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Ballast Degradation under Heavy Axle Load Trains at Western Mega Site

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Summary

In conjunction with Union Pacific (UP) Railroad, Transportation Technology Center, Inc. (TTCI) and University of Illinois Urbana-Champaign (UIUC) investigated ballast performance under 36-ton heavy axle load (HAL) traffic at the western mega site. Ballast degradation and deformation behavior of four mainline-quality ballast materials were monitored with periodic sampling and laboratory tests.

Main conclusions from this testing program are as follows:

- Ballast degradation rates due to HAL traffic differed substantially among the four mainline-quality ballast types. In general, Types I and III had the lower degradation rates due to material types.
- Higher percentages of degradation and organic carbon content in the ballast, in general, corresponded to higher permanent deformation in laboratory testing, with increasing traffic volume.
- With additional screening of the Type II ballast over the Type V control ballast at source gradation, Type II ballast stayed cleaner to the test termination.
- For the western mega site, it took 737 million gross tons (MGT) to accumulate significant amounts of carbon-based fines that were observed in ballast sampling.

In November 2010, new ballast materials from four sources, labeled Types I through IV, were installed in a 2-degree curve and tangent test zones subjected to 220–250 MGT per year. Ballast Types I–IV were screened after delivery and prior to installation to remove particles less than 3/8-inch screen size. Type V material was identical to Type II material, but it was installed as delivered without additional screening. Steel boxes separated the ballast types, and samples were collected at six different times over the testing period of 737 MGT. Sieve analyses were performed on the sampled ballast to determine changes in the gradation with tonnage. Permanent deformation trends of the ballast samples were evaluated using a large-scale repeated load triaxial test device. Finally, the ballast sample organic carbon contents from coal car lading were measured using a carbon, hydrogen, and nitrogen chemical test.

Testing was performed in a joint effort by the Association of American Railroads, Federal Railroad Administration, and UP to quantify the effects of ballast gradations and material types on ballast degradation, measure the relationship between degradation and deformation, and monitor track settlement to gain a better understanding of ballast life cycles and performance.[1,2]

INTRODUCTION

Abrasion and breakdown of ballast particles from repeated wheel loads and maintenance, plus infiltration of material from the outside are root causes of ballast degradation 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 2½ and 2¾ inches and no material smaller than the No. 4 sieve. The large inter-particle void spaces found in these gradations facilitate drainage and permit some initial particle 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 traffic was the subject of a major investigation at the western mega site on the UP's South Morrill subdivision near Ogallala, Nebraska. This site carries approximately 220 to 250 MGT of traffic annually on Track 2.

Particle size degradation and deformation behavior of five ballast materials were monitored with sieve analysis and repeated load triaxial testing. Measurement of the relationship between gradation and deformation characteristics results in a better understanding of field settlement performances and the corresponding life cycles of different ballast types.

BALLAST DEGRADATION MONITORING

Degradation monitoring began in November 2010 with new ballast materials from four separate sources, labeled as Types I through IV in the test zones. The control ballast was labeled Type V. Test sections included a 2-degree curve and a tangent location. Table 1 summarizes the ballast types and their mineral compositions. The ballast types were contained in 14-foot long by 12-foot wide by 12-inch high steel boxes in both test zones, with ballast depth beneath the ties of about 14 inches. The boxes in the curve zone had steel bottoms, and the boxes in the tangent zone had fabric bottoms to isolate the ballast from the subgrade. Eight boxes were used in each section.

Table 1. Mineral Compositions of Ballast Type

BALLAST	MINERALOGY
Type I	Orthoclase, feldspar, quartz, hornblende phenocryst
Type II	Basalt (no minus 3/8-inch material)
Type III	Quartzite
Type IV	Rhyolite, quartz phenocryst
Type V	Basalt (includes minus 3/8-inch material)

Types I–IV were sieved after delivery and before installation, to remove material finer than 3/8-inch. The control ballast in boxes 5 through 8, Type V, consisted of Type II material installed in the as-delivered condition without additional screening.

The new ballast was sampled before installation in November 2010 and additional samples were taken in April and November 2011, May and November 2012, and May and November 2013 at estimated tonnage levels of 120, 283, 417, 516, 615, and 737 MGT of traffic. Shallow samples were collected at all traffic volumes from the bottom of the tie to approximately 10 inches below bottom of the tie. Deep samples were only collected at 737 MGT (the test conclusion) and taken from 10 inches below the bottom of the tie to the bottom of the steel box at 14 inches below the bottom of the tie.

