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In-Track Measurement of Ballast-Tie Interface Pressures Using Matrix Based Tactile Surface Sensors

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Summary

To further understand the in-track load environment of the ballast and tie, Transportation Technology Center, Inc., in cooperation with the University of Kentucky, used matrix based tactile surface sensors (MBTSS) to study the pressure distribution along the length of the ballast-tie interface. MBTSS technology allows the loads generated from individual ballast particle contact points to be measured in a fine-scale pressure matrix. This research was conducted to characterize the ballast-tie pressure distribution and contact areas over a range of ballast surface conditions.

- Eight MBTSS sensors allowed about 75 percent of the footprint of each tie to be instrumented.
- As seen in laboratory ballast box tests, the in-track results show that ballast-tie contact area increases under increasing applied load.
- The contact area was also shown to vary significantly across the range of ballast gradations.
- Sixty percent of pressure distributions along the length of the tie showed increased stresses adjacent to the rail (in the areas conventionally tamped), not directly under it as often assumed.
- Contact areas under a heavy axle load (HAL) car ranged from 31.2 percent of the tie footprint for new ballast to 77.4 percent for sand degraded ballast.

In-track testing was conducted in 2013 at the Transportation Technology Center's Facility for Accelerated Service Testing, Pueblo, Colorado. Ballast-tie pressure measurements were taken along the footprint of 15 conventional concrete ties reacting against five different ballast gradation surfaces (sand filled ballast, pea gravel, heavily degraded ballast, moderately degraded ballast, and new ballast). A test train consisting of a 6-axle locomotive, an empty hopper car, and a HAL hopper car was used to apply loading.

The pressure distribution at the ballast-tie interface plays a key role in track support. Ballast and tie degradation can result from loads that exceed the respective strengths of these track components, causing track geometry degradation and increased levels of maintenance. The ballast-tie load environment, specifically its characterization using MBTSS, has implications in tie structural design, ballast degradation, under-tie pad design, and ballast/tie degradation rates. Future work will include analyzing the peak pressures observed in track and comparing them with laboratory ballast box testing.



INTRODUCTION

An influential area in the conventional railroad track structure exists between the ballast and tie. Contributing to functions of the tie and ballast, the interface serves the purpose of initiating pressure distribution through the ballast layer, allowing for adjustment of track geometry and providing vertical, lateral, and longitudinal stability.

The ballast-tie contact surface is typically approximated as two-thirds the tie footprint (the outer third on each end of the tie). In North American practice, a uniform and average pressure distribution is assumed over this contact surface.¹ In reality, however, ballast-tie pressures vary continuously along the length of the tie.² More specifically, the ballast-tie interface is characterized by high pressures due to low effective contact areas between the tie and the discrete, angular ballast particles that make up the contact surface. Low contact area and the resulting high pressures on the ballast particles and tie may contribute to ballast particle breakage, tie surface degradation, ballast degradation, and track settlement.³

A thorough understanding of the forces at the ballast-tie interface and their variability under load is required to better understand issues that negatively impact the life of track and track components. MBTSS were deployed in-track at the Facility for Accelerated Service Testing (FAST). Previous laboratory testing has proven the feasibility of using this technology for the loading environment at the ballast-tie interface.⁴

MBTSS SYSTEM

The MBTSS system used for this study consists of a pressure sensor (a), a data acquisition handle (b), and a computer running MBTSS software (c), as Figure 1 shows.

The pressure sensor consists of a matrix of sensing elements, or “pressure pixels,” that measure the force applied over the element’s area. The sensors used for this study have a resolution of 20.7 sensing elements per square inch and an element area of 0.048 in². The sensor’s active area measures 9.67 inches square.⁵

Being a nonuniform, rough contact surface, the ballast-tie interface application of MBTSS requires careful attention to the protection of the sensor component.

