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Ballast Degradation Characterized through Triaxial Testing

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Summary

Transportation Technology Center, Inc. provided support to members of its Affiliated Laboratory Program at the University of Illinois at Urbana-Champaign (UIUC) to develop a large-scale triaxial test device for testing large-size ballast aggregate materials. This new test equipment has unique capabilities and can characterize shear strength, resilient modulus, and permanent deformation behavior of railroad ballast materials through monotonic compression and repeated load testing. Different factors affecting strength, modulus, and permanent deformation characteristics of railroad ballast materials can be investigated.

Preliminary test results from ongoing research, aimed at evaluating the ballast characteristics at different stages of its life-cycle, were recently evaluated using the test device.[1] Degraded crushed limestone ballast samples were generated through Los Angeles (LA) abrasion tests to simulate ballast degradation due to breakage and abrasion. The laboratory sieve analysis and triaxial tests produced the following results:

- Ballast degradation can cause significant changes in ballast grain size distributions as well as particle shape properties when compared to the corresponding properties of new ballast materials. Upon degrading the same ballast samples in staged LA abrasion tests, particles tended to break down considerably. Particles that did not break became more rounded and smoother in texture.
- In permanent deformation testing, the heavily degraded crushed limestone ballast specimen with a Selig Fouling Index of 40 for large size ballast had the highest permanent axial strains compared to the other specimens of new clean ballast and coarse aggregate fraction of degraded ballast specimen. The specimen with only coarse aggregate fraction (particles larger than 3/8 inch) from the degraded ballast yielded higher permanent deformation than that of the new ballast specimen.
- Ballast degradation did not necessarily result in a significant strength loss from the monotonic shear strength tests. On the contrary, for the dry sample conditions, the degraded ballast with or without materials finer than 3/8 inch yielded higher strength than the new, clean ballast specimen.

The test results demonstrated the capabilities of the newly developed large-scale ballast triaxial test setup at UIUC. The preliminary findings indicated the ballast behavior at different levels of degradation could be captured adequately. The current and future use of the triaxial test setup is intended to better understand factors affecting ballast life-cycle and field performance.

The investigation is being performed as part of the Association of American Railroads Strategic Research Initiatives Program in cooperation with the Federal Railroad Administration.

BACKGROUND AND INTRODUCTION

Crushed limestone ballast consisting of large-sized aggregate particles with uniform size distribution was tested. Ballast with a uniform size distribution is an essential component of the track substructure to facilitate track stability and drainage. As freight tonnage accumulates with traffic, ballast will accumulate an increasing percentage of fines due to either aggregate breakdown and degradation or contamination by other materials such as lading material dust and subgrade soil intrusion. Degradation affects shear strength and the load carrying ability of ballast layer especially under wet conditions. According to Selig and Waters, ballast aggregate degradation involves up to 76 percent of all fine mineral degradation cases.[2]

Transportation Technology Center, Inc. provided support to members of its Affiliated Laboratory Program at UIUC to develop a large-scale triaxial test device (TX-24) for testing ballast size aggregate materials (see Figure 1).

The device consists of an internal load cell (Honeywell Model 3174) with a 20-kip capacity placed on top of the specimen top platen. Three vertical linear variable differential transformers are placed around the cylindrical test sample at a 120-degree angle to measure the vertical deformations of the specimen from the three different side locations.

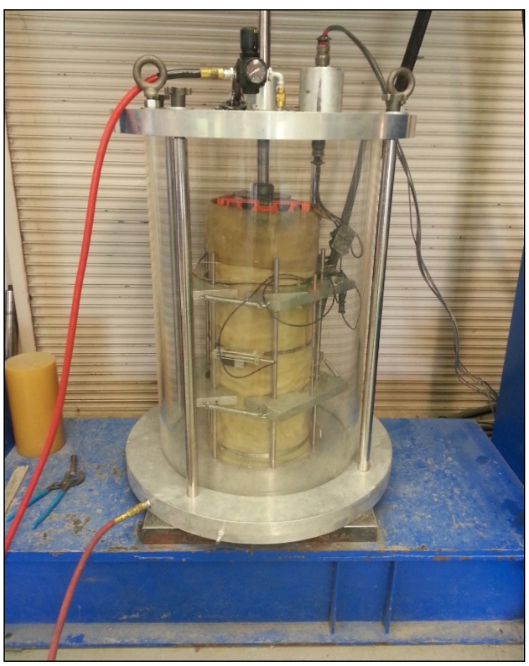


Figure 1. Ballast Triaxial Tester

To investigate the effects of ballast aggregate breakdown and degradation on the mechanical behavior, LA abrasion tests were performed to generate ballast fine particles caused by ballast breakage and abrasion under a well-controlled laboratory environment. The changes in particle size and shape properties during the LA abrasion tests were quantified and studied through image analysis technology.[3] Large-scale triaxial tests were performed on specimens of new ballast, degraded ballast coarse particle fraction (without fines; i.e., material passing 3/8-in. sieve), and full gradation of degraded ballast (with fines) under repeated loading and monotonic compression. Important findings of this preliminary study on characterizing ballast degradation are presented here.

