ABSTRACT

Transportation Technology Center, Inc. has developed and evaluated improved performance foundations for crossing diamonds and turnouts. Under sponsorship of the Federal Railroad Administration and the Association of American Railroads, foundations for a No. 20 turnout and high angle crossing diamonds were developed and evaluated at the Facility for Accelerated Service Testing (FAST). The results of the evaluations show that dynamic loading and required maintenance can be reduced for heavy haul operations.

A prototype high angle crossing diamond was built to evaluate the effects of frog design and foundation parameters on dynamic wheel-rail forces. The prototype was installed in the High Tonnage Loop (HTL) of FAST for testing under 315,000-pound traffic. A series of 13 configurations were built and measured using load measuring, strain gaged wheelsets under 315,000-pound railcars. The results showed that dynamic load reductions of 20 to 30 percent were possible at mainline speeds of 40 mph.

In a separate test, a tie mat with a larger footprint was developed for high angle crossing diamonds. The concept involves interlacing crossties to create a lattice or mat with a larger bearing area (under the frogs) that is still tampable. A prototype was built from 10-inch wide crossties using half lapped joints between ties. The prototype was installed in the HTL of FAST for long term testing under 315,000-pound traffic. The foundation produced lower ballast pressures, lower average settlement and lower differential settlement over the 300 million gross tons (MGT) duration of the test. Measurement of track stiffness on the prototype over time confirm that the tie mat track is stiffer than conventional crosstie track with the same crossing diamond platework.

Another year of testing the No. 20 turnout with under-tie pads was completed. An interim report on the performance of this turnout was presented at the 2015 AREMA conference. The turnout continues to perform well, with lower average and differential settlement. The under-tie pads have now survived 300 MGT of heavy axle load traffic.
INTRODUCTION

High angle crossing diamonds and mainline turnouts have a very demanding service environment that can cause more rapid degradation than the surrounding track. The service environment differs in the following ways:

- More traffic than either of the tracks leading to the diamond/turnout
- Higher dynamic loading due to impacts at flangeway gaps

The typical high angle crossing diamond has largely conventional track components except for the frogs. Similarly, a mainline turnout has largely conventional components, except at the switch and frog. In many cases the foundation (from the bottom up) is the native subgrade, subballast, ballast, and crossties. Subgrade strengthening, such as a geogrid or hot mix asphalt may be used. Crossties may also be altered under the frogs to have larger cross sections, smaller spacing, or skewed to provide the same angle with respect to the centerline of each track. The currently used designs are often unsuccessful at reducing degradation to the levels of surrounding track. Figure 1 shows a high angle crossing diamond with a degraded foundation. The photograph illustrates commonly found problems of track surface deviations, degraded ballast, and poor drainage.

![High angle crossing diamond with a degraded foundation](image)

Figure 1. High angle crossing diamond foundation degradation

Foundation degradation likely contributes to foreshortened service lives of the diamond superstructure as well. Additional penalties to efficiency, reliability, and capacity can result from condition based speed restrictions at these locations. Turnouts can have the same vertical performance issues with the additional problem of high lateral loading and degradation rates at switches and frogs. Thus, a study of how to improve foundations for special trackwork was begun by Federal Railroad Administration (FRA) and Association of American Railroads (AAR). The FRA project focused on the more intractable problem of high angle crossing diamonds, whereas the AAR program concentrated on both mainline turnouts and crossing diamond foundations.

CROSSING DIAMOND FOUNDATIONS

An extensive study of ways to improve the performance of crossing diamonds was conducted by the AAR over the past 25 years. The initial work focused on the superstructure of the crossing diamond and yielded concepts like flange bearing frogs (1). More recent efforts by AAR and FRA have focused on foundations. Under this effort, Transportation Technology Center, Inc. (TTCI) performed a series of tests, under FRA funding, which evaluated the potential beneficial effects of various configurations of high angle frogs and frog foundations on wheel-rail vertical forces and frog performance (2). The tests were conducted under 315,000-pound cars with nominal 39-ton axle loads on the High Tonnage Loop (HTL) of the Facility for Accelerated Service Testing (FAST) at the Transportation Technology Center (TTC) in Pueblo, CO (Shu, Davis, Jimenez unpublished 2015 and 2016).

