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Behavior of Wet Degraded Ballast Investigated through Triaxial Testing

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Summary

A large-scale triaxial device was used for testing ballast materials at an Association of American Railroads (AAR) Affiliated Laboratory, where researchers at the University of Illinois at Urbana-Champaign (UIUC) investigated the behavior of wet degraded ballast at different moisture contents. Results of triaxial testing of heavily degraded ballast specimens indicated that moisture significantly affects the ballast in terms of permanent deformation under repeated load triaxial test conditions and from monotonic shear strength tests conducted in a well-controlled laboratory environment.

The study was completed through a research program jointly funded by the AAR and the Federal Railroad Administration. Degraded ballast samples were generated through Los Angeles (LA) abrasion tests to simulate ballast breakage and abrasion, followed by different amounts of moisture mixed with the degraded ballast to prepare wet degraded ballast specimens. The following are the findings summarized from the laboratory tests:

- Moisture was found to have a significant effect on the behavior of degraded ballast in terms of permanent deformation under the repeated load triaxial test conditions. When moisture content was below a certain threshold, degraded ballast with some moisture showed higher densities to better resist repeated loading effects and yielded less permanent deformation compared to the dry condition. However, when moisture content increased beyond this threshold, the wet degraded ballast exhibited considerably higher permanent deformation than the dry degraded ballast under the same test conditions. This threshold was found to be close to the optimum moisture content at the maximum dry density of the degraded materials (i.e., smaller than 3/8 inch (9.5 mm) in size).
- Moisture was found to have a significant effect on the degraded ballast samples tested from monotonic shear strength tests. It was found that adding even 3 percent moisture (by weight of degraded materials) to the test samples caused approximately 50 percent decrease from shear strength of the dry but degraded ballast. Wet degraded ballast samples could only sustain low levels of maximum deviator stress under this type of loading conditions.

The findings from this study are based on testing heavily degraded (by LA Abrasion method) ballast specimens, which may represent a worst-case scenario, although indicative of moisture states in revenue service. Generally, maintenance activities are scheduled before a ballast layer reaches such heavily degraded conditions in revenue service.



INTRODUCTION

Large-scale triaxial tests were performed under a well-controlled laboratory environment to investigate effects of moisture on degraded ballast.³ The degraded ballast used in this study was generated by Los Angeles (LA) abrasion test, which was used to simulate ballast abrasion and breakdown under traffic loading.^{2,3} Both shear strength and repeated loading tests were performed on degraded ballast samples at different moisture contents.

Ballast consisting of large sized aggregate with uniform size distribution is an essential component of the track substructure to facilitate load distribution and drainage. As freight tonnage adds up, ballast will accumulate an increasing percentage of fine materials due to either aggregate breakdown/abrasion or outside contamination such as dust and subgrade soil intrusion. Such degraded ballast conditions can significantly affect ballast behavior. Selig and Waters reported ballast breakdown from traffic to occur in up to 76 percent of all degradation cases.¹ UIUC performed series of large-scale triaxial tests to evaluate ballast behavior due to aggregate degradation in dry conditions.² When moisture is trapped within the degraded ballast, performance of ballast can be negatively impacted, and is the focus of the study reported in this *Technology Digest*.

BALLAST SAMPLES

Figure 1 shows gradation curves of new (clean), degraded ballast without fines, and degraded ballast samples with fines at Fouling Index (FI) = 40.

