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Continued Performance of a High-Angle Crossing Diamond at FAST

Part 1: Frog Bolts

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Summary

This is the first in a two-part series of *Technology Digests* in which the results of testing using a high-angle crossing diamond are summarized. Part 1 evaluates the performance of frog bolts; Part 2 (TD-17-027)[1] evaluates the performance of castings and rails in the superstructure of the crossing. Further details of the results/findings discussed in this two-part series will be published in an AAR Research Report. The results of the frog bolt performance test have identified the need for further research, design modifications, and testing to extend the maintenance cycle and increase the service life of bolted connections in special trackwork. This study was performed under AAR's Strategic Research Initiative on special trackwork.

In November 2015, 48 new frog bolts (12 at each of the four frogs in the castings/rails connections) were installed in the existing, 73-degree, straight rail reversible crossing diamond for evaluation. When the bolt test started, the crossing diamond had been in service 62.53 million gross tons (MGT) on the High Tonnage Loop (HTL) of the Facility for Accelerated Service Testing (FAST) during three previous test phases, which were tests of frog foundation configurations conducted for the Federal Railroad Administration (FRA).

Following are the results:

- During the 38 MGT test, 17 of 65 total bolts fractured and were replaced; and eight bolts at five locations of 65 total bolts loosened and were retightened.
- The clamping force provided by the bolts is apparently not sufficient to keep the five components in the stacks (bolted connections) from moving relative to each other, resulting in the bolt shear failures that occurred.
- The primary failure modes/maintenance were (a) fractured bolts, (b) loose bolts, and (c) rail cracks.
- The performance of the bolts, in terms of fractures, was likely influenced more by location in the crossing diamond and the various different track/environmental/operational conditions described in this digest than by the bolt type.
- The lock nut/washer/thread designs of the bolts that were installed in the crossing diamond corners, where two or less occurrences of loosening were recorded, performed well.
- Fractured bolts appear to be well correlated with crossing diamond geometry, as most fractured bolts occurred in the northwest (first in eastbound direction) and southeast (first in westbound direction) corners of the crossing diamond. These corners are the ones that the passing wheel impacts first, so diamond geometry may influence the distribution of forces and stresses in the diamond. Chipped railheads are a second possible influence, as the number of fractured bolts near the chipped railhead increased with the size of the chipped railhead. Cracked rails and chipped castings did not appear to be correlated with fractured bolts.

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BACKGROUND

Prior to the bolt test, TTCI conducted three phases of the "Next-Generation Foundations for Special Trackwork" research for FRA, which produced significant improvements in the dynamic performance of a prototype crossing diamond under test conditions at FAST. Phases I and II testing involved preliminary research, modeling, and field testing.[2] The Phase III results indicated that ramped running surfaces, frog configuration, and specially engineered, full-coverage rail seat pads placed between the crossing diamond superstructure and the platework, contributed significantly to the reduction of wheel-rail impact forces.[3] Reductions of 20 to 30 percent were measured for vertical dynamic wheel loads. Under test conditions at FAST, the full-coverage pads were able to reduce vertical dynamic wheel loads at 40 mph to a level similar to that at 20 mph without pads. As a result, the crossing diamond was in service under severe heavy axle load (HAL) traffic for 100 MGT during which period track surfacing was not required for about 97 MGT. Such a test was not possible a few years ago.

Upon completion of Phase III, TTCI focused on addressing frog bolt failures using the same crossing diamond. The crossing diamond had been in service 62.53 MGT on the HTL during three previous test phases when the bolt test started.

OBJECTIVE

Five types of frog bolts donated by three manufacturers were used in the test with objectives to:

- Quantify the performance of bolts based on the type and frequency of maintenance required.
  - Type of maintenance: Fractured bolts replaced, loose bolts retightened
  - Frequency of maintenance: Based on traffic (MGT) over the crossing diamond
- Identify the failure mode(s) of the bolts
- Identify the conditions that may affect the performance of bolts in a crossing diamond
- Make recommendations to increase the maintenance/service life of frog bolts.