BALLAST AND SUBGRADE EXPERIMENTS

A scaled panel with rail surface discontinuities (i.e., flangeways) was built at FAST to simulate the impact on frog and crossing, as Figure 2 shows. Two types of rail discontinuity structures, simulating the...
flangeway gap of cast and three-rail crossings in revenue service, were implemented side by side in the test panel to investigate the rail structure and foundation effects on wheel-rail impact.

In Figure 2, the rail with a flangeway gap milled in the head is referred to as the rigid gap in this report; the rail with flangeway gap made with two rails and a set of joint bars is referred to as the flexible gap.

![Figure 2. Scaled test panel with two different types of gaps (lower rail – rigid gap, upper rail – flexible gap)](image)

November 1-10, 2011, load measuring instrumented wheelsets (IWS) tests were conducted at FAST. Two IWS were installed on the leading truck of a loaded gondola car with 39-ton axle loads. Table 1 lists nine test cases conducted on a scaled gapped foundation test panel and a full scale three-rail crossing and various foundation conditions. Figure 3 shows the panel test case 1 configuration, which consisted of wood panels on ballast with steel rail seat plates. Figure 4 shows panel test case 4, a non-ballast foundation test configuration case, which used four 10-inch by 10-inch wood ties as foundation to replace ballast.

Table 1. Scaled panel foundation test and full scale three-rail crossing test at FAST Section 40

<table>
<thead>
<tr>
<th>Test Date</th>
<th>Scaled Panel Foundation Test</th>
<th>Full Scale Three-Rail Crossing Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>11/2/11</td>
<td>Case 1: Existing wood panels &amp; ballast (as found); steel rail seat plates</td>
<td>Standard three-rail crossing, no rubber rail seat pads</td>
</tr>
<tr>
<td>11/3/11</td>
<td>Case 2: Existing wood panels &amp; ballast; after tamping; steel rail seat plates</td>
<td>rubber rail seat pads</td>
</tr>
<tr>
<td></td>
<td>Case 3: Existing wood panels &amp; ballast; rubber rail seat pads</td>
<td>rubber rail seat pads, no other changes</td>
</tr>
<tr>
<td>11/4/11</td>
<td>Case 4: Rubber panels; 4-timber foundation; steel rail seat plates</td>
<td>rubber rail seat pads, no other changes</td>
</tr>
<tr>
<td>11/7/11</td>
<td>Case 5: Rubber panels; 4-timber foundation; rubber rail seat pads (No VTM)</td>
<td>rubber rail seat pads, no other changes</td>
</tr>
<tr>
<td></td>
<td>Case 6: Wood panels; 2-timber foundation; rubber rail seat pads (No VTM)</td>
<td>rubber rail seat pads, loose inside rail crossing corner running rail bolts</td>
</tr>
<tr>
<td>11/9/11</td>
<td>Case 7: Wood panels; 2-timber foundation; steel rail seat plates</td>
<td>rubber rail seat pads, inside rail bolts retightened, loose outside rail crossing corner running rail bolts</td>
</tr>
<tr>
<td>11/10/11</td>
<td>Case 8: Wood panels; 4-timber foundation; steel rail seat plates.</td>
<td>rubber rail seat pads, no other changes</td>
</tr>
<tr>
<td></td>
<td>Case 9: Wood panels; 4-timber foundation; rubber rail seat pads</td>
<td>rubber rail seat pads, no other changes</td>
</tr>
</tbody>
</table>
Figure 3. Panel Test Case 1 configuration

Figure 4. Panel Test Case 4 configuration

The results of this series of tests are presented in Figure 5. The plot shows peak-to-peak (P2P) forces measured at 40 mph for the various track panels and stiffness values tested. The P2P forces are a measure of the vertical dynamic forces at the wheel-rail interface. Here, it can be seen that dynamic wheel-rail forces are correlated with track stiffness. All else being the same, a stiffer crossing diamond will generate higher wheel-rail forces. Of course, track damping is not constant across these cases, but varies with the track stiffness and track configuration. The effect of the flangeway gap configurations, as described above, will be discussed in detail later in this report.