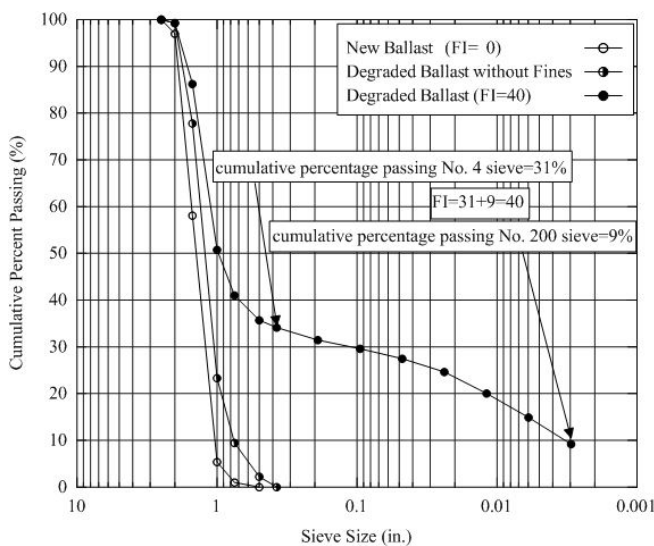


Figure 1. Gradation curves of ballast materials

FI is defined as 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.¹ In this study, the term “fines” or degraded materials is referred to as those particles with sizes less than 3/8 inch (9.5 mm). As FI approached 40, nearly all the voids created by the large aggregate were filled with fine particles. Figure 2 shows the side and top views of ballast samples before and after degradation with the corresponding FI.

Both the new ballast and the degraded ballast without fines had void ratios of 0.68 and 0.61, respectively.³ Hence, both the new ballast and the degraded ballast without fines are free draining materials and will not retain significant moisture within the aggregate skeleton both in the laboratory and field applications. When present, fines can fill in the voids created by larger particles and have the ability to absorb moisture and prevent ballast drainage.



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

Figure 2. Side and top views of ballast samples

Figure 3 shows the results of the compaction test and unsoaked California bearing ratio (CBR) test (a simple test to measure the strength of soil specimens) of fines or degraded ballast materials. The fines were mixed with water at the target moisture contents of 3, 6, 9, and 12 percent. The maximum dry density was achieved at optimum moisture content of 9 percent. The CBR value first increased when moisture content increased from 3 percent to 6 percent, but dramatically dropped at the optimum moisture content of 9 percent and approached zero at 12 percent, indicating when the material was saturated it could not sustain much load.

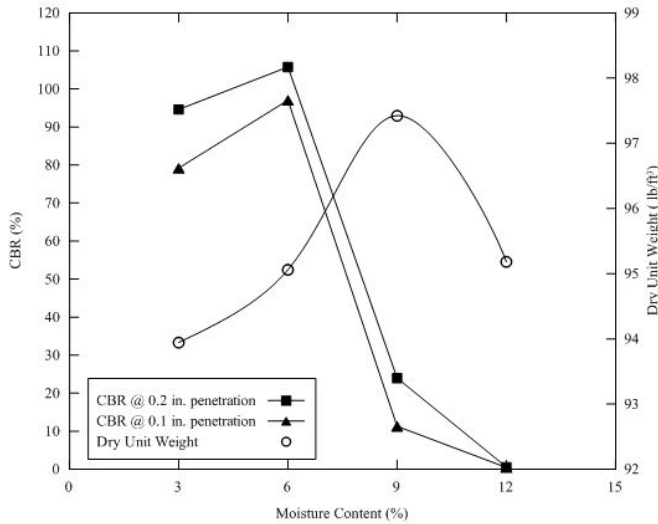


Figure 3. Compaction curve and CBR test results of degraded ballast samples with fines

TRIAXIAL TESTING RESULTS

A realistic field train loading dynamic pulse with 0.4-second load duration and 0.6-second rest period was selected for the repeated loading test. The peak deviator stress repeatedly applied on the specimen was 24 psi and the confining pressure was 8 psi. Further, a typical loading strain rate of 1 percent per minute, which corresponded to 0.004 inches (0.1016 mm) per second of actuator speed, was selected in order to evaluate shear strength characteristics. All test specimens were monotonically loaded up to 10 percent axial strain at a confining pressure of 10 psi. The test specimens were prepared by compacting ballast materials in four lifts. Specimens consisting of degraded ballast with fines were prepared at 0, 3, 6, and 9 percent moisture by weight of fines, respectively. For comparison purposes, clean ballast and degraded ballast without fines were also tested at 0 percent moisture content. The triaxial test details are summarized in Table 1.

