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Continued Performance of a High-Angle Crossing Diamond at FAST

Part 2: Casting and Rail Components

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Summary

This is Part 2 in a two-part series of *Technology Digests* in which the results of testing using a high-angle crossing diamond are summarized. Part 2 addresses the performance of casting and rail components in the superstructure of the crossing. Part 1 (TD-17-026)[1] evaluates the performance of frog bolts. Further details of the results/findings discussed in this two-part series will be published in an AAR Research Report. Traditionally, the fasteners (i.e., bolts) have served as the sacrificial weakest link in joints between frogs and conventional open track rail. With improvements in fasteners, frog foundations and frog castings, the crossing diamond may serve long enough to develop fatigue failures in additional components. The essential problem to be solved remains: The reduction or elimination of high contact stresses between joint components.

The castings and rails performance results were documented at the conclusion of a 38 million gross ton (MGT) test designed to evaluate the performance of frog bolts. The crossing diamond had been in service about 62 MGT when that test started and it was in service for a total of 100 MGT. The test was discontinued on March 22, 2017, and the crossing diamond was removed from track due primarily to concerns over a series of cracks in the leg (running) rails.

- The rail cracks were identified (using ultrasonic testing) at three (of 16 total) three-bolt connections.
- Evidence of rail crack initiations were located as follows: four at bolt holes and four near the rail-web/rail-head radius that is in contact with casting support tabs.
  - The crack initiations located at the bolt holes are directly related to contact with the bolts, where the walls of the holes are subjected to vertical wheel impact forces and longitudinal rail stress.
  - The crack initiations identified at locations where the casting support tabs are in contact with the rail, high on the web, are directly related to vertical wheel impact forces.

During the 38 MGT test, 17 of 65 total bolts used in the test fractured and were replaced. The observed factors of track geometry, chipped railheads, fractured rail webs, and chipped castings were compared with the locations of the fractured bolts.

- Crossing diamond geometry (73-degree crossing tracks) appears to be well correlated with broken bolts, as most fractured bolts (15 of 17) occurred in the northwest (first in eastbound direction) and southeast corners (first in westbound direction) of the crossing 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 correlate with fractured bolts.

This study was performed under AAR's Strategic Research Initiative on special trackwork.

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INTRODUCTION

Improvements in the performance of crossing diamonds due to ramped running surfaces on castings, frog configuration and full-coverage rail seat pads[2] allowed the 73-degree, straight rail reversible (SRR) crossing diamond used in this test to survive long enough to conduct the bolt test discussed in Part 1 and to identify and evaluate other superstructure components failures that occur later in the service life of crossing diamonds. Such a test was not possible a few years ago under the heavy axle load (HAL) train at FAST due to rapid failure of major components. The running surface of the castings on the north rail (northwest and northeast corners) shelled more than those on the south rail during testing prior to the start of the bolt performance test. Given the reversible-castings design of this crossing diamond, the north running rail castings were swapped with the unused castings on the south rail before the start of the bolt test.

RAIL FATIGUE CRACKS ANALYSIS

One broken rail that initiated at a bolt hole occurred at the northwest (NW) corner (red oval in Figure 1) of the crossing diamond before the start of the bolt test discussed in TD-17-026 Part 1, when the crossing diamond had been in service 59 MGT.[1] That leg rail was replaced. The test was discontinued on March 22, 2017, and the crossing diamond was removed from track due primarily to concerns over a series of cracks identified in additional running leg rails after 100 MGT of service (yellow ovals in Figure 1).

Out of track, the crossing was disassembled for a detailed inspection of components and documentation of conditions, as shown in Figure 2.

As a result of the post-test disassembly, detailed inspection, and metallurgy analysis, evidence of fatigue rail crack initiation were located as follows: four at bolt holes and four near the rail-web/rail-head radius that is in contact with casting support tabs.

As an example, Figures 3a through 3d illustrate the fatigue crack initiation sites identified in the northeast (NE) leg rail at bolt hole 1 and above bolt holes 2 and 3, where the casting tab contacts the web of the rail. The crack initiations located at the bolt holes are directly related to contact with the bolts, where the walls of the holes are subjected to vertical wheel impact forces and longitudinal rail stress. The crack initiations identified at locations where the casting support tabs are in contact with the rail, high on the web, are directly related to vertical wheel impact forces.

