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Slab Track at Facility for Accelerated Service Testing: Performance and Serviceability

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13. ABSTRACT (Maximum 200 words) The Transportation Technology Center, Inc., with funding by the Portland Cement Association and the Federal Railroad Administration, documented the available records associated with the performance of the concrete slab track section in the High Tonnage Loop at the Facility for Accelerated Service Testing (FAST) at the Transportation Technology Center near Pueblo, CO. The concrete slab track section was retired in August 2014, after more than 10 years of satisfactory performance under heavy axle load train operations at FAST. The report provides the results of analysis and discussion of available maintenance and test records gathered during the slab track's service life. It also includes a discussion about the visual inspection of the slab and fastening systems before and during demolition of the slab.				
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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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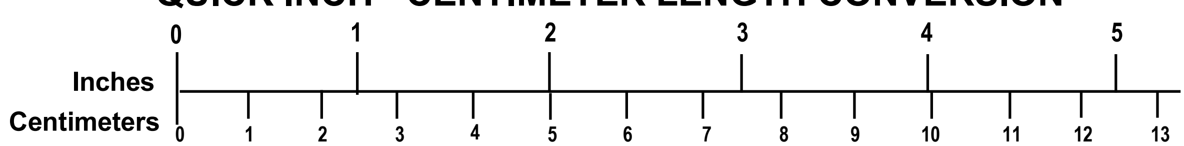
QUICK INCH - CENTIMETER LENGTH CONVERSION



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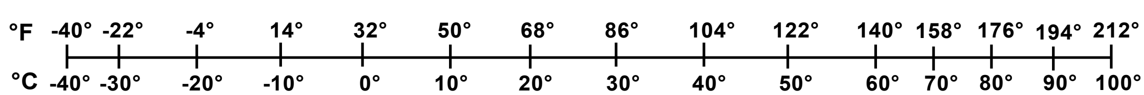

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Contents

Illustrations

Tables

Executive Summary

The Transportation Technology Center, Inc. (TTCI), with joint funding from the Portland Cement Association and the Federal Railroad Administration (FRA) for the initial slab design and construction, documented the available records associated with the performance of the concrete slab track section in the High Tonnage Loop (HTL) at the Facility for Accelerated Service Testing (FAST). The concrete slab track section was retired in August 2014, after more than 10 years of satisfactory performance under heavy axle load (HAL) train operations at FAST. Funding for removal of the slab was included as part of the original funding for the project.

This report provides the results of analysis and discussion of available maintenance and test records gathered during the slab track's service life. The report also includes a discussion about the visual inspection of the slab and fastening systems before and during the demolition of the slab.

1. Introduction

TTCI has been operating a short test section of concrete slab track in the HTL since its original construction in 2003 at FAST, at the Transportation Technology Center (TTC) in Pueblo, CO. The decision was made to remove this section and replace it with standard track construction due to the track space needed for other testing purposes, as well as increasing concerns over maintenance of the fastening system. This report covers the examination of maintenance records, test records, and the condition of the slab track and fastening systems before its demolition in August 2014.

1.1 Background

The concrete slab track section was built in 2003 as a demonstration project, and jointly funded by the Portland Cement Association and FRA. The original schedule for the demonstration project was 3 years, and it was designed to demonstrate slab track capability under HAL traffic, while providing low maintenance and a safe track structure necessary for shared track territories where freight traffic and high speed rail might coexist. Previous reports provide detailed information of the construction and behavior of the slab track section [1] [2] [3] [4] [5].

The total length of the slab track section is 500 feet with approaches to the slab on each end totaling an additional 50 feet. The slab track section was built to incorporate a 5-degree curve with 4 inches of superelevation. The slab includes the spiral section of the curve on one end with the full body of the curve for the remainder of the slab track section.

The slab track section was built using two separate fastening systems. The first type is the Independent Dual Block Track (IDBT) system. The second type is the Direct Fixation Slab Track (DFST) system. The spiral for the 5-degree curve was located at the end of the IDBT section, and the DFST section is in the body of the curve with the full 4 inches of superelevation. Each system performs the same function in a different manner. The systems are described in more detail in the appropriate sections, as well as the analysis of their condition.

At the end of the demonstration project, the slab track was left in place [1]. In late 2013, TTCI and FRA made the decision that additional tests for the slab track at FAST were no longer needed, and that the occupied track space could be used for other purposes of HAL freight train operations. In addition, concerns over the condition and cost of repair and maintenance of the fastening systems provided another reason to perform an evaluation of the slab track section. In August 2014, the slab was removed after accumulating a total test tonnage of 565.2 million gross tons (MGT) across the slab during its service life.

1.2 Objectives

The objectives of this report are to: (1) document the condition of the slab track section at the time of its retirement with an examination of its maintenance records; (2) compile and analyze available existing test data; and, (3) examine and assess the fastening systems used on the slab track.

1.3 Overall Approach

The overall approach was to assess the FAST slab track at the time of its retirement and replacement. The approach consisted of the following main activities:

- Examine the slab track section before the removal of the rail to assess the condition of those portions of the fastening system. The examination included a detailed review of the fastening systems while they were still performing their intended function.
- Examine the slab track section after the removal of the rail to assess the condition of other portions of the fastening system and the slab itself. This allowed for a more complete inspection of the overall performance of the fastening system.
- Examine the condition of the fastener components upon removal from the slab.
- Gather and analyze available test data in the database at TTC to assess maintenance activity and overall performance of the slab under load conditions.

1.4 Scope

The scope consists of three major items related to the overall performance of the slab track section:

- Analyze existing maintenance records to assist in the evaluation of the cost of maintenance of the slab track.
- Analyze the test data available to assess the performance of the slab over time.
- Assess and document the condition of the fastening systems.

1.5 Organization of the Report

Section 1 of this report presents the introduction, problem statement, objectives, and scope of the research. Section 2 provides an analysis of the existing maintenance records for the slab track section. Section 3 examines the test data that is available for the slab track and provides analysis of that data. Section 4 sets forth the results of the examination of the fastening systems. Section 5 reviews the conclusions available from the different records and examinations performed.

2. Examination of Maintenance Records for Slab Track

Maintenance records for the slab track section are included in a computer database for all maintenance activities on the HTL. The database has been in use since 2006 and includes all records for maintenance. The slab track was built in Section 38 of the HTL. Section 38 includes the standard track approaches to the slab. The records available were sorted to examine only those that pertain to maintenance activities on the slab track. Surfacing activity was included from the standard track approaches in this analysis since this activity would not be required if the slab track had not been installed. Some tie repair work was noted in the approaches, but it was not included, because this work may not be directly attributed to the slab track.