LOS ANGELES ABRASION TEST AND IMAGE ANALYSIS

The ballast material specifically selected for the laboratory degradation study was a crushed limestone, which meets AREMA No. 24 gradation requirements. Approximately 10 kilograms of clean ballast materials were placed in the LA abrasion drum together with 12 steel balls, which are used in the standard LA abrasion test (Standards: AASHTO T 96 or ASTM C 131). The average drum rotation speed was set at 50 turns per minute; so the total number of drum turns for the limestone ballast sample to reach the ballast condition with a Selig Fouling Index (FI) of 40 for large size ballast was 1,500 revolutions. FI is the sum of the percent by weight of ballast sample passing the No. 4 sieve and the percent passing the No. 200 sieve according to Selig and Waters.[2] The ballast sample was taken out of the drum and evaluated for gradation and imaging based size and properties after every 125 drum turns. To minimize loss of fine materials, both the inside of the drum and the steel balls were carefully hand brushed after each operation. All particles above 1.0 inch were also brushed to collect dust and fine material before sieving.

This procedure was repeated until enough materials were generated to conduct large-scale triaxial tests and all of the generated degraded ballast materials was evenly mixed before preparing the triaxial test specimens.

Figure 2 shows the gradations of clean and degraded ballast specimens (after 1500 turns of LA abrasion test). Another gradation curve, which represents only the gradation of the large particles (coarse fraction) is also given in Figure 2. The specimen of the degraded ballast after the LA abrasion testing excluded particles smaller than 3/8 inch, which is representative of undercut track.

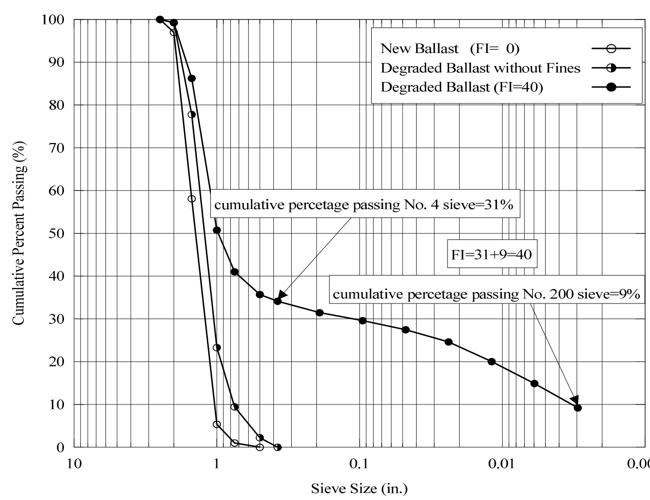
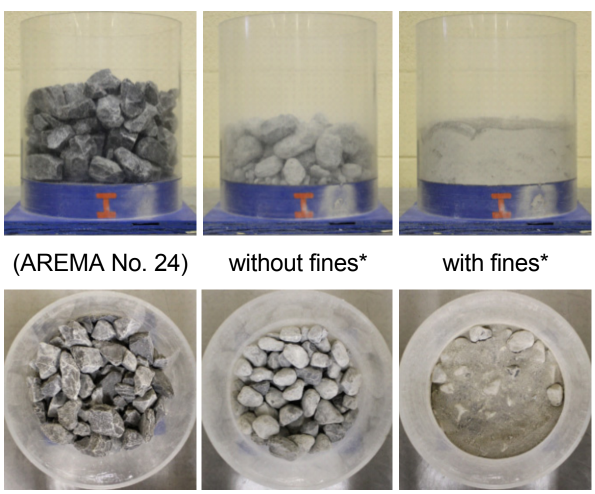


