Shear Strength Characteristics of Ballast Subjected to Particle Breakage and Mud Pumping using Parallel Gradation Technique

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Abstract: Ballasted rail tracks are most commonly used in rail track structure and are designed to provide a stable, safe and economic foundation. Main components of ballasted rail track structure can be grouped as track superstructure and track substructure. The cyclic loading by the train will be distributed from the superstructure to substructure. Sri Lanka currently uses the Indian standard gradation for almost all the tracks. Most of the ballast material used in Sri Lanka is obtained from biotite gneiss rock which is available in abundance. However, ballast is constantly subjected to degradation throughout its service due mainly to ballast breakage and migration of fine particles from the subgrade into the ballast layer, which is known as mud pumping. In this study, the effect of ballast particle breakage and mud pumping on the shear strength characteristics of ballast is investigated. Parallel gradation technique was used to model the sample as it is difficult to handle large size ballast in the conventional direct shear box. Sample was collected from Elugoda quarry (in the Kandy District) from where the ballast material is supplied to upcountry railway construction. Scaled down sample was sieved and test sample was prepared according to Indian standard gradations using the parallel gradation technique and the direct shear test was carried out under three normal pressures of 15 kPa, 30 kPa and 90 kPa. The study revealed that the shear strength of ballast is decreased for lower degrees of fouling due to ballast breakage and mud pumping and starts to increase with increased degree of fouling, but not as much as that of fresh ballast.

Key words: Ballast, Shear strength, Particle breakage, Mud pumping

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1. Introduction

Railway transportation plays an important role in the mass transportation sector of a country and contributes to sustaining a dynamic economy. Efficiency and safety of the rail transportation is relied upon the quality of rail track structure. Ballasted rail tracks are most commonly used in rail track structure and are designed to provide a stable, safe and economic foundation. Main components of ballasted rail track structure can be grouped as track superstructure and track substructure (Rahman, 2013). Superstructure consists of fasteners, sleepers, and substructure consists of ballast, subballast and subgrade. The cyclic loading by the travelling train will be distributed from the superstructure to the substructure. Main functions of ballast are to resist vertical, lateral and longitudinal forces, provide resiliency and energy absorption, provide immediate drainage, maintain the stability and reduce the pressure from sleeper bearing area to an acceptable stress level distributed to the underlying material (Waters, 1994). Ballast performance depends on four major geotechnical properties (index and engineering) of ballast material: (i) characteristics of its constituent particles (size, shape, surface roughness, particle crushing strength and resistance of attrition etc.), (ii) Bulk properties of the granular assembly (particle size distribution, void ratio or density and degree of saturation),(iii) Loading characteristics (current state of stress, previous stress history and applied stress path), (iv) particle degradation (combined effect of grain properties, aggregate characteristics and loading) (Anbazhahan, 2013). Ballast Gradation is a primary factor affecting the stability safety and drainage of tracks (Anbazhahan, 2013). Gradation standards used in various part of the world include European standard, Australian standard, British standard, French standard, Indian standard (Alemu, 2011). In Sri Lanka, there are no standard gradations of its own. However, Sri Lanka currently uses the Indian standard. Compared to other gradations, Indian standard fulfill the drainage criteria and has the highest performance in load bearing characteristics and stability (Pakalavan et al, 2015).

Ballast fouling is highly related to the ballast and its properties. Ballast fouling can be due to contamination or the filling of voids as a result of ballast breakdown and infiltration of foreign materials through the ballast surface or from the base of the ballast layer. It will change the ballast gradation and lead to loss of performance (Anbazhahan, 2013). Some possible factors for ballast fouling are repeated loading, presence of fine material, presence of water, aggregate breakage, infiltration from sub-ballast, infiltration from ballast surface, sub-grade intrusion, wearing, coal dust, mud, mineral fillers and growth of vegetation etc. (John M. Waters 1994; Rahman 2013; Alemu 2011). According to Rahman (2013), coal and clay showed a significant decrease in strength of ballast. Since coal is not a transport commodity in rail transport in Sri Lanka, its affect can be neglected. In addition, it was shown that aggregate breakage has a major contribution in fouling (Alemu 2011). In this research, the effect of particle breakage of ballast and mud pumping on shear strength characteristics is investigated.

2. Literature Review

Several rock types such as limestone, basalt, and slag are used for ballast. In Sri Lanka biotite gneiss type of ballast is currently used. According to Waters (1994), a good ballast material should be angular, crushed, hard, uniformly graded, free of dust and dirt, and not prone to cementing action. Kaya's study (2004) presented the method of selecting ballast based on physical testing of representative specimens to ensure that materials are of the suitable rock type, with no inherent planes of weakness such as foliation and cleavage (Petrographic Analysis), grain shape and size distribution, adequate wearing resistance (Los angle Abrasion), and weathering resistance (Freeze-Thaw, Wetting and Drying, and Absorption) tests.