Figure 5. Effect of track stiffness on rigid gap impact
Crosstie Experiments

Crossties are a key element in the track structure, especially at crossing diamonds. This study explored ways to reduce ballast pressures at crossing diamonds while still having a track configuration that could be surfaced. A simplified model of a crossing diamond foundation was developed using Geotrack®, a track foundation modeling tool (3). This model simulated a high angle crossing diamond by varying tie dimensions and spacing for conventional crosstie track. Loading was increased to represent the dynamic loading seen at high angle frogs. Figure 6 shows the effect of varying tie spacing for various width ties. Note that the industry recommendation for maximum pressure at the tie/ballast interface is 80 psi (4). Thus, it is not possible to design a crossing diamond ballasted track foundation that keeps ballast pressures below the AREMA recommendations using conventional 9-inch wide crossties and conventional 19- to 20-inch spacings. However, it is possible to reach the recommended limit for maximum ballast pressure by using a smaller tie spacing, a wider tie, or some combination of the two. Figure 6 shows some configurations that may be difficult to machine tamp, due to the width of the ties and/or the lack of clear space between ties.

![Figure 6. Predicted maximum ballast pressures versus tie spacing for various tie widths](image)

Figure 6. Predicted maximum ballast pressures versus tie spacing for various tie widths

Figure 7 shows the effect of varying tie width for three tie spacings of 16, 20, and 24 inches. Note that the effect of tie width is nonlinear, with decreasing incremental benefit as tie width increases.

![Figure 7. Predicted maximum ballast pressures versus tie width for three tie spacings](image)

Figure 7. Predicted maximum ballast pressures versus tie width for three tie spacings

The modeling results suggest that it will be difficult to configure a conventional crosstie layout that will perform well for a high dynamic load service environment like a crossing diamond. Thus, alternative configurations will likely be required. Currently, high angle crossing diamonds use a wide composite timber under the frogs of the mainline route. These timbers are generally wide enough to serve as a base.
for the platework and frogs. They also provide continuous support under the rails and frogs for the mainline route. This case is best represented in the modelling as the 24-inch wide tie on 24-inch spacing in Figures 6 and 7. The predicted ballast pressures are well below the recommended maximum. However, this configuration is difficult to surface with any method (tamping machines or by hand tamping).

**Test Crossing Diamond Tie Configuration**

A crosstie configuration that has a larger footprint per track length, continuous rail support, and the potential to be machine tamped was developed. The prototype, shown in Figure 8, is a simplified version of a 90-degree diamond foundation. It utilizes half lapped joints to provide crossies for both tracks in the frog areas of the diamond. This increases the footprint of the crossties supporting the frogs by about 60 percent over open track (and about 10 percent over the current crossing diamond foundation designs), while also providing large enough ballast crib space for surfacing operations. Figures 8-10 show the crosstie panel as built and two in-track configurations on the HTL of FAST.

![Prototype crosstie mat module with half lapped joints](image1)

**Figure 8. Prototype crosstie mat module with half lapped joints**

![Prototype crosstie mat in test on the HTL of FAST](image2)

**Figure 9. Prototype crosstie mat in test on the HTL of FAST**
Figure 10. Prototype crosstie mat configured to generate high dynamic loads (with frog plates and rail flangeway gaps) in test on the HTL of FAST

Vertical Stiffness

The tie mat with platework representative of a crossing diamond had about 14 percent higher vertical track stiffness than a conventional crossing diamond being tested nearby. Figure 11 shows the measured vertical stiffness of the conventional diamond and the tie mat with large platework. For comparison, the vertical stiffness of a similarly configured track panel with a rubber slab and with a concrete slab with very stiff rail seat pads are also shown. The rubber mat is 40 percent less stiff and the concrete slab without rail seat pads is 2.5 times stiffer than the conventional diamond.

Figure 11. Measured track stiffness of prototype crossing diamond foundations on the HTL of FAST

Track stiffness on the crosstie mat was measured after 300 million gross tons (MGT) of traffic. The measurement was made after at least 100 MGT of operations without surfacing. The crosstie mat is close enough to actual crossing diamonds that it does get surfaced when the track is raised at the crossing diamonds. Figure 12 shows the average track stiffness of the crosstie mat at two intervals. Also shown is the average measured stiffness of two crossing diamonds with conventional platework and tie configurations in an adjacent test section.
Settlement

Track settlement was measured for the first 60 MGT of heavy axle load (HAL) operations of the timber mat in service. Comparison of the settlement in the timber mat section versus the track immediately adjacent (i.e., the approaches) was made. The tie mat had about 20 percent less settlement. Note that the total settlement was large due to the disturbance of the ballast layer to below tie depth over the entire test zone. Figure 13 shows the top of rail elevation (average of left and right rail) after 60 MGT of HAL traffic. It is apparent from the plots that the tie mat has settled less, creating a change in the track gradient. During the subsequent 300 MGT of testing to date, the tie mat has not required surfacing. Thus, it is not settling at a significantly different rate than the surrounding track.