The appendix contains the unabridged available data on Section 38 from the computer database. Maintenance records before 2006 exist, but were not archived in a computer database format. Additionally, the slab track section was built in 2003 under close scrutiny during the test phase. Activities during the time between construction in 2003 and 2006 have been documented in other major reports, and were not included in this report [1,2,3,4,5].

2.1 Slab Track Maintenance Analysis

The slab track by design has fewer maintenance activities than a typical ballasted track section. The slab track section replaces ties and ballast with the slab on a foundation. The slab and foundation function to maintain appropriate cross level curvature and surface on the track. Specialized fastening systems maintain gage. Both the slab and fastening systems must act together to maintain the overall alignment that the track was built to follow.

Standard track maintenance of surfacing and ballast tamping are not required with the slab replacing the ties and ballast in a typical track section. The risk of "sun kinks" due to high compressive forces is also eliminated since the slab provides significantly more lateral stiffness to the track versus standard ties in ballast. Although rail neutral temperature is still an important criterion to be watched, the criticality of its nature is greatly reduced on the slab track. This is the case with the FAST slab in the HTL.

The maintenance records for Section 38 show 28 maintenance events between March 2006 and its retirement in August 2014. The record sometimes includes multiple lines of entry for a single event depending upon the amount of work that was required to be done to effect repairs. Regarding the 30 actionable items on the list, six categories cover all the items with rail being the major item of repair during the life of the slab. The breakdown of the repairs is as follows:

- Broken and defective rail welds 9
- Broken and defective rails 7
- Tamping and surface approaches 5
- Fastener maintenance 5
- Gage rod installation 3
- Sand buildup and cleaning 1

For the discussion of maintenance on the slab track section, it is important to distinguish between those items that are directly attributable to the slab track, as well as those items that might have to occur without concern for the type of track that is installed. Regarding the categories listed for the maintenance work on the slab, tamping and surfacing approaches, fastener maintenance, and gage rod installation are the only items that can be directly attributable to slab track.

In the last 8 years, broken and defective rail welds and rails are half of the maintenance issues for the slab track section. Given the environment of the HTL and the amount of annual gross tonnage of loadings that are applied to the rail over time (approximately 125 MGT per year minimum), maintenance personnel for the FAST program did not find the rail on the slab track section likely to break or have other issues than rail on any of the standard track locations on the HTL.

Sand buildup and cleaning of the slab also affects the standard track as well as the slab track. In the southwest United States, blowing sand and accumulation of fouling materials in track is a continual issue that must be resolved. Standard tie and ballast track allows for more time between cleaning (for better or for worse) as sand can infiltrate into the ballast before it accumulates around the rail base and ties. Concerning the slab track, no infiltration is available so the accumulation of sand and other debris begins quickly. Figure 1 shows typical accumulation of sand and other debris around the fastenings and rail at the slab track section.

Figure 1. Sand and Debris Accumulation on the Slab Track

2.2 Slab-Specific Maintenance Issues

The two categories of maintenance issues associated with the slab track section are the fastener maintenance and gage rod installation. Fastener maintenance is typical for any slab track installation, and the gage rod installation is specifically related to the HTL slab track section.

2.2.1 Fastener Maintenance

This section concentrates on the maintenance records associated with the fasteners. Additional information and analysis of performance of the fastening systems is included in Section 4.

The fasteners from 2006 to 2014 were included in the maintenance records five times. Two occurrences were for checking bolt torque and tension in the DFST slab section. The remaining three occurrences were for repair and installation of insulators and refastening clips in the rail seats of the IDBT slab section.

Bolt Tension on DFST Track

Bolt tension is an important issue for the plates used in the DFST slab portion. The bolts attach the base plate to the slab. The bolts engage serrated washers to the base while the bolts are threaded into an insert into the slab. Bolt torque (and the resulting tension in the bolt from the torque) is required to provide sufficient hold-down force to keep the DFST plate in place so that the rail does not move laterally. They are critical for maintaining gage on the track. The torques were checked in December 2010. In May 2014, the manufacturer was onsite again to examine the plates and check bolt torques. There were several issues with loose and broken bolts that caused concern about the serviceability of the plates while in that condition. More information on the overall performance of the DFST plates is included in Section 4.

Insulator Breakage on IDBT Track

Insulator breakage on the IDBT slab track section was an issue that resulted in periodic maintenance of the slab track section. Insulator replacement began in October 2006 and was repeated in January 2011 and in May 2013. Replacement of the insulators included ordering proprietary insulators required for the IDBT fasteners. Very few installations of this type of fastener have occurred in North America and more than a nominal expense was associated with the insulators used in these repairs. The frequency of these repairs (three times in 7 years) raised concerns with maintenance personnel about service life for the system.

2.2.2 Gage Rod Installation

Testing records were available for Track Loading Vehicle (TLV) data ranging from 2008 to 2013. Gage widening was beginning to appear in the spiral of the IDBT section. Spiral portions of curves can have increased lateral/vertical (L/V) ratios due to the change in curvature over the length of the spiral. Gage rods were installed on the slab in 2011, and the maintenance records show that broken gage rods were repaired in 2014. Figure 2 shows the condition of the IDBT spiral section near the end of the service life. The 5 gage rods were placed at approximate 5-foot intervals from the end of the slab for a total of 25 feet. The fasteners at the end of the slab needed to have additional elastomer pads installed at the end of the concrete block to shift the blocks toward the center of the track. In regards to the need to install additional material to maintain gage in association with gage rods, one can assume that the integrity of the rubber boot holding the concrete block had been compromised and is no longer functioning properly.

Figure 2. Installation of Gage Rods in IDBT Section at Curve Spiral

2.2.3 Rail Replacement

Rail replacement on the slab track section was a regular occurrence during its life, consistent with the rest of the HTL. Welding in new rail sections required additional effort over standard tie and ballast track. Using a thermite weld, the rail needs to be sufficiently clear for the mold to fit properly. In standard tie and ballast track, the rail can be unclipped from the ties. Ties can be shifted and the ballast crib can be removed to make room for the mold if needed. That option is not available on the slab track, so the rail must be raised to make room for the mold. This requires additional unclipping over what is typically required for ballast track.

