate cracks.

Figure 1 shows four of the most common failure modes of current joint bars, which are cracking initiated from the top, at the bottom, in the center, and at the bolt holes. The new profile is likely to reduce three of these failure modes; i.e., cracking from the top, in the center, and at the bolt holes.

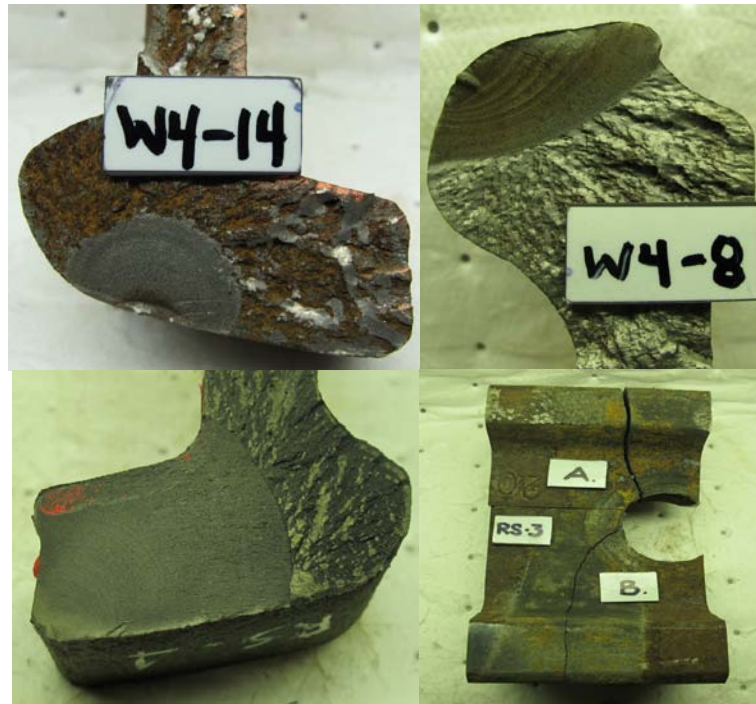


Figure 1. Joint Bar Most Common Failure Modes (Clockwise from Top Left Corner)
Crack Initiated from Joint Bar Bottom Center, Top, Bolt Hole, and Bottom

Cracking at the bottom edge is material related, and research to improve the material mechanical properties has been presented in a separate TD.¹

Joint Bar Design

The main goal of the new design is to provide high relief and to increase the contact area of the standard joint bar. The increase in contact area will likely reduce the joint bar contact stresses, which currently tend to cause metal flow and crack initiation.

To do this, the cross sections of different joint bar designs for 136RE rail were compared. In order to match the current joint bar properties, attempts were made to keep the weight of the joint bar to about 60 pounds, keep the moment of inertia close to 16 inches⁴, and lift the neutral axis of the joint bar as much as possible.

Many cross sections meeting the above criteria were reviewed. The final shape chosen had a moment of inertia equal to 14.75 inches⁴, an estimated weight of 61 pounds and a neutral axis that lies approximately 2.5 inches below the top of the bar.

Finite Element Analysis: Supports and Forces

The finite element analysis was conducted on this design and the current standard joint bar design to compare the performance of the joint bars.

Loading was identical for both the new and standard designs. A fixed support was placed on two lines that exist on

the bottom of the rail in the X-direction, as Figure 2 shows. Each bolt was loaded axially with 36,000 pounds of force. Each nut also had loading equal and opposite its paired bolt. Vertical loading was applied to two rectangular areas, one on each railhead. The magnitude of the 60,000-pound vertical load was evenly distributed pressure equal to 48,000 pounds per square inch over a 1.25 square inch area. The vertical load represents the wheel load of a 315,000-pound car with 50 percent impact. For the stability of the model, elastic supports were added to the nuts with a small magnitude of 15 lb-force/in³.

