SECM/15/099

SHEAR STRENGTH CHARACTERISTICS OF DIFFERENT GRADATIONS OF BALLAST USING PARALLEL GRADATION TECHNIQUE

V.Pakalavan[1*], B.Nirvekala[1] and L.C.Kurukulasuriya[1]

[1]University of Peradeniya, Peradeniya, Sri Lanka
*E-Mail: pakalnivi@rocketmail.com, TP: +940755634148

Abstract: Ballasted rail tracks are most commonly used rail track structure and to be designed to provide a stable, safe and economical foundation. Main components of ballasted rail track structure could be subdivided as track superstructure and track substructure. The loading from the train will be distributed from the superstructure to substructure. The main structural component of substructure is considered as track ballast which is generally crushed hard stones. Railway authorities specify gradation specifications for selection of ballast for rail tracks. Sri Lanka railways also specified a gradation limits in the selection of ballast for rail tracks. Current standard is closely resembled to the Indian rail track ballast specifications. Commonly, the ballast used in Sri Lanka is crushed gneiss rocks which are in abundance. It is well understood that granular materials derive its strength by resistance to shearing. However, there is no examination conducted to evaluate the performance of rail track ballast used in Sri Lanka considering the shear behaviour. The objective of this preliminary study is to investigate the shear strength characteristics of ballast gradation used in Sri Lanka and compare with selected other ballast gradation specifications. Parallel gradation technique was used to model the sample as it is difficult to handle large size ballast in the conventional direct shear box. Direct shear tests were conducted under three normal pressures of 15 kPa, 45 kPa and 90 kPa on different ballast gradations including current Sri Lankan specification. The results showed that the Current Sri Lankan ballast gradation specification which is the same as Indian standard gradation has the highest shear strength compared to other ballast gradations tested.

Keywords: ballast, ballast gradations, shear strength, parallel gradation technique

1. Introduction

Railway transportation plays an important role in the mass transportation sector of a country and contributes in sustaining a healthy 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 structures and are designed to provide a stable, safe and economic foundation. Main components of ballasted rail track structure can be divided into track superstructure and track substructure [1]. Track superstructure consists of fasteners, sleepers and substructure consists of ballast, subballast and subgrade. The loads from trains will be distributed from the superstructure to the substructure. Main functions of ballast are to resist vertical, lateral and longitudinal forces, provide sufficient resiliency, energy absorption, facilitate drainage, reduce the pressure from sleeper to an acceptable stress and distributed to the subgrade [2]. Different countries use different ballast material depending on the availability. The ballast material should be angular, crushed, uniformly graded hard rocks free of dust or dirt and shall not prone to cementing action for better performance. In Sri Lanka gneiss rock is commonly used as rail track ballast. The method of selection of ballast has been based on the 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), acceptable grain shape and size distribution, adequate wearing resistance and weathering resistance (freeze-thaw, wetting and drying, and absorption) [4]. Among all, the gradation has a greater influence over the collective behavior of ballast grain as it controls the packing behavior. Therefore, different countries have specified different ballast gradations considering expected performance of ballast bed. European standard gradation, American standard gradation (AREMA), Australian standard gradation, Indian standard gradation and British standard gradation, etc. are some of these ballast specifications [3].

Sri Lankan Railway currently uses a ballast gradation specification similar to the Indian standard gradation. Due to the increased demand for a safer and quick transportation, Sri Lanka railways under the pressure to develop new rail tracks and upgrade the existing tracks to cater for increased hauling capacity and speeds yet no proper study has been conducted to evaluate the engineering behavior of ballast.

It is well understood that the shear strength of granular media is affected by the grain packing behavior. Being a granular medium, shear strength of ballast should also be affected by the particle size distribution. Previous researches [4, 5] have shown that if well graded aggregate mixtures are used, then density of granular mixture is increased and could obtain higher shear resistance [6]. Essentially, the ballast bed should have sufficient voids to sufficient hydraulic conductivity employing a very well-graded aggregate distribution as track ballast is not practical. Therefore, this study is focused to study the shear behavior of different ballast gradations and thus study the shear behavior of current Sri Lankan ballast gradation and evaluate the performance in the aspect of shear strength.

The size of the ballast grains is larger to study in conventional direct shear test apparatus available in the laboratory. Hence, it is required the ballast aggregate to be modeled to a smaller particle size distribution which could be tested in small direct shear test devices. The parallel gradation technique could be used to scale down ballast particle distribution. The modeled sample should closely duplicate the behavior of the larger prototype and could be successfully used to study the shear behavior [7].

2. Materials and Methods

European standard gradation, American standard gradation (AREMA No. 4), Indian standard gradations and British standard gradation were used for the study. It was not possible to use the prototype ballast aggregates in conventional direct shear apparatus. Hence, the parallel gradation technique was used to scale down the original gradation to a gradation with smaller particle sizes could be tested in conventional direct shear apparatus. In order to maintain the properties of rock the same with prototype ballast in rail tracks, the specimens were prepared from the material obtained from a quarry which supply ballast to Sri Lanka Railways. The lower limits of the selected standard gradations were taken for the study since it was the coarsest aggregate distribution. The Figure 1 shows the particle size distribution curves used for the study.

