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FAST Steel Bridge Repairs for Effects of Corrosion and Corrugated Rail

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Summary

Transportation Technology Center, Inc. (TTCI) researchers have installed several repairs to cracks in the two spans of the steel bridge at the Facility for Accelerated Service Testing (FAST). The cracks appear to have initiated due to various causes including the effects of corrosion, impact loading from corrugated rail, or poor weld details, in combination with the heavy axle load (HAL) traffic. Many of the repairs are experimental in nature, to evaluate whether or not they might be viable options for use in revenue service. Observations to date include:

- Major web and tension flange cracks in the 65-foot welded girder span appear to be caused by constraint-induced fracture resulting from a weld detail connecting bracing members to girder and stiffener.
- HAL traffic running on corrugated rail on the bridge increased dynamic loading by about 10 percent, resulting in about a 15 percent increase in cyclic stress range, and about a 50 percent increase in fatigue accumulation per train pass.
- In each single-angle bracing member that cracked in the 55.5-foot riveted girder span, about 50 percent of the section was corroded.
- Corrosion was most prevalent in horizontal components, such as horizontal legs of bracing angles, and horizontal gusset plates, where water might not drain quickly. Vertical components typically show little corrosion by comparison.
- Simple splice repairs of cracked bracing members are performing well, several with over 1,000 MGT of traffic accumulated. In some cases, repairs such as these can be installed with less track time than conventional member replacement.

This research is part of the Association of American Railroads' Strategic Research Initiatives and FAST Bridge Research Programs to investigate performance of steel bridge spans to extend their safe service life under HAL service. With regular inspection, maintenance, monitoring, and several experimental repairs, the FAST steel bridge continues to carry HAL traffic. The steel bridge is made up of two spans: a 55.5-foot riveted girder span that is 101 years old and has been in service for 460 MGT at FAST, and a 65-foot welded girder span that is 56 years old and has been in service for 2,008 MGT at FAST.

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INTRODUCTION

The steel bridge at FAST continues to provide railway bridge engineers with results to help extend the life of existing railroad bridges. The HAL traffic operation subjects the spans to higher forces than would typically be experienced in revenue service, providing quicker results, as well as an indication of the issues that might arise if axle loads are increased. The 101-year-old 55.5-foot riveted girder span is providing results typical of an older span with evidence of years of corrosion. The 56-year-old 65-foot welded girder span is providing results typical of more recent welded construction, with its fatigue-sensitive details. Both spans are serving to test the performance of various repair techniques.

Past results have shown the importance of reducing dynamic loads by removing rail joints.[1,2,3] Current results indicate that corrugated rail can also produce high dynamic loads resulting in a significant increase in fatigue damage. For operation of HAL traffic over bridges, it is recommended that the rail surface be maintained as smooth as possible and free of discontinuities in order to minimize dynamic loading on the structure.

Recent Cracks in 65-foot Welded Girder Span

In April 2012, several new cracks were noted in the 65-foot welded girder span, and rapid growth was noted in several existing cracks. Most significantly, a second major web and tension flange crack developed in the 65-foot welded girder span just before the summer shutdown of FAST train operations. All cracks in the welded span appear to have initiated at weld details.

Figure 1 shows the major web and tension flange 8-inch crack, which is very similar to the previous major web and tension flange crack that initiated in 1998.[4] Both cracks appear to have initiated where a horizontal gusset plate from the bottom lateral bracing system is welded to the web of the girder at a vertical web stiffener location. The result is a small area with intersecting welds that is constrained from movement in all three directions. The steel at this location is unable to yield or deform under load, resulting in a brittle crack initiation termed constraint-induced fracture (CIF), as reported by Connor et al.[5] This phenomenon has resulted in significant failures of welded steel girders in at least three highway bridges.

At the direction of the AAR Bridge Technical Advisory Group (TAG), a sample of the cracked gusset plate was cut out and sent to Purdue University for fractographic analysis and material characterization by Dr. Robert Connor, a leading expert in fatigue and fracture of steel bridges.

