TECHNOLOGY DIGEST

TD-14-006

©MAY 2014

TIMELY TECHNOLOGY TRANSFER

The work described in this document was performed by Transportation Technology Center, Inc., a wholly owned subsidiary of the Association of American Railroads.

Laboratory Measurement of Ballast-Tie Interface Pressures using Matrix Based Tactile Surface Sensors

Mike McHenry, Sirius Roybal, and Michael Brown

Summary

In order to understand the load environment of the ballast and tie, Transportation Technology Center, Inc. (TTCI), in cooperation with the University of Kentucky, used matrix based tactile surface sensors (MBTSS) to study the pressure distribution at the ballast-tie interface. MBTSS technology allows the loads generated from individual ballast particle contact points to be measured using a fine-scale pressure matrix. This research was conducted to characterize the ballast-tie peak pressures and contact areas over a range of ballast surface conditions. The highly nonuniform ballast-tie interface pressures measured were significantly higher than those currently used in North American design practice.

- Conservative measurements of peak pressure under a typical HAL wheel load on new ballast averaged 1450 psi for new ballast and 680 psi for degraded ballast.
- Contact area percentages under a typical HAL wheel load varied expectedly across the range of ballast gradations from 20.4 percent on new ballast to 75.5 percent on sand.
- The contact area increased under increased applied load for all ballast gradations affirming the dynamic nature of the ballast-tie contact surface.
- The effects of tie material on ballast pressures (e.g., due to ballast particle embedment) are unclear at this point

Laboratory ballast box testing was conducted in TTCI's Component Testing Laboratory in 2012. Three 24-inch tie sections (concrete, wood, and composite) were used to apply cyclic loads, typical of North American heavy axle loads (HAL), to five gradations of granular material (sand, pea gravel, heavily degraded ballast, moderately degraded ballast, and new ballast).

Understanding the forces that act on the ballast and tie is required to design higher performing track. Results from the laboratory ballast box testing provide valuable insight into the load environment at the ballast-tie interface. Ballast-tie pressure distribution data has implications in tie design, under-tie pad design, and ballast/tie degradation rates. Ballast-tie interface pressure research using the MBTSS has continued including in-track testing at the Facility for Accelerated Service Testing.

Please contact **Mike McHenry (719) 584-0605** with questions or concerns regarding this *Technology Digest.* E-mail: mike_mchenry@aar.com.

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 resistance for lateral and longitudinal track stability.

The ballast-tie contact surface is typically represented 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, the ballast-tie interface is characterized by high pressures due to low effective contact areas between the tie and the rough, angular ballast particles that make up the contact surface. Sufficiently 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 differential track settlement.

Early research to study the pressure distribution at the ballast-tie interface noted the wide range of support conditions (pressure distributions) observed in-track.[2] The reduced contact area at the interface has also been documented.[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 track quality. MBTSS was applied in laboratory ballast box testing to study the pressure magnitudes and contact areas for various ballast gradations.

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.

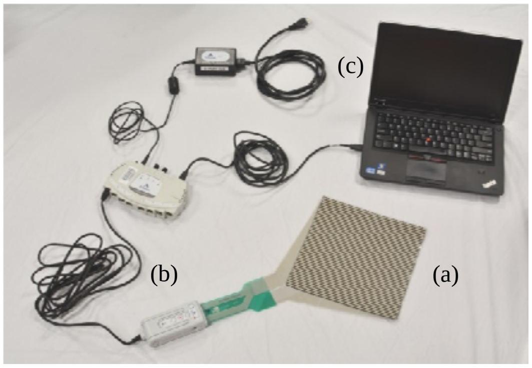

Figure 1. MBTSS System Components

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 in^2. The sensor's active area measures 9.67 inches square.

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).