The sampling was performed with a small backhoe and narrow bucket that fit in the cribs between ties. The procedure consisted of removal of the upper ballast between ties (without removing ties), sampling only the ballast beneath the bottom of ties as close to the rail seat as possible. One 5-gallon bucket was filled with material from the gage side and another bucket was filled from the field side of the rail. Combined gradations of the ballast materials sampled from different track locations 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. It should be noted that this field ballast sampling method, although commonly used for ballast degradation analysis, can cause large random errors in terms of finer materials not being properly collected. To address variations due to sampling errors, ballast samples were taken at multiple locations over multiple times (at various tonnage levels), and analysis is mainly to look at the general trends, rather than variations at small scales.

One additional objective for this research effort was to investigate the accumulation of mineral dust in the track ballast over time. Pure carbon based fines from Wyoming mines are nonplastic in nature with a 55–58 percent organic carbon content.[3] The percentage of the organic carbon from carbon, hydrogen, and nitrogen (CHN) chemical analyses was found to be a reliable indicator of pure carbon mineral content in a soil-coal dust mixture.[3] The organic carbon content of the sample was removed by pretreating the samples with 1 mL, 1N HCL solutions prior to running a CHN test.[3]

TRIAXIAL TESTING

Because of short distance in the field from one ballast type to another, the accumulation of permanent deformation was evaluated as the field settlement potential of the track ballast using the UIUC Triaxial Ballast Tester (TX-24)[2,4] shown in

Figure 1. This laboratory test is done under controlled, repeatable conditions that supplement track settlement measurements, while eliminating field variables that could compromise results. 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 8 psi confining pressure.[2,4]

Figure 1. UIUC Triaxial Ballast Tester

Both the resilient (elastic recoverable) and permanent deformations of the specimen are measured during each load cycle.

Specimens were tested using 10,000 pulses of a constant 2,714-pound applied load (24-psi vertical pressure). Three longitudinal displacement transducers positioned 120-degrees apart on the sides of the specimen were used to measure the specimen's axial displacement. Mishra et al. describe a more complete description of the loading parameters, intervals, sample preparation, and mounting.[4]

RESULTS AND DISCUSSION

Figure 2 shows the general trend of accumulation of material finer than 3/8 inch. Different ballast types with the mineral compositions listed in Table 1 showed different rates of degradation as traffic accumulated. Fluctuations of results can be attributed to field sampling error as mentioned earlier.

Types II and V are both basalt from the same source (see Table 1) with the difference that Type II materials had undergone an additional screening process to remove material finer than 3/8 inch when installed. As Figure 2 shows, the degradation was generally much higher for Type V than for Type II. In addition the final field measurement of Type II (and Type V with the same mineral type) showed the highest degradation among the four types monitored. Previous results from Mill Abrasion (MA) testing also showed that Type II material had the highest MA value, indicating that it has the highest potential for abrasion degradation.[5] On the other hand, Type I ballast exhibits the smallest gradual increase in the percentage of minus 3/8-inch material over time, both in terms of general trends and the final measurement. Note that the significant drop of ballast degradation result for Type IV at 516 MGT was most likely caused by field sampling error.

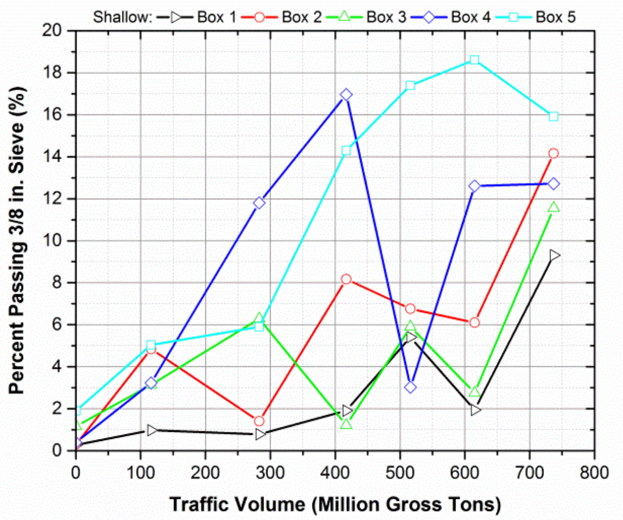

Figure 2. Accumulation of Materials Finer than 3/8-inch with Traffic

Figure 3 shows Type I ballast permanent deformation test results for 10,000 load cycles at 283, 417, 516, 615, and 737 MGT. Type I ballast accumulated the lowest permanent deformation amounts over time among all ballast types. As ballast degradation increased with tonnage, deformation shown in Figure 3 also increased with tonnage.

