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MOISTURE EFFECTS ON DEGRADED BALLAST SHEAR STRENGTH BEHAVIOR

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ABSTRACT

Ballast consisting of large sized aggregate particles with uniform size distribution is an essential component of the track substructure, to facilitate load distribution and drainage. As freight tonnage accumulates with traffic, ballast will accumulate an increasing percentage of fines due to either aggregate breakdown or outside contamination such as subgrade soil intrusion and coal dust collection. According to the classical text by Selig and Waters [1], ballast degradation from traffic involves up to 76% of all fouling cases; voids will be occupied by fines from the bottom of ballast layer gradually causing ballast clogging and losing its drainage ability. When moisture is trapped within ballast, especially fouled ballast, ballast layer stability is compromised. In the recent studies at the University of Illinois, the focus has been to evaluate behavior of fouled ballast due to aggregate degradation using large scale triaxial testing. To investigate the effects of moisture on degraded ballast, fouled ballast was generated in the laboratory through controlled Los Angeles (LA) abrasion tests intended to mimic aggregate abrasion and breakdown and generate fouled ballast at compositions similar to those observed in the field due to repeated train loadings. Triaxial shear strength tests were performed on the fouled ballast at different moisture contents. Important findings of this preliminary study on characterizing wet fouled ballast are presented in this paper. Moisture was found to have a significant effect on the fouled ballast strength behavior. Adding a small amount of 3% moisture (by weight of particles smaller than 3/8 in. size or smaller than 9.5 mm) caused test specimens to indicate approximately 50% decrease in shear strength of the dry fouled ballast. Wet fouled ballast samples peaked at significantly lower maximum deviator stress values at relatively smaller axial strains and remained at these low levels as the axial strain was increased.

INTRODUCTION

Ballast consisting of large sized aggregate particles with uniform size distribution is an essential component of the track substructure, to facilitate load distribution and drainage. As freight tonnage accumulates with traffic, ballast will accumulate an increasing percentage of fines due to either aggregate breakdown and abrasion or contamination by other materials such as coal dust, traction sand, and subgrade soil. Previous research studies have concluded that ballast degradation and fouling with increased freight tonnage could significantly affect ballast behavior in dry condition [2, 3].

When fines accumulate due to particle degradation and breakdown under traffic loading, voids among large particles will be occupied by fines starting from the bottom of ballast layer gradually causing ballast clogging and loss of drainage ability. When moisture is trapped within ballast, especially fouled ballast, contacts between ballast particles change and can negatively impact ballast layer stability.

Ebrahimi et al. [4] conducted large scale triaxial tests on fouled ballast materials under cyclic loading and reported higher fouling and moisture content resulted in higher plastic strain. For the same fouling condition, the specimen with the highest moisture content yielded the highest permanent deformation. Two types of fouling agents were used to add into clean ballast, one was "mineral filler" material which comprised of 70% dolomite and 30% quartz and the other one was coal. Trinh et al. [5] sampled fouled ballast specimens from an old railway in France, where the ballast was mainly fouled due to mixing with subgrade soil. They conducted large-scale triaxial tests on these samples and found that when the fouled ballast specimen was saturated, its apparent cohesion was significantly lower than the fouled ballast specimens at lower water contents although the friction angle remained the same. Recently, Indraratna et al. [6] performed large scale triaxial tests on ballast fouled with coal dust. The results indicated that when fouling level increased, the specimen shear strength dropped rapidly. Indraratna et al. [6] described the wet coal dust had both "lubrication effect" and "cushioning" effect in the aggregate matrix.

According to Selig and Waters [1], ballast degradation from traffic involves up to 76% of all degradation cases. It is important to investigate fouled ballast behavior due to material degradation and breakdown and for the more detrimental effects of moisture on degraded ballast behavior. Qian et al. [7] recently performed series of large-scale triaxial tests to evaluate behavior of fouled ballast due to aggregate degradation and breakdown in dry condition. To investigate the effects of moisture on fouled ballast, large-scale triaxial tests were performed under a well-controlled laboratory environment. The fouled ballast used in this study was generated by the Los Angeles (LA) abrasion test which was used to mimic ballast abrasion and breakdown under traffic loading [8]. Both shear strength and repeated loading tests were performed on the fouled ballast samples at different moisture contents. Important findings of this preliminary study on moisture influencing degraded ballast shear strength behavior are presented herein.