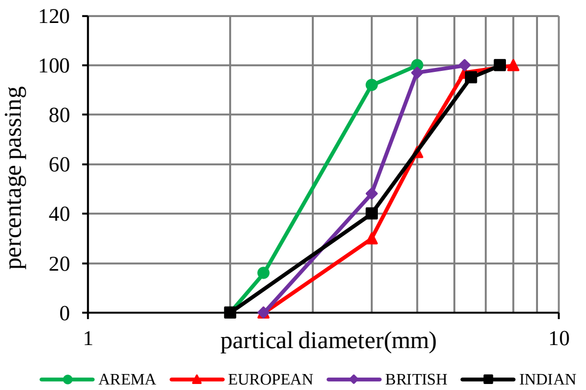

Figure 1 Different ballast gradations used for the study

The physical properties of ballast material were investigated first. The specific gravity, aggregate impact value (AIV), aggregate crushing value (ACV) and water absorption was found using relevant standards and results are tabulated in table.1. Available sieves to BS, ASTM standards were used to prepare the modeled ballast samples to follow the original prototype ballast gradations.

Table 1: Physical properties of ballast

Properties	Values
Specific Gravity	2.684
AIV	35%
ACV	28.5%
Water absorption	0.194%

The direct shear tests were conducted to investigate the shear behavior of different ballast specimens as it is the most efficient method to study the shear behavior of granular material [8, 9]. A 100 mm diameter standard direct shear device was used for the current study.

Each test sample was compacted in three layers inside the shear box applying the same compacting effort. The tamping was done using 8mm diameter steel rod with 25 blows per layer in shear box. Depending on the gradation, initial density of the specimen were not the same. The initial specimen densities are given in table 2. All the direct shear tests were conducted at the same shearing rate of 0.2mm/s under three normal pressures of 15 kPa, 30 kPa and 90 kPa.

Table 2: Density, Uniformity coefficient (C_u) and Coefficient of curvature (C_c) of tested standard gradations

Gradations	C_u	C_c	Density (kg/m^3)
European	1.68	1.14	14.52
British	1.57	1.01	14.09
AREMA	1.5	0.97	15.12
Indian	1.96	1	14.74

3. Results and Discussion

Figure 2 shows the variation of shear stress to the shear displacement under all the normal pressures for tested ballast gradations.

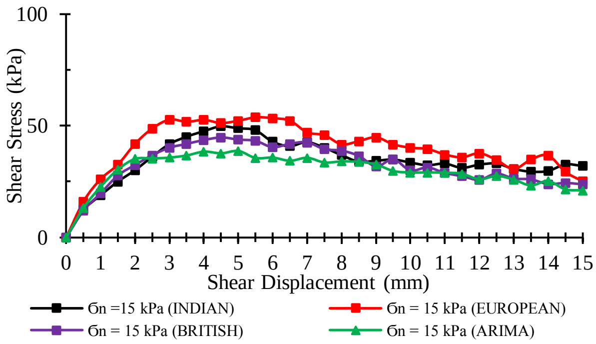

Figure 2(a)

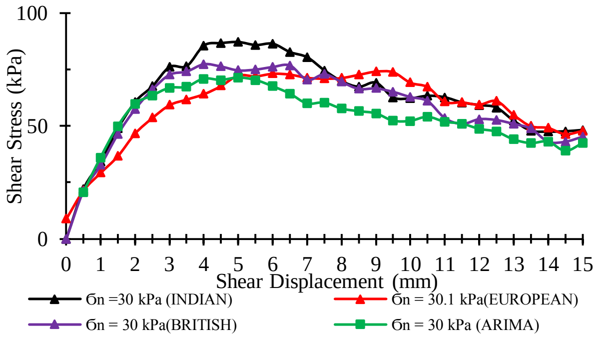

Figure 2(b)

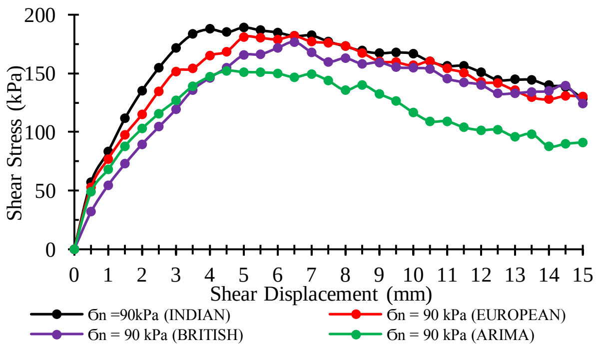

Figure 2(c)

Figure 2: Shear stress-Shear displacement relationships for normal pressures of (a)15 kPa (b) 30 kPa and (c) 90 kPa.

According to figure 2, it is seen that Indian standard gradation has the highest shear strength at high normal stress. Both Indian and European standard gradations have higher shear strength at low normal stress compared to that of other standard gradations tested.