During preliminary testing, rubber was determined to be an effective protection material for the upper and lower portion of the pressure sensor. Shore durometer 60A rubber was used (3/16 inch thickness on the ballast side of the sensor and 1/16 inch on the tie side). This rubber protection has the effect of distributing the discrete loads across a slightly larger contact area.

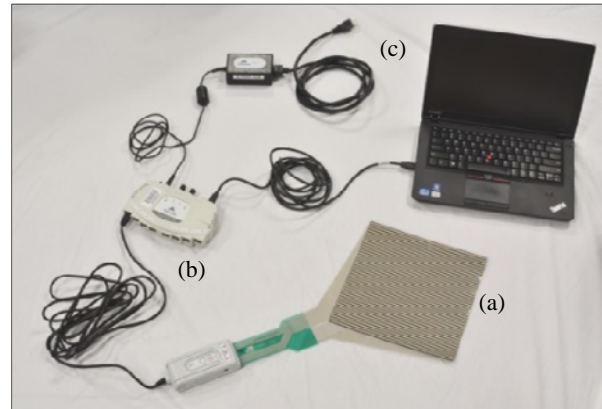


Figure 1. MBTSS System Components

TEST SETUP

In-track testing was conducted at FAST, Section 33, in June 2013. Section 33 is tangent track with conventional monoblock concrete ties (with a footprint 102 inches long by 10.5 inches wide) spaced at 24 inches on center. Five three-tie test zones were established (15 total test ties). To simulate the effect of various ballast gradations at the ballast-tie interface, different ballast materials were installed beneath each zone’s three ties. Five gradations representing a wide range of contact surfaces (sand degraded ballast, pea gravel, heavily degraded ballast, moderately degraded ballast, and new ballast) were used. Prior to testing, the ballast was excavated down 2 to 3 inches below the ties and the existing ballast replaced with the test gradations. The installation of the ballast material only disturbed the reaction surface. About 1 MGT of traffic resealed the new contact surfaces before testing.

To install the MBTSS system, the ballast was excavated down to the bottom of the ties, the rail fasteners removed from adjacent ties, the test tie raised slightly, then the pressure sensors and rubber protection sheets were slid beneath the tie, as Figure 2 shows.



Figure 2. One of Five Test Zones with Three Test Ties in each Zone showing Excavated Crib Areas and the Installation and Location of Pressure Sensors

The tie was then lowered onto the sensors and fasteners reinstalled on adjacent ties. Seven sensors were installed adjacent to each other starting at the south end of the tie, while the eighth sensor was placed directly under the north rail.

The consist used to apply loading was made up of one 6-axle locomotive, a 4-axle empty hopper car, and a 4-axle loaded hopper car operated counterclockwise on the loop. Table 1 shows the axle loads for each vehicle in the train.

Table 1. Axle loads for the Three Consist Vehicles

Vehicle	Axle Load (lb)
Locomotive	71,825
Empty Hopper	16,688
Heavy Hopper	79,425

Each test was one consist pass over each test tie. At least two tests were run over each tie — one pass in each direction. The train speed varied between 5 and 10 mph. The limited train speed reduced the effect of any dynamic forces. Figure 3 shows a truck of the empty car passing over the test tie.

Data was collected at a sample rate of 100 Hz. In total, 46 tests were performed over the 15 test ties. With eight sensors for each test, there were 368 MBTSS recordings and over 2.5-million data frames collected.