2.3 Condition of Concrete Slab

The concrete slab remained in very good condition during the entire test period. By the end of the life of the slab track, only minor crack widths were experienced. No repairs to the slab were made at any time during its life nor were any required. Many cracks existed, but they were typical of shrinkage cracks in slabs. The surface of the slab, while more than adequate for the service, was not typically smooth, so cracking was more frequent. Also, the open box sections for the IDBT fasteners were prone to crack from the corners. Once demolition of the slab was completed, a cursory examination of the rubble pile did not find any extensive rust on exposed rebar or signs of corrosion. The slab itself was maintenance-free for the installation.

The cracks in the slab were originally mapped in 2006. Prior to removing the rail, the slab was re-examined to find and measure additional cracks that were developed. Figure 3 shows the map for the IDBT section and Figure 4 shows the map for the DFST section. Both sections had additional cracks that were developed, but the majority of cracks in the slab were the early cracks documented in 2006.

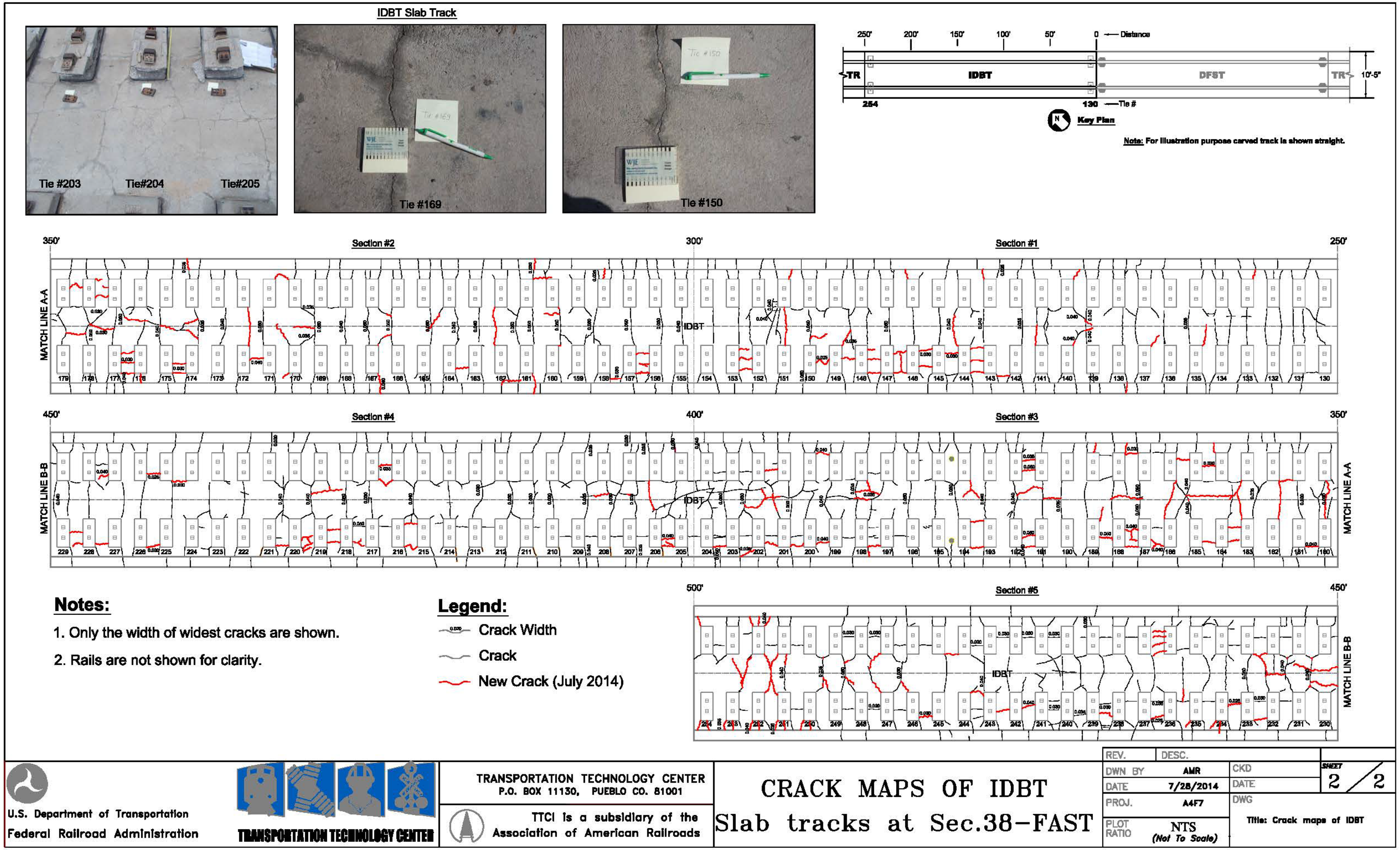

Figure 3. August 2014 Crack Map for IDBT Slab Track Section

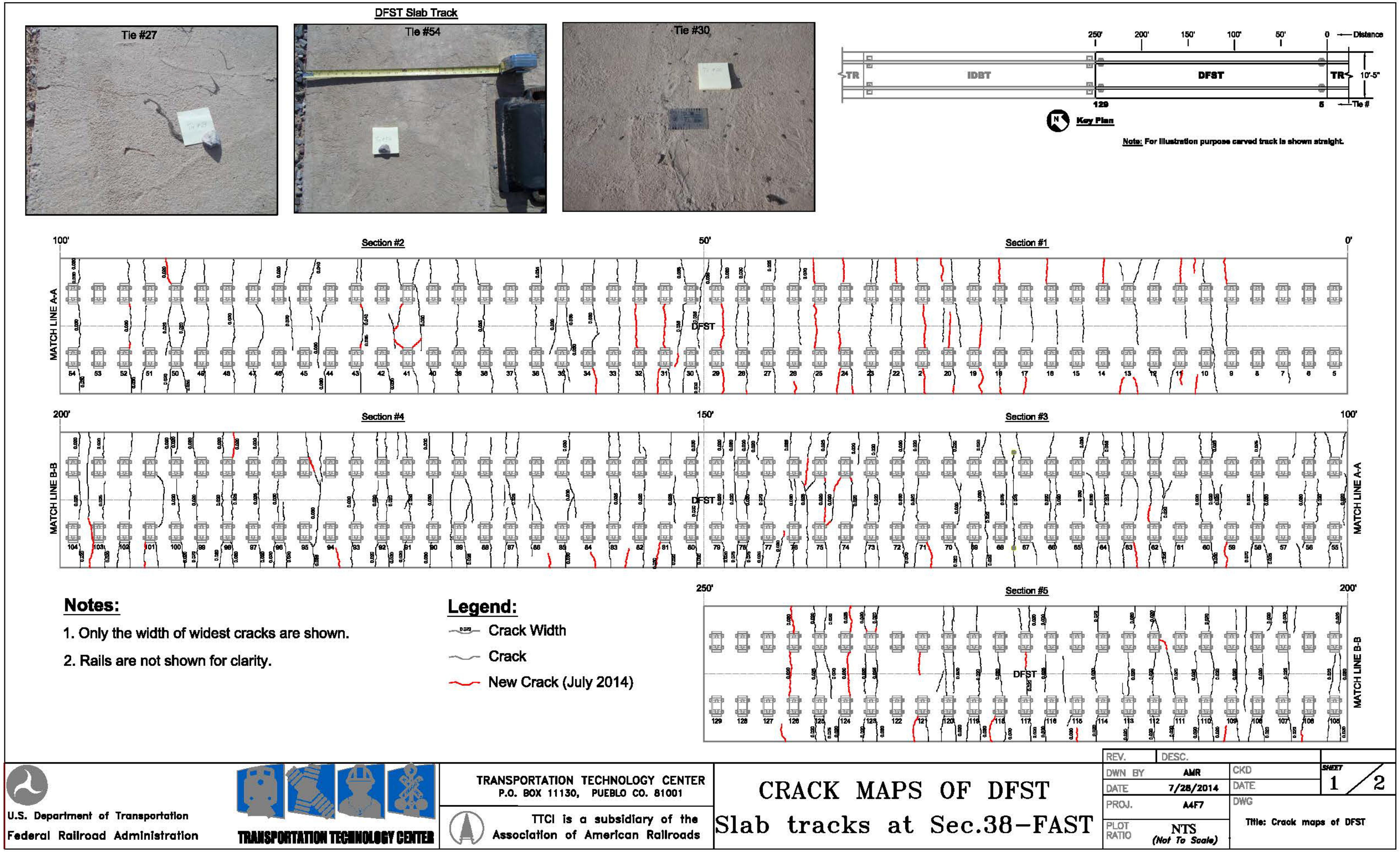

Figure 4. August 2014 Crack Map for DSFT Slab Track Section

3. Analysis of Available Test Data from Slab Track

Testing of the HTL is recurrent and provides the opportunity to follow the history of behavior for certain data sets. The entire list of available electronic information on the FAST slab is included in the appendix.

Given the available information, track geometry data and instrumented wheelset (IWS) data provided the best sources of data over the life of the slab.

3.1 Instrumented Wheelset Data

Testing performed with IWS provided information concerning variation in wheel load as the wheel travels across a segment of track. One advantage of IWS data is that the data is continuous and provides a complete picture of the variation in load as a vehicle travels over the slab track. Available IWS data across the HTL concrete slab track was acquired from testing in 2003 to 2005 and during 2011 and 2012. Results were consistent with IWS on different 315,000-pound coal cars during these tests. Testing with IWS equipped cars occurred