There are standard lower and upper bound gradation curves for ballast which are adopted by different countries for their ballast material. It is a primary factor affecting the stability, safety and drainage of tracks (Anbazhahan, 2013). In Sri Lanka, Indian standard is used which shows considerably higher strength than other standard gradations for the ballast material used in Sri Lanka.

Since the size of the ballast is large, it is not possible to conduct direct shear tests for the ballast using the conventional direct shear apparatus without scaling down size of the particles. Method of scaling down the size of particles was presented by Lowe (1964) as the framework for the parallel gradation modelling technique. The only difference between prototype and model sample is the difference in size of particles. The model sample should closely duplicate the behavior of the larger prototype. As a result of using this technique, there will be a small decrease in shear strength, but it has no significance for the comparison of shear behavior of standard gradations.

To study the effect of mud pumping and particle several tests were done. The first investigation on the influence of varying concentrations of rock particles on the shear strength of cohesive soil rock mixtures was investigated by Miller and Sowers (1951). Raymond and Diyaljee (1979) conducted a study on the fractural crushing of granular material, in which they stated that the particle degradation occurred in three ways that are angular projection breakage (major breakage), breakage of particles into equals parts, grinding off small scale asperities. As ballast consists of angular particles major breakage derives from corner degradation and attrition. According to McDowell et.al. (1996), the probability of particle breakage increases with applied macroscopic stress, particle size, reduction in the coordination number (number of contacts with neighbouring particles) and on the shape of the particles.

3. Materials and Methods

Ballast samples (specific gravity = 2.6259) were obtained from a quarry in Elugoda (Kandy District, Sri Lanka) which supplies ballast for the Sri Lanka Railways. However, determination of shear strength characteristics in a laboratory scale using the conventional direct shear test apparatus requires particles to be of a smaller scale. Therefore, sampling of ballast was based on the parallel gradation technique in which a predetermined reduction factor is applied on the particle size to generate a scaled down gradation curve which can be used for testing. The ballast sample for this study was prepared to conform with the upper bound of the Indian Standard gradation which defines the worst initial particle size distribution that can be selected for ballast.

Particle breakage index **(Bg)** defined based on the method introduced by Marsal (1967) which is the sum of the difference in percentage retained on sieves, having the same sign before and after particle breakage was used to characterise the particle breakage.

The particle breakage was induced on the initial ballast sample by subjecting a ballast sample to a predetermined number of revolutions in a Los Angeles Abrasion Value testing machine. In this process, no charges were used to prevent ballast particles from crushing in the rotating drum. The relationship of ballast breakage index as defined by Marsal (1967) and the number of revolutions of the drum is shown in Figure 1.

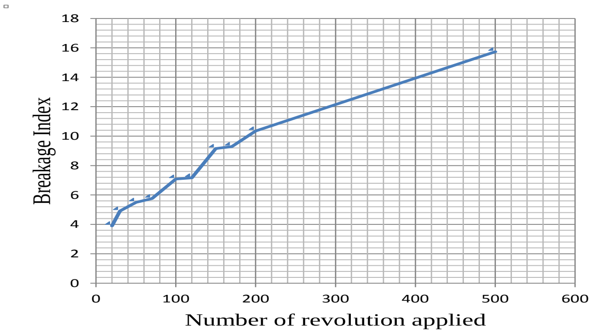

Figure 1. Variation of induced ballast breakage and number of revolution of drum

Particle size distribution curves obtained from the sieve analysis of ballast subjected to increasing number of revolutions in the LAAV testing machine drum is given in Figure 2. Ballast samples degraded to correspond with breakage indices of 10.35 and 15.73 were selected in this study. A portion of the broken sample representing ballast with the desired ballast breakage index was selected for the experiments.

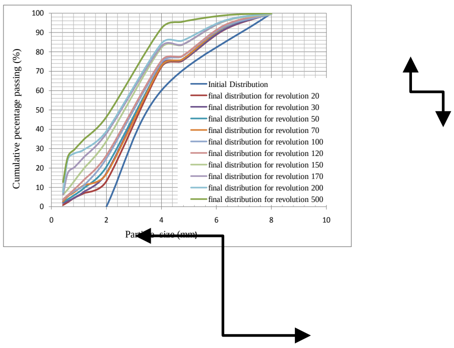

Figure 2. The variation of particle size distribution of ballast with number of revolutions

Ballast specimens for direct shear testing were prepared using the parallel gradation technique with a reduction factor of ten on the upper bound curve of the Indian standard gradation. Direct shear tests were carried out (BS 1377, Part 7, 1990) by compacting the samples to a dry density of 1.82 g/cm^3 in the 100 mm diameter, 42 mm high direct shear mould and shearing at a rate of 0.15 mm/min under normal pressures of 15 kPa, 30 kPa and 90 kPa.

