Evaluation of Turnout Foundation Improvements for Heavy Axle Load Service

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ABSTRACT

Turnout characteristics can lead to significant dynamic loading due to running surface conditions and track structure changes. Significant progress has been made on running surface conditions with industry efforts to eliminate running surface discontinuities (e.g., spring frogs) and smooth switch transitions (e.g., tangential, spiral alignments). To address track structure changes, Transportation Technology Center, Inc. tested a mainline turnout with and without under-tie pads. The pads are designed to minimize track stiffness variations between the turnout and surrounding track and also within the turnout. Testing involved No. 20 AREMA-style alignment turnouts with railbound manganese frogs at the Facility for Accelerated Service Testing at the Transportation Technology Center in Pueblo, CO. The under-tie pads were applied to a timber crosstie turnout. Three pad designs were used: One for the transitions to adjacent track, one for the higher dynamic loading of the frog and the third for the rest of the turnout.

Preliminary results are encouraging. The turnout with pads has less settlement and less surface variation than the turnout without pads. The paper will describe the testing and the preliminary results after 200 MGT of heavy axle load train operations.

INTRODUCTION

Special trackwork includes turnouts and crossing diamonds. Turnouts allow trains to move from one track to another. Crossing diamonds allow trains on one track to cross another track at grade. Due to their function and unique structure, where turnouts and diamond crossings are located high dynamic forces may be generated. These forces come from a variety of sources. The most obvious are from the frog flangeways. These are gaps in the running rails that can cause impact loads. The turnout switch may have an alignment discontinuity on the diverging route. A non-tangential switch, typically used in North American freight operations, has an entry angle that can generate large lateral forces over a relatively short distance.

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 (1,2,3). This has resulted in significantly longer service lives for special trackwork under heavy axle loads (HAL) (4). 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

Transportation Technology Center, Inc. (TTCI) is conducting a series of experiments using a No. 20 turnout on the High Tonnage Loop (HTL) at the Facility for Accelerated Service Testing (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 revenue service across North America. The test turnout has hardwood timber crossties.
The foundation experiment described here involves use of under-tie pads intended to create uniform vertical stiffness throughout the turnout and 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 portions of the turnout with and without the under-tie pads. 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) was removed and the Phase I test turnout was installed. Figure 1 shows the newly installed turnout on the HTL. 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, when the padded switch panel is being tested. The side view photo of Figure 1 shows the under-tie pads during turnout installation. The pads are about 3/8-inch thick and cover the entire bottom surface of each tie. The pads have a harder wear layer that faces the ballast.

![Figure 1. Newly Installed No. 20 Turnout Used in Foundation Tests](image)

**RESULTS**

**Vertical Stiffness**

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 ties were installed without the under-tie pads. 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 2 shows the results of vertical stiffness tests conducted on the two No. 20 turnouts on the HTL at FAST, and it illustrates abrupt changes throughout the turnout. 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 (location 408) for this experiment. Figure 2 shows that the base case turnout also exhibits numerous changes in stiffness throughout, with the highest measured at the frog.

Figure 2. 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 3 is an overlay of the vertical stiffness measured on the base case turnout (no pads) and that measured on the Phase I test turnout (with under-tie pads) 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 3. Reduced Vertical Stiffness and Variation in Stiffness in Phase I Test Turnout 408 (pads from closure panel 1 to end of turnout) Compared to Baseline Turnout (no pads)

Figure 4 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 4 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.

Figure 4. Reduction in Vertical Stiffness and Variation in Under-tie Pad Section of Turnout 408 Sustainable after 58 MGT of HAL Traffic

Vertical Settlement

Figure 5 illustrates the amount of vertical settlement and the variation in settlement along the entire turnout from top of rail elevation measurements during 82 MGT of HAL traffic. A reduction in differential settlement; i.e., improvement in track surface uniformity, is one of the performance goals of under-tie pads. A comparison of the frog panel section of the turnout with under-tie pads and the switch panel section without pads indicates less settlement variation in the frog panel between 20 and 50 percent based on standard deviation.

Figure 5. Top of Rail Elevation Measurements along Turnout 408 Show Differential Settlement between Sections with and without Under-tie Pads as well as Variations within Each Section

Figure 6 indicates that the portion of the turnout with under-tie pads (closure panels 1 and 2, frog panel, and panel 5) settled about 30 percent less than the switch panel without pads throughout the period of performance.
Figure 6. Thirty Percent more Vertical Settlement in Switch Panel without Under-tie Pads than in Rest of Turnout Where Ties were Fitted with Pads

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 7 shows average top of rail settlement for each switch and the rest of the turnout.

Figure 7. Average Settlement for Each Switch panel and the Rest of the Turnout

Vertical Forces
Wheel vertical and lateral forces of the Phase I turnout were measured when it was newly installed. The forces were measured when the instrumented wheelset car was running counterclockwise on a facing point diverging move through the turnout at 40 mph.