TEST SETUP

Laboratory ballast box testing was conducted at the Transportation Technology Center, Pueblo, Colorado, in July and November of 2012. Ballast boxes 25 inches long by 24 inches wide by 24 inches tall were used to contain the ballast material. Five gradations of dried granular material were used (1) new ballast, (2) moderately degraded ballast, (3) heavily degraded ballast, (4) pea gravel, and (5) sand. Representative samples of the three ballasts were selected. Granular fines were added to a rounded, degraded ballast to create the "heavily degraded ballast." The pea gravel was uniformly graded and the sand was representative of a typical concrete sand with no ballast sized particles. Figure 2 shows the gradations of the five granular materials used.

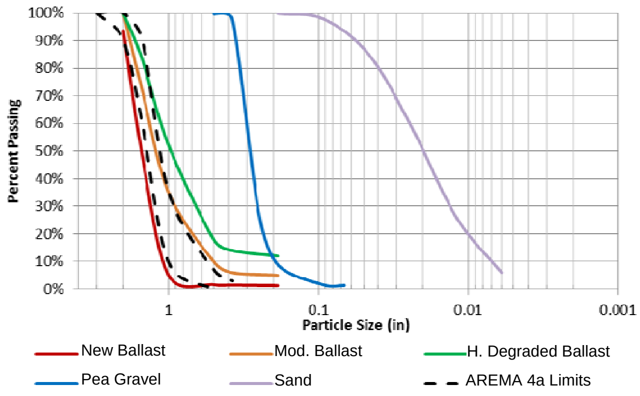

Figure 2. Granular Material Gradations (AREMA 4a limits shown for reference)

The ballast boxes were filled with each of the five gradations and placed in the load frame. A custom rail loading fixture constructed using the bottom half of a 6-inch rail base section was fastened to the actuator and to the rail seat of a section of tie. Three tie types (concrete, composite, and wood) were tested. Each tie section was 24 inches long. Prior to testing on each granular material, a compaction phase of 20 kips applied at 1 Hz for 1500 cycles was performed. The tie was then lifted off the surface of the ballast, and the MBTSS system installed directly beneath the rail seat. Figures 3 and 4 show the configuration of the test setup and location of the pressure sensor.

Each test consisted of a series of cyclic loading increments. Load was applied for all increments at a rate of 1.5 Hz. Each increment lasted 200 cycles. The first load increment was at 2 kips. The peak load magnitude was increased by 2 kips for each subsequent increment, up to 20 kips. An applied load of 20 kips corresponds to roughly 71 psi of average pressure over the active area of the sensor. This falls between the two maximum ballast pressure limits found in the AREMA *Manual for Railway Engineering*, namely 65 psi and 85 psi.[1]

Thus, the 20-kip load increment in the lab setup can be considered a reasonable estimate of a typical heavy axle wheel load.

For each increment, data was collected for a 10-second interval at a sample rate of 500 Hz. The duration of the collection interval allowed at least 14 cycles to be recorded for each increment. In total, 39 tests were performed varying the granular material and the tie type.

To calibrate the laboratory data, the load acting through the sensor was conservatively assumed. The active sensor area represented about 40 percent of the tie area. As a conservative estimate, TTCI test engineers assumed that 33 percent of the applied load acted through the sensor.

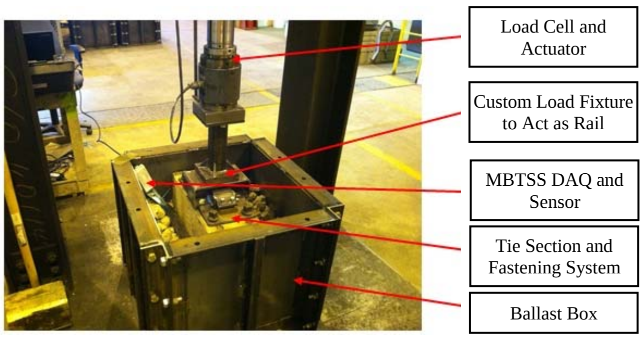

Figure 3. Laboratory Ballast Box Testing Configuration

Figure 4. Detail of MBTSS/Protection beneath Tie

RESULTS

The MBTSS system can distinguish 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 “duller” pressure peaks. Sand distributions were relatively uniform and lacked any significant peaks of pressure. Figure 5 shows a typical pressure distribution for each of the five gradations.

