Effect of Rail Track Ballast Degradation on Shear Strength

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ABSTRACT: Ballast is the selected, crushed, granular material placed as the top layer of the substructure of a rail track in which the sleepers are embedded. The mechanical properties of ballast layer result from a combination of the physical properties of individual ballast material and its in-place physical state. The ballast particle size distribution is continuously changed due to the progressive degradation and contamination from external fouling agents at service. It has been accepted that ballast breakdown is the major source of fouling compared to the other sources of fouling such as subgrade migration or external agents. This paper presents the findings of an investigation conducted to study the effect of ballast fouling by particle degradation on the shear behavior of rail track ballast. A total of twelve direct shear tests were conducted on modeled ballast samples with relative ballast fouling ratio varying from 0% to 92% under 15 kPa, 30 kPa and 90 kPa normal stresses. Results indicated that for moderately fouled ballast, the particle degradation increased the peak shear strength. Further, it was revealed that the influence of fouling due to ballast degradation on the peak friction angle is minimal.

1 INTRODUCTION

Ballast is the selected crushed granular material placed as the top layer of the substructure of a rail track in which the sleepers are embedded. Traditionally, ballast is uniformly graded, angular, crushed good quality rocks or stones free of dust and dirt with minimal cementing action when wet. This granular layer has been relied upon its ability in providing optimum resiliency, effective transmitting of wheel loads to the subgrade after reducing to a permissible level, preventing excessive settlement and lateral dispersion upon repeated loading from moving trains. Under loading, the lateral spreading of ballast material is restrained by the presence of shoulder ballast and interlocking action of ballast particles. These mechanical properties of the ballast layer are derived from a combination of the physical properties of individual ballast material and its in-place physical state (Selig & Waters, 1994).

Ballast generally consists of medium size to coarse gravel sized particles with a small percentage of cobble sized particles. In service, the ballast gradation is continuously changed due to the combination of progressive degradation of ballast particles and contamination from external fouling agents.

The particles finer than the smallest size of the ballast used for the rail track construction is considered as the “fines” or “fouling material”. That clearly represents the fouling material and therefore, the degree of fouling or contamination could be quantitatively represented by the percent by weight of fouling particles. Fouling material could be identified as fines generated from breakage of ballast particles, material migrated from underlying subgrade or capping layer, material produced by sleeper wearing and foreign material from wagon spillage. It was thought to be the track subgrade was the major source of fouling by the phenomenon called “mud pumping”. Mud pumping is the process in which fines from the subgrade migrate in to the ballast bed and cause ballast contamination. However, studies have indicated that mud pumping is a minor source of fouling and fouling due to ballast breakdown is the major source of fouling as shown by Selig and Waters, 1994 (Fig.1).

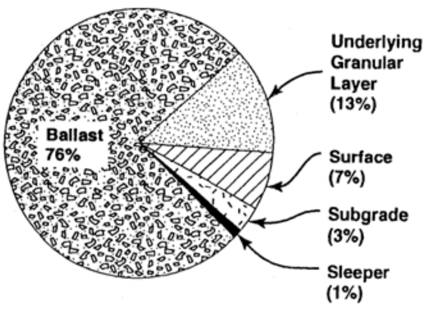

Fig. 1 Source of ballast fouling for a general rail track (Selig & Waters, 1994)

The effect due to fouling depends on the amount and characteristics of the fouling material. In this regard, Dombrow et al., (2009) and

Tennakoon et al., (2012) conducted direct shear tests on ballast contaminated by coal dust and stated that the shear strength tends to be decreased with increased level of coal dust fouling and increased dilation leading to additional settlement of track. Selig and Waters (1994) stated that sand and fine gravel sized fouling particles increased the shear strength and stiffness of ballast. They also noted that the tracks with high fouling percentages resulted in an increased the settlement of ballast.