Assembling all the ballast types at various traffic volumes and sampling depths, Figure 4 shows the accumulated permanent deformation after 10,000 load cycles for the four ballast types (Types I–IV) and for the control ballast (Type V) at shallow sampling depths. Permanent deformation results for the deep sampling depths are also shown for 737 MGT.

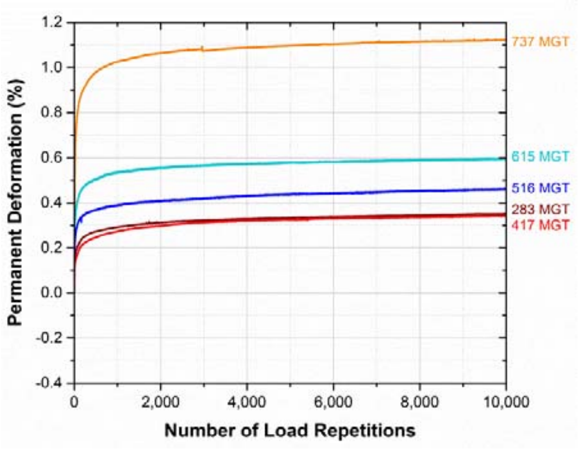

Figure 3. Permanent Deformation and Sieve Results for Type I

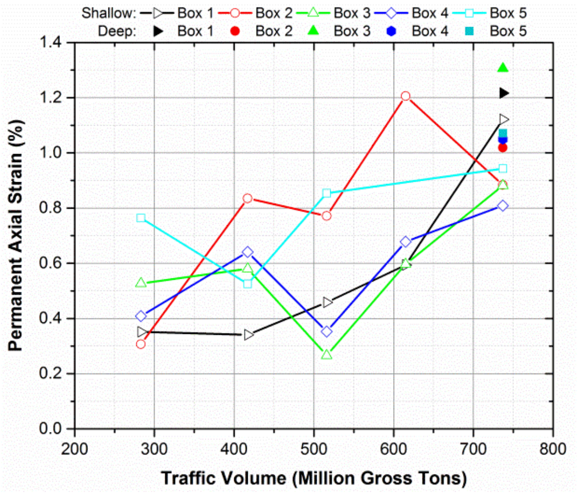

Figure 4. Permanent Deformation at 10,000 Load Cycles for all Ballast Types graphed with Traffic Volume

Ballast Types II and V at shallow depth generally exhibit the highest permanent deformation for most traffic volumes. The remaining ballast Types I, III, and IV at shallow depth do not show a consistent trend in relation to each other, but rather all shallow samples do generally show an increase in permanent deformation with increasing traffic volume. The exception is at 516 MGT where test results show a drop in permanent deformation that is most likely due to field sampling error.

Ballast types II and V, having the same mineralogy and higher degradation rates, indicate higher contact abrasion and degradation potential. By comparison, the Type I material, a less abrasive material, shows a lower increase in degradation over time and a correspondingly lower permanent deformation accumulation with traffic volume except for the last measurement.

Figure 5 shows the organic carbon contents obtained from CHN testing of the minus No. 200 sieve fraction of the five ballast types at different MGT levels. An increase in the accumulation of organic carbon contents; i.e., coal dust, at 737 MGT is shown for most ballast types, especially for the deep samples. Type V consistently shows the lowest organic carbon accumulation over time, which may be caused by the filtering effects of increased percentage of fine material.

What is important to note is that during field ballast sampling, dark organic carbon (i.e., coal dust), fine materials were not observed in the ballast, except for the deep ballast layer exposed at 737 MGT, indicating no significant accumulation until then. In addition, as Figure 5 shows, fines from deep boxes generally showed higher organic carbon contents compared to shallow boxes, indicating the downward migration of coal dust with time.

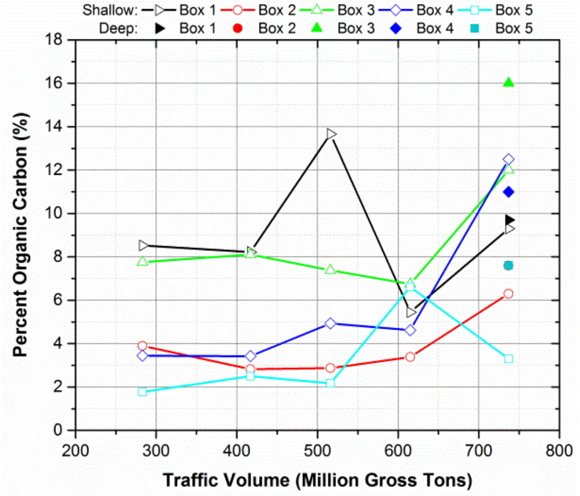

Figure 5. Organic Carbon Present in All the Ballast Types over Time

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