Durability

The tie mat was built with untreated timbers for proof of concept testing. As such, its long term durability against environmental factors cannot be assessed. The performance of the half lapped joints is being monitored over time.

FROG AND PLATEWORK EXPERIMENTS

Previous work showed that dynamic wheel-rail vertical forces could be reduced by adding flexibility to the frog. This concept allows vertical differential movement of one side of a frog with respect to the other side of the flangeway. This concept, illustrated in Figure 2, was demonstrated in track panel tests and tests.
with a full three-rail diamond (Shu, Davis, Jimenez unpublished 2015). Figure 14 shows the measured forces in a flexible frog and a rigid frog side by side.

**Figure 14. Flexible and rigid gap wheel-rail forces**

In addition to the frog design tests, a series of tests were conducted to assess the effects of adding damping with rail seat pads higher in the track structure. A full crossing diamond with milled plates was built to test rail seat pads. The test prototype, shown in Figures 15 and 16, is a modified version of the voestalpine Nortrak (Nortrak) Straight Rail Reversible (SRR) crossing diamond (5). This design was selected because the frog configuration has four separate castings bolted together through flangeway spacers for each frog. The SRR design was modified to allow more vertical relative movement between the four castings in a frog. The following design modifications include:

- Two-part flangeway spacers (split spacers) between the running rails and the guardrails
- “Tile” type flangeway spacers at the intersection of the four casting corners of each frog (Figure 17)
- Milled seat platework
- ½-inch rubber pads between the rails/castings and the platework (Figure 18). The tile spacer keeps the flangeways open, but does not provide any capability to carry tensile, longitudinal load

The prototype crossing diamond was designed to evaluate the benefits that were achieved in previous short-term, as well as scaled panel tests; flexibility in the superstructure resulted in the reduction of the wheel-rail impacts.
Figure 15. The test prototype crossing diamond as installed is a modified version of the basic SRR crossing diamond design.

Figure 16. The crossing diamond was installed in typical HTL test configuration, where traffic runs over a single route.

Figure 17. Tile type flangeway spacer on the casting corners and two-part (split) running rail/guardrail flangeway spacer.
The effects of rail seat pads were significant. Over the years, crossing diamonds of various angles, frog designs, and materials have been evaluated under HAL traffic. This section provides a global view and comparison of the vertical wheel load environment over various existing crossing diamond types and the Phase III prototype frog evaluated during this test. Figure 19 shows the maximum vertical wheel load versus speed for three currently used designs. The most flexible designs (the three-rail and the flexible frog) had the lowest maximum vertical wheel loads. A confounding factor is the angle of the frogs in each crossing diamond. The higher angle frogs are known to produce higher forces. A better comparison can be made between the solid design 76-degree crossing diamond and the flexible design 78-degree crossing diamond. In this comparison, the flexible design produced 32 to 17 percent lower maximum forces at speeds of 20 to 40 mph. Although a 76-degree versus 78-degree crossing diamond comparison was better, it was still not adequate to determine the relative effects of rail seat pads and flexible frog design.

Using the Phase III prototype frog, the effects of rail seat pads and frog configuration were determined independently. Figure 20 shows how the addition of rail seat pads to the SRR crossing diamond decreased maximum vertical forces by 20-30 percent. The figure also shows that split flangeway spacers did not significantly affect maximum vertical forces (the SRR 78 with pads and Flexible 78 with pads comparison). Also, note that the more flexible SRR design without pads had maximum vertical forces similar to a 76-degree solid design frog crossing diamond.

Additional tests evaluated two configurations of flexible frog by using four or two split flangeway spacers per frog (i.e., all four frog corners can move vertically relative to the others versus only the common corner can move relative to the other three). Figure 21 shows 99th percentile vertical forces over the crossing diamond. A better comparison can be made using 99th percentile forces instead of maximum
forces. The reduced freedom between the four frog castings resulted in less alignment degradation and maintenance. Figure 21 shows there was some small benefit of either flexible frog configuration at 20 and 30 mph, but no reduction in vertical forces at 40 mph. Also note that there was almost no performance difference between the full flexible frog and the easier-to-maintain partial split spacer flexible frog.