over a range of speeds and data is available for that range of speeds. The testing speeds varied between 10 and 50 mph at 10 mph intervals. The variation in test speeds were performed over the years in which IWS data was available. The results are presented for all speeds with the data for 40 mph chosen for additional examination. Note that 40 mph is the typical operating speed for the HAL train at FAST. IWS data was collected per standard operating practice at FAST with a minimum sample rate of 500 Hz and low-pass filter of 100 Hz.

3.1.1 Cumulative Gross Tonnage on Slab Track by Year

The total cumulative tonnage (MGT) on the slab section by year where IWS are available is:

- 2003 – 2.0 MGT
- 2004 – 61.9 MGT
- 2005 – 137.8 MGT
- 2011 – 393.8 MGT
- 2012 – 470.1 MGT

3.1.2 IWS Data for All Speeds

Figure 5 displays the data for average vertical wheel loads of the IWS test runs for all test speeds recorded from five test runs that the concrete slab test section was in service. The complete service life of the slab track section was 10 testing seasons from July 2003 to August 2014. Average wheel loads show the effects of superelevation and train speed. Nominal superelevation on the slab track section was 4 inches. Balanced speed for this curve was approximately 34 mph.

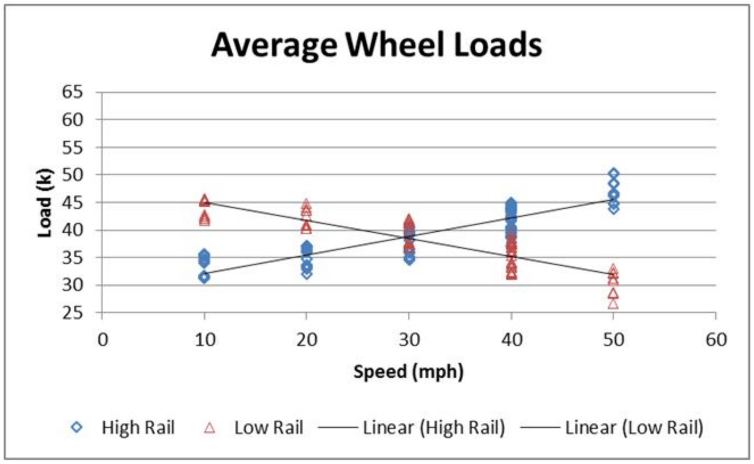

Figure 5. Average Wheel Loads (High Rail and Low Rail) for All Test Runs

Design guidelines for slab track in North America are provided in Chapter 8, Part 27, of the American Railway Engineering Maintenance-of-Way Association (AREMA) *Manual for Railway Engineering* [6]. The guidelines recommend using the same impact load criteria used for concrete ties in Chapter 30. Concrete ties perform a similar function with the same materials, and there is a wealth of experience for concrete ties compared to concrete slab track.

Figure 6 shows maximum vertical wheel loads based on the speeds of the test train. The maximum wheel loads display a slightly different behavior than the average wheel loads. Maximum wheel loads show the effects of increased speed, which is in line with the design recommendations. A maximum load of 60 kips at 50 mph indicate a normal dynamic vehicle-track interaction for the slab track test section. In fact, an increase of speed from 40 mph to 50 mph did not cause a significant increase in maximum wheel load.

