Shear and degradation behavior of rail track ballast contaminated with fines: An experimental study

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ABSTRACT: Rail transport is one of the highly demanded transport modes due to its safety, reliability and economic profits. The ballast layer, major component by weight and volume, effectively transmits the train exerted loads from sleepers to the underlying layer at a minimal level. Ballast is degraded over time because of repetitive train loads. Ballast fouling is one of the major factors that affect the load-bearing capacity of the ballast layer as well as deters the permeability. This experimental based research primarily analyzes the changes in shear and degradation behavior of rail track ballast after fouling by other foreign material. The outcomes of the laboratory tests clearly indicate that fouling by sand increases the overall density of the sample, therefore, increases the shear strength and clay fouling acts as a lubricant thus reduces the shear strength. Ballast breakage under static loading increases with the increment in vertical load and decreases with fouling agents.

1 INTRODUCTION

Currently, ballasted rail tracks and slab tracks are widely used in many countries all over the world. The ballast layer is used to transmit the loads from sleepers to the underlying layers in ballasted tracks in contrast concrete slab is used under the sleepers in slab tracks. Because of the availability of low-cost raw material of ballast, simplicity of construction and low initial construction expenditure, the ballasted tracks are the most popular compared to slab tracks (Al-Douri et al., 2016). Ballast is a highly angular granular material with high load-bearing capacity sourced from granite, quartzite, limestone, basalt, dolomite and other crushed stones, and provides highly porous medium (Chan and Johan, 2016, Navaratnarajah, 2017, Tennakoon et al., 2012). Ballast has high shear strength, high specific gravity, resistance to weathering, high toughness and hardness (Indraratna et al., 2009). Ballast gradation is the major factor that affects the stability and drainage of tracks. Various gradations of ballast are adapted in different countries based on the shear strength and permeability requirements.

The performance of ballast decreases with time due to lack of lateral confinement, ballast breakage, and ballast fouling. Ballast fouling is a phenomenon where the voids in the ballast layer are partially or fully filled with foreign materials such as sand, coal, silt, dust, clay and by its own degradation (Anbazhagan et al., 2012, Esmaeili et al., 2014). The quantification of ballast fouling is hard due to the huge variation in particle size and the specific gravity of the ballast and fouling agent. Ballast fouling reduces permeability, decreases the energy absorbing capacity and leads to vegetation growth, therefore affects the track function and longevity (Anbazhagan et al., 2012, Tennakoon et al., 2012).

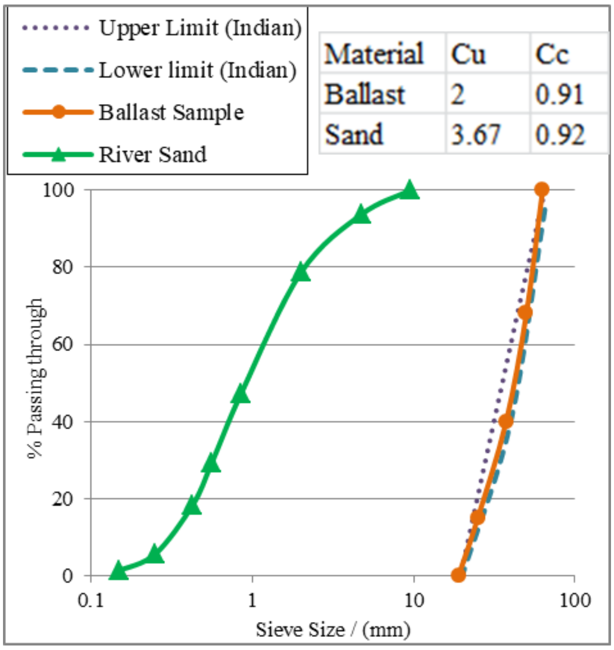
The major issues of track deterioration are differential settlements, cracks in sleepers, damages on railheads, misalignments of rails and imperfections in wheel and rail contact surfaces due to the repeated heavy load and high speed of moving trains and environmental conditions (Al-Douri et al., 2016, Ataei et al., 2014, Navaratnarajah et al., 2016). This leads to regular monitoring and high-cost maintenance activities such as ballast tamping and stone blowing (Chan and Johan, 2016, Navaratnarajah and Indraratna, 2020). The insertion of geosynthetics into ballast or sub-ballast layer or at ballast and sub-ballast interface and the insertion of resilient rubber mats under the sleepers or under the ballast layer, reduce the rate of deterioration (Askarinejad et al., 2018, Navaratnarajah et al., 2015, Navaratnarajah and Indraratna, 2017, Navaratnarajah et al., 2018, Nimbalkar and Indraratna, 2016).