Ballast particle degradation could be caused by either due to traffic loading or tamping during maintenance. During any of these processes, ballast particle undergo crushing, breaking or grinding off sharp edges thus altering the original particle size distribution and transforming the ballast shape to comparatively rounded particles. This would therefore, reduce the inter particle interlocking.

There are several methods proposed to quantify the degree of fouling based on mass of fouling material and percentage void contamination. Selig and Waters (1994) proposed that the fouling material could be considered as the material passing 9.5 mm sieve and "Percentage of fouling" may be expressed as the ratio of dry weight of fouling material passing to the dry weight of total sample. Fouling Index (FI) is defined as the sum of the percentage (by weight) of fouled ballast passing 4.75 mm (No. 4) sieve and 0.075 mm (No. 200) sieve (Selig and Waters, 1994). Indraratna et al. (2011) proposed "Relative ballast fouling ratio" ($R_{b\text{-}f}$) which is defined as the ratio of the dry weight of fouling particles (passing 9.5 mm sieve) to the dry weight of ballast particle retaining on 9.5 mm sieve and is expressed as,

$$R_{b-f} = \frac{M_f \times \frac{G_{s-b}}{G_{s-f}}}{M_b} \times 100\% \qquad (1)$$

where, M_f and $G_{s\text{-}f}$ are the mass and the specific gravity of fouling material (fines), M_b and $G_{s\text{-}b}$ are the mass and specific gravity of ballast.

Anbazhagan et al (2012) suggested that for Indian ballast gradation; fouling index (FI) may be calculated using the following expression,

$$FI_{IN} = P_{0.075} + P_{20} \qquad (2)$$

where, $P_{0.075}$ and P_{20} are percent by weight of material passing 0.075 mm sieve and 20 mm sieve respectively.

Further, they suggested that "Percentage of Fouling" for Indian ballast could be estimated by taking the ratio of dry weight of material passing 20 mm sieve to the dry weight of total sample and any material passing 20mm sieve could be treated as fines.

This paper investigates the effect of particle degradation on the shear behavior of Sri Lankan rail track ballast through a series of direct shear tests conducted on modeled ballast samples at laboratory conditions. The fouling was quantified using "Relative ballast fouling ratio" (Indraratna et al, 2011) and the fouling material was considered as particles passing 20 mm sieve.

2 MATERIAL AND METHOD

Fresh biotite gneiss ballast samples for the study were obtained from a quarry near Peradeniya, (Elugoda, Peradeniya, Sri Lanka) which supplies ballast to the Sri Lanka Railways, in order to maintain the material properties consistent with actual ballast at field. The physical characteristics of ballast are given in Table 1.

Table 1. Physical properties of ballast

Property	Test value
Aggregate Crushing Value	28.5%
Aggregate Impact Value	35%
Water Absorption	0.194%
Specific Gravity	2.68

In order to conduct the experiments using the 100 mm diameter direct shear test box available in the laboratory, ballast gradations were modeled using the parallel gradation technique with a maximum size of 6.3 mm to avoid boundary effects. The parallel gradation technique was initially proposed to study dam materials and ever since successfully used to evaluate the strength of granular media such as road bed material and ballast materials (Soni and kumar, 2014).

The modeled fresh ballast sample was prepared parallel to the lower limit of the particle size distribution specified in the Indian specification (INS LB) for rail track ballast since it is the current standard in Sri Lanka.

The fouled ballast samples with 17%, 45% and 92% Relative ballast fouling ratios ($R_{b\text{-}f}$) were prepared from the modeled fresh ballast samples subjected to a repetitive compaction effort using standard proctor hammer. The particle size distribution curves of test sample are illustrated in Fig.2.