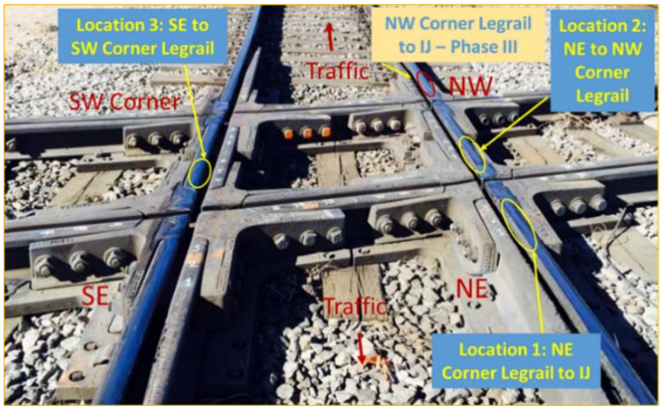

Figure 1. Rail break at the NW corner (red oval) at 59 MGT. The crossing diamond had been in service 100 MGT when a series of rail cracks were detected in the leg rails (yellow ovals)

Figure 2. Crossing diamond being disassembled out of track for detailed inspection of components

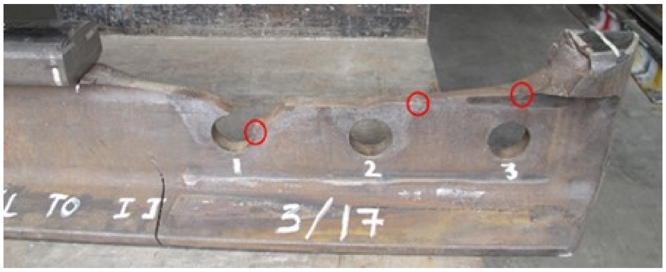

Figure 3a. Leg rail between the NE corner and the insulated joint. Top portion removed along the crack for evaluation. The vertical band-saw cut in the base of the rail was made during inspection of the fracture surfaces.

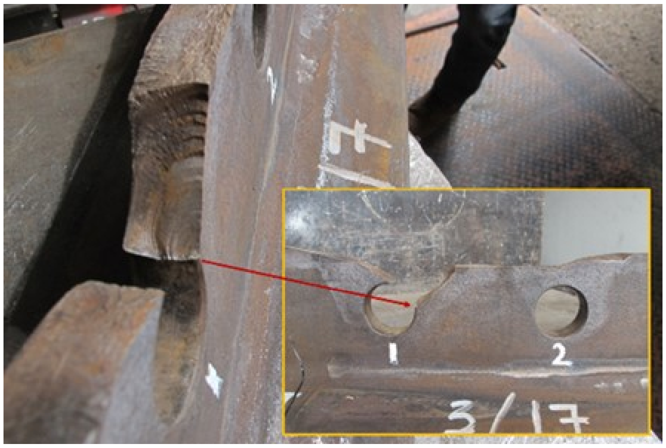

Figure 3b. Fatigue crack initiation at bolt hole 1, NE corner

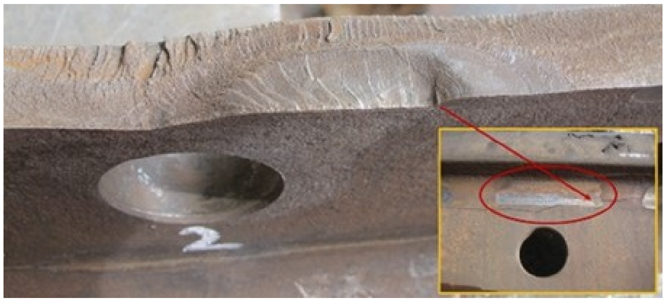

Figure 3c. Fatigue crack initiation at casting support tab contact with the rail above bolt hole 2. Red oval around surface fatigue caused by bearing on the casting support tabs.

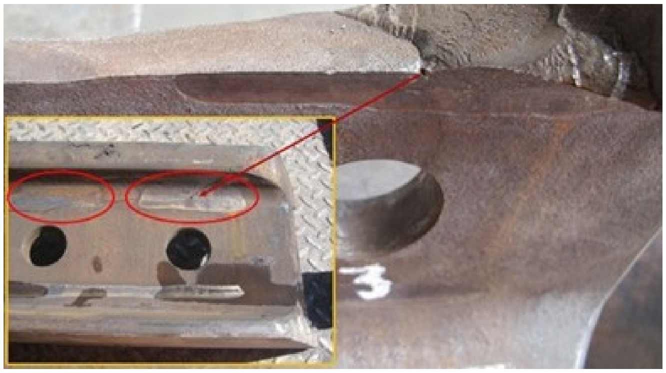

Figure 3d. Location of final fracture above bolt hole 3. Red ovals denote surface fatigue caused by bearing on the casting support tabs.