Figure 2. Gradation Curves of Ballast Materials

It is not obvious how to relate gradation information to ballast layer functional characteristics and the governing mechanisms that would impact ballast layer structural and drainage behavior. To investigate particle contact and particle packing characteristics before and after degradation, approximately 22 pounds of ballast material obtained from the before and after 1,500 turns in LA abrasion tests were poured into an acrylic chamber with dimensions of 10.0 inches in diameter and 10.0 inches in height. Figure 3 presents the side and top views of aggregate packing photos taken before and after degradation with the corresponding FI values. Photos of the degraded ballast without fines are also shown in Figure 3 for comparison. After 1,500 turns, the same weight (22 lbs) of degraded ballast occupied less volume, compared to the new ballast in the acrylic chamber. However, for the same weight of degraded ballast, the specimen height remained nearly the same with or without fine particles, as Figure 3 shows. This is because the fine particles generated during degradation occupied the voids created by the large particles. As FI approached 40, nearly all the voids created by the large particles were filled with fine particles.

New ballast Degraded ballast



FI=0 FI=0 FI=40

*Fines refer to particle sizes passing 3/8-inch sieve

Figure 3. Side and Top Views of Ballast Aggregate Packing

TRIAXIAL TESTING

A realistic train loading dynamic pulse with 0.4-second load duration and 0.6-second rest period was selected in order to evaluate permanent deformation characteristics of the ballast materials obtained before and after LA abrasion tests. The peak deviator stress repeatedly applied on the specimen was 24 psi and the confining pressure was 8 psi. Figure 4 shows the details of the loading pulse used in this study.

A typical loading strain rate of 1 percent per minute, which corresponded to 0.004 inch per second of actuator speed, was selected to evaluate shear strength characteristics of the ballast materials obtained before and after the LA abrasion tests. All test specimens were monotonically loaded up to 10-percent axial strain at a confining pressure of 10 psi.

The tested ballast specimens were prepared by compacting ballast materials in four lifts. The appropriate amount of ballast material was prepared carefully according to the gradation requirements (see Figure 2). Before making the triaxial test specimen, the ballast material was mixed thoroughly and divided into four even parts to minimize segregation. The height of each lift after compaction was 6 inches, and, for each lift, the compaction was applied with the same electric jack hammer for 4 seconds to ensure the same compaction energy was applied to all the test specimens for all the different ballast materials. Table 1 summarizes the shape properties and details of the triaxial test specimen.

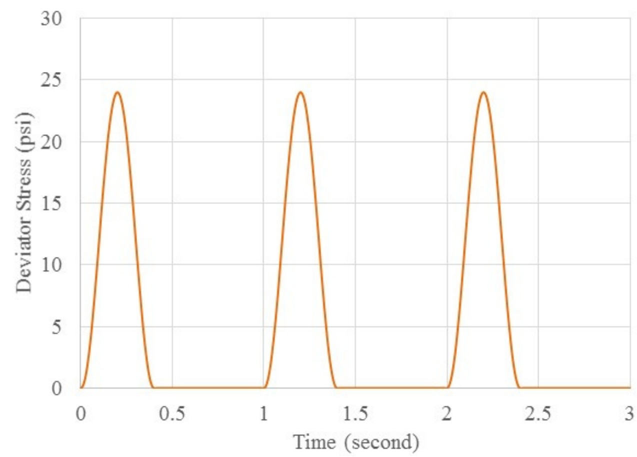


Figure 4. Loading Pulse used in Repeated Load Triaxial Tests

Table 1. Triaxial Test Specimen Details and Shape Properties of Large–Sized (above 3/8 inch) Particles

	New Ballast	Degraded Ballast (Without Fines)	Degraded Ballast (With Fines)
Specimen height	24 in.	24 in.	24 in.
Specimen diameter	12 in.	12 in.	12 in.
Specimen weight	154 lb	161 lb	207 lb
Compaction time	16 seconds	16 seconds	16 seconds
Void ratio	0.68	0.61	0.25

Note: Fines refer to particle sizes passing 3/8-inch sieve

TEST RESULTS

Figure 5 presents the results of the permanent deformation tests on the new and degraded limestone ballast cylindrical specimens for up to 10,000 cycles. The fully degraded ballast specimen (FI=40) resulted in the highest permanent axial strain. After 10,000 load cycles, the new ballast specimen had an average permanent strain of 0.62 percent; whereas, the degraded ballast specimen yielded a permanent axial strain of 1.32 percent. The degraded ballast without fines (passing 3/8-inch sieve size) gave a permanent axial strain of 0.92 percent, which was between the new, clean ballast and the fully degraded ballast.