Figure 2 shows the sample that was cut out of the span. Figure 3 shows the repair installed on the welded span in the area from which the sample was removed. Because of the amount of material removed with the sample, the repair is much bigger than would otherwise have been needed. The repair was based on a similar repair installed on one of the highway bridges that experienced a large CIF crack.[5]

Figure 1. New 8-inch Crack in Web and Tension Flange of 65-foot Welded Girder Span

Figure 2. Sample Removed for Fractographic Analysis of Major Crack

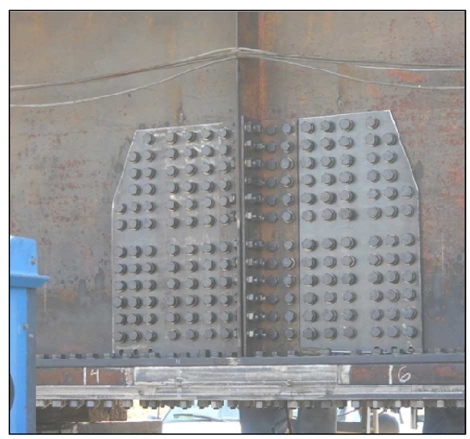

Figure 3. Repair Installed on Web and Tension Flange of 65-foot Welded Girder Span

All of the other cracks noted in the same time frame were in secondary members including bracing, stiffeners, and gusset plates. A variety of repairs were installed, using bolted splices and doublers as much as possible. The AAR Bridge TAG was again consulted for guidance. In some cases, weld repairs were made, where a bolted repair would have required much more extensive work. Performance of all of these repairs is being monitored.

Increased Dynamics Caused By Corrugated Rail

Dynamic loads from corrugated rail and bolted rail joints cause a severe increase in the local stresses and strains of railroad bridges. One of the most effective ways to reduce the stress state in railroad bridges in order to carry HAL traffic is to maintain a smooth continuous rail surface across the bridge and the adjoining approach track. On the FAST steel bridge, there has been strong correlation between presence of rail joints or corrugated rail on the bridge and crack initiation and growth. Under HAL traffic, there is less reserve capacity in the bridge to be able to withstand these additional loads, which result in the need for additional maintenance and repairs.

The cause of the increased rate of crack initiation and crack growth in each one of the secondary member cases is suspected to be corrugated running rail on the welded span of the steel bridge during the spring of 2012. Just before the rails were ground, the corrugations were measured to have a depth of 0.090 inch on the north rail and 0.110 inch on the south rail. These corrugations were considered to be moderate. It had been noted that train traffic over the span was resulting in a great deal of noise from the bridge while the corrugated rail was in place. The noise subsided after the rail was ground smooth.

Figure 4 shows tension flange strains near the center of the 65-foot welded girder span measured under the HAL train operating over the corrugated rail compared to smooth rail after grinding. The peak strains are about 10 percent higher. The effective stress range for fatigue is about 15 percent higher using a rainflow cycle counting calculation. This higher stress range results in about a 50 percent increase in fatigue accumulation per train pass under corrugated rail as compared to smooth rail. Fatigue computations are based on the methodology recommended by the American Railway Engineering and Maintenance of Way Association (AREMA) in Chapter 15 of the *Manual for Railway Engineering*.[6]

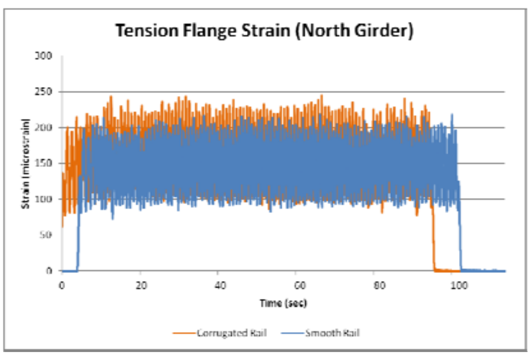

Figure 4. Increased Bridge Strains Due to Corrugated Rail on FAST Steel Bridge

Data from TTCI's Instrumented Freight Car (IFC) also indicate increased dynamic activity when the corrugated rail was on the bridge. Side frame accelerations from the IFC with corrugated rail on the welded span of the steel bridge showed a vertical peak acceleration of 4 g and 12 events of 2 g or higher in the area of the steel bridge per train pass. After the rail was ground to a smooth condition, all peak values of side frame accelerations from the IFC were less than 2 g.

The rail corrugations were present over most of the welded span, which explains why the new cracks and rapid crack growth were noted at several secondary member locations throughout the span. In previous studies where rail joints were noted to increase crack activity, the crack activity was in close proximity to the joint. Corrugated rail introduces higher dynamic forces and increased crack activity over a more widespread area. It is likely that the corrugated rail also contributed to the initiation of the new major web and tension flange crack, which was found after 23 MGT of traffic had run since the rail had been ground smooth on the bridge.

A bolted rail joint was installed on the welded span 3.2 MGT prior to the crack being found. The bolted rail joint was tight, had a perfect railhead match, and was located about 20 feet away from the location of the new crack. Strain and accelerometer measurements on the girder showed no significant impacts from this new bolted rail joint at the time the crack was found. The bolted rail joint has since been removed. It is possible that both the corrugated rail and the bolted rail joint combined to generate enough higher stress range cycles to initiate the major crack.