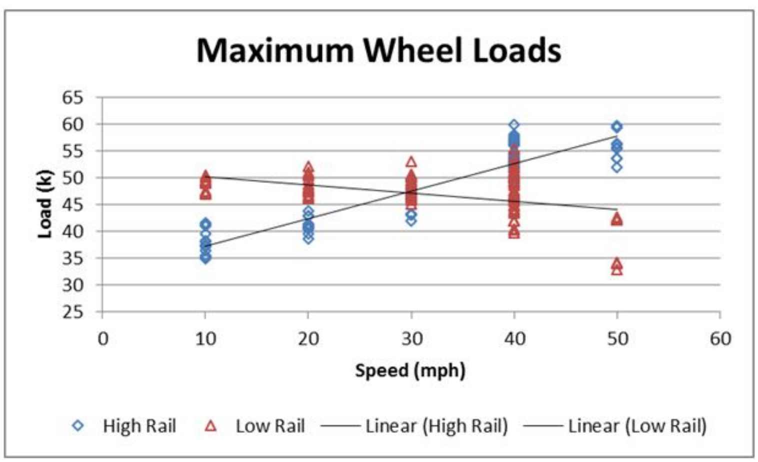

Figure 6. Maximum Wheel Loads for All Test Runs

IWS data can be used to show how the concrete slab track performed on a long-term basis. An examination for the average and maximum wheel loads provided a picture of how the wheel loads interact with the slab track. The examination of the yearly available data provided a better perspective of the long-term performance of the concrete slab track, especially for maximum wheel loads.

3.1.3 IWS Data from Standard FAST Testing Speed

The available IWS data runs were examined to see what data would be most available to provide a comprehensive picture for the years the concrete slab track had been in operation. Per the data, the speed of 40 mph was chosen since more data was available at that speed for all the years, and 40 mph represents the typical operating speed of the test train at FAST. The data for 40 mph was analyzed in a similar fashion as the other IWS data for different speeds, but was kept separate by years to see if any trends were noticeable in the performance of the concrete slabs.

Figure 7 shows that with the slab track in place, the average load at 40 mph remained consistent over time. Figure 8 shows that the maximum wheel loads increased over time. Over the service life, the approaches to the slab track required periodic surfacing maintenance, because of the track transition issues in differential deformation and change of track stiffness from standard tie and ballast track to the slab track. The maximum wheel loads increased due to track irregularities that developed. The ratios of the maximum wheel load to the average wheel load were calculated from the IWS data for each run. The ratio for the years of testing increased from 1.26 in 2003 to 1.38 in 2012.

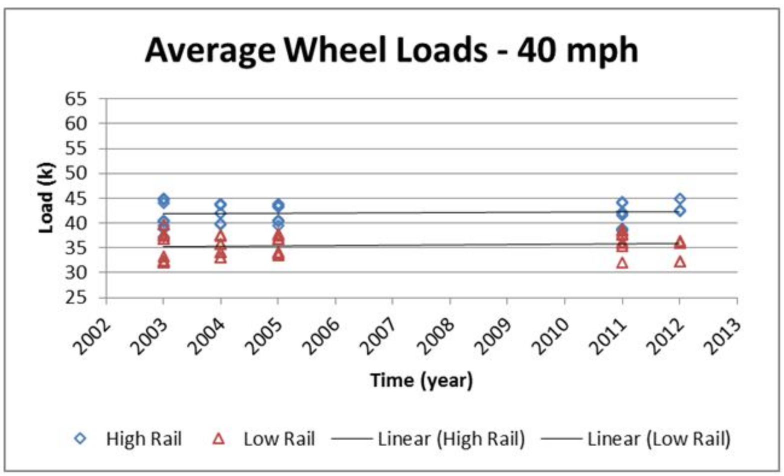

Figure 7. Average Wheel Loads by Year for 40 mph

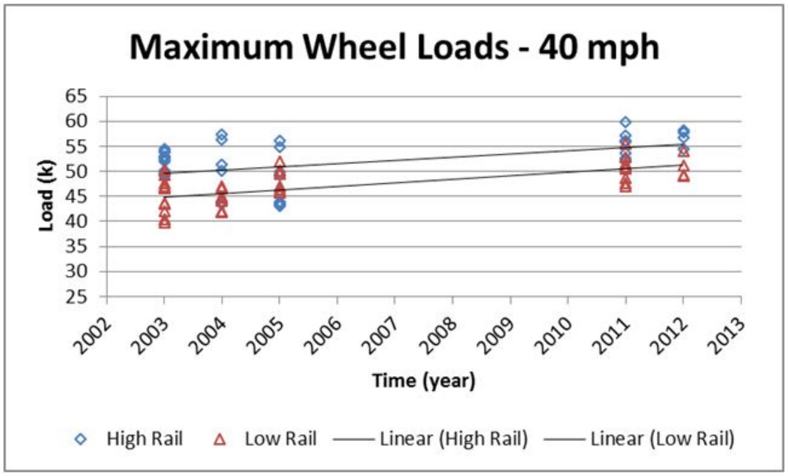

Figure 8. Maximum Wheel Loads by Year for 40 mph

Figures 7 and 8 provide a clear indication that over time the condition on the slab remained quite stable in terms of the response to the axle loadings. Average loads remained constant while maximum loads increased over time. As with any type of track, subtle changes create minor effects that can increase dynamic augment of the wheel load increasing impact. The wheel load values are all reasonable and within the range of assumed design values.

3.2 Track Geometry Data

Track geometry records provide a pictorial history of the slab from the available data. The graphical presentation of the data provided the necessary information to show the effect of train operations over the slab track on track geometry. The following figures provide a range of measurements which show the positive effects of slab track in the realm of track geometry.

In all cases except for the gage in the end of the IDBT portion adjacent to the curve spiral on the approach, the figures show that the slab track construction was better than the adjacent standard ballast/tie track construction. Surface measurements benefited from slab track and superelevation (cross level) was stable throughout testing. Alignment, along with gage, was equal to standard track, but both were affected by the gage issue at the end of the IDBT portion.

Changes in stiffness from ballasted track to slab track are evident in the surface and alignment measurements where the immediate transition zone shows roughness behavior. Figures 9–12 display the characteristics.

In general, the slab track performed better than the adjacent standard ballasted track, and the surface on the slab track was especially stable. The evidence of the spiral gage issue displays itself in the figures. Boot deterioration in the spiral was the primary reason for the loss of the gage restraint.