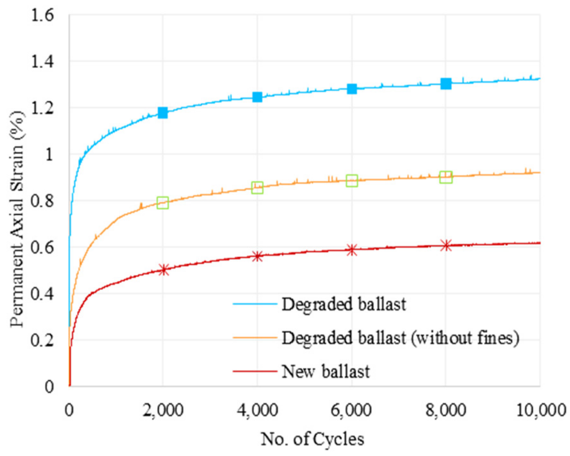


Figure 5. Permanent Axial Strains up to 10,000 Load Cycles

The difference between the new ballast and coarse aggregates fraction of the degraded ballast is mainly due to the differences in particle shape properties. In other words, no fine degrading materials; i.e., particles smaller than 3/8 inch, were present in the specimens of these two materials. The coarse fraction of the degraded ballast had more rounded and smoother aggregate particles with lower imaging based angularity and surface texture indices.

The fully degraded (FI=40) ballast specimens had the highest permanent axial strains recorded. In fact, the difference between the degraded ballast and the coarse aggregates fraction was due to the degrading material, i.e. fines (particles smaller than 3/8 inch) generated during the LA abrasion tests. These fine materials not only filled the voids but also caused loss of contact between large particles in the heavily degraded ballast aggregate skeleton.

Figure 6 presents the results of the monotonic shear strength tests on the new and degraded limestone ballast cylindrical specimens for up to 10-percent axial strain. Interestingly, particle degradation did not result in significant strength loss in the dry, degraded ballast specimens when compared to the new, clean ballast material. On the contrary, both the degraded ballast and the coarse aggregate fraction of degraded ballast yielded higher strength than the clean ballast specimen under dry sample testing conditions. Comparing the gradations of the three ballast materials (see Figure 2), the coarse aggregate fraction of degraded ballast comprised higher number of smaller particles and was more "well" graded than the clean ballast material. The smaller particles within the degraded ballast matrix helped to achieve higher density and better packing.

For the specimen prepared with the degraded ballast (FI=40), the fines (material finer than 3/8 inch) filled the voids created by larger particles. However, the presence of excessive fines in the aggregate matrix may have resulted in the loss of contact between some of the large particles to yield lower shear strength than the coarse aggregate fraction of degraded ballast. This could also be the reason why the degraded ballast had much smoother stress-strain curves during monotonic shear strength tests. However, all the test results presented here were under dry sample preparation conditions. Upon introduction of moisture into the specimens, the shear strength properties of degraded ballast are expected to drop substantially.

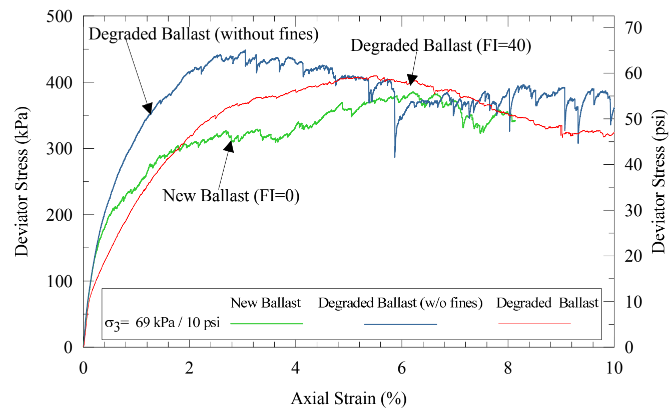


Figure 6. Shear Strength Test Results

CONCLUSIONS

The degradation tests on crushed limestone ballast produced the following results:

- As ballast degradation took place in the LA abrasion tests, particles tended to become smaller in size and significant amounts of fines (particles smaller 3/8 inch) were generated. Particles that did not break became more rounded and smoother in texture.
- When Selig's FI approached 40, nearly all the voids were filled with fines, which resulted in loss of contact between large particles in the degraded ballast aggregate skeleton.
- Fully degraded ballast with fines (FI=40) yielded the highest permanent deformation followed by the coarse fraction of the degraded ballast (with no fines).
- The new, clean ballast resulted in the lowest deformation. On the contrary, the degraded ballast with or without fines yielded higher strength than the new clean ballast specimens when tested under dry conditions.

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