This study analyzed the shear stress and breakage behavior of ballast with various fouling materials such as sand and clay with different percentages under three different static normal loads by performing large scale direct shear tests. The standard direct shear apparatus is not capable to conduct the tests with these larger ballast materials. Therefore a large-scale cylindrical direct shear apparatus was used for this study.

2 LABORATORY TESTS

2.1 *Material collection*

Materials used in this study are ballast and fouling materials such as river sand and clay. Ballast was collected from the Gampola stockpile, clay material was collected from Digana area and available river sand in Geotechnical laboratory was used. First, the ballast material was sieved using ISO 3310-1 standard sieve series and particles with various sizes were separated. Then, the ballast was washed with water and allowed to dry in order to remove any impurities like dust or other soil particles.



Material	Cu	Cc
Ballast	2	0.91
Sand	3.67	0.92

Fig. 1 Particle size distribution curve of the ballast sample and sand used in this study

The particle size distribution (PSD) is shown in Fig. 1, of the prepared ballast sample based on Indian standard which is adapted by Sri Lankan Railways. River sand was dried and sieved. Clay (LL = 37, PL = 23) was air-dried and pulverized to eliminate undesired particles.

2.2 *Large Scale Direct Shear Tests*

Large scale direct shear apparatus consists of two equal cylindrical halves with 400 mm diameter and 150 mm height each. The upper part is stationary and the lower part is movable with the application of shear load. A static load lever arm method is adapted to apply the normal load to the test material through a vertically movable top loading plate. The components of this test apparatus are illustrated in Fig. 2.

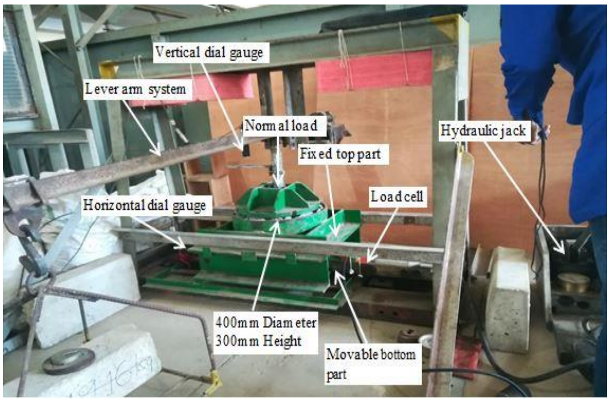


Fig. 2 Large scale direct shear test apparatus

The field unit weight of 16.1 kN/m^3 (Dissanayake et al., 2016) was maintained throughout the tests. The calculated amounts of ballast by sizes based on PSD were mixed properly before placing them into the apparatus. The ballast was placed into the apparatus in three layers, each layer was compacted using a rubber-padded hammer to attain field density. For sand fouled ballast, 10% and 15% fouling by ballast mass of sand were used. The sand was poured on top of the ballast sample and forced settled down into the voids of the ballast using a shutter vibrator.

(a) (b)

(c)

Fig. 3 Large scale direct shear test samples of (a) Fresh ballast; (b) Sand fouled ballast; (c) Clay fouled ballast

However, for clay fouled ballast 5% fouling by ballast mass of clay was coated to the ballast using the wet mixing method before placing it into the apparatus. This method incorporates with real situation where the clay fouling happens via mud pumping (intrusion of clay from subgrade) and surface runoff (in hill countries the clay particles are moved from mountains with rainwater runoff and deposited on top of the track foundation). After drying, the clay-coated ballast was placed into the apparatus in three layers. Fig. 3 shows the various test materials in the test apparatus, as explained above.

The large scale direct shear tests were conducted under various normal stresses such as 30, 60 and 90 kPa and a constant shearing rate of 4 mm/min. All tests were carried out up to a maximum of 15% shear strain (a horizontal displacement of 60 mm). Data logger was used in obtaining the readings of horizontal and vertical displacements and the shear load with the help of dial gauges and load cells, respectively.

3 RESULTS AND DISCUSSION

3.1 *Shear and dilation behavior of ballast with various normal loads*

Shear stress-strain variation of ballast is shown in Fig. 4. Shear stress of fresh ballast gradually increased with shear displacement and after reaching peak shear stress there was a marginal change in shear stress with horizontal displacement. There was an increase in shear stress with the normal load increment as predicted for ballast, and this increment was due to high frictional resistance attained by higher interlocking between angular particles. The shear stress variations of fouled ballast samples with shear strain as well as with various normal loads were followed the similar trend of fresh ballast. At lower normal loads like 30 and 60 kPa, the shear stress of fresh ballast is significantly higher than the fouled ballast. This was due to the lubricant behavior of fouled soil particles within the ballast void spaces. But in sand fouled ballast, the shear stress is larger than the fresh ballast at 90 kPa, because of the increase in friction resistance as a result of the rise in the overall density of the sample that restricts the independent movement of ballast particles and the buildup of contact at shear plane by the intrusion of sand particles. At 90 kPa, the lubricant behavior of clay was minimal compared with interparticle contacts. Therefore, there was a marginal reduction in shear stress of clay fouled ballast at 90 kPa than that of fresh ballast.