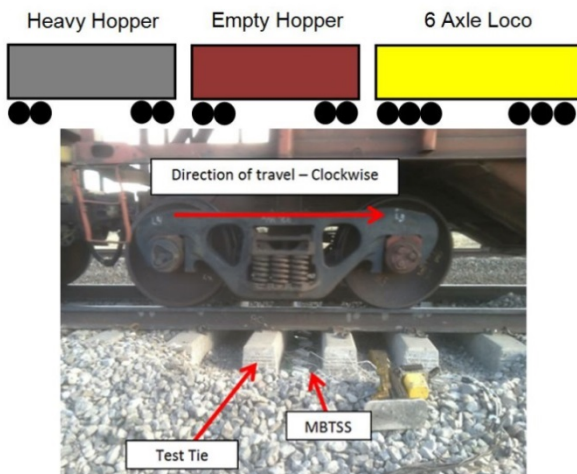


Figure 3. Test Consist

RESULTS

The MBTSS system can distinguish fine-scale variations in pressure distribution for the range of ballast gradations tested. Expectedly, new ballast exhibited sharp pressure peaks and low contact area. Degraded ballast distributions had higher contact areas and slightly lower pressure peaks. Sand distributions were relatively uniform and lacked any significant peaks of pressure. Figure 4 shows an example of pressure distribution along the length of a tie.

The MBTSS system was calibrated by assuming the magnitude of the load acting through the sensor system. As presented in the AREMA Manual for Railway Engineering (2012) for concrete tie track with 24-inch spacing, 50 percent of the applied axle load was assumed to act through each test tie.¹

The contact area, average pressure, and peak pressure were analyzed for each sensor at its respective location along the length of the tie under a given axle load.

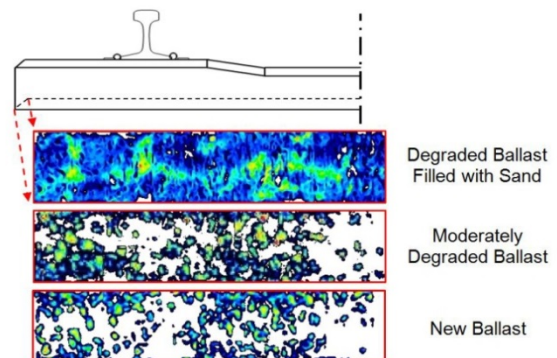


Figure 4. An Example Pressure Distribution along the Footprint of the Tie for Three Variations of Ballast

Table 2 shows the average contact area (as a percentage of the sensor area) for each zone of ballast gradations. The particle size corresponding with 30-percent passing (D_{30}) is given for each granular material.

Table 2. Average Contact Area (as a percentage of sensor area) for each Ballast Zone under each Axle Load

Ballast-Tie Surface	D_{30} (in.)	Contact Area			
		Unloaded	Empty	Loco	Heavy
New Ballast	1.24	7.4%	21.9%	29.6%	31.2%
Moderate Deg. Ballast	0.90	13.3%	35.7%	42.0%	43.0%
Heavy Deg. Ballast	0.72	2.5%	28.4%	37.7%	39.7%
Pea Gravel	0.25	8.2%	47.6%	66.5%	71.0%
Sand Deg. Ballast	0.08	13.1%	59.7%	73.3%	77.4%

As a general trend, contact area increased under increasing applied load. The moderately degraded ballast surface had higher contact areas than the heavily degraded ballast, likely because it was the existing ballast in the section and its surface was not disturbed prior to testing. Contact areas varied along the length of the tie as well. Figure 5 shows the contact area at each sensor along the length of the tie for Tie 40 (reacting on a new ballast surface).

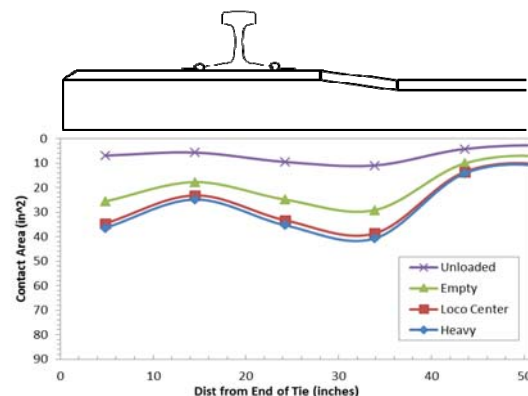


Figure 5. Contact Area at each Sensor along the Length of Tie 40 (new ballast surface)

Figure 6 shows the measured average pressure distribution along the length of Tie 3 in the moderately degraded (existing) ballast zone. The distribution recommended by AREMA¹ (assuming the outer thirds of the tie are in bearing) is shown for the heavy car load for comparison.