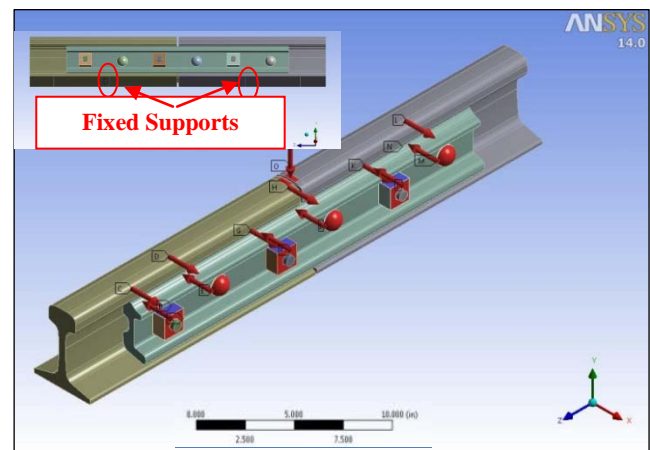


Figure 2. Rail Joint Finite Element Analysis Model

Finite Element Analysis: Results

Three important metrics were used to analyze the effectiveness of the joint bars when the results were compared; i.e., deflection, von Mises stresses, and contact with the rail. The deflection of the bars under loading is important because it affects the ride quality of the train over each joint and is a verification of the effects of the shape of the cross section of the joint bar body. Plots of the equivalent or von Mises stress were compared to ensure that the stress fields were similar. The final metric was the amount of contact each bar had with the rail when loaded.

The deformation in the standard joint bar and the new joint bar looked very similar. Figure 3 shows the deformation in the Y-direction for the new bar. The maximum deformation for the bars occurred in the center near the top of the joint bar, note the dark blue. For the new joint bar design, the maximum value of displacement was 0.014 inch. For the standard joint bar design, the maximum displacement was 0.011 inch. The high amount of bending is likely due to the differences in the moment of inertia of each bar.

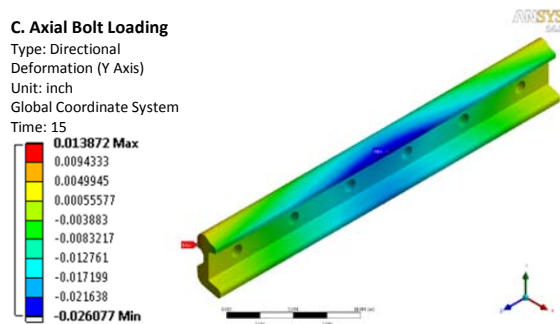


Figure 3. New Joint Bar Design Y-Direction Displacement

Solutions for the von Mises stress were evaluated. Again, the profiles of the standard joint bar and the new design were very similar (Figure 4). The major difference is how the holes of the joint bar distributed the stress. In the new design, the stress was concentrated more toward the top of the bar. An explanation for this may be that the new design has more material near the bottom of the holes, which changes the stress field. In both bars, the red regions have stress values above 35,000 pounds per square inch.

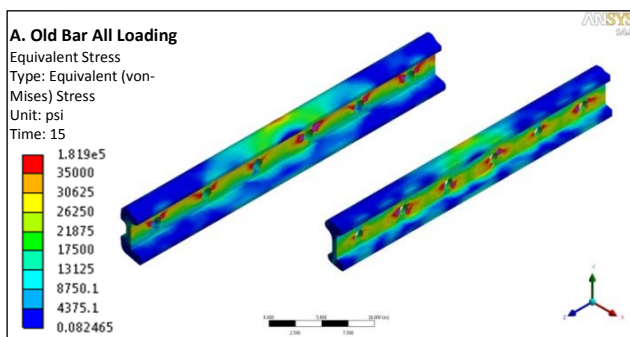


Figure 4. Von Mises Stress Plot of (L) New Joint Bar and (R) Current Joint Bar

Figure 5 shows the interaction between the joint bars and the rails. It shows a new joint bar on the right side and the corresponding rail interaction on the left side. Areas of no contact are dark blue. Areas where contact is occurring or very close to occurring are yellow. Areas where contact rubbing is occurring are orange. The figure shows the contact area for the new joint bar design is significantly increased, which helps to carry longitudinal load, preserve rail neutral temperature, and extend joint bar service life.

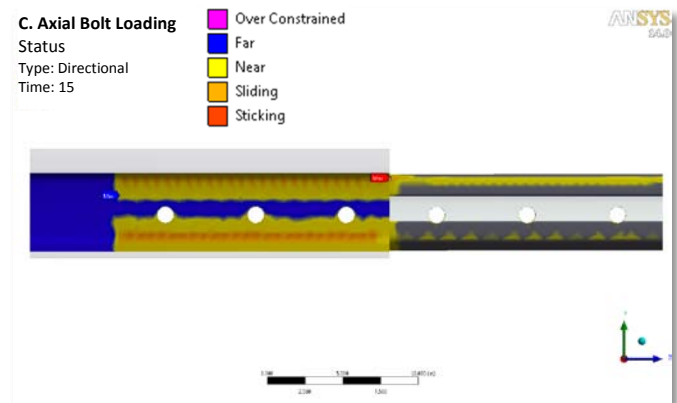


Figure 5. Contact Status of Joint Bars

FUTURE WORK

Prototype joint bars are being manufactured and will be tested side by side with the standard joint bars to experimentally evaluate the benefits of the new design compared with standard joint bars.

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