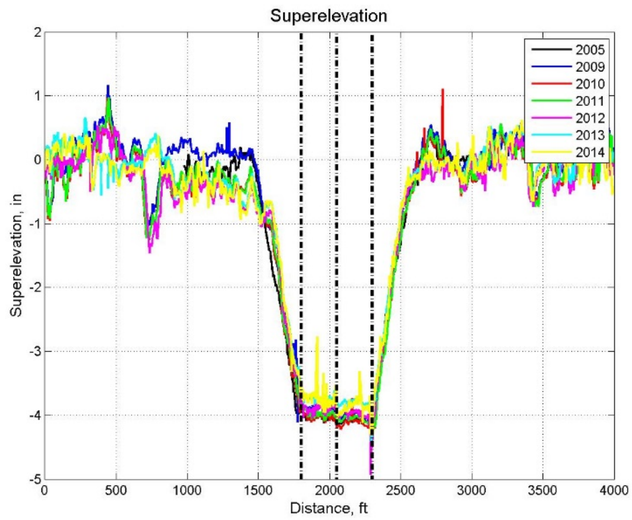

Figure 9. Superelevation Measurements Over Time on Slab Track

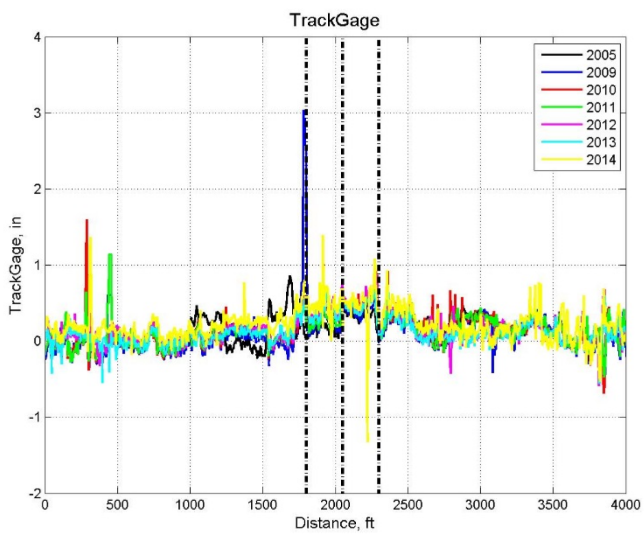

Figure 10. Gage Measurements Over Time on Slab Track

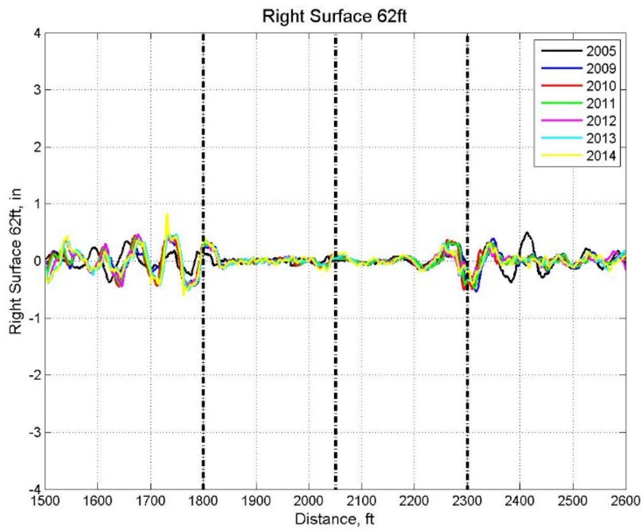

Figure 11. High Rail Surface (62-foot chord) Over Time

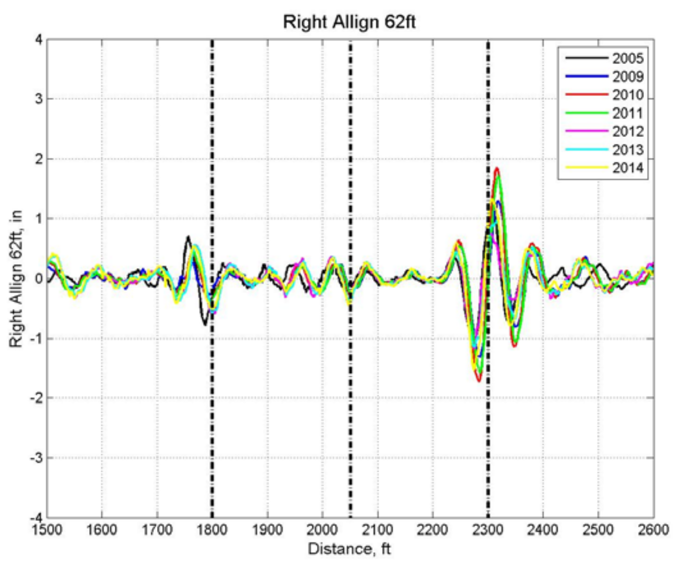

Figure 12. High Rail Alignment (62-foot chord) Over Time

4. Analysis of Fastening Systems Used on Slab Track

The slab track was built with two different types of fastening systems, the IDBT and DFST fastening systems, as part of the demonstration project. Each system performed its function during testing and displayed maintenance issues that required attention during the life of the slab track. The details of the issues with each fastening system are discussed in the following sections.

4.1 IDBT Fastening System Analysis

The IDBT system consists of a concrete block that has the rail fastener base cast into the top of the block. The fastener is resilient and clips into the base using a plastic insulator on top of the rail base and a polymer pad under the rail base to isolate the rail electrically for signal circuit continuity. Figure 13 displays a top view of a typical IDBT fastener installation.

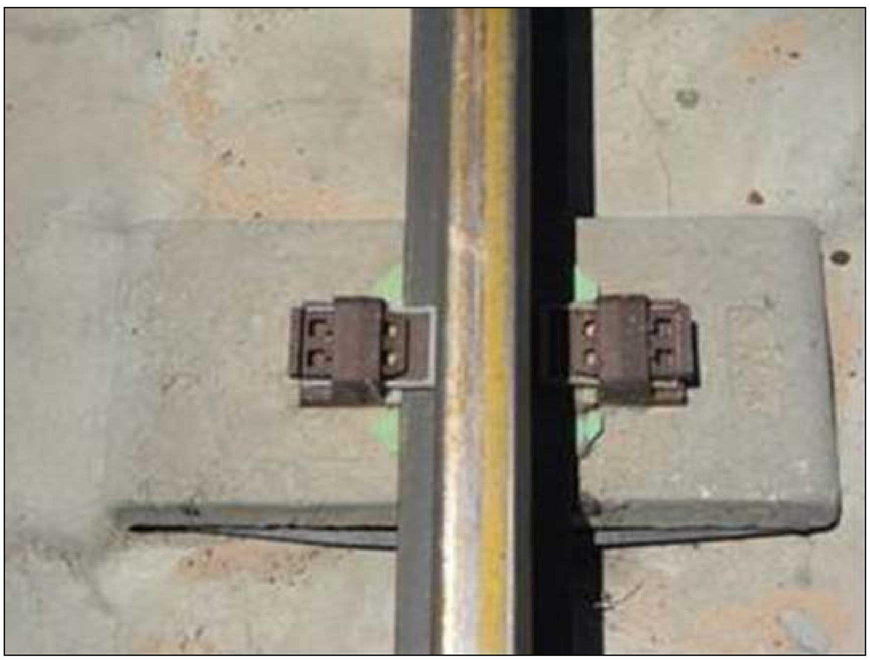

Figure 13. Typical IDBT Fastener Installation

The entire concrete block assembly fits into a rubber boot (with resilient pad in the bottom) and the block and boot assembly is placed into a void cast into the concrete slab. The design assumes that the concrete block will fit in the void, which will restrict its movement and help in the function of maintaining track geometry integrity. The rubber boot also functions as additional electrical insulation for signal circuit continuity in case an issue develops with the clip and insulator. Figure 14 is a photograph taken during demolition of the slab that shows the general concept of the blocks.

