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Interim Results of Heavy Axle Load Ballast Testing at UP Mega Site

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Summary

Transportation Technology Center, Inc. (TTCI) is investigating ballast performance under 36-ton axle load coal traffic at the Union Pacific (UP) heavy axle load revenue service mega site. The ballast test zones and surrounding track are also part of a ground penetrating radar (GPR) test project sponsored by the Federal Railroad Administration (FRA).

Particle size degradation and deformation behavior of five ballast materials are being monitored with periodic sampling and laboratory tests. TTCI is measuring the relationship between fouling and deformation of several mainline quality ballast materials to gain a better understanding of ballast life cycles and performance. GPR technology is being used to inspect the ballast at the same time the test ballast samples are taken to determine the capability of GPR to monitor ballast gradation/fouling changes.

Test results after approximately 320 million gross tons are as follows:

- Sieve analysis of field samples show substantial differences in the particle breakdown rates of the different ballast materials being tested.
- Permanent deformation results from repeated-load triaxial lab testing included:
  - The ballast type with the least particle size degradation had the least amount of deformation.
  - The ballast type producing the most deformation was midrange in terms of particle size degradation, and the ballast types with the most degradation were midrange in terms of deformation.
  - The ballast type with the highest mill abrasion value accumulated the highest permanent deformation.
- GPR ballast fouling results were in general agreement with the sieve analysis of samples taken at the same time

New ballast material from four UP sources, labeled Types I-IV, was installed in test locations with a 2-degree curve and tangent track in November 2010. Ballast Types I-IV were screened after delivery and before installation to remove particle sizes less than 3/8 inch. Some of the Type II material was also installed as delivered without additional screening to serve as the control ballast. The ballast types are separated by steel boxes, and samples were collected in April and November 2011 and May 2012. Sieve analysis was performed on the sampled ballast to determine changes in the particle size distribution, or gradation, with tonnage. Deformations of the ballast samples are evaluated using a large-scale repeated load triaxial test device at the University of Illinois at Urbana-Champaign.

The ballast box testing is part of the Strategic Research Initiatives Program sponsored by the Association of American Railroads and FRA, and is also part of UP's internal ballast research program.

INTRODUCTION

Fracturing and abrasion of ballast particles from repeated wheel loads and maintenance, plus infiltration of material from the outside are root causes of ballast fouling and loss of functionality. The American Railway Engineering and Maintenance-of-Way Association (AREMA) recommends several gradations for mainline ballast that can be generally defined as having uniformly graded particle sizes between an upper limit of 2 1/2 inches and lower limit of 3/4-inch and no material smaller than the No. 4 sieve (approximately 3/16 inch). The large interparticle void spaces found in the AREMA gradations facilitate drainage and permit some initial particle size breakdown before ballast performance is compromised. Over time, the percentage of fine material increases filling the voids and reducing the ballast drainage capacity and strength.

Ballast performance under 36-ton axle load coal traffic is being investigated at the UP's South Morrill subdivision near Ogallala, NE. The South Morrill currently carries about 230 million gross tons (MGT) of coal traffic annually on Track 2 and is the location of the western heavy axle load (HAL) revenue service test mega site. Particle size degradation and deformation behavior of five ballast materials are being monitored with sieve analysis and repeated load triaxial testing. Measuring the relationship of gradation with strength and deformation allows a better understanding of the behavior and life cycles of different ballast types.

The investigation is being performed as part of the Track Substructure and HAL Revenue Service Test Strategic Research Initiatives Program sponsored by the Association of American Railroads and FRA. The project is also part of UP's internal ballast research initiative.[1]

FRA-sponsored research into ballast degradation monitoring using GPR began in May 2012 in the general location of the ballast test.

BALLAST DEGRADATION MONITORING

Degradation monitoring began in November 2010 with new ballast material from four separate UP sources labeled Types I-IV, along with control ballast being installed in test zones established at a 2-degree curve and tangent location. The ballast types are separated by 14-foot-long and 12-foot-wide steel boxes in both zones, with ballast depth beneath the ties of about 14 inches. The boxes in the curve zone have steel bottoms, and the boxes in the tangent zone have fabric bottoms to isolate the ballast from the subgrade.

The layout of both zones was the same with boxes 1 through 4 containing ballast types I through IV respectively (Figure 1). Types I-IV were sieved after delivery and before installation to discard material smaller than 3/8 inch. The control ballast in boxes 5 through 8 was the Type II material installed in the as-delivered condition without additional sieving.

The new ballast was sampled before installation in November 2010, and additional samples have been taken in April and November 2011 and May 2012 at estimated tonnage levels of 120, 234, and 320 MGT. The sampling is performed with a small backhoe and narrow bucket that fits in the cribs between ties (Figure 2). The procedure is to remove the top ballast and sample only the ballast beneath the bottom of ties and as near to the rail seat as possible. One 5-gallon bucket is filled with material from the gage side and one bucket is filled from the field side of the rail. Gradations of the samples are determined using the ASTM C136 sieve analysis procedure that measures the percentage of the total sample weight that passes through a stack of decreasing sieve sizes.