Bracing Repairs and Repair Performance

In the 55.5-foot riveted girder span, corroded bracing members continue to break. Experimental repairs are being installed where possible. There have been no problems to date with the main girders of the span. All cracks in this 55.5-foot riveted girder span appear to have initiated at areas with significant corrosion.

In most cases, experimental repairs are being installed as cracks develop or components break. They can be performed from the underside of the bridge without taking the bridge out of service or requiring track time. In many cases, smaller bolted splice repairs have been used successfully, and to date these repairs have performed very well. Experimental weld repairs have been installed in selected cases. Stop-hole drilling has also been successful in arresting cracks in selected locations.

Corrosion effects appear to have been responsible for all cracks and broken components in the 55.5-foot riveted girder span. The corrosion damage has been found primarily in secondary members such as horizontal gusset plates and the horizontal legs of bracing angles, with a local corrosion loss near 50 percent of the cross section.

Figure 5 shows a typical example of a cracked bracing member. The bottom horizontal leg of the angle was completely corroded near the connection. An area of fatigue cracking and crack growth can be seen near the corner of the angle. Eventually, the vertical leg of the angle fractured. This particular bracing member was repaired with a bolted splice, similar to those used previously to repair bracing in the FAST bridge spans.[2,3,7,8] A total of five bracing members in the 55.5-foot riveted span have required repairs due to significant corrosion and cracking. In four cases, bolted splice repairs were applied. In the remaining case, the corrosion loss in the bracing and the gusset plate were so extensive that the entire bracing member needed to be replaced.

Figure 5. Typical Corrosion and Fracture of Bracing Angle Member in 55.5-foot Riveted Girder Span at FAST

Member replacement is the typical repair made in revenue service, but installation of a replacement member often requires equipment and track time. By contrast, all the parts and tools required for bolted splice repairs can be hand carried to the member being repaired.

Horizontal gusset plates in the 55.5-foot riveted girder span also show evidence of corrosion. Several of these were replaced prior to installing the span at FAST. Figure 6 shows one top lateral gusset plate that was not replaced, but has since separated into three parts. This separation was noted when some deck ties were being changed. Note that the one portion of the crack is only visible from above, because the bracing member blocks the view from below. When the deck ties are in place, this type of defect is not at all visible unless it happens to be located between deck ties. At the direction of the Bridge TAG, this member has not yet been repaired, in order to experience the effects of delaying a somewhat more difficult repair. This cracked secondary member has been in service for 260 MGT since it was first discovered. Some innovative repair plans have been proposed, all with potential for being installed completely from below, without need for track time or opening the deck.

Figure 6. Top Gusset Plate Defects in 55.5-foot Riveted Girder Span at FAST

Periodic lateral movement measurements are being taken to monitor changes and the necessity for a repair. Figure 7 shows lateral deflection measurements with the full lateral bracing system intact and with the broken gusset. The AREMA recommended limit is also shown for reference.[6]

With the broken gusset plate, the lateral deflection is about 40 percent higher compared to when the span was first installed, but it is still well within the AREMA recommended limit for maximum lateral deflection in a span of this length. These measurements are all for normal operation of the HAL train at FAST.

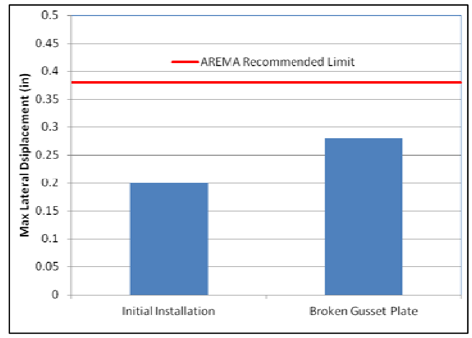

Figure 7. Lateral Deflections in 55.5-foot Riveted Girder Span at FAST under HAL Train Operations

Description of FAST Train Operations

The accelerated service environment at FAST is provided by running a 110-car HAL train equipped with 315,000-pound cars, pulled by three SD70 six-axle locomotives. Normal train operations are at 40 mph. The FAST train does not usually contain any cars with flat wheels or other defects that might produce large wheel impacts. The FAST steel bridge is described in the references.[1,2,3,4,7,8]

FUTURE WORK

Fractographic analysis and material characterization is being performed at Purdue University. HAL traffic continues operation over the bridge, and deflections near the major splice repair are being monitored for changes. To date, 78 MGT of HAL traffic has accumulated on the major repair.

ACKNOWLEDGEMENTS

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