Figure 14. Concrete Boots for the IDBT Fastening System

4.1.1 Deterioration of the Rubber Boot

The condition of the rubber boots at the IDBT portion of the slab track became a maintenance issue. As stated earlier in the report, the problem with the boots at the spiral end of the slab was suspect in allowing wide gage and necessitated the installation of gage rods. Concerning visual observations of the slab, the deterioration could be observed progressively from the time of construction.

The cause of the deterioration was due to the accumulation and infiltration of sand and dirt into the boot (between the concrete block and the boot). The block and boot assembly did not fit snugly enough into the voids, which allowed movement or dislocation. This allowed sand and dirt to infiltrate the boot creating an abrasive condition which slowly degraded the boots. Figure 15 shows a typical amount of sand and dirt in the bottom of and extracted boot.

The movement of the block and boot assembly in the void also created other issues with the rubber boot. The abrasion caused wear holes, and split seams and corners; many of the boots had already come apart as they were removed. Water was also able to infiltrate the boots during rainy weather and the abraded boot material would float out of the block and boot assembly. The evidence of the water issue is shown in Figure 16. The staining on the slab was consistent through the length of the IDBT portion. A more detailed look at typical boot deterioration buildup is shown in Figures 17 and 18.

The wear of the boots, if allowed to continue, would likely have resulted in loss of electrical insulation and secondary protection for signal continuity. If the event of such wear of the boots was on a typical main line track, locating a grounded condition would be difficult.

Figure 15. Sand and Dirt Infiltration into the Rubber Boot

Figure 16. Staining of the Concrete Slab from Rubber Boot Abrasion

Figure 17. Close-up of Rubber Boot Deterioration and Staining

Figure 18. Close-up of Rubber Boot Abrasion and Deterioration

Ultimately, as discussed earlier, the boot deterioration contributed to wide gage in the spiral end of the IDBT portion of the slab track. As standard maintenance was minimized by using this type of fastener, program maintenance would be needed to repair the deterioration that would occur, and it would require substantial effort to remove rail and fastenings to access the block and boot assembly. These repairs would possibly need to be programmed at the same time as rail replacement simply to take advantage of the opportunity.

4.1.2 *Insulator Breakage*

As discussed earlier, three separate instances of insulator replacement were performed during the service life of the slab.

4.2 DFST Fastening System Analysis

The DFST fastener is a self-contained unit that is bolted to the concrete slab with four anchor bolts. The bolts require a threaded anchor insert cast into the slab. The entire plate with bolts constitutes the fastening assembly. The plate with bolts and inserts are cast into the slab during the casting of the concrete. The bolts develop hold-down force through special serrated washers mated to anchor slots on the base plate. The plate uses a standard spring clip on each side to hold the rail to the plate. The unit is insulated for signal continuity. Figure 19 shows a top view of a typical installation.

Bolt tension on the anchor bolts is a critical factor in fastener performance. If the bolt is not working to engage the other mechanisms of the fastener, the bolt itself must provide all the resistance against movement including bearing against any movement. This will result in a failure of the anchor bolts. The plate needs to be solidly in place to prevent gage spread. The bolt tension adds greatly to increase the amount of lateral force necessary to shift the plate (and the rail) laterally. Bolt tension and bolt condition in general has declined over time. At the time of the demolition of the slab track, program maintenance to address essentially all plates could have been planned. A detailed inventory of loose or missing bolts was undertaken before the rail was removed for demolition. Table 1 provides the results of the bolt tension inventory.

Figure 19. Typical DFST Fastener Installation

Table 1. Bolt Tension Inventory in DFST Fasteners

	Low Rail		High Rail	
	FIELD	**GAGE**	**GAGE**	**FIELD**
Loose Washer	103	97	91	98
Very Loose Washer	3	2	16	21
Missing Bolt	0	0	13	3
Skewed Washer	37	30	36	46

The bolt was considered loose if a slight tap of a hammer would jar or move a serrated washer under a bolt. A very loose bolt allowed the serrated washer to be dislocated by fingers. Skewed washers are not seated properly, but are snug and cannot be moved. Some bolts were missing and this included both missing bolts and broken bolts where the bolt is broken off in the anchor insert.

The data also indicates counts by location in the track. For loose and skewed washers, location did not seem to suggest any trends, whereas the very loose washers and missing bolts were predominantly toward the high rail.

The installation included a total of 1,000 anchor bolts on the 250 plates comprising the installation of the DFST fasteners. The following points can be made from the data:

- Over 40 percent bolts were considered loose or very loose.
- An additional 15 percent of the washers were skewed.

Additional investigation into the raw data for Table 1 provided the following points:

- Forty-one low-rail and 38 high-rail fasteners had either 3 or all 4 bolts classified as loose or very loose. That was just under one-third of all DFST fasteners.
- Ninety-five low-rail and 117 high-rail fasteners had 1 of the above conditions reported. That represented 85 percent of all the DSFT fasteners.

Figures 20–22 provide photo documentation for some of the conditions found at the installation of the DFST fasteners.