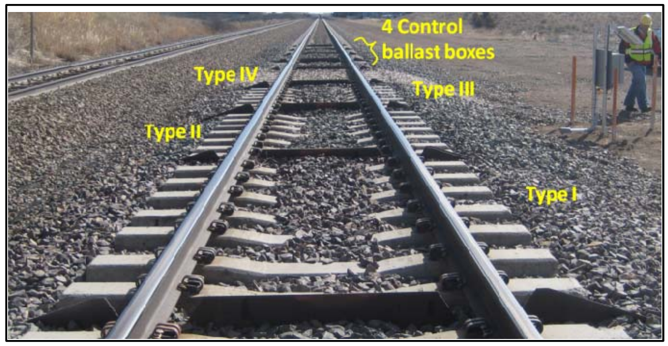

Figure 1. Tangent Zone Ballast Box Layout

Figure 2. Ballast Sampling with Backhoe

In Figure 3, percentages of the sampled ballast passing the 1/2-inch and No. 4 sieves at 0 and 320 MGT of traffic are compared. Material passing the 1/2-inch sieve is roughly equivalent to the waste from a full ballast undercutting operation, and material passing the No. 4 sieve is considered to be fines.

Types I and III show substantially less particle size degradation than the control ballast and Types II and IV. After 320 MGT, Types I and III are still below the AREMA gradation 4a limit of 7-percent passing the 1/2-inch sieve and show no appreciable degradation of material passing the No. 4 sieve. The control ballast and Types II and IV have 2 to 4 times the percentage of material passing the 1/2-inch sieve compared to Types I and III, and roughly 2 to 3 times the percentage passing the No. 4 sieve.

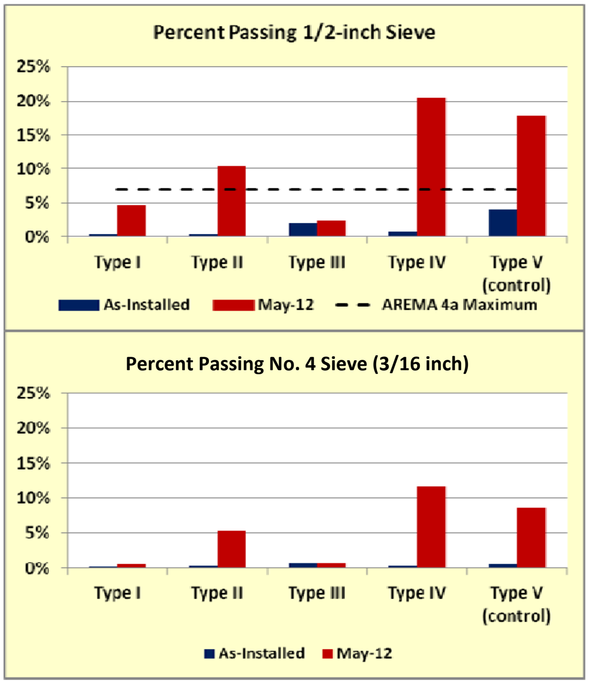

Figure 3. Ballast Degradation Comparison

TRIAXIAL AND MILL ABRASION TESTING

The potential for permanent deformation and settlement of the test ballast was evaluated with the University of Illinois Triaxial Ballast Tester (TX-24), designed and built under the direction of Dr. Erol Tutumluer (Figure 4). Triaxial testing involves a cylindrical ballast specimen being subjected to a number of repeated load pulses along its longitudinal (vertical) axis and simultaneously subjected to a constant surrounding or confining pressure. Both the elastic (or resilient) and plastic (or permanent) deformation of the specimen was measured during each load cycle.

The TX-24 accommodates a 12-inch diameter by 24-inch high cylindrical ballast specimen. Axial load pulses were applied with a programmable hydraulic actuator operating in load control mode. The loading sequence was a 0.4-second duration load pulse representing the combined input generated by the trailing truck of the leading car and the leading truck of the trailing car followed by a 0.6-second rest period. This load sequence is roughly equivalent to a car with 40-foot truck centers operating at 40 mph. A maximum of 10,000 load pulses of 2,714 pounds (24-psi stress) was applied while maintaining a confining stress of 8 psi. The confining pressure around the specimen was applied using compressed air inside a 24-inch inner diameter, 3/4-inch-thick acrylic chamber. Three longitudinal displacement transducers positioned 120-degrees apart and one circumferential displacement transducer mounted on a horizontal chain were used to measure specimen axial and radial deformation. The recorded axial deformation was computed as the average output of the three longitudinal transducers.

Figure 5 shows the accumulated axial deformation of the 320 MGT ballast samples after 10,000 load cycles. The Figure 5 dataset also includes the Type IV material tested dry and with water added to create an approximate 3-percent moisture content.

