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Heavy Axle Load Testing of Prototype Rail Joint Bars

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Summary

Prototype rail joint bars were evaluated in the laboratory and in heavy axle load track tests at the Transportation Technology Center, Inc. (TTCI) in a project sponsored by the Association of American Railroads' Strategic Research Initiatives Program. TTCI tested the joint bars at the Facility for Accelerated Service Testing (FAST), and the prototypes did not provide improved performance under heavy axle load traffic. This *Technology Digest* describes the testing and performance results of the prototype bars.

The prototype bars failed after 25 MGT of 39-ton axle load traffic at FAST. This is less than 10 percent of the expected life of standard joint bars under 39-ton axle loads. The prototype bars failed from fatigue cracks that began at the bottom of the bar (centered laterally and longitudinally). Inspection of the cracks revealed that they began at indentation marks, where the rail end contacts the joint bar. The crack initiation location (bottom, lateral center) suggests the fit with the rail was less than optimal. The machined bar surfaces were not conformal to the rail and negated the intent of the design, which was to increase the bar-rail surface contact. The poor fit created stress raisers, which caused the bars to fail before the design features could be evaluated. Laboratory testing showed that the prototype joints had lower longitudinal strength than the joints with standard bars.

The prototype bars differ from standard bars in cross section profile and material properties. The cross section has more contact area with the rail, especially in the web of the rail. This is expected to minimize or prevent rail-joint bar slip as temperature changes in track. A stronger joint with a small rail end gap should have lower dynamic forces.

Additionally, the prototype bars are made from stronger steel. The prototypes are made from ASE Grade 4140 steel, rather than the conventional 1045 steel. The higher yield strength should help resist notching from rail end contact, whereas the higher ultimate strength should provide a longer fatigue life.

INTRODUCTION

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 prototype joint bar has a maximum weight of ~60 pounds. Bending stresses in the prototype joint bars are likely to be similar to the current joint bar designs. 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 prototype joint bar. The joint bar also provides higher relief for worn (i.e., tall flange) wheels.

This *Technology Digest* (TD) describes the laboratory and field tests conducted on the prototype joint bar with new profiles as described in a previous TD.[1]

BACKGROUND

The current joint bar profile was designed to minimize contact with the rail (allowing longitudinal movement of the rail relative to the bars), causing the joint bar to make line contact with the head and base of the rail. This small contact area induces stress raisers, 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, decrease in rail temperature 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.[2] 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, in extreme cases, may exceed the shear capacity of six bolts, and a 53-degree temperature change in that range would exceed the sheer 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 fact that part of the load is 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 stresses in bolts is complex, because the 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 is possible.

The above analysis suggests that a higher longitudinal capacity rail joint may be desirable for CWR track. 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 this TD.

The prototype joint bar profile was designed at TTCI.[1] The two pairs of joint bars were machined from AISI/SAE 4140 steel. After machining, the joint bars were heat treated to increase material mechanical properties.[3] Table 1 gives the mechanical properties of 4140 and the currently used 1045 steels. Note that the proposed steel should produce a rail joint that is stronger and has a longer fatigue life under the same stresses.

Table 1. Properties of Current and Proposed Steels for Joint Bars

	1045 Steel	**4140 Steel (Quenched and Tempered)**
Carbon	0.35–0.6	0.38–0.43
Manganese	1.20 maximum	0.75–1.00
Phosphorus	0.04 maximum	0.03 maximum
Sulfur	0.05 maximum	0.04 maximum
Silicon		0.15-0.30
Chromium		0.80–1.10
Molybdenum		0.15–0.25
Yield strength	85 ksi	145 ksi
Tensile strength	135 ksi	160 ksi
Elongation	14%	15%
Reduction of area	33%	49%

The joint bars were tested in laboratory as well as in track to estimate if the new profile provided expected benefits over the current profile.

Laboratory Testing

The main feature of the new joint bar design is more contact with the rail. The feature is likely to allow rail joints to resist thermal loads without slippage; i.e., the rail joint performs as friction-type joint instead of current bearing-type joint.

Two joints were assembled using standard and new joint bars. The load was applied to create shear between rail and joint bars. Linear Variable Differential Transformers (LVDTs) were installed to measure relative movement of the joint bars with respect to the rail. Figure 1 shows the test setup. Load was measured using load cells on the squeeze frame. During the application of load, a sudden increase in relative joint bar movement and simultaneous reduction in load showed a joint bar slip. Each joint bar was tested at three levels of bolt torque.