Figure 20. DFST Fastener with Three Missing Bolts

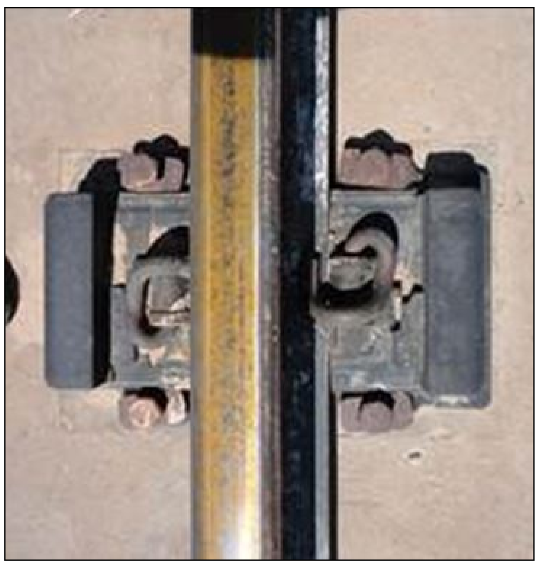

Figure 21. DFST Fastener with Four Loose Bolts

Figure 22. Concrete Slab Under a DFST Fastener

The DFST fastener system performed well during its life in the concrete slab in the HTL. Over time, bolt tension became an issue where the bolts were allowing dislocation of the serrated washers, which developed resistance to movement. Bolt tension was examined in 2010 and again in 2014. The inventory of the plates showed that a significant number of anchor bolts were not providing adequate hold-down force to the serrated washers to maintain adequate lateral resistance. As with the IDBT fasteners, program maintenance would have likely been required to address all the anchor bolt issues at the same time.

5. Conclusion

The concrete slab track section in the HTL at FAST was installed in 2003 as a 3-year demonstration project. The construction was jointly funded by the Portland Cement Association and FRA. The slab track section was ultimately left in service until August 2014, resulting in 10 testing seasons on the HTL.

The slab track section provided very good service while it was installed. The major issue during later service was gage widening experienced on the spiral in the IDBT portion of the slab. The widening required installation of gage rods to maintain service conditions.

The concrete slab performed well during the 10-year test period. No maintenance was required on the slab during the entire test. Half of the recorded maintenance activities on the slab section were related to rail replacement due to broken or damaged welds and rail. The rail related work could not be directly attributed to the slab, however, as rail and weld breakage at the HTL is the main maintenance activity and no discernable increase or decrease was noticed for the slab section. Maintenance related to the gage issue was related to the slab section. However in the end, 13 maintenance activities in the records were attributable to the slab track, including tamping and surfacing of the standard tie and ballast track approaches to the slab section.

The rubber boot used to surround the concrete block in the IDBT system suffered deterioration due to sand and dirt infiltration. The abrasion due to the infiltration resulted in degradation of the rubber boots. Repair of the boots would have been a program maintenance item, which would be timely if done with a rail replacement. The rail needed to be removed to efficiently repair or replace the rubber boots.

Insulator breakage for the rail base clip on the IDBT system was an issue. The repairs required a proprietary insulator not common in North American practice. Maintenance of bolt tension in the DFST system was challenging.

Track geometry and IWS records showed that the slab track section performed better than the adjacent standard tie and ballast track. The surface of the track was enhanced by the concrete slab, while the approaches proved to be challenging to keep in good condition. IWS data showed that the measured wheel forces were typical of values used in design recommendations. The maximum wheel loads increased over time, but were still at acceptable levels.

Overall the slab track section performed very well over the test period. The condition of the fastening systems was such that the need for program maintenance was becoming apparent. As there was no further need for test purposes from its original intent and no funding avenue to perform further slab track testing, the slab section was retired on August 1, 2014.

6. References

1. Li, Dingqing. (2010, August). "Slab Track Field Test and Demonstration Program for Shared Freight and High-Speed Passenger Service." DOT/FRA/ORD-10/10, U.S. DOT, Federal Railroad Administration. Washington, DC. Available at https://www.fra.dot.gov/eLib/details/L01311#p1_z5_gD_y2010_m8_lRT.
2. Bilow, David N. and Li, Dingqing. (2005, September). "Concrete Slab Track Test on the High Tonnage Loop at the Transportation Technology Center." 2005 AREMA Technical Conference. Chicago, IL.
3. Li, Dingqing and Bilow, David N. (2008). "Testing of Slab Track under Heavy Axle Loads," Transportation Research Record, Journal of The Transportation Research Board, No. 2043, pp. 55-64. U.S. National Academies.
4. Li, Dingqing, Bilow, David, and Sussmann, Ted. (2010, April 27–29). "Slab Track for Shared Freight and High Speed Passenger Service," *Joint Rail Conference on High-Speed and Intercity Passenger Rail.* Urbana, IL.
5. Dick, Stephen M., Otter, Duane, and Mademann, Curt. (2013, August). "Slab Track Long-Term Performance and Behavior at FAST." *Technology Digest* TD-13-020. Association of American Railroads, Transportation Technology Center, Inc. Pueblo, CO.
6. American Railway Engineering and Maintenance-of-Way Association. (2014). *Manual for Railway Engineering.* Lanham, MA.

Appendix A – Available Test Records for Slab Track

Track Loading Vehicle and Track Geometry

2004-04-07, Track Geometry

2005-01-28, Track Geometry

2005-08-05, Track Geometry

2008 Gage Widening data from Devin

2009 October 06 measurements, TLV

2010 April measurements, TLV

2011 Nov 07, TLV gage testing

Track Geometry

HTL 2009 Q4 Bypass CCW St M1-0.geo

HTL 2010 Q2 Bypass CCW St M1-41-0.geo

HTL 2010 Q4 Bypass CCW St M1-41-0.geo

HTL 2011 Q1 Bypass CCW St M1-41-0.geo

2012-09-20, HTL, Q3 Bypass 2 laps, CCW

2013-02-07, TLV- Q1_HTL_Gage

2013-02-12. Q1, Track Geometry

2014, Q1, Track Geometry

2012-5-31, HTL, Q2 Bypass 2 laps, CCW

2010 Nov 08, Q4 – Track Geometry

2011 March, Q1, CCW bypass and Main – Track Geometry

Wheelsets

2004-07, FAST IWS

2005-08, FAST IWS

2008, FAST IWS

2009-04-29, FAST_IWS

2009-07-14, FAST IWS

2011-05, FAST_IWS

2011-11, FAST IWS

2012-09, FAST_IWS

2013-12, FAST IWS

Abbreviations and Acronyms

AAR	Association of American Railroads
AREMA	American Railway Engineering Maintenance-of-Way Association
DFST	Direct Fixation Slab Track
FAST	Facility for Accelerated Service Testing
FRA	Federal Railroad Administration
HAL	Heavy Axle Load
HTL	High Tonnage Loop
IDBT	Independent Dual Block Track
IWS	Instrumented Wheelset
L/V	Lateral/Vertical Ratio
MGT	Million Gross Tons
TLV	Track Loading Vehicle
TTC	Transportation Technology Center
TTCI	Transportation Technology Center, Inc.