The investigation of the effect of mud pumping on the shear strength characteristics of ballast was carried out using the fine fraction of the pumped out mud samples taken at places along the side of the rail track along Peradeniya-Gampola rail track near Peradeniya railway station. The particle size distributions of three such samples obtained using hydrometer analysis are given in Figure 3. The mud sample for mixing with ballast was prepared by mixing equal weight of all the mud samples together. The degree of mud pumping was defined based on the extent of voids in the ballast sample occupied by mud. Therefore, the maximum value of mud pumping is limited by the void ratio of the uncontaminated sample. For this study, 5%, 10% and 15% mud pumping ratios were selected.

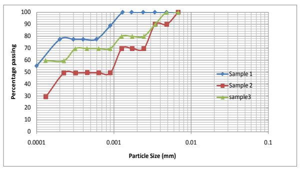

Figure 3. Particle size distribution of mud samples

4. Results and Discussion

The peak shear strength of ballast subjected to a breakage index of 10.53 is lower than that of fresh ballast (Figure 4). This reduction of peak shear stress is attributed to the reduction of interlocking due to breakage of ballast at lower values of ballast breakage index. However, at a higher breakage index of 15.73, higher shear strength than that corresponding to a breakage index of 10.53 is shown. This increase is attributed to the filling up of voids of the ballast sample with finer ballast particles to represent a more or less a well graded assemblage compared to that at lower indices of ballast breakage, thereby exhibiting higher shear strength.

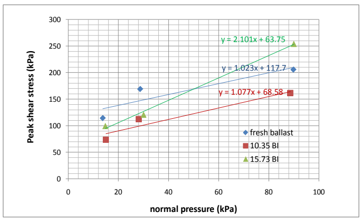

Figure 4. Peak shear stress Vs Normal pressure for ballast fouled by breakage

Based on the above direct shear tests variation of peak friction angle and the cohesion were computed for each breakage index.

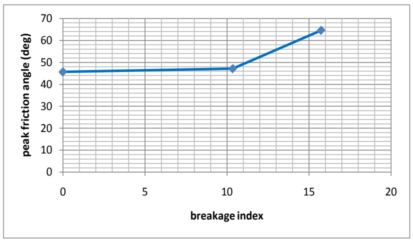

Figure 5. Variation of peak friction angle with breakage index

The breakage index has not affected the peak friction angle significantly until the breakage index is high. The increase in the peak friction angle can be attributed to filling of voids by the broken ballast which will increase the coordination number that would bring the particle assemblage into a more well graded distribution. The initially high cohesion of the fresh ballast sample is due to the assumption of the applicability of linear Mohr-Coulomb relationship for ballast at low normal pressures, which however is non-linear due to aggregate interlocking and dilation during shearing (Indraratne et.al, 1998). This high apparent initial cohesion vanishes with ballast degradation due to smoothening of ballast surface.

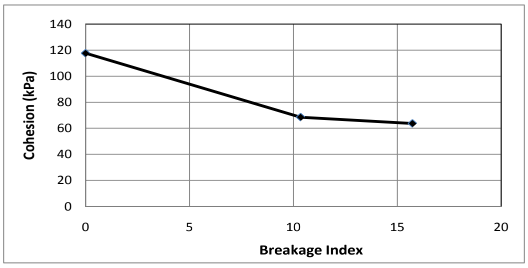

Figure 6. Variation of cohesion with breakage index

As a result of mud pumping, a significant reduction of peak shear stress can be observed (Figure 7). This is attributed to mud acting as a lubricant reducing the peak shear stress. The increased lubrication due to increased mud percentage appears to have facilitated the rearrangement of ballast particles during shearing to obtain a high friction angle (Figure 8). The increase in percentage mud fouling also causes the reduction of apparent initial high cohesion (Figure 9) due to the effects of lubrication as described earlier.