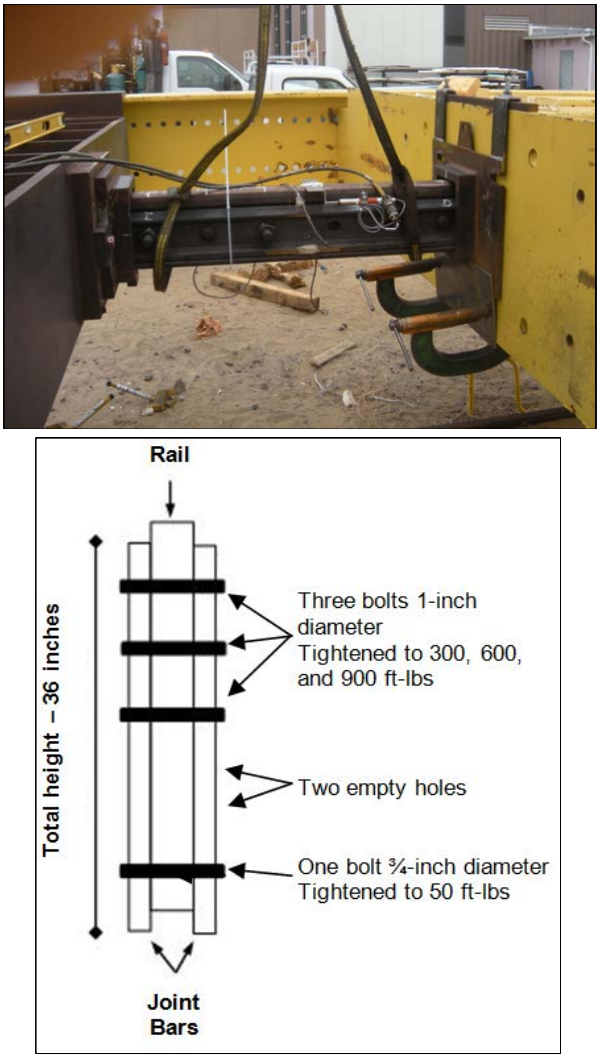

Figure 1. Rail Joint Test Setup

The applied shear force time history is shown in Figure 2 (top). Slippage of joint bars was characterized by a sudden reduction in force, referred to as resistance; i.e., the force a joint can resist without slippage while performing as a friction-type joint bar.

Figure 2 (bottom) compares the resistance force of each joint at various torques. In the tests, a rail joint with new joint bars showed lower resistance force than with standard joint bars. This is contrary to expected performance. It seems like the machining marks and sharp corners at compound curves did not allow the joint bar surfaces to make more contact with the rail. This was confirmed by the inspection after disassembling the joint that contact was minimal with the rail. The results may have been better if rolled joint bars were used.

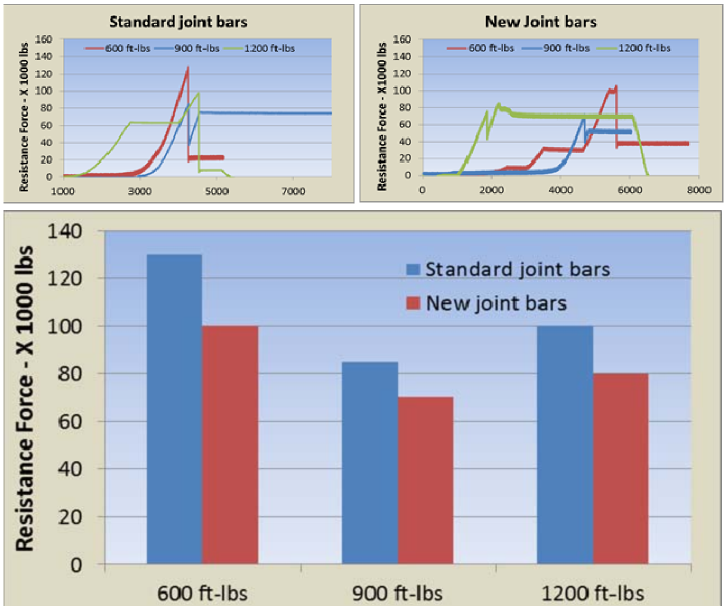

Figure 2. Resistance Force of Rail Joints

In Track Testing

Bending stress data was collected from new and current joint bars under the test train at FAST. Bending strains were measured in the bottom of the joint bars. The strains in both joint bars were nearly similar, suggesting that the slight reduction in bottom section modulus did not reduce joint bending strength significantly. The rail ends gap and daily ambient temperature were logged to understand the thermal force and joint gap relationship. However, both joint bars broke after 25 MGT, effectively ending the test. The gap and temperature data collected was not enough to understand the effect of the larger contact feature of the joint bars. In both joint bars, cracks started from the middle bottom center of the joint bars and propagated horizontally. The horizontal crack followed the machining indentation along the joint bars. Figure 3 shows the cracks.

Figure 3. Cracked Joint Bars

Joint bar Failure Analysis

Joint bar cracking at 25 MGT was an unexpected event, thus requiring a detailed failure analysis. According to a TTCI survey of eight heavy haul railroads, the expected service life of joint bars in heavy axle load service is 775 MGT. A metallurgical analysis provided the following insight:

1. Analysis of both fracture surfaces indicates that both cracks originated at the surfaces and progressed into the joint bars as fatigue cracks until critical failure.
2. The outside surfaces of both joint bars exhibited rough surfaces with material buildup (metal flow). Either one of these surface irregularities could have been a factor in the buildup of stress concentration during train operations. Stress concentration at the crack origin is most likely what led to crack initiation. Crack origination was close to metal flow or indentation due to rubbing against the rail base top surface. See Figure 4.

Figure 4. Indentation at Joint Bar/Rail Contact

3. Cross-sectional metallography of the joint bars did not reveal any microstructural abnormalities. Both microstructures represent typical air cooled 4140 steel microstructures.
4. Hardness profiles in the cross sections directly below the crack origin did not indicate any hardness buildup close to the crack origin.

Summary

The joint bar prototypes tested did not improve the longitudinal strength of the joint, despite the larger rail contact area. This is attributed to poor fit with the rail due to the prototypes being machined. Fatigue cracking occurred very early in the test (at 25 MGT). The poor fit created stress raisers, which caused the bars to fail before the new design features could be evaluated.

Future Work

Additional prototype bars should be made with improved fit to the rail so that a better design evaluation can be made. A finish that approximates rolled bars is needed so that a fair comparison of the cross section design and material properties can be made.

The service life of joint bars is strongly influenced by the service conditions and maintenance received in track as well as the design of the components. A subsequent TD will be prepared describing the effects of maintenance and service conditions on rail joint performance.

References

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