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Load Environment of Standard Rail Joint Bars used in 39-ton Axle Load Service

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Summary

Transportation Technology Center, Inc. conducted a study to quantify the load environment for standard joint bars in 39-ton axle load service. Five pairs of standard joint bars were installed on wood tie tangent track on the High Tonnage Loop at the Facility for Accelerated Service Testing (FAST). The following observations were made:

- Joint bars are commonly installed with only four bolts, leaving the two center bolt holes blank (i.e., not drilled) for future welding. Joint bar bending stresses can be reduced significantly if all six bolts are installed and tightened to full torque.
- The measured bending tensile strains on the top edge of the joint bar under dynamic load are too low to cause fatigue related cracking of the undamaged section. Cracking appears to be design related, and likely to be reduced or eliminated by providing relief (i.e., clearance for the bottom of the railhead under load) as recommended by American Railway Engineering and Maintenance of Way Association (AREMA).
- Measurement of residual stresses in joint bars removed from service show the top edge of the joint bar has compressive residual stresses, and the bottom edge of the joint bar has tensile residual stresses. These stresses can be as high as the live load stresses. The cause(s) of the residual stresses should be investigated, so they can be reduced.
- Generally, joint bars have lower mechanical properties than the rail. During very cold weather, the total stress in joint bars may be equal to the current AREMA recommended minimum yield strength. The minimum yield and strength properties of joint bars should at least be equal to the current minimum recommendations for rail.

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Introduction

Bolted rail joints are installed on heavy haul mainlines as a temporary measure to repair broken rails. If left in the track too long, the joint bars tend to crack and break. Contrary to findings from stress analysis, 97 percent of broken joint bars reportedly failed from cracks initiated on the top edge of the joint bar. Apparently, there are some forces in action that cause this cracking and require further investigation.

The study quantified the load environment of standard joint bars used in 39-ton axle load service. Also, long-term joint bar performance was assessed using the experimental data.

Five pairs of 6-hole, 36-inch long joint bars were installed on tangent wood tie track with 136RE rail at the Facility for Accelerated Service Testing (FAST). The joints were installed with the rail ends over a ballast crib, which is standard railroad practice. The joint bars were instrumented with bending strain gage circuits on the top and the bottom of the bars.

Four different bolt torque and bolt configurations were tested:

- Six bolts tightened to full torque
- Six bolts tightened to half torque
- Four bolts tightened to full torque
- Four bolts tightened to half torque

In the last two configurations, no bolts were installed in the two middle holes.

Dynamic load environment data collected under the train at FAST showed that the tops of joint bars are subjected to minimal tensile stress. Thus, cracks on top of the joint bar appear to be design related, not load related, and may be avoided by providing correct relief on the top of the joint bar as recommended by AREMA guidelines. Tensile stresses in the bottom of the joint bar exceed the endurance limit, and joint bars can develop fatigue cracks in this area at some point during their service lives.

The relief provided on most of the joint bars is not in accordance with AREMA guidelines, and it does not serve the objective, which is to reduce contact stresses. The bottom of the rail ends under loaded conditions tends to make a notch, which is likely the cause of cracks on the tops of the joint bars.

During very cold weather, the total stresses (i.e., thermal, residual, and bending stresses) may be equal to the current minimum recommended strength of joint bars. Thus, the need to increase the recommended mechanical properties of joint bars is imminent.

Static Load

The effects of bolt torque and the number of bolts installed in the joint bars were evaluated under static load conditions by locating the wheel of a fully loaded 315,000-pound coal car at various positions on the joint bar. Mid-span deflections and bending strains were measured immediately after joint bar installation and during the static load testing. As compared to all other load cases, having the wheel centered on the joint was the most severe load case. As Figure 1 shows, the stress was the highest in the bottom of joint bars installed using four bolts with half of the recommended bolt torque value, whereas joint bars installed using six bolts tightened to the recommended bolt torque value produced the lowest stress levels in the bottom of the joint bars. Loaded deflections followed the same trend.

