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Behavior evaluation of geogrid-reinforced ballast-subballast interface under shear condition

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A B S T R A C T

The effective functioning of a railway track under operating conditions depends largely on the performance of various rail track interfaces (e.g. ballast-subballast interface, subballast-subgrade interface). In this context, a series of large-scale direct shear tests were conducted to investigate the shear behavior of unreinforced and geogrid-reinforced ballast-subballast interfaces at different normal stresses (σ_n) and rates of shearing (S_r). Fresh granite ballast and subballast having average particle size (D_{50}) of 42 mm and 3.5 mm respectively, and five geogrids with different aperture shapes and sizes were used in this study. Tests were performed at different normal stresses (σ_n) ranging from 20 to 100 kPa and shearing rates (S_r) ranging from 2.5 to 10.0 mm/min. The laboratory test results confirmed that the shear strength of ballast-subballast interface was highly influenced by the applied normal stress (σ_n) and rate of shearing (S_r). The friction angle (φ) of unreinforced ballast-subballast interface was found to decrease from 63.24° to 47.82° and dilation angle (ψ) from 14.56° to 5.23° as the values of σ_n and S_r increased from 20 to 100 kPa and 2.5–10.0 mm/min, respectively. Further, the breakage of ballast (B_g) was found to increase from 2.84 to 6.69%. However, geogrid inclusions enhanced the shear strength of the ballast-subballast interface and also reduced the extent of B_g. The results indicate that it is possible to establish a relationship between the friction angle (φ) and breakage of ballast (B_g), wherein the friction angle (φ) of both unreinforced and geogrid-reinforced interfaces reduces with the increase in breakage (B_g). The interface efficiency factor, defined as the ratio of the shear strength of the geogrid-reinforced ballast-subballast interface to the original shear strength of ballast-subballast interface varies from 1.04 to 1.22. Moreover, the current study revealed that the shear behavior of ballast-subballast interface was influenced by geogrid aperture size (A).

1. Introduction

Ballast and subballast layers, comprising of different sized particles, form an essential component of a conventional rail track foundation. The layer of ballast, provided immediately below the sleepers, is responsible for distributing the applied train load to the subballast at an acceptable level while maintaining the track alignment. On the other hand, the subballast acts as a separation layer between the ballast and subgrade soil and also helps in reducing the stress intensity to the subgrade soil transmitted from the overlying ballast layer. However, both ballast and subballast layers owing to their unbound granular nature often undergo vertical settlement and lateral deformations when subjected to the repeated cyclic loading induced by the passage of trains. In addition, the ballast layer comprising of relatively bigger sized particles also undergoes a significant amount of particle breakage. The fines generated as a result of breakage fill up the voids of ballast and hinders the track drainage thereby further endangering the track stability. Moreover, the extent of aforementioned track problems increases with the increase in train speed. To avoid any untoward incident of derailment, the rail authorities are forced to carry out frequent maintenance operations that are not only expensive but also disrupt the traffic. For instance, Indian railways spend around 600–700 million dollars annually on track maintenance and renewals operations, of which an estimated portion of 15–20% are for ballast related problems alone.

In the recent past, the railway engineers across the world have resorted to the use of geosynthetics to stabilize the railway tracks. Geogrids have been extensively used to reduce the settlement and lateral spreading of ballast (Bathurst and Raymond, 1987; Raymond and Ismail, 2003; Brown et al., 2007; Indraratna et al., 2013; Qian et al., 2015; Hussaini et al., 2015a, 2016; Liu et al., 2016a; Esmaeili et al., 2017). In practice, a layer of geogrid is generally placed at the bottom of the ballast layer (i.e. at the ballast-subballast interface) as the same should not hinder the future track maintenance (e.g. ballast cleaning)

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operations. When used as reinforcement, the geogrid holds the ballast in position and inhibits its lateral spreading that subsequently prevents track misalignment. However, the overall functioning of such a geogrid-reinforced ballasted track obviously depends upon the performance of the newly generated ballast-geogrid-subballast interface.

To better understand the shear behavior of granular medium-geogrid interfaces, several researchers have conducted comprehensive studies using direct shear apparatus (Lee and Manjunath, 2000; Palmeira, 2009; Liu et al., 2009; Liu et al., 2016b; Indraratna et al., 2012; Hussaini et al., 2012; Biabani and Indraratna, 2015; Liu and Martinez, 2015; Vieira et al., 2015; Mvelase et al., 2017; Afzali-Nejad et al., 2017; Chen et al., 2018; Sweta and Hussaini, 2018). Liu et al. (2009) have evaluated the interface shear behavior of different granular soils (sand, gravel and laterite) stabilized with PET-yarn geogrid. Hussaini et al. (2012) captured the effect of the aperture size of geogrid to stabilize the ballast of a given gradation. Indraratna et al. (2012) explored the shear behavior of various ballast-geogrid interfaces at a single and uniform rate of shearing. They have established that the shear strength of ballast-geogrid interface is influenced by the geogrid aperture size (*A*). On the other hand, Biabani and Indraratna (2015) assessed the performance of subballast-geosynthetic interface at different rates of shearing. Moreover, the recent studies by Sweta and Hussaini (2018) investigated the effect of shearing rate on the behavior of various ballast-geogrid interfaces. However, there is no reported literature that describes the effect of geogrid reinforcement on the shear behavior of ballast-subballast interface. Moreover, a rail track under operating conditions may be subjected to different shear rates depending upon the magnitude of cyclic stress and the train speed. In this context, large-scale direct shear tests were conducted to investigate the effect of applied normal stress (σ_n) and shearing rate (S_r) on the interface shear behavior of ballast-subballast with and without the inclusion of geogrids.