Table 1. Triaxial test dry specimen details

	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

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

Figure 4 shows permanent deformation test results of the degraded ballast with fines at different target moisture contents of fines for up to 10,000 cycles as well as the average permanent deformation test results of the degraded ballast in dry condition for comparison purposes. When the moisture content of fines was relatively low, the specimen produced less permanent deformation compared to the specimen tested under dry conditions. For the specimen with 3 percent moisture content, the permanent axial strain after 10,000 cycles was approximately 0.99 percent, which was lower than the permanent axial strain of 1.21 percent from the specimen prepared with the same degraded ballast with fines under dry conditions, but higher than the permanent axial strain of 0.93 percent from the specimen prepared with the degraded ballast without fines under dry conditions. For the specimen with 6 percent moisture content, the permanent axial strain after 10,000 cycles was 0.82 percent, which was lower than the permanent axial strain of 0.93 percent from the specimen prepared with the degraded ballast without fines in dry condition, but higher than the permanent axial strain of 0.62 percent from the specimen prepared with the clean ballast in dry condition. However, when the moisture content increased to 9 percent, the permanent axial strain went up to 2.05 percent after 10,000 cycles, which was significantly higher than all the other cases. For the highest moisture content, i.e., 12 percent, a specimen could not even stand by itself after the aluminum split mold was detached.

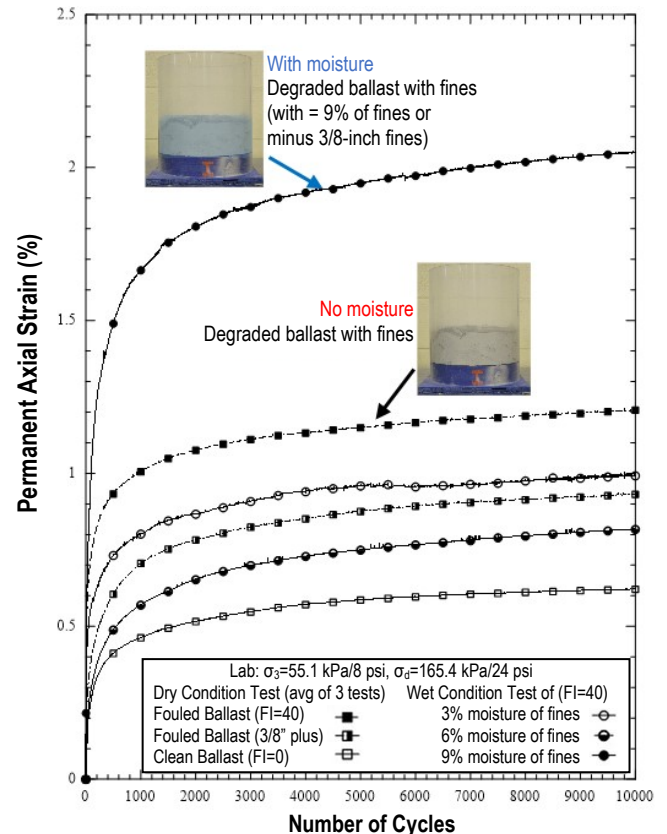


Figure 4. Permanent axial strains up to 10,000 load cycles

The observed permanent deformation behavior of the degraded ballast with fines agrees with the findings from the unsoaked CBR test results of fines (see Figure 3). Based on the limited experimental results, it can be hypothesized that a small amount of moisture could help to compact the fines, making fines stronger in unsoaked conditions. In this way, the fines may assume a stabilizing role within the aggregate matrix and cause lower permanent axial strains. When moisture content increases but is still below a certain threshold, the stabilizing effect of fines becomes more pronounced. However, when the moisture content of fines approaches the optimum moisture content of 9 percent, unsoaked CBR drops significantly, indicating a remarkable decrease in strength. At moisture contents above 12 percent, unsoaked CBR value is close to 0, meaning the degraded ballast with fines had already lost its ability to take any load. This trend suggests that when the trapped moisture in degraded ballast is above the optimum moisture content, degraded materials have low strength and control the ballast deformation behavior.