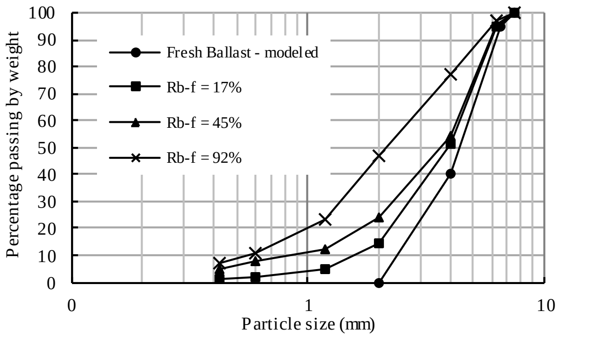

Fig.2 Particle size distributions of tested ballast samples.

The direct shear apparatus used in this study could accommodate a specimen of diameter 100 mm and height 40 mm; at the execution of the test it could shear the sample into two equal halves. Top loading plate was free to move vertically and the normal load was provided using automatic pneumatic loading system. Vertical movement of top plate was measured using attached displacement transducer to the center of loading plate and the shear displacement was measured by another horizontally aligned displacement transducer to a side of the lower part of shear device. The shear force was measured by a load cell attached to the bottom part of shear apparatus and the data were acquired by a data logger connected to a computer. Shear force was applied continuously by an electric motor at a displacement rate of 0.2 mm/min.

The test sample was compacted in three layers inside the shear box applying the same compacting effort to each layer by tamping. In this study, twelve tests were conducted on ballast with 0% (fresh), 17%, 45% and 92% relative ballast fouling ratios representing clean, moderately fouled, fouled and highly fouled ballast. The initial average unit weights of samples were 16.14 kN/m^3 (R_{b-f} = 0%), 16.10 kN/m^3 (R_{b-f} = 17%), 16.17 kN/m^3 (R_{b-f} = 45%) and 16.19 kN/m^3 (R_{b-f} = 92%). Direct shear tests were conducted at three normal stresses of 15 kPa, 30 kPa and 90 kPa until samples achieve a 15 mm maximum shear displacement corresponding to 15% from the sample diameter.

3 RESULTS AND DISCUSSION

Fig.3 (a) and (b) show the shear stress and vertical displacement against shear displacement of clean and fouled ballast samples for the range of normal stresses.

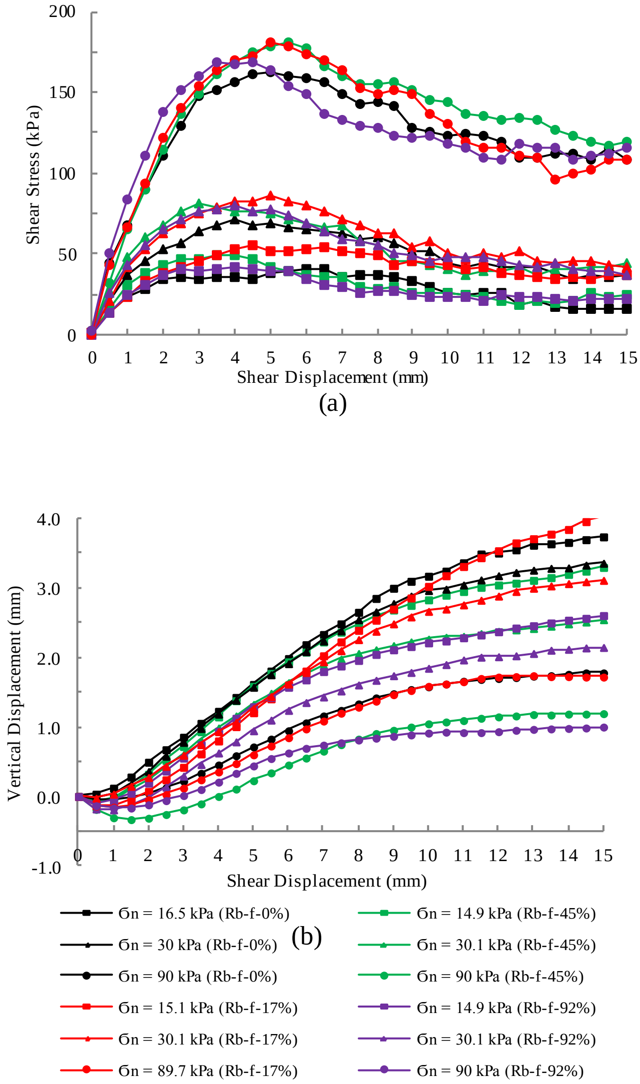

Fig.3 Direct shear test results of ballast with various degree of relative ballast fouling ratio