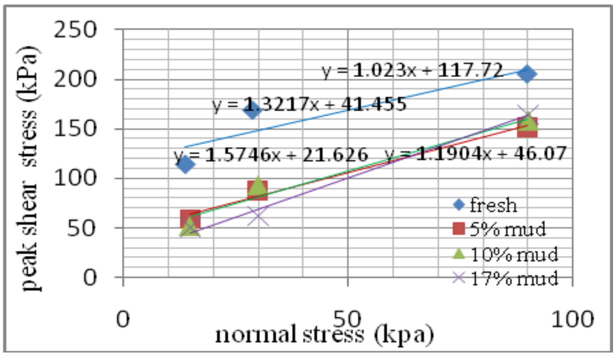

Figure 7. Peak shear stress vs. Normal pressure for ballast fouled by mud pumping on fresh ballast

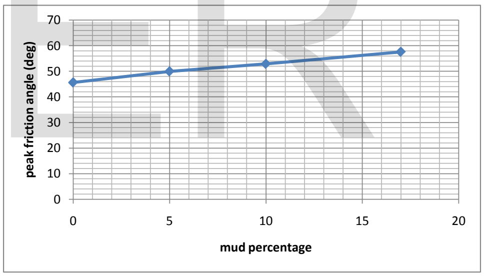

Figure 8. Variation of peak friction angle with mud percentage on fresh ballast

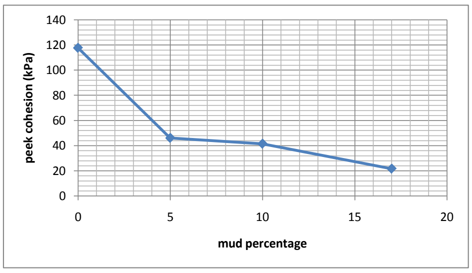

Figure 9. Variation of cohesion with mud percentage on fresh ballast

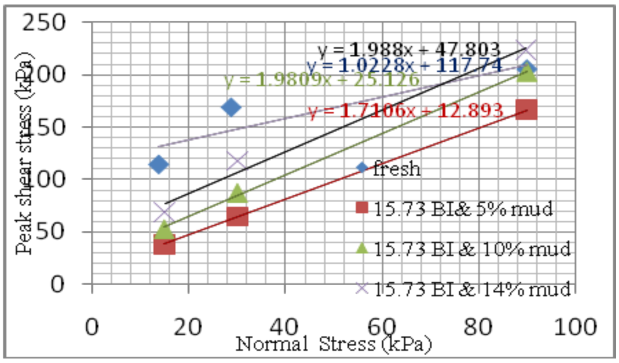

Figure 10 Peak shear stress vs. normal pressure for ballast fouled by breakage and mud pumping

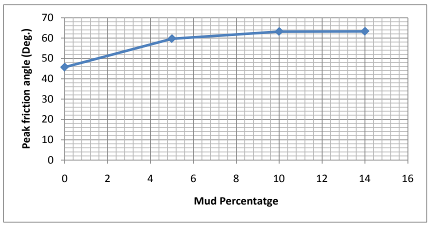

Figure 11 Variation of peak friction angle with mud percentage on ballast fouled by ballast breakage index of 15.73%

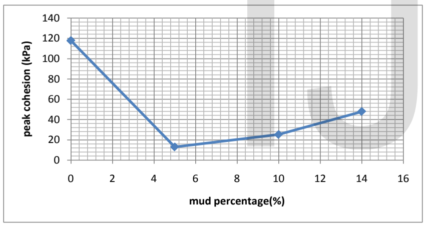

Figure 12 Variation of cohesion with mud percentage on ballast fouled by ballast breakage index of 15.73%

The combined effect of ballast breakage and mud pumping is illustrated in Figure 10 in which the shear strength of fresh ballast is compared with that of ballast fouled by ballast breakage and mud fouling. It can be seen that the ballast having the maximum breakage index of 15.73 and mud pumping percentage of 17% exhibits an improved shear strength than that having lower degrees of fouling and mud pumping due to the combined effects of changing the ballast gradation to a more well graded assemblage and the contribution from cohesion of mud. This is apparent clearly in Figure 11 which shows the increase of friction angle due to improved interlocking of degraded ballast and, initial reduction of apparent cohesion due to lubrication effect and the subsequent increase due to contribution of mud as shown in Figure 12. However, even with these combined effects the shear strength of fouled ballast is lower than that corresponding to the fresh ballast.

5. Conclusions

1. As compared with the shear strength of fresh ballast, ballast fouled with mud shows lower shear strength irrespective of the degree of ballast breakage.
2. Initially, shear strength decreases with increasing mud percentage and for higher mud percentages it increases again.
3. As compared with the shear strength of fresh ballast, ballast degraded to a lesser degree by particle breakage causes the shear strength to decrease. However, ballast with a greater degree of particle breakage shows an increased shear strength though not as much as that of fresh ballast.
4. Influence of mud pumping on the peak shear strength is much significant than that due to particle breakage.
5. Combined effects of greater degrees of particle breakage and mud pumping causes the shear strength to increase from an initially reduced strength under lesser degree of fouling, though not as much as that of fresh ballast.

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