Bending tensile stresses in the bottom of joint bars ranged from 12 to 18 kilo-pounds per square inch (ksi). With the wheel load at the center of the joint, deflections ranged from 0.14 to 0.32 inch. No conclusive relationship between stresses and deflections was observed.

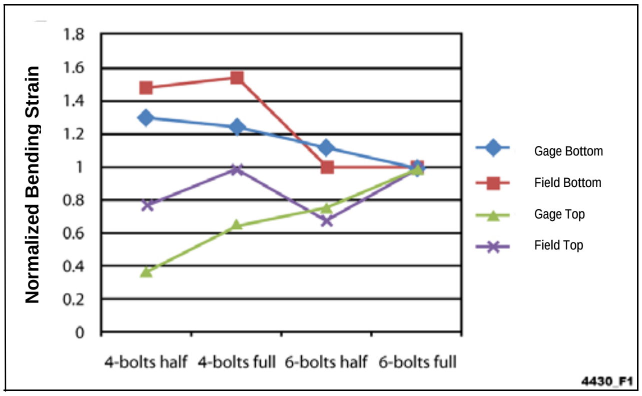

Figure 1. Effect of Bolt Torque and the Number of Bolts on Joint Bar Stress

In order to quantify joint bar load environment under degraded support conditions, the ballast was manually disturbed to produce joint bar deflections up to 0.75 inch. As Figure 2 shows, under these conditions joint bar stresses increased up to 4 times more than stresses measured under good support conditions.

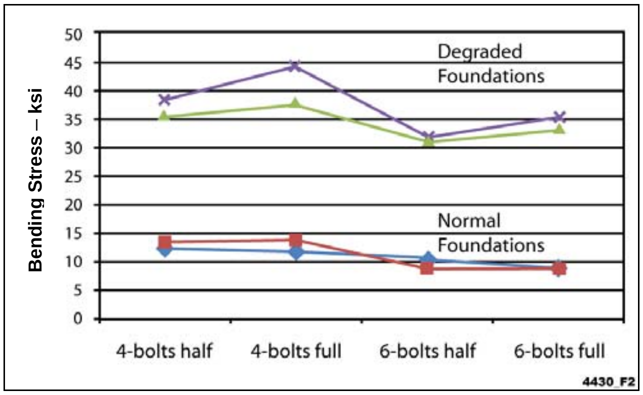

Figure 2. Effect of Degraded Foundations on Joint Bar Bending Stresses

Thermal Stress

Data was collected from rail and joint bars to measure any differences in response to thermal changes. It shows joint bars and rail respond similarly to thermal changes. As Figure 3 shows, a force of approximately 2,000 pounds developed for every 1°F change in temperature. Linear interpolation suggests that operating temperatures below 0°F will generate thermal tensile stresses of 20 ksi.

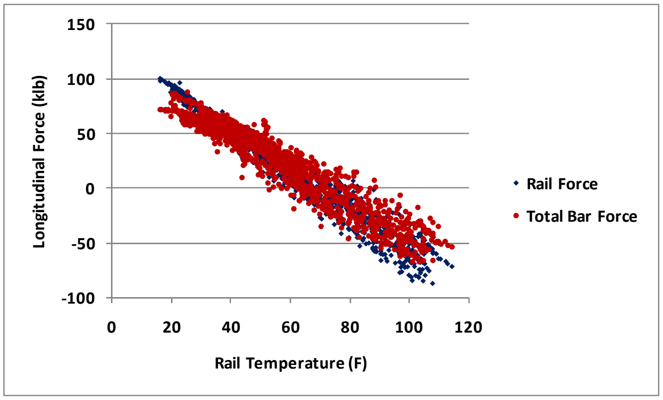

Figure 3. Temperature — Thermal Force Relationship

Dynamic Load

Bending strains were measured at 30 million gross ton (MGT) traffic intervals under the FAST train for a total accumulated tonnage of 120 MGT. Joint foundations were not tamped during this period. In order to determine if there was a correlation between stresses and deflections, static deflections under a loaded coal car were measured at the same intervals. As Figure 4 shows, joint bar deflections and bending tensile stresses increased with tonnage. Some of the variability in the data is likely due to seasonal temperature changes.