TEST BOLTS AND INSTALLATION

Initially, TTCI installed 48 new frog bolts, 12 at each of the four frog castings/rails connection corners (northwest (NW), northeast (NE), southwest (SW), southeast (SE)), of the 73-degree, straight rail reversible crossing diamond shown in Figure 1. Five types of frog bolts donated by three manufacturers were used in the test. Traffic ran in both directions (clockwise and counterclockwise) over one line only on the HTL, vertical along the page in Figure 1. No traffic ran on the line horizontal to the page. This is the typical configuration for tests that involve crossing diamonds on the HTL. Figure 2 shows the 12-bolt configuration used at each of the four corners to identify each bolt (NE corner shown). Figures 3a through 3e are head and nut photos of each bolt system. The threaded bolts were installed to about 2,400 ft-lb of torque and the lock bolts were installed to a clamping force of about 130,000 pounds (according to Huck).

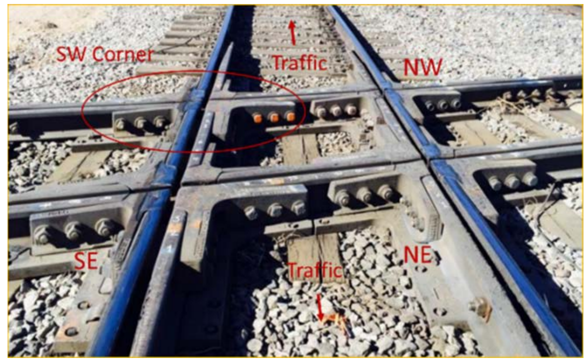

Figure 1. A total of 48 new frog bolts were installed in the four corners of the crossing diamond. One corner is circled for illustration.

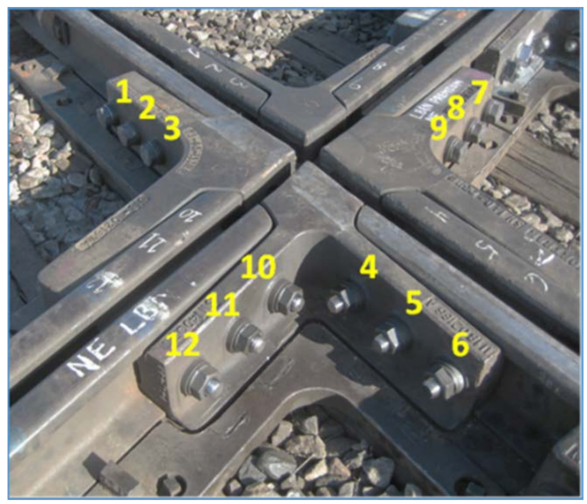

Figure 2. Typical 12-bolt configuration at each corner of the crossing diamond, NE corner shown. Traffic ran in both directions along the 1 through 6 bolt line.

TEST ENVIRONMENT

- Crossing diamond installed on tangent track; HTL Section 40
- Twelve bolts of each type were installed in each of the four corners of the crossing diamond (Figure 2)
- About 2,400 ft-lb torque on the threaded bolts and about 130,000 pounds of clamping force on the lock bolts
- Traffic in both directions over one track of the diamond
- 2,374 HAL trains over the bolts in test for the longest duration
  - 1,266 trains in clockwise direction
  - 1,108 trains in counterclockwise direction