Figure 20. Maximum vertical wheel load versus speed for various crossing diamonds foundations evaluated at FAST

Figure 21. Maximum vertical wheel load versus speed for various rail seat pad and flangeway spacers evaluated at FAST

TURNOUT FOUNDATION EXPERIMENTS

The turnout foundation design issues are similar to those of crossing diamonds. The vertical stiffness of the track changes less abruptly in turnouts. There is the added complication of switch entry angle in the lateral plane, which causes uneven loading on left and right wheels of the same axle.

Much effort has been expended by the industry to eliminate or mitigate the impact causing features of turnouts and crossing diamonds, such as better alignment design and improved performance frogs (5,6,7,8). This has resulted in significantly longer service lives for special trackwork under HAL. However, relatively high dynamic loads are still measured in these improved performance turnouts and crossing diamonds.

In addition to these sources of dynamic load, there are the more subtle ones related to changes in track structure. Longer crossties as the two tracks in the turnout or crossing diamond diverge make the special trackwork stiffer than the surrounding track. In the same way, multiple rails and tie plates that span multiple ties can change the stiffness and damping characteristics of the special trackwork. The following sections will describe the development and evaluation of turnout and crossing diamond foundation modifications for HAL applications.

Test Turnouts
A series of experiments is being conducted using a No. 20 turnout on the High Tonnage Loop (HTL) at FAST. The Canadian Pacific Railway turnout has an AREMA-style secant alignment and a fixed point frog that is representative of mainline turnouts being installed in service across North America.

The foundation experiment described here involves use of under-tie pads intended to create uniform vertical stiffness throughout the turnout and to reduce the effects of impact loads. Two different stiffness pads were used in the turnout, with the softer pad being used under the frog. Due to the sequencing of additional experiments, the turnout was installed with the under-tie pads on all ties except for the switch panel (the first 40 feet of the turnout). Performance comparisons were made between the padded and unpadded portions of the turnout. Comparisons were also made between the test turnout and previous turnouts at this location.

**Test Turnout Installation**

Canadian Pacific Railway donated a complete No. 20 turnout fitted with donated Getzner, USA, polyurethane under-tie pads, plus an additional switch panel without the pads. The existing turnout and approaching track 225 feet long was removed, and the Phase I test turnout was installed. Figure 22 shows the newly installed turnout. The 136RE rail in the turnout panels were welded using electric flash and thermite welds. Phase I consisted of two closure panels, the frog panel, and an additional panel beyond the frog, all with under-tie pads. The switch panel without the under-tie pads was installed during Phase I, and new granite ballast was installed throughout the turnout. The focus of Phase I was to quantify the performance of the switch panel without pads as compared to the rest of the padded turnout and to gather data for direct comparison with Phase II padded switch panel test.

**Figure 22. Newly Installed No. 20 turnout used in foundation tests**

**Turnout Vertical Stiffness Measurements**

The vertical track stiffness over the mainline route of the turnout was determined using TTCI’s Track Loading Vehicle (TLV). The TLV applied 10,000- and 40,000-pound static vertical loads at each of 46 locations along the turnout. The change in vertical deflection measured between the two vertical loadings was used to calculate stiffness in terms of pound-inch.

Six turnout approach measurements were taken over 21 feet of open track ahead of the switch point where unpadded ties were installed. Fourteen measurements were taken over the 57-foot switch panel: 12 measurements over closure panels 1 and 2, 8 measurements over the 42-foot frog panel, and 6 measurements over the 37-foot panel past the frog panel.

Figure 23 shows the results of vertical stiffness tests conducted on the two No. 20 turnouts on the HTL at FAST and illustrates abrupt changes throughout. Also evident are the hard points that can increase dynamic loads and cause differential settlement. The stiffest part of the FAST location 407 turnout was measured near the point of switch where hollow steel ties designed for concrete turnouts were installed.
The turnout that was in track before the test turnout was installed for Phase I is the primary base case for this experiment. Figure 23 shows this turnout also exhibits numerous changes in stiffness throughout, with the highest measured at the frog.

**Figure 23. Two No. 20 turnouts on the HTL at FAST without under-tie pads exhibiting changes in vertical stiffness and stiff areas of the switch points and frog**

Figure 24 is an overlay of the vertical stiffness measured on the base case turnout (no pads) and that measured on the Phase I test turnout at the same location.

The Phase I test turnout fitted with under-tie pads from closure panels 1 through 5 exhibits reduced stiffness variation and a significant reduction in maximum stiffness in the frog panel.