For each test, the contact area was extracted and the average pressure and peak pressure were calculated assuming 33 percent of the applied load acted through the sensor.

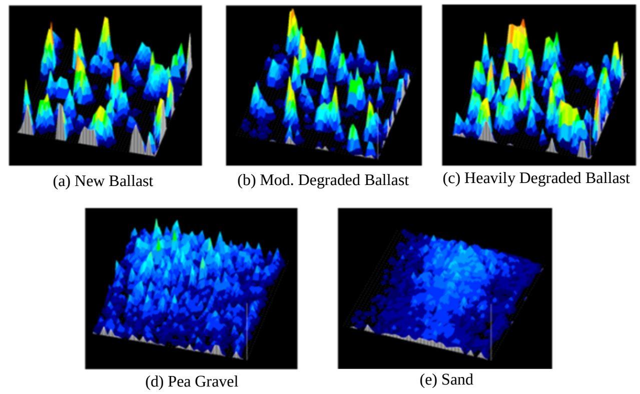

Figure 5. A Typical Pressure Distribution for Each of the Five Ballast Gradations

BALLAST-TIE CONTACT AREA

Figure 6 presents the range of contact areas for the five ballast gradations versus the applied load.

At typical wheel loads, contact areas ranged from 20.4 percent for new ballast to 75.5 percent for sand. Contact area tended to increase with increased applied load. The differences in contact area between the five ballast gradations are more distinct at higher applied loads.

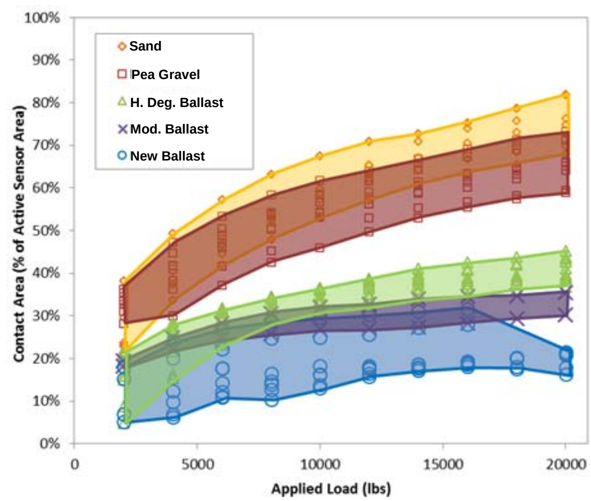

Figure 6. Contact Area vs. Applied Load for the Five Ballast Materials used in Laboratory Testing

BALLAST-TIE PEAK PRESSURE

Peak pressure was obtained for each test by determining the highest loaded sensing element on the sensor and applying that load over the element’s area.

Figure 7 shows the peak pressures at each applied load for the five ballast gradations. The uniform pressure is shown for reference.

Peak pressures were expectedly higher for the new ballast than for the other materials tested. Peak pressure appears to increase with increasing nominal particle size of the ballast.

The new ballast also showed a greater variability of peak pressure throughout the loading increments. Table 1 shows the average peak pressures for the five ballast gradations at an applied load of 20 kips. Comparison with the uniform pressure is shown.

Figure 7 and Table 1 highlight the contrast between peak pressure, the maximum load experienced by a ballast particle, and uniform pressure (equal to the load acting through the interface distributed uniformly across the ballast surface).