2. Material and methods

A series of laboratory tests were conducted using large-scale direct shear apparatus that consists of two square boxes of size 450 mm × 450 mm, and having an overall depth of 300 mm (Fig. 1). The equipment used is specifically designed for testing the coarse granular materials at high strain rates and normal loading. The upper box of this equipment is free to move while the lower box is fixed in position during the test. The capacity of load cells employed to measure the applied normal stress and shear stress is 300 kN/m^2. The maximum shear displacement that could be allowed using this apparatus is up to 100 mm.

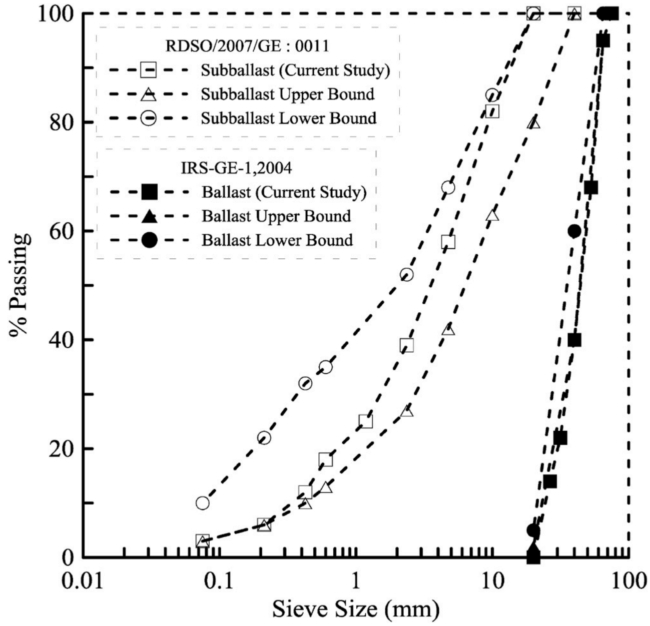

Fig. 2. Particle size distribution of ballast and subballast used in current study.

The material used for ballast was fresh granite, collected from a quarry near Pakud, Jharkhand, while the subballast was a mixture of crushed granite and sand. The particle size distribution (PSD) of ballast and subballast (Fig. 2) were adapted as per the guidelines provided by the Indian Railways (IRS-GE-1, 2004; RDSO-GE-0011, 2007). The grain size characteristics of ballast and subballast are shown in Table 1. The maximum (D_{max}) and average particle sizes (D_{50}) of ballast were 65 and 42 mm and those of subballast were 20 and 3.5 mm, respectively. Five geogrids (labeled *G1* to *G5*) with different aperture sizes (*A*) and shapes were used in the current study. The physical and technical specifications of geogrids are listed in Table 2.

The sample was prepared by the thorough mixing of the sieved ballast and subballast separately as per the gradation curve shown in Fig. 2. The subballast was placed in the lower box and compacted in two layers by a means of hand-held electric vibrator to achieve a required density of 2000 kg/m^3 which is representative of field

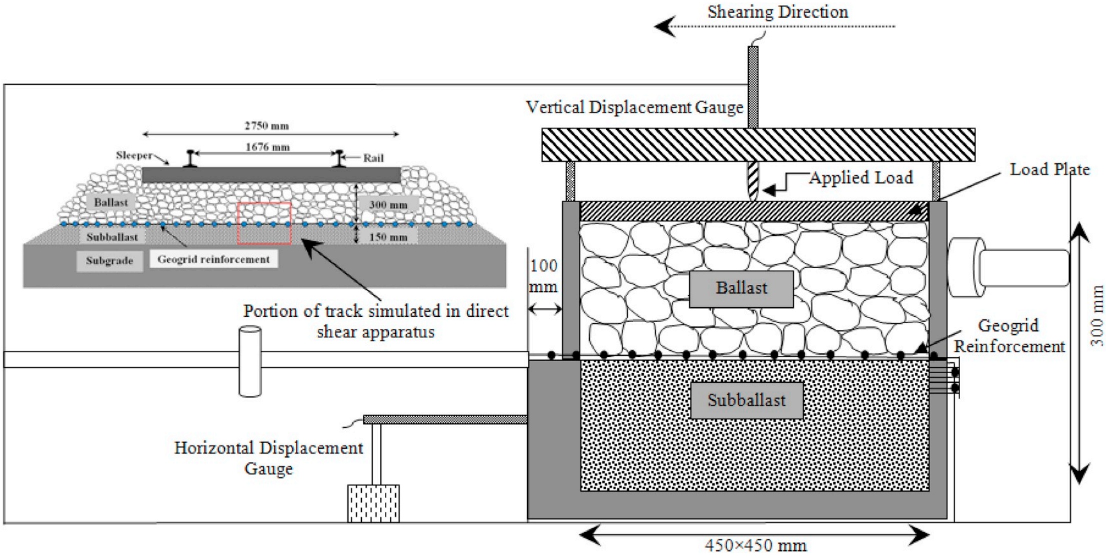

Fig. 1. Schematic illustration of large-scale direct shear apparatus and the portion of track it simulates.