Figure 4. TX-24 Triaxial Ballast Tester

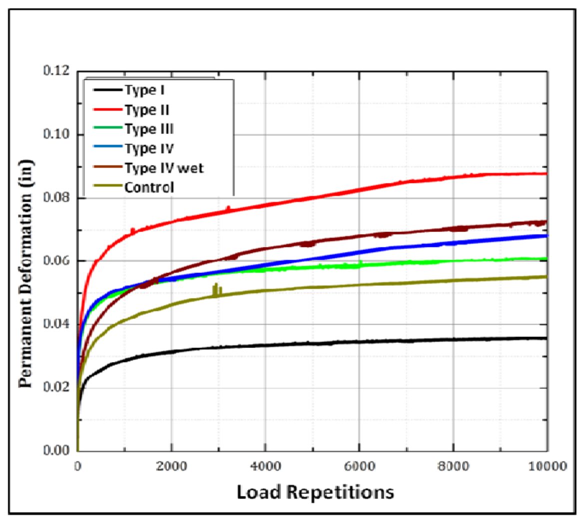

Figure 5. Axial Deformation of 320 MGT Ballast Samples

Note that unlike the particle degradation trends observed in Figure 3, the permanent deformation data accumulation in Type II ballast was the highest, followed by Type IV and Type III. The Type II ballast produced the most deformation but was midrange in terms of the material passing the No. 4 sieve. The Type IV and Control ballasts with the most particle size degradation tested midrange in terms of deformation. The best correlation was the Type I material that had the least amount of material passing the No. 4 sieve and the least deformation. Ideally, it would the best practice to correlate the permanent deformation test results to gradations and fouling conditions of the samples actually tested as specimens in the TX-24 setup.

Table 1 shows the results of mill abrasion (MA) tests performed by the University of Massachusetts on new as-installed Type I-IV ballast samples (the control ballast was not MA tested as it is the Type II but without post delivery screening).[2] The MA test is a wet abrasion test that determines the amount of material finer than the No. 200 (0.003-inch) sieve as a percentage of the total sample weight. The MA test is an indicator of ballast material hardness and abrasion resistance.[3]

Ballast Type II had the highest MA value (8.3%) and the most deformation, but not the most particle size degradation. The agreement between triaxial and MA results and lack of agreement with sieve analysis suggests the possibility of Type II particles abrading during triaxial loading and producing higher permanent deformation.

Table 1. Mill Abrasion Test Results

Type I	Type II	Type III	Type IV
4.4%	8.3%	1.2%	1.2%

GPR TESTING

A 2-mile segment on Track 2 of the South Morrill division, including the tangent and curve ballast box zones, was inspected with GPR technology in May 2012 as the initial survey of the FRA-sponsored GPR project. The survey was performed to determine GPR capability for ballast gradation monitoring using 2 GHz antennas for ballast fouling analysis and 400 MHz antennas for layer depth interpretation.

The data in Table 2 compares the percentage of material passing the 3/8-inch sieve from the May 2012 samples with the GPR generated fouling index (FI) values.[4] The results are reasonably similar with the notable exception of the Type IV curve and the Type III tangent.

Table 2. Comparison of GPR and Sieve Analysis FI Results

Ballast Type	Tangent % passing 3/8 inch	Tangent GPR	Curve % passing 3/8 inch	Curve GPR
I	3 moderately clean	8 moderately clean	1 moderately clean	4 moderately clean
II	13 moderately fouled	8 moderately clean	3 moderately clean	7 moderately clean
III	1 clean	19 moderately fouled	1 moderately clean	9 moderately clean
IV	1 clean	2 moderately clean	35 fouled	3 moderately clean
Control Box 6	20 moderately fouled	24 fouled	8 moderately clean	10 moderately clean
Control Box 7	20 moderately fouled	12 moderately fouled	5 moderately clean	12 moderately fouled

SUMMARY AND CONCLUSIONS

Results of the HAL Ballast Test after 320 MGT of 36-ton coal traffic at the western mega site are as follows:

- Sieve analysis of samples collected in May 2012 indicates significantly different rates of particle size degradation for the different ballast types. Ballast Types I and III are showing minimal change in gradation, whereas the control ballast and Types II and IV have 2 to 4 times the percentage of material passing the 1/2-inch sieve compared to Types I and III and roughly 2 to 3 times the percentage passing the No. 4 sieve.
- The Type II ballast produced the most permanent deformation after 10,000 triaxial test load cycles but was midrange in terms of particle size degradation from sieve analysis. The Type IV and control ballasts with the most particle size degradation tested midrange in terms of deformation. The best correlation between gradation and deformation was the Type I material that had the least amount of particle size degradation and the least amount of deformation.
- The Type II ballast produced the highest MA value indicating it has the highest potential for abrasion of the ballast types.
- Adding water to the Type IV ballast produced a slight increase in the deformation.
- The GPR ballast generated fouling data was reasonably similar to the sieve analysis data of the May 2012 samples with the exception of the Type IV ballast at the curve zone where the sample showed much more fouling than the GPR output.

The relationship between ballast gradation and triaxial test deformation results is anticipated to improve with increased tonnage as the amount of fouling increases.

The next ballast sampling, triaxial testing, and GPR inspection cycle was conducted October 2012. The test is scheduled to continue at least through November 2013.

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