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TEST MATERIAL AND EQUIPMENT

Degraded Ballast Material

The degraded ballast material used in the laboratory was generated by LA abrasion testing from a 100% crushed clean limestone, which adequately met AREMA No. 24 gradation requirements. The fully degraded ballast sample resulted in a Fouling Index of 40. The Fouling Index (FI) is defined *as* the summation of the percent by weight of ballast sample passing the No. 4 sieve plus the percent passing the No. 200 sieve [1]. Further details on generating degraded ballast samples through LA abrasion tests have been provided elsewhere [8]. The gradations of the degraded ballast specimens and the gradation of the new ballast before LA abrasion test are shown in Figure 1.

Qian et al. [8] has investigated particle contact and particle packing characteristics before and after degradation. Approximately 10 kilograms of ballast materials obtained from before and after conditions of the 1,500 turns in LA abrasion drum were poured into an acrylic chamber with dimensions of 25.4 cm (10.0 in.) in diameter and 25.4 cm (10.0 in.) in height. Figure 2 presents the side and top views of aggregate packing photos taken before and after degradation. It is clearly seen that after 1,500 turns, the same weight (ten kilograms) of degraded ballast occupied less volume as compared to the new ballast in the same acrylic chamber. Basically, 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.

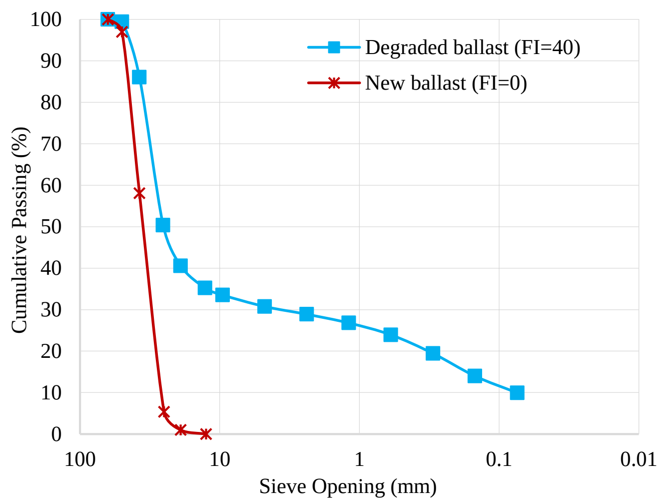
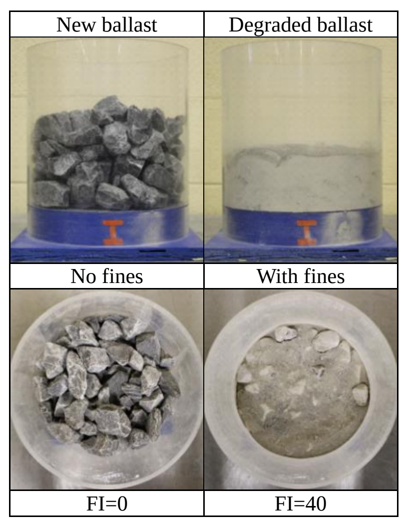


Figure 1. Ballast gradations before and after LA abrasion tests



Fines: Passing 9.5-mm or 3/8-in. size

Figure 2. Photos of side and top views of aggregate packing

New clean ballast sample had all particles above 9.5 mm in size and the specimens used in triaxial tests had void ratios of 0.68. Hence, the new ballast is a free draining material and will not retain moisture within the aggregate skeleton both in laboratory and field applications. The fines, referred to herein as smaller than 9.5 mm, can fill the voids (see Figure 2) created by larger particles and have the ability to absorb moisture and prevent ballast drainage. Accordingly, it is meaningful to study the material properties of fines (smaller than 9.5 mm or 3/8 in. size) first. Standard Proctor compaction and unsoaked California Bearing Ratio (CBR) tests were performed on fines.