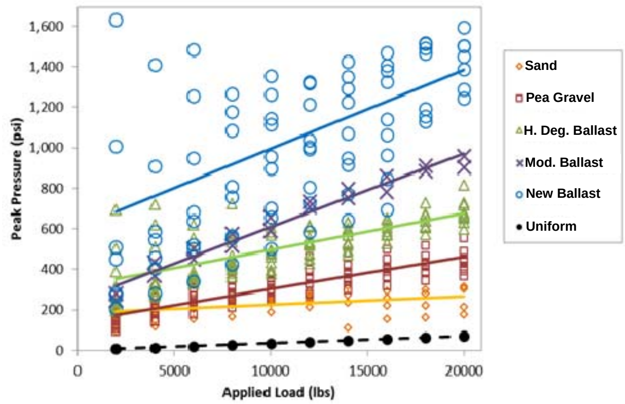

Figure 7. Peak Pressure vs. Applied Load for the Five Ballast Materials

Table 1. Average Peak Pressure for Each Ballast Material under an Applied Load of 20 kips

Ballast Material	Average Peak Pressure	Percent of Uniform Pressure
Sand	283.9 psi	399%
Pea Gravel	444.1 psi	624%
Heavily Degraded Ballast	681.3 psi	958%
Moderately Degraded Ballast	929.7 psi	1,307%
New Ballast	1,449.9 psi	2,036%

CONCLUSIONS

Contact area was observed to increase with increasing applied load. While some of this increase can be attributed to the rubber protection sheet between the ballast and the sensor, results show additional ballast particles are engaged as load is applied.

Peak pressure is important to consider, because it is the maximum stress placed on a ballast particle and, oppositely, on the tie surface. This load, applied cyclically over time, may exceed the strength of a ballast particle leading to fracture, powdering, rounding, and degradation. Further research is required to study ballast behavior in the context of these peak loads and may lead to an improved method of characterizing ballast performance for the industry.

The peak loads vary greatly for various granular material gradations. It is likely that ballast degradation generated at the ballast-tie interface is related to these peak loads and thus to ballast gradation. In this sense, the results of this ongoing research could be applied to optimizing ballast gradation, tie design, and modeling.

The effects of tie material are unclear at this point. Because the tie sections used in this study were only 24 inches long, the effects of material stiffness were not evident. The bending stiffness of various tie materials would clearly have an impact on the pressure distribution along a full length tie. Increases in contact area due to ballast embedding itself into wood ties or under-tie pads cannot be directly measured with the MBTSS system as the sensor needs to be placed between the two contact surfaces.

Overall, the use of MBTSS to characterize the actual ballast-tie pressure distribution represents a step forward in further understanding 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

In-track testing to measure the pressure distribution along the length of the tie has been completed and the results are currently being analyzed. Preliminary results show that the MBTSS system can be successfully implemented in-track to obtain similar data as the laboratory testing.

The results of laboratory and in-track testing at the ballast-tie interface could be used to feed or validate ballast degradation models such as those presented by Tutumluer et al. and Huang.[4,5] Ballast degradation models could then be linked with "superstructure" models to obtain a more comprehensive track model.

REFERENCES

1. American Railway Engineering and Maintenance-of-Way Association (AREMA). 2012. *Manual for Railway Engineering*. Lanham, MD.

2. Talbot, A.N. 1919. *Stresses in Railroad Track*. The Second Progress Report of the ASCE-AREA Special Committee on Stresses in Railroad Track, Reprinted, 1980. Published by the American Railway Engineering Association.

3. Henn, W. 1978. "Auswirkung von Oberbauform und Betriebsbelastung auf die Veränderung der Gleishöhenlage." Archiv für Eisenbahntechnik (33) p. 51-64.

4. Tutumluer, E. Qian, Y., Hashash, Y., Ghaboussi, J.Garcia, and D. Davis. 2011. "Field Validated Discrete Element Model for Railroad Ballast." *Proceedings of the 2011 American Railway Engineering and Maintenance-of-Way Association Conference*. Minneapolis, MN.

5. Huang, H. 2010. "Discrete Element Modeling of Railroad Ballast Using Imaging Based Aggregate Morphology Characterization," dissertation presented to University of Illinois at Urbana-Champaign, Urbana, IL, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.