The variation in the vertical stiffness over the frog panel was reduced by approximately 70 percent using the under-tie pads based on the measured range. The stiffness throughout the frog panel of the previous turnout without pads varied approximately 269,000 lb/in (500,000 lb/in maximum and 231,000 lb/in minimum) as compared to the frog panel with under-tie pads, which varied about 72,000 lb/in (267,000 lb/in maximum, 195,000 lb/in minimum).

**Figure 24. Reduced vertical stiffness and variation in stiffness in phase I test turnout (pads from closure panel 1 to end of turnout) compared to baseline turnout (no pads)**
Figure 25 illustrates the vertical stiffness of the Phase I turnout when newly installed and after 58 MGT. The data indicates that the significant reduction in stiffness measured at the frog and the reduction in variability throughout the portion of the turnout with under-tie pads is sustainable after 58 MGT.

Figure 25 indicates that the switch panel of the Phase I test configuration and the open track approaching the turnout, both without under-tie pads, continue to exhibit higher stiffness and variation after 58 MGT.

![Average Vertical Track Stiffness, Inside Rail](image)

Figure 25. Reduction in vertical stiffness and variation in under-tie pad section of the turnout sustainable after 58 MGT of HAL traffic

**Track Settlement**

Shortly after the 82 MGT measurement, the switch panel was replaced with one that had under-tie pads. Settlement measurements were made on the entire turnout for a similar tonnage amount so that a direct comparison between switches could be made. Figure 26 shows average top of rail settlement for each switch and the rest of the turnout.

![Number 20 Turnout Settlement](image)

Figure 26. Average settlement for each switch panel and the rest of the turnout

The under-tie pads were inspected after about 180 MGT and were still intact, with visible indentations from individual ballast particles. Further inspections at up to 300 MGT (at the tie ends only) have shown similarly good pad conditions.

**SUMMARY AND CONCLUSIONS**

The potential to improve the performance of special trackwork through foundation design innovations is quite significant. Changes in the substructure can reduce wheel-rail dynamic forces by 20 to 40 percent.
This will result in longer maintenance intervals and service lives. Use of under-tie pads can greatly improve the efficiency of the crosstie-ballast interface. Adding more bearing area under frogs by reconfiguring the crossties can reduce ballast pressures to recommended ranges. More work is needed to make these configurations practical for field applications.

Rail seat pads were shown to significantly reduce wheel-rail dynamic forces in a high angle crossing diamond. Similar to under-tie pads the rail seat pads improve the efficiency of the casting to plate interface. They also add damping to the track, which helps protect all components below from impacts. Two pads with somewhat different properties were both successful in reducing dynamic loads and being durable enough to withstand HAL traffic.

Frog configurations were explored in this study as well. The rigid (one piece) frog designs used today are robust and reliable. However, they can contribute to the high dynamic wheel-rail forces that often limit allowable speeds in service. Test results showed that adding some flexibility to the frog, in terms of differential vertical movement across the flangeway gap, can significantly reduce wheel-rail dynamic forces. This can result in 30 percent lower forces for the same train speeds or perhaps 10-20 mph higher speeds for the same dynamic load environment.

ACKNOWLEDGEMENTS
The FRA and AAR sponsored the research and development projects described in this paper. TTCI thanks the Railway Tie Association for donation of the untreated crossties that were used to make the timber mat test panel. TTCI also thanks voestalpine-Nortrak and Getzner for donating rail seat pads for the crossing diamond. Getzner also donated the under-tie pads installed in the turnout. The turnout itself was donated by Canadian Pacific Railway.

REFERENCES
The Development and Evaluation of Special Trackwork Foundations

David Davis¹
Rafael Jimenez¹, Xinggao Shu¹, Duane Otter¹
and Luis Maal²

¹Transportation Technology Center, Inc.
²Federal Railroad Administration
Presentation Overview

- Evaluation of potential improvements to foundations for crossing diamonds and turnouts
  - Ballast and Subgrade
  - Crosstie Configurations
  - Platework and Frog configurations
  - Under-Tie pads for Turnouts
- Design and Prototype evaluations
- Conclusions

Background

- Special trackwork foundation has a unique service environment
  - Track structure changes
  - Potential for high dynamic loading
  - Different traffic rates by track
  - Drainage issues
- Special trackwork can have an ordinary foundation
  - Results in early failures (as compared to adjacent track)
  - Potential safety issues related to track geometry and component fatigue