Monotonic strength tests were performed following the permanent deformation tests on the wet degraded ballast specimens. Figure 5 presents the monotonic triaxial shear strength test results of the degraded ballast with fines at 3, 6, and 9 percent target moisture contents of fines. Figure 5 also shows the test results with the degraded ballast with fines in dry condition, which is denoted as 0 percent moisture content. As shown, the peak deviator stresses (or strength) of all wet specimens were significantly less than the peak dry strength of the specimens. The peak deviator stresses for the specimens with 3, 6, and 9 percent moisture contents of fines were approximately 31, 37, and 27 psi, respectively, while the peak deviator stress for the dry specimen (0 percent moisture content of fines) was 59 psi.

Among the three wet specimens, Figure 5 shows the specimen with 6 percent moisture as the strongest and the specimen with 9 percent moisture as the weakest, which agreed with the permanent deformation test results shown in Figure 4. The stress-strain curves of the three wet specimens presented in Figure 5 generally showed the same pattern: peak deviator stress was quickly achieved within a relatively small strain range, followed by little change in strain level up to 10 percent. Such stress-strain trends of the wet specimens were different than those of the specimens in dry condition (the three specimens shown in Figure 5: new ballast, degraded ballast without fines, degraded ballast with fines but dry).

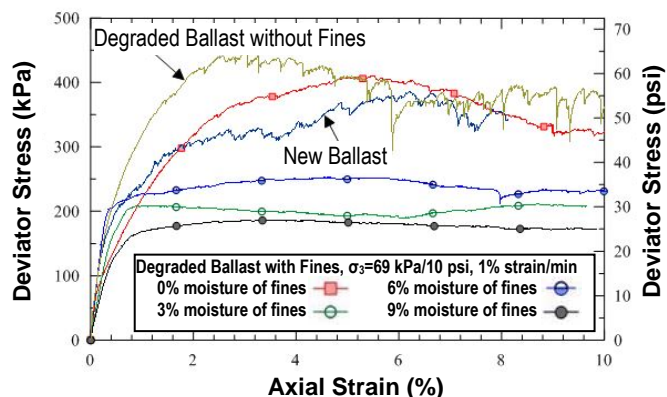


Figure 5. Triaxial shear strength test results

Another observation from Figure 5 is that the stress-strain curves of specimens at 3 percent and 6 percent moisture contents had higher initial slopes than the stress-strain curve of the specimen in dry condition, whereas the initial slope of the stress-strain curve of the specimen at 9 percent moisture content was lower. This observation suggests that in a relatively small strain regime, the mixture of fines and water possibly acted as a matrix “stabilizer” by bringing coarse particles together when the moisture content of fines was within a certain range. When the strain regime became relatively large, coarse particles were mobilized during the shearing process and the mixture of fines and water provided somewhat of a “lubricating” role.

As a note, results of triaxial testing of degraded ballast specimens indicated that high moisture would significantly affect ballast performance in terms of permanent deformation and shear strength. As such, ballast testing technologies such as ground penetrating radar (GPR) that can test both ballast degradation and ballast moisture content would help railroads determine ballast maintenance needs.

In addition to the lab testing, TTCI has planned a field test at the High Tonnage Loop of the Facility for Accelerated Service Testing starting in the summer of 2016, to investigate how ballast degradation and moisture affect track performance.

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3. Qian, Yu. *Integrated Computational and Experimental Framework for the Assessment of Railroad Ballast Life-Cycle Behavior*, PhD Dissertation, University of Illinois at Urbana-Champaign, Urbana, IL. 2014.

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