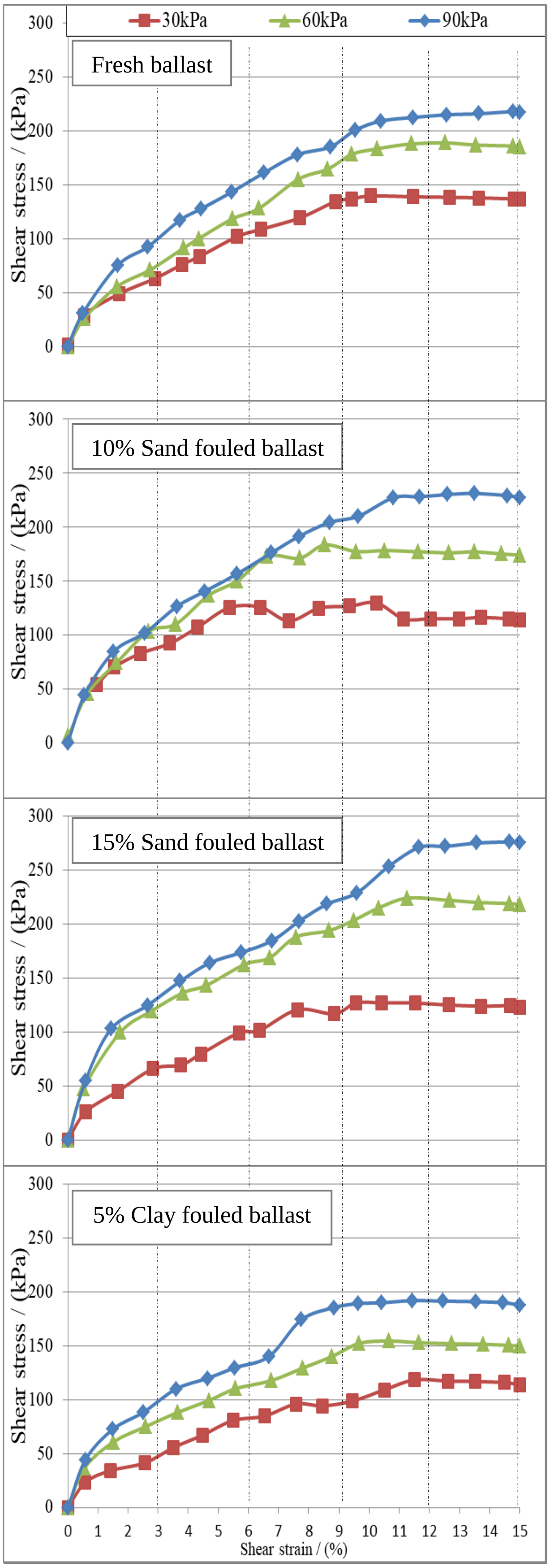


Fig. 4 Variation of shear stress with the shear strain of ballast

The peak shear stresses were obtained using shear stress vs shear strain curves. Fig. 5 exhibits the variation of peak shear stresses of fresh, 10 % sand fouled, 15 % sand fouled and 5 % clay fouled ballast samples under different normal stresses. As the cohesion of ballast is small, intercepts of trend lines were set to zero for the comparison of friction angle variation with fouling. It clearly indicates that the sand fouling increases the shear stress of ballast as the friction angle increased from 70° of fresh ballast to 71° and 73° of 10% and 15% sand fouled ballast, respectively. There is a reduction in friction angle from 70° of fresh ballast to 67° of 5% clay fouled ballast.

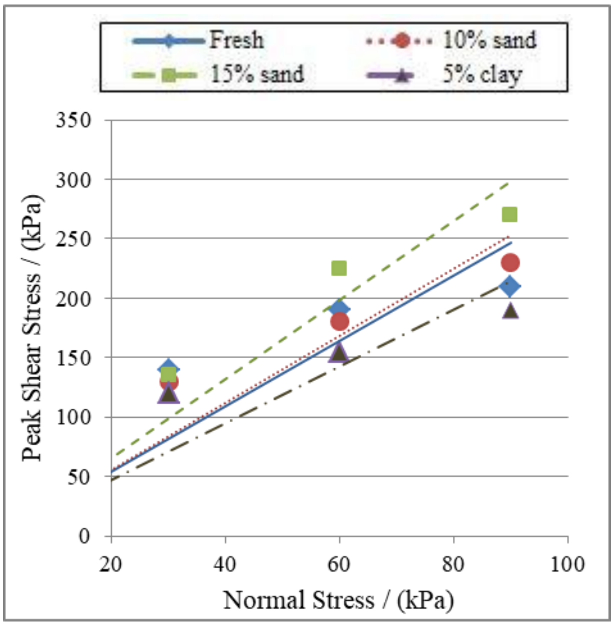


Fig. 5 Peak shear stress variation of fresh and fouled ballasts with various normal loads