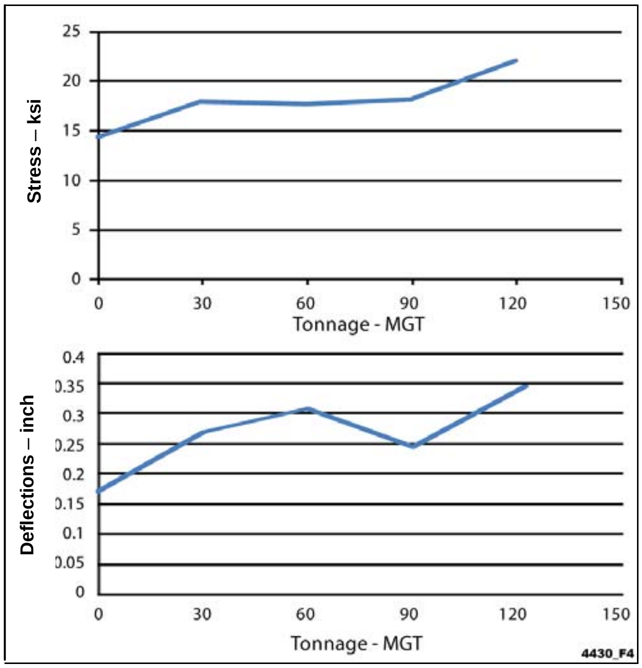

Figure 4. Effect of Tonnage on Joint Bar Stresses (top) and Joint Bar Deflections (bottom)

Stress history of the train at FAST over joint bars shows that reverse bending, i.e., tension on top of a joint bar after a wheel moves to the next crib, was in the range of 0 to 5 ksi, which is too low to cause any crack initiation or crack growth. It appears that crack initiation on top is design related and not load related.

Residual Stresses

In their as manufactured condition, many standard joint bars are bent upward, downward, and sideways. Track crews often use a hammer to straighten the bars during installation. This may cause mechanical damage in the form of surface defects that can create a stress raiser in joint bars. Residual stresses are the likely cause of joint bar bend. To measure residual stresses, strain gages were installed on the top and bottom of two joint bars, as well as around the bolt holes. The joint bars were saw cut close to strain gages. Differences in strain before and after saw cutting were used to estimate residual stresses induced in joint bars during manufacturing. Figure 5 shows tensile and compressive residual stresses in the bottom and top of both joint bars, respectively.

Residual stresses up to 23 ksi were measured around the bolt holes. These stresses were produced during the drilling process.

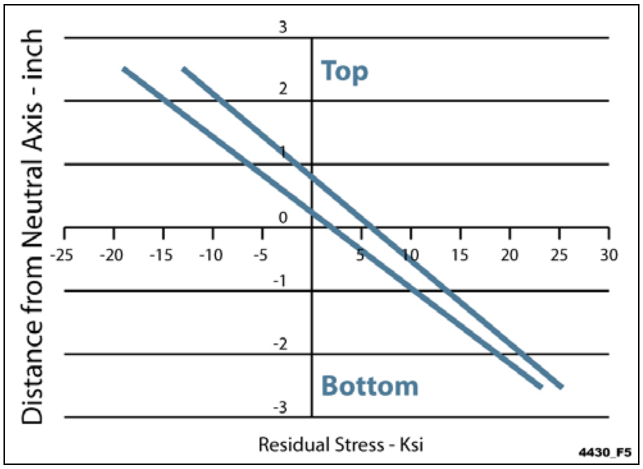

Figure 5. Measured Residual Stresses in Two Joint Bars

Joint Bar Load Environment

Figure 6 provides a summary of different types of forces measured in joint bars. The total force is slightly lower than the recommended AREMA yield strength for joint bars. Joint bar cracking and breaking may be reduced by increasing the strength properties, increasing the cross section, or reducing the magnitude of forces induced in joint bars.