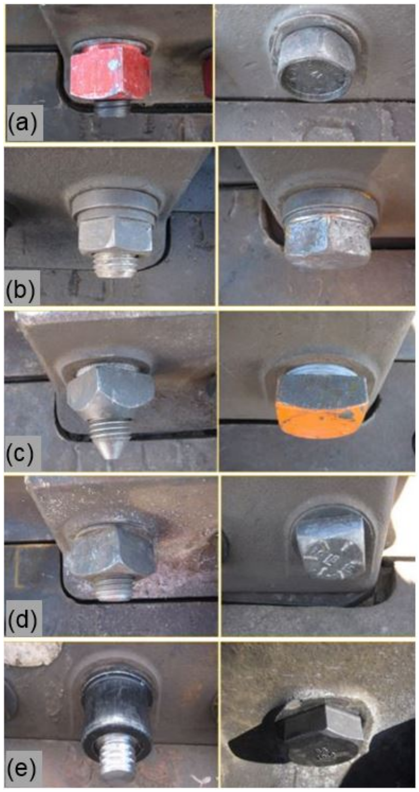

Figure 3. (a) NW Corner – Huck 360 Threaded Bolt; (b) NE Corner – Lewis Bolt & Nut (LB&N) Self-Centering Threaded Bolt; (c) SW Corner – Copper State Threaded Bolt; (d) SE Corner (Phase I) – LB&N Standard Threaded Bolt; (e) SE Corner (Phase II) – Huck Bobtail Lock Bolt.

- Average train lengths: 82 and 110 cars/locomotives (train length changed during the test)
- HAL cars: 315,000 pounds gross rail load; 39-ton axle load
- Train speed: 40 mph
- Vertical wheel impact forces measured over the crossing diamond at 40 mph during the special trackwork foundations test[2] using instrumented wheelsets
  - Maximum: ~75 kips (clockwise) and ~77 kips (counterclockwise)
  - 99th percentile: ~65 kips (clockwise) and ~66 kips (counterclockwise)

TEST FINDINGS

The primary failure modes/maintenance were fractured bolts, loosened bolts, and rail cracks. At the conclusion of the 38 MGT test, 17 of 65 bolts (26 percent) fractured and were replaced, and 8 of 65 bolts (12 percent) loosened and were retightened. Two bolts were retightened twice.

Loosened and Fractured Bolts

The graph in Figure 4 shows the record of loosened and fractured bolts over the course of the test. Six of the 8 bolts (75 percent) that loosened were in the difficult to tighten locations near the vertex of the acute angle (Bolts 3, 4, 9, and 10). When bolts loosened, they were re-torqued and when they fractured, they were replaced with the same type of bolt.

- The graph allocates a column in which to enter the loosened (blue dots) and fractured data points (red dots) for each of the 12 bolt locations at each of the four corners of the crossing diamond.
- The y-axis indicates the tonnage accumulated from the time the bolts in each corner were installed.
- The green horizontal line indicates the tonnage accumulated at each corner at end of test. That tonnage value is indicated along the x-axis.

Thirty-six bolts in three of the crossing diamond corners were installed on the same date: NE corner (LB&N Self-Centering), SW corner (Copper State) and SE corner (LB&N Standard). The 12 bolts in the NW corner (Huck 360) were installed 2.34 MGT later. The bolts in the NE and SW corners were in service for the duration of the test; they accumulated 37.93 MGT. The bolts in the NW corner were in service until the end of test; they accumulated 35.59 MGT, because they were installed later in the test.