Figure 7 shows the average pressure distribution along the length of Tie 39 (reacting against new ballast).

As shown, for Tie 3, the highest pressure occurred beneath the rail. Tie 39, however, shows a distinct decrease in pressure directly beneath the rail. The higher areas of pressure adjacent to the rail in Figure 7 correspond with the areas tamped during conventional maintenance procedures. Sixty percent of the ties tested showed increased pressure adjacent to the rail and not directly beneath it.

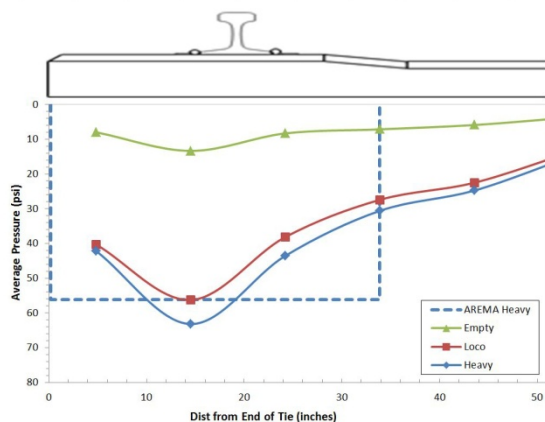


Figure 6. Average Pressure Distribution under Tie 3 (moderately degraded ballast surface) for 3-axle Loads

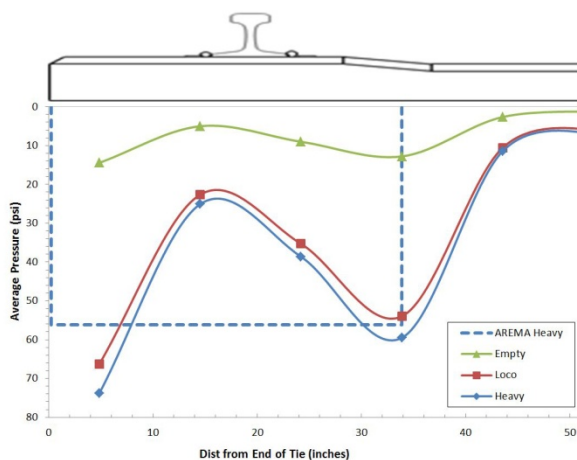


Figure 7. Average Pressure Distribution under Tie 39 (new ballast surface) for 3-axle Loads

CONCLUSIONS

As in the laboratory testing,⁴ contact area was observed to increase with increasing applied load for the in-track testing. While some of this increase can be attributed to the rubber protection sheet needed between the ballast and the sensor,

results show additional ballast particles are engaged as load is applied.

Expectedly, results show that the contact area at the ballast-tie interface is significantly impacted by the gradation of the material beneath the tie.

Most of the ties exhibited increased pressure on either side of the rail (in the area conventionally tamped), and not directly underneath the rail. It is unclear how this variability in the pressure distribution compares with tie suppliers' design loads for tie bending. This type of distribution likely leads to increased positive bending of the concrete tie rail seat area.

The use of MBTSS to characterize the actual ballast-tie pressure distribution in-track provides further understanding of the load environment of the tie and ballast. The ballast-tie load environment has implications in tie structural design, ballast degradation, under-tie pad design, and overall track bed support conditions.

FUTURE WORK

Future work will seek to analyze the peak pressures from in-track testing on the various ballast gradations as well as the effects of various tie materials on the ballast-tie pressure distribution. Peak pressure is an important consideration as it is the worst-case loading applied to individual ballast particles.

The laboratory and in-track ballast-tie pressure data could be used to feed or validate ballast degradation models. Ballast-tie interface data would allow ballast degradation models to be linked with superstructure models to obtain a comprehensive track model.

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