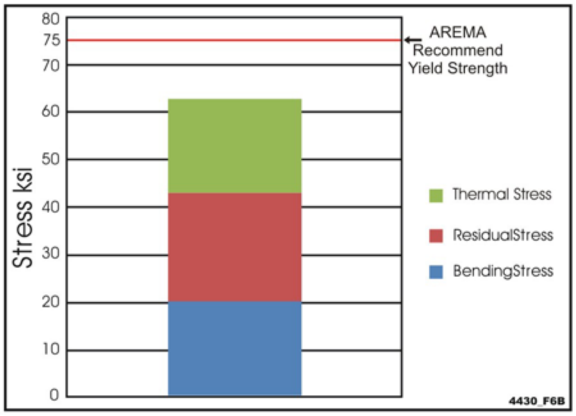

Figure 6. Summary of Joint Bar Load Environment

To reduce joint bar fatigue, the AREMA recommended yield and tensile strengths should be increased. Generally, joint bars have lower strength than rail, and thus, represent a weak link in the track structure. The minimum mechanical joint bar properties should be increased so that the joint has the same load capacity as the rail.

Increasing the cross section of joint bars is a feasible, but not necessarily an effective way of increasing the strength of joint bars. The effect of rail size on bending stresses for various track moduli has shown that increasing the cross sectional area has little effect on track modulus.[1] However, increasing the joint bar length and cross section may be helpful in increasing track modulus and in reducing the stresses in joint bars.

Future work in this area is needed to investigate the material properties and the manufacturing processes to reduce residual stresses in joint bars. However, it is possible to reduce the effects of thermal forces on joint bars by using anchors or better fastening systems.

Joint Bar Mechanical Properties

Two joint bars, one manufactured in 1970 and one in 2008, were tested to compare yield strength, tensile strength, and fracture toughness. Fracture toughness was measured using the Charpy notch test. AREMA does not currently have fracture toughness requirements for joint bars.

Both joint bars had similar mechanical properties, and both exceeded the current AREMA requirements for joint bars (Table 1). Based on this limited data set, it appears that fracture toughness may have tripled in the last four decades. The mechanical properties of the joint bars are considerably lower than head hardened rail.

Table 1. Joint Bar Mechanical Properties

Manufactured in	No.	BHN	YS 0.2% ksi	UTS ksi	Charpy ft-lbs
March 1970	1	209	88.5	135.0	4
	2	204	77.0	125.0	3
	3	195	87.5	136.0	6
	AVG	**203**	**84.3**	**132.0**	**4**

Manufactured in	No.	BHN	YS 0.2% ksi	UTS ksi	Charpy ft-lbs
March 2008	1	222	94.0	132.0	15
	2	224	93.5	139.0	7
	3	230	93.5	135.0	16
	AVG	**225**	**93.7**	**135.3**	**13**
AREMA			**75**	**100**	

Conclusions

- Joint bars are commonly installed with only four bolts, leaving the two center bolt holes blank (i.e., not drilled) for future welding. Joint bar bending stresses can be reduced significantly if all six bolts are installed and tightened to full torque.
- The measured bending tensile strains on the top edge of the joint bar under dynamic load are too low to cause fatigue related cracking of the undamaged section. Elimination of stress raisers, such as notching from railhead contact is needed.
- Measurement of residual stresses in joint bars removed from service show the top edge of the joint bar has compressive residual stresses, and the bottom edge of the joint bar has tensile residual stresses. These stresses can be as high as the live load stresses. The cause(s) of the residual stresses should be investigated, so they can be reduced.
- Generally, joint bars have lower mechanical properties than the rail. During very cold weather, the total stress in joint bars may be equal to the current AREMA recommended minimum yield strength. The minimum yield and strength properties of joint bars should be increased.

Future Work

Additional work will focus on developing ways to reduce all three major stress components (bending, thermal, and residual stresses) in rail joints. Working with railroads and suppliers, prototypes will be developed and tested under heavy axle load traffic.

References

1. Hay, William W. 1982. *Railroad Engineering*. 2nd ed. Indianapolis: John Wiley and Sons, Inc.