Next Generation Foundation for High Angle Crossing Diamond Frogs

Background:
- There are ~5,000 Crossing Diamonds in North America
  - Significantly affect capacity, efficiency and reliability of RR
- Project to reduce forces at high angle frogs by improving foundations and running surfaces
- Test panel built to evaluate tie, pad and foundation materials

Next Generation Foundation for High Angle Crossing Diamond Frogs (continued):
- Test panel built to evaluate tie, pad and foundation materials
  - One simulated flangeway gap in each rail
    - One milled in the rail head with a fixed gap of 2 inches
  - Rigid type frog (e.g. casting)
  - One flangeway made adjustable by cutting rail and using spacers
    - Flexible type frog (e.g. 3-rail design)

Wood Panel with Ballast Foundation

Case 1

Rubber Panel Non-Ballast Foundation

Case 4
### Measured Forces with Different Foundations

**Results:**
- Flexible gap: Up to 26% reduction due to foundation changes.
- Rigid gap: Up to 37% reduction due to foundation changes.
- Flexible versus rigid gap: 17% ~ 49% reduction.

### Measured Forces on Full Crossing Diamond

**Results:**
- Effect of track stiffness on wheel/rail forces.

#### 99th Percentile Vertical Force - CW

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#### 99th Percentile Vertical Force - CW

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### AAR Turnout Foundation Test

- **Crosstie Configurations**
- **Modeling suggests potential benefits in performance**
  - Difficult to reduce ballast pressures to AREMA recommended using a tamp-able configuration.

### AAR Turnout Foundation Test

- **Timber Mat for crossing diamonds**
  - Built and installed in 2011
  - Tested with and without flangeway gaps

### Next Gen Foundation for High Angle Crossing Diamond Frogs

**Background:**
- Measured wheel/rail forces on Flexible joint gap considerably lower than on Rigid gap.
  - True for all foundation configurations tested.

**Test Results:**
- Small change in track stiffness.
- Significant decrease in track settlement.
  - Initial settlement is ~60 percent less.
Phase 2 Test Results

- Flexible frog has lower forces in 3-rail crossing diamond

**Prototype to evaluate frog design and foundation parameters**
- Used casting patterns from Northport, NE diamonds
- Milled seat platework for railseat pads
- Flangeway spacers
  - Tile spacers @ flangeway intersections
  - Split spacers allow more differential movement

**Flexible Frog Concept**
- Vertical damping layer provided by railseat pads
- Differential movement across flangeway gaps
  - Split spacers and tile spacers provide this
    - Also allow unwanted differential movement in other two planes

**Effect of Pads can be Significant** (e.g. 10 – 20 mph)
**Effect of Frog Flexibility**
- Less important for this design

**AAR Turnout Foundation Test**

**Description of Test**
- Vertical stiffness variations due to longer ties, platework and extra rails in turnouts
- Under-tie pads installed in turnout
  - Uniform stiffness 200,000 – 250,000 lbs/in

**AAR Turnout Foundation Test**

**Preliminary Results**
- Uniform stiffness 200,000 – 250,000 lbs/in
- Reduction in settlement by ~33%
- More uniform settlement

**AAR Turnout Foundation Test**

**Special Trackwork Foundations**
- Summary
  - Effect of ballast and subgrade
    - 20-40% reduction of wheel/rail forces possible
  - Effect of crossties
    - Half lapped joint mat can reduce ballast pressures to AREMA limits
    - Under-tie pads reduce track settlement and ballast pressures
  - Effect of railseat pads
    - Potential reductions of 25%
    - Compromise of dynamic properties with durability
  - Effect of frog configuration
    - Less rigid frogs can lower wheel/rail forces by 20-50%
    - Maintenance challenges
      - Allow differential vertical movement
      - Without differential lateral & longitudinal movement

**AAR Turnout Foundation Test**

**Frog Foundations Research**
- Future Work
  - Disseminate Findings amongst Special Trackwork Engineers
  - Revenue Service Demonstration
  - Interest in locating pads further down in track structure
  - Longer term durability test
Acknowledgements & Stakeholders

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  - AAR member railways
  - Volpe National Transportation Systems Center
- BNSF & CP (Frog & TO donations)
- voestalpine Nortrak & Getzner (pad donations)
- Railway Tie Association (tie donations)