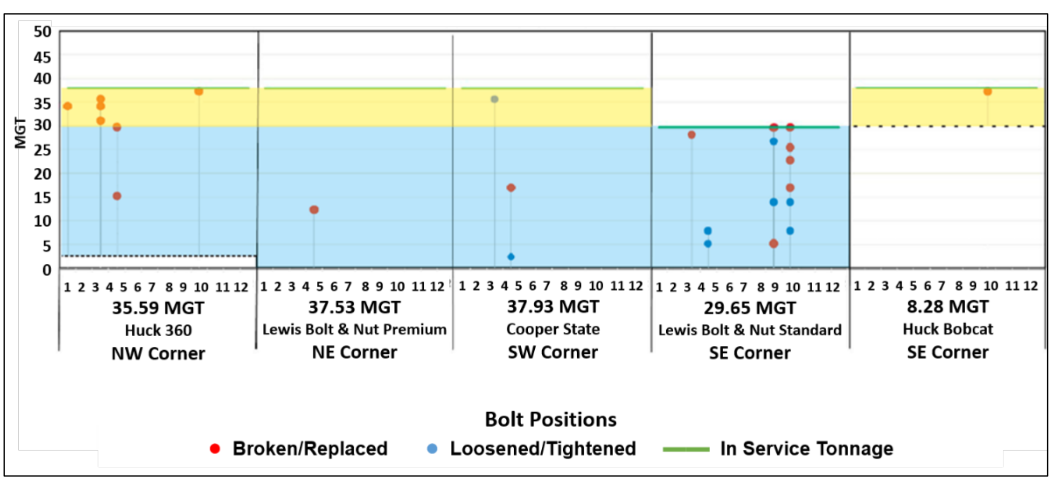

Figure 4. Record of loosened and fractured bolts

The LB&N Standard bolts in the SE corner (Phase I) were removed and replaced with Huck Bobtail® Lock bolts (Phase II) after 29.65 MGT (labelled "Test Completed" in Figure 4), once sufficient data had been collected. The Bobtail bolts had accumulated 8.28 MGT when the bolt test concluded.

Bolt fractures occurred (a) near the head/shank radius, (b) at the shank, and (c) in the threads, as shown in Figure 5. The likely cause of failure was fatigue cracking.

Figure 5. (a) NW Corner, Bolt 3 (Huck 360), 33.23 MGT; (b) SW Corner, Bolt 4 (Copper State), 16.90 MGT; (c) NE Corner, Bolt 4 (LB&N Self-Centering), 12.32 MGT

Bolt Failure Metallurgical Study

Two bolt heads were taken to TTCI's onsite metallurgy lab for failure analysis: Sample 1 bolt hole 3, NW corner, fractured at 31.70 MGT, and Sample 2 bolt hole 3, NW corner fractured at 33.23 MGT. The fracture faces of both bolts were mostly light grey with a fine texture; each face also contained a darker, coarse grained area (Figure 6a). Because the fractures were similar, the photographs in this report were all taken from Sample 2. The likely cause of failure was fatigue cracking. The cracks initiated at multiple locations, some of which are shown in Figure 6b. No void, inclusion, or other discontinuity was found as a root cause for the fatigue crack. The propagating crack created the fine, light grey surface. When the bolt could no longer support the loading conditions, fast final fracture occurred and created the coarse, dark areas.

Frog Bolt Performance Factors

It is difficult to determine with certainty the conditions that cause bolts to fail in one location of the crossing diamond with more frequency than in another location. Potential conditions include (a) vertical impact loads (running surface anomalies, i.e., flangeway gaps, crossing diamond geometry, chipped railhead, battered castings); (b) rail/casting and rail/spacer block interface (interface wear, chipped casting); (c) bolt hole misalignment (thermal stresses); and (d) rail stresses (train loading), etc.

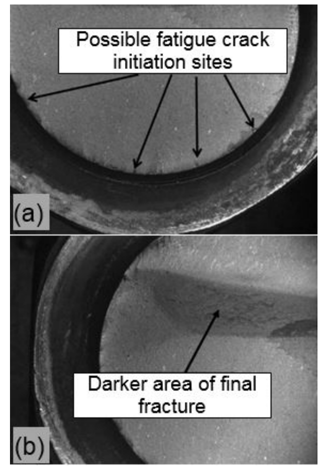

Figure 6. (a) Course region indicates final fracture area; (b) Possible multiple crack initiation sites

FUTURE RESEARCH

The results of the frog bolt performance test have identified the need for further research, design modifications, and testing to extend the maintenance cycle and increase the service life of bolted connections in special trackwork.

Given the bolt failures and related bolt hole-initiation cracking that occurred in the rail during this test, the focus going forward may be on eliminating contact between the bolts and the bolt holes, reducing/modifying contact between castings and rails, and providing a stronger rail section (e.g., thick web) at the connections. A simple solution may be to use larger diameter holes in the running rails than those used in the castings and filler blocks.

ACKNOWLEDGEMENTS

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References

1. Jimenez, R., S. Wilk, K. Jones, D. Davis. October 2017. "Continued Performance of a High-Angle Crossing Diamond at FAST. Part 2: Other Superstructure Components." *Technology Digest* TD-17-027. AAR/TTCI. Pueblo, CO.
2. Federal Railroad Administration. DOT/FRA/ORD-13/10, "Next-Generation Foundations for Special Trackwork Phase I," February 2013.
3. Federal Railroad Administration. DOT/FRA/ORD-16/14, "Next-Generation Foundations for Special Trackwork Phase III," May 2016.