RAIL-END CHIPS

In addition to the flangeway gap, rail-end chips at the interface between the leg rails and the castings are a source of dynamic wheel impact loads. Figure 4 illustrates a 1-1/4-inch chip that developed at the NW corner during the 38 MGT bolt test. Bolts at the location nearest to this chip fractured in short succession. A 1-inch chip at the southwest (SW) corner and a ½-inch chip at the southeast (SE) corner developed prior to the start of the bolt test and remained until the end of test.

Figure 4. Rail chip at the NW corner developed during the 38 MGT bolt test

CASTING SUPPORT TABS

Evidence of high localized stresses was observed from rail web cracks that initiated at the rail/casting block interface (Figure 5). Since all the rail fractures not at bolt holes initiated from the rail/casting tabs interface and not at the rail/spacing block continuous interface, the higher stresses from the lower contact area of the tabs and increased relative movement are suspected as possible reasons.

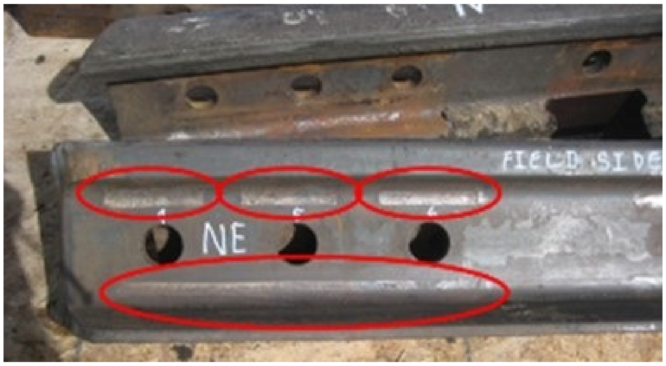

Figure 5. Rail wear from contact with the casting tabs

CHIPPED CASTINGS

Figure 6 is an example of the seven chipped castings that were observed at the NW, SW, and SE castings during the post-test inspection.

Figure 6. Chipped casting tab that contacts high on the web of the rail at the SW corner

BOLT HOLE MISALIGNMENT

Bolt hole misalignment is a condition that could possibly lead to increased shear stress within diamond bolts. Each bolt passes through five components – field side casting, guardrail, spacing block, running rail, and gage side casting – and misalignment between any of the components can produce shear stresses within the bolt, leading to an increased chance of failure.

This misalignment can occur from manufacturing, which was investigated because the majority of bolt failures occurred due to shear stresses. After checking all the bolt spacings for all five components (Figure 7), no manufacturing bolt hole misalignments were observed.

Figure 7. Measurement of bolt hole spacing

THERMAL EXPANSION

Thermal expansion/contraction is another factor that may produce bolt hole misalignment. In the regions where the running rail approaches or exits the diamond, the differential thermal expansion between the running rail and spacing block/casting may be large enough to induce significant shear stresses on the bolts.

Evidence suggesting the influence of thermal expansion was the difficulty of installing one set of bolts in the midafternoon, but easily removing it in the morning about a week later. It took about 15 minutes to install three bolts. Figure 8 shows deformations from the installation process, as they were driven by a sledge hammer, which are evident on the horizontal sides of the bolts.

The passing of a train in a crossing diamond may also produce longitudinal rail stresses, and these increased rail stresses would be expected to be unevenly distributed across the crossing diamond. More investigations into this effect are needed before conclusions of influence can be made. Evidence of increased rail stress was indicated from rail fractures that initiated at eight locations within the crossing diamond, where four of the eight rail fractures initiated at bolt holes.

Figure 8. Deformation along the side of the bolts resulting from forced installation by sledge hammer

RECOMMENDATIONS AND FUTURE RESEARCH/TESTING

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 and providing a stronger thick web rail section at the connections.

One potential solution may be to use a specially designed application of AAR's keyed Insulated Joint (IJ) concept, where: (a) the bolts can be kept from contacting the holes, thereby providing tensile/clamping force instead of the shear conditions that cause failure, and (b) using thick-web rail section that provides a stronger connection.

Another simpler solution may be to use larger-diameter holes than those used in the castings and filler blocks, in thick-web running rails.

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.

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 1: Frog Bolts." *Technology Digest* TD-17-026. AAR/TTCI, Pueblo, CO.
2. Federal Railroad Administration. DOT/FRA/ORD-16/14, "Next-Generation Foundations for Special Trackwork Phase III," May 2016.