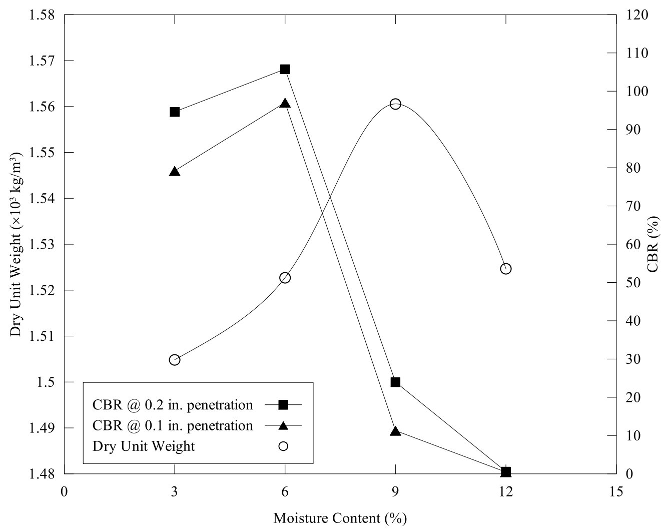


Figure 3. Moisture-density vs CBR of fines

Figure 3 gives both the compaction curve and the unsoaked CBR test results of the minus 9.5 mm or 3/8 in. fines. Basically, the fines were mixed with water for the target moisture contents of 3%, 6%, 9%, and 12%. The maximum dry density was achieved at an optimal moisture content (OMC) of 9% (see Figure 3). The CBR value first increased when moisture content increased from 3% to 6% but dramatically dropped when reaching the OMC of 9% and approached zero at 12%, meaning the material was saturated and could not sustain much load. When such moisture is trapped within fouled ballast, ballast particles may completely move and reorient themselves to drastically impact ballast layer stability. Other details regarding tests performed on fines can be found elsewhere [9].

Triaxial Shear Strength Testing

A large scale triaxial test device has recently been developed at the University of Illinois for testing specifically ballast size aggregate materials (see Figure 4). An internal load cell (Honeywell Model 3174) with a capacity of 89 kN (20 kips) is placed on top of the specimen top platen. Other details about the large-scale triaxial test device were provided elsewhere [10].

It is very challenging to prepare test specimens of degraded ballast with moisture in a heavily fouling condition (in this case, the FI is 40). It requires a large-scale mixer which can hold more than 94 kg of degraded ballast if all the dry materials are mixed together with water. However, such a large-scale mixer was not available in the laboratory. Thus, an alternative approach was taken in this study. Because it is the fines that will absorb the moisture, an appropriate amount of fines (according to the gradation of degraded ballast, see Figure 1) was sieved, weighed, and mixed with water in a rotational mixer. The fines were blended with water to achieve target moisture contents of 3%, 6%, 9%, and 12%. After the fines and water were mixed thoroughly, the mixture was poured into dry aggregates (larger than 9.5 mm or 3/8 in. size) of the degraded ballast. In other words, coarse fraction of degraded ballast was placed on a tarp and mixed quickly with wet fines using shovels until all the materials were mixed thoroughly. The mixed fouled ballast was then divided into four piles as previously with preparing degraded ballast in dry condition, and each pile was used to construct one lift of the specimen [2]. For comparison purposes, new ballast and degraded ballast were also tested with 0% moisture content. The details of the triaxial test dry specimen are summarized in Table 2.

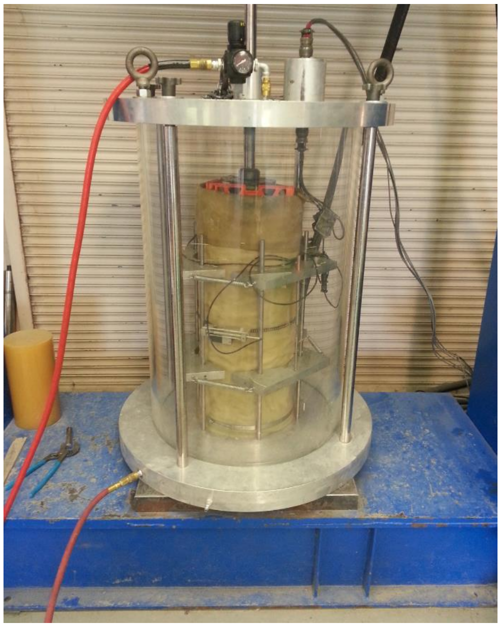


Figure 4. University of Illinois Ballast Triaxial Tester [2]