Dilation of ballast particles is followed with initial compression for higher normal loads. With the continuous application of shearing, the granular ballast particles started to roll over the other ballast particles and dilated. Dilation was reduced with higher normal loads as well as with fouling. But a clear trend was not obtained from this test results.

3.2 *Degradation behavior of ballast with fouling and various normal loads*

The calculation method of Ballast Breakage Index (BBI) was proposed by Indraratna et al. (2005) and it uses the area of shifting in PSDs of each sample before and after testing with respect to an arbitrary boundary of maximum breakage as illustrated in Fig. 6.

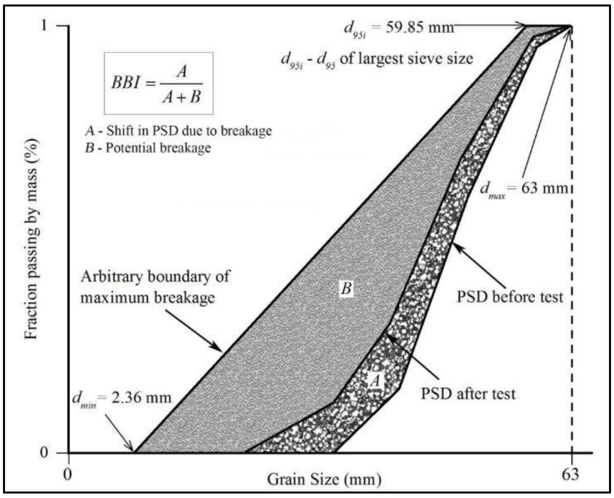


Fig. 6 Ballast Breakage Index (BBI) calculation method (Adopted from Navaratnarajah (2017))

BBIs of fresh and fouled ballasts with under different normal loadings is shown in Fig. 7. The BBI of ballast increased with the rise in normal stress, due to the compression of ballast that leads to high breakage at higher normal stresses. When the ballast is fouled with sand and clay materials, the BBI was reduced. This is because of the densification of the sample by sand intrusion and reduction in frictional resistance by clay intrusion. Moreover, the ballast breakage reduction is also resulted from the higher number of contacts in the fouled ballast compared to fresh ballast due to the accumulation of fines inside the voids in the ballast layer where fines partly transferred the contact forces (Ngo et al., 2014).

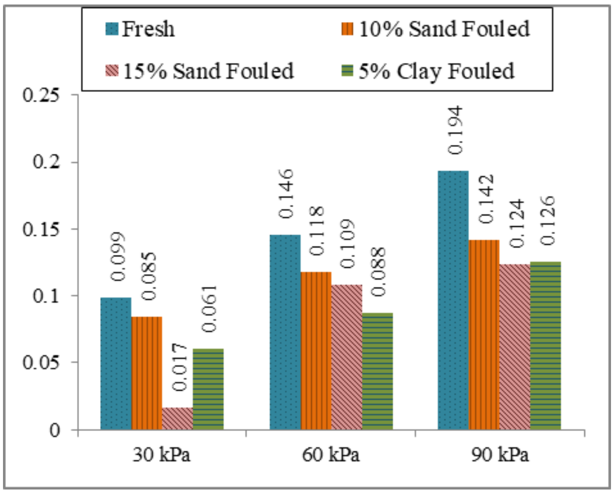


Fig. 7 Ballast breakage index with various normal loads of fresh and fouled ballast

4 CONCLUSIONS

Tests on fresh and fouled ballast under static loads clearly demonstrated that applied normal loads, fouling material and fouling percentage have impacts on shear stress, dilation and breakage behavior of ballast. Shear stress increases with the increase in applied normal stresses. Shear stress of sand fouled ballast is higher than the fresh ballast due to the higher frictional resistance. Clay coated ballast particles slide over the other particles thus reduction in surface friction as well as a decline in shear stress than that of fresh ballast. Ballast breakage increased with normal loads and decreased with fouling agents.

Drainage property of ballast was not studied in this research. Permeability of the ballast layer has an influence on track longevity. Therefore, it is mandatory to study the variation in drainage pattern of ballast after fouling, despite the merits such as improvement in shear stress and decline in ballast breakage. As ballast is a coarse granular material, it does not show the same behavior under static and dynamic loading conditions. This research only considered the static loading condition.

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