Figure 8 shows the standard deviation of the measured vertical dynamic axle load in the turnout area — the bigger the standard deviation, the bigger the vertical dynamic response variation.

The vertical dynamic response in the adjacent open track and unpadded switch panel (i.e., the first two panels of Figure 8) are generally bigger than other padded panels (i.e., the last four panels in Figure 8). Note that the same transitions and, thus, the same vertical behavior is measured on the mainline and diverging routes of the turnout. In Phase II testing, the effects of padded ties on switch dynamic response will be directly assessed.
Figure 8. Standard Deviation of Vertical Axle Dynamic Forces

Figure 9 indicates that for the baseline turnout, where no pads were used, the 95th percentile dynamic load measured over the stiffer long turnout ties was greater than those measured over the standard ties. The 95th percentile dynamic load was approximately 7 percent higher over the long turnout ties than over the standard ties.

By comparison, when the pads were installed under the long ties of the test turnout but not in the standard ties beyond, the 95th percentile dynamic load was reduced at this critical interface. Further, the differences in vehicle performance between turnout (long ties) and open track (standard ties) have been reduced by using under-tie pads at this transition.

Other experiments being conducted on this turnout include:

- Alignment test—A time series comparison of a pre-steered switch (1) and an AREMA style secant alignment switch. This test is ongoing. Results are expected to be published in 2015.
- Switch lateral stiffness test—Comparison of switch performance under different switch lateral stiffness (5). This was accomplished by removing stock rail braces from some locations.

Figure 9. 95th Percentile of Vertical Dynamic Forces at the Interface between the Long Turnout Ties and the Standard Ties approaching the Turnout in the Trailing Point Direction
FUTURE WORK
The test will continue at FAST until a full life cycle of the turnout has been reached. This will allow a better assessment of the long-term effectiveness and durability of the under-tie pads. It will also provide the data necessary to make a cost-benefit analysis for this application. Already, the results are sufficiently promising that revenue service evaluations have begun or are being contemplated by railways for heavy haul freight and passenger applications.

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REFERENCES
Evaluation of Turnout Foundation Improvements for Heavy Axle Load Service

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Overview

TTCI developed and evaluated methods to reduce dynamic loading at Special Trackwork through changes in foundation and frog designs:
• Applied under-tie pads to a mainline turnout
  – Reduced variation in vertical track stiffness by approximately 70 percent
  – Lowered track settlement by 30 percent in a mainline turnout by use of under-tie pad
• Redesigned crossing diamond frogs to add flexibility
  – Lowered maximum dynamic loads by 25 to 50 percent

Background

Remaining issues
• Ride quality
• Running surface degradation
• Foundation performance
  – Track stiffness variations
  – Dynamic loads, more settlement
  – Differential settlement
  – Shortened maintenance cycles
  – Alignment degradation
  – Non-tangential alignments

Measured track stiffness of typical #20 mainline turnouts at FAST
• Generally higher than open track
  – Large variations
• Hard spots associated with:
  – Rail Bound Manganese frogs
  – Steel switch ties (HSTs) in timber tie turnouts

Turnout Foundation Experiment

♦ Objectives: Test prototype turnout foundations to reduce stiffness changes
  – Conceptual Design

• New #20 timber tie turnout donated by CP Rail
• Under-tie pads (UTPs) installed
  – Three pads: 1) transition to open track, 2) shorter switch ties & 3) longer ties near frog
• Compared to performance of:
  – Previous turnout (similar design & components)
  – Same switch panel without UTPs
Under-Tie Pad Test Configurations

- Phase 1: Under-Sleeper Pads installed in turnout except for switch panel
  - Done to accommodate switch alignment experiments
  - Allows comparison of switch and rest of turnout
  - Allows comparison with previous turnout

- Phase 2: Under-Tie Pads (UTPs) installed with second switch panel
  - Allows comparison of switch and rest of turnout
  - Allows comparison with previous un-padded switch
  - Allows comparison with previous turnout

Turnout Foundation Experiment

Phase 1: Under-Sleeper Pads installed in turnout except for switch panel
- Note improvement in stiffness uniformity (compared to previous turnout)
- Note higher stiffness in switch panel (w/o UTPs)

Phase 2: New switch panel with UTPs installed. Entire turnout was surfaced
Turnout Foundation Experiment
Phase 2: Under-Tie Pads (UTPs) installed with new switch panel
- Switch with UTPs has 1/3 less settlement than that without
- Switch with UTPs has same settlement rate as rest of turnout

Turnout Foundation Experiment
♦ Initial Assessment of UTP Durability

Panel 3, Tie 90. Under a railseat (right)

Panel 4, Tie 106. Permanent deformation due to loading at ballast/pad contact location (bypass)

Summary
TTCI developed and evaluated methods to reduce dynamic loading at Special Trackwork through changes in foundations:
- Applied under-tie pads to a mainline turnout
  - Reduced variation in vertical track stiffness by approximately 70%
  - Lowered track settlement by 30% in a mainline turnout by use of under-tie pad