Results shows that peak shear strength of fresh ballast is low compared to fouled ballast at all normal stresses. Fouled ballast with 17% relative ballast fouling ratio has the highest shear strength followed by the ballast sample which has relative ballast fouling ratio 45% and relative ballast fouling ratio 92% consecutively. It is seen that at 17% R_{b-f}, the amount of finer particles effectively filled the voids in the aggregate skeleton and produce more inter-particle contacts and more interlocking action yielding higher shear strength. With the increase of finer particles at high relative ballast fouling ratios, the excess fine materials after filling the voids tend to separate larger ballast particles and act as bearings in between reducing the shear strength. This could be attributed to the gradual decrease of peak shear strength of ballast samples with the increase of R_{b-f}. Since fouled ballast is broadly graded than fresh ballast, it still could produce high shear strength than fresh ballast due to higher inter locking and friction.

Results of vertical displacement versus shear displacement show that all ballast samples experienced initial compaction followed by dilation exhibiting strain softening behavior. Uniformly graded, relatively larger particles of fresh ballast sample could not accommodate the voids in the aggregate skeleton and thus produced low compaction and rolling over at further shearing produced high dilatation. At high fouling levels, smaller particle could fill the voids and produce high volume reduction and relatively low dilatation compared to fresh ballast.

With increased level of fouling the peak shear strength was reached at low shear strain and it is attributed to the grinding off and breakage of sharp edges of ballast particles making the grains more spherical due to increased number of repetitive load applied at sample preparation.

The resulting peak friction angle values for the tested samples were determined based on best fit linear Mohr – Coulomb (MC) approach, which is the current standard of practice and results are shown in Fig.4.

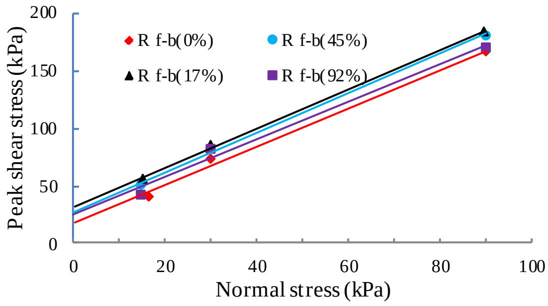

Fig. 4 Linear Mohr - Coulomb (MC) failure envelope for various relative ballast fouling ratio

According to Fig.4, at all levels of relative ballast fouling ratios the peak friction angle remains approximately equal. It should be noted that, this linear MC approach produce cohesion intercept which shall not be expected for cohesion less granular material as ballast. It is suggested that this inconsistency is attributed to the nonlinear behavior of granular material and particle breakage at shearing (FHWA-HRT-13-068, 2013) yielding an apparent cohesion intercept. For this study, the friction angle values obtained from linear MC approach vary from 59^{o} to 60^{o}.

4 CONCLUSIONS

The influence of ballast fouling due to particle degradation on the shear behavior of track ballast was investigated at laboratory conditions. The study was conducted using direct shear tests on various degree of fouled ballast due to particle breakage at three different normal stresses (15kPa, 30kPa, 90kPa). Total of twelve direct shear tests were conducted. Results showed that,

(a) It was observed increased of the peak shear strength of rail track ballast at moderate degree of fouling by particle breakage.

(b) The peak shear stress was attained at low shear strain at higher degree of fouling, indicating the change of particle shape from angular to more spherical.

(c) Observed peak friction angle for the tested material was between 59^{o} and 60^{o}. The influence of ballast fouling by aggregate degradation on the peak friction angle is minimal.

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