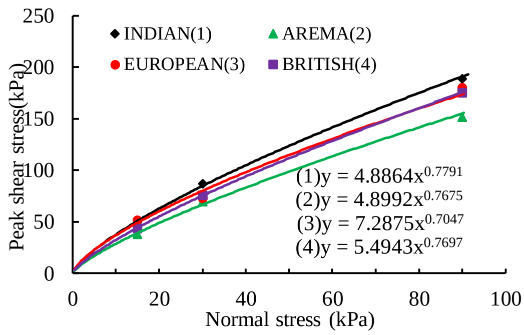

Figure 3: Relationships of peak shear strength and normal stress

Figure 3 shows the variation of peak shear strength with normal stress ballast. It was observed that for all ballast samples, the shear strength envelope at failure is better resembled to nonlinear behavior. It has been explained that this nonlinear behavior was due to particle interlocking of their highly angular nature [10]. The results of the study assuming nonlinear Mohr Coulomb failure criteria shows, Indian standard gradation has comparatively higher shear strength than the other gradations. European and British standard gradations show intermediate shear strength while AREMA No.4 ballast gradation has the lowest shear strength.

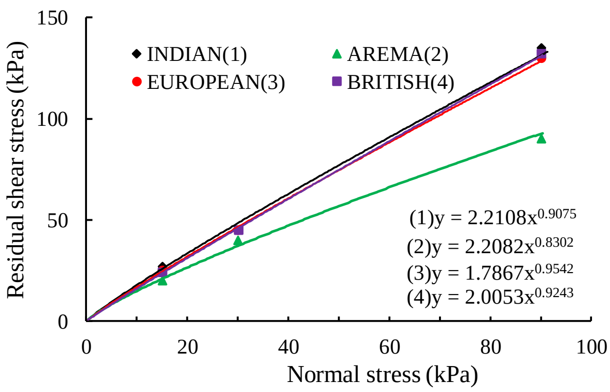

Figure 4: Variation of residual shear stress with normal stress

Figure 4 shows the variation of residual shear stress to the normal stress. It can be observed that a reduced nonlinearity of Indian, British and European ballast standards indicating a decreased interlocking and particle breakage at larger strains.

Indian, British and European ballast gradations has comparatively similar residual shear strength and American standard gradation has shown a lower residual shear strength compared to the other gradations.

It is further seen that, the friction angle is decreasing with the increase of normal stress due to the nonlinear behavior. Also it was observed an increasing trend of friction angle with the increase of uniformity coefficient for the ballast tested [12]. The observations indicate that most compacted and well graded aggregate gradations have better ability to resist loads than uniformly graded aggregates.

Table 3: Peak and residual friction angles of tested standard ballast gradations.

Gradations	Cu	peak friction angle(°)	residual friction angle(°)
European	1.68	60.0	54.6
British	1.57	59.8	55.3
AREMA	1.5	55.9	42.1
Indian	1.96	61.1	55.5

5. Conclusion

The friction angle of ballast is decreasing with the increase of normal stress.

Shear strength is increased with increase of uniformity coefficient for the ballast used in this study.

Indian standard gradation has the highest shear strength than that for European, AREMA and BS standard ballast gradations. Thus, concluded that ballast graded to Indian standard has the highest performance in load bearing characteristics and stability of track embankment.

References

[1]. Rahman, A. (2013) Permeability, Resistivity and Strength of Fouled Railroad Ballast, B.S., University of Kansas, Lawrence, Spring 2013.

[2]. John M Waters, E.T.S. (1994) Track Geotechnology and substructure management, Thomas Telford Publications.

[3]. Alemu, A.Y. (2011) Survey of Railway Ballast Selection and Aspects of Modelling Techniques, Division of Highway and Railway Engineering, Department of Transport Science,School of Architecture and the Built Environment,Royal Institute of Technology.

[4]. Kaya, M. (2004) A study on stress-strain behaviour of railroadballast material by use of parallel gradation technique, the graduate school of natural and applied sciences,the middle east technical university.

[5]. Mozhgan Asadzadeh, Abbas Soroush (n.d) 'Direct shear testing on a rockfill material', The Arabian Journal for Science and Engineering, vol. 34, Number 2B.

[6]. Indraratna, B. H.K.W.S. (1991) 'Geotechnical properties of ballast and the role of geosynthatics intrack stabilization'.

[7]. Sharma Pankaj , Mahure NV , Gupta SL , Dhanote Sandeep, Singh Devender, ‘Estimation of Shear Strength of Prototype Rock fill Materials’. 1-5 Central Soil and Materials Research Station, New Delhi, India. 424

[8]. Domenica Cambio, a.L.G. 'effects of parallel gradation on strength properties of ballast materials'.

[9]. Fityus, T.N.a.S. (n.d) 'Direct Shear Testing of a Marginal Material Using a Large Shear Box', Geotechnical Testing Journal, vol. 31, No. 5.

[10]. Methods of test for Soils for civil engineering, Part 7 (1990), authority of board of BSI.

[11]. Raymond, G. P.and Davies, J. R. (1978). Triaxial tests on dolomite railroad ballast, Journal of the Geotechnical Engineering Division, ASCE, vol. 104, No. GT6, pp. 737-751