Table 2. Triaxial test dry specimen details

	New ballast	Degraded ballast
Specimen height	610 mm	610 mm
Specimen diameter	305 mm	305 mm
Specimen weight	68 kg	94 kg
Compaction time	16 seconds	16 seconds
Void ratio	0.68	0.25

*fines refer to particle sizes passing 3/8-in. sieve

The monotonic loading triaxial shear strength tests were conducted at a confining pressure of 68.9 kPa (10 psi) in displacement control mode at the shearing rate for the slow conventional strength testing, which was 1% strain per minute corresponding to 0.1016 mm/s.

TEST RESULTS

Figure 5 presents the triaxial shear strength test results of the degraded ballast at 3%, 6%, and 9% target moisture contents of fines (smaller than 9.5 mm or 3/8-in.). Figure 5 also shows the test results with the new ballast in dry condition and the degraded ballast with fines in dry condition, which is denoted as 0% moisture of fines. The peak deviator stresses of all wet specimens were significantly lower than the deviator stress of the specimen in dry condition. The peak deviator stresses for the specimens with 3%, 6%, and 9% moisture contents of fines were 211 kPa, 252 kPa, and 186 kPa, respectively, while the peak deviator stress for the specimen in dry condition (0% moisture content of fines) was 410 kPa.

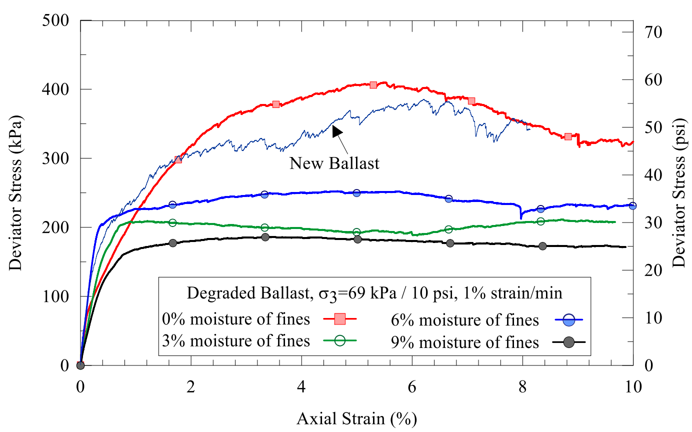


Figure 5. Triaxial shear strength test results

Figure 5 highlights the specimen with 6% moisture of fines as the strongest one and the specimen with 9% moisture of fines as the weakest one among the three wet specimens. The stress-strain curves of the wet specimens in Figure 5 generally had the same pattern; peak deviator stress is quickly achieved within a relatively small strain range followed by a little change in strain levels up to 10%. Such stress-strain trends of the wet specimens were quite different than those of the specimens in dry condition [7].

CONCLUDING REMARKS

This experimental study investigated the moisture effects on degraded ballast shear strength behavior from large-scale triaxial tests. Los Angeles abrasion tests were performed to generate heavily fouled/degraded ballast materials. Large-scale triaxial tests were then conducted on specimens of new ballast and degraded ballast. The following conclusions can be drawn from the study findings:

- Ballast degradation generates fine materials (particles smaller than 9.5 mm or 3/8 in. in size) and moisture can be absorbed/trapped by these fines.
- Moisture can cause significant changes in the degraded ballast shear strength behavior.
- From the monotonic compression tests conducted in this study, adding even 3% moisture (by weight of minus 3/8 in. size or smaller than 9.5 mm) to ballast strength test specimens caused approximately 50% decrease in shear strength of the dry fouled ballast.
- Wet fouled ballast samples reached the significantly lower maximum deviator stress values rather quickly at a relatively small axial strain level and remained at the same level as the axial strain was increased.

ACKNOWLEDGMENTS

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