Geotextiles and Geomembranes 43 (2015) 240–249

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

journal homepage: www.elsevier.com/locate/geotexmem

An evaluation of the interface behaviour of rail subballast stabilised with geogrids and geomembranes

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ARTICLE INFO

Article history:
Received 22 November 2014
Received in revised form
14 March 2015
Accepted 5 April 2015
Available online 21 April 2015

Keywords:
Geosynthetics
Subballast
Geogrid
Geomembrane
Shear strength
Relative density

ABSTRACT

In a rail track, the compacted granular medium (subballast) placed underneath the ballast influences track resiliency, and controls the load propagation to the softer subgrade (e.g. clay). A series of large-scale direct shear tests were carried out to investigate the interface shear strength of subballast stabilised with geogrids and geomembranes, respectively. In this study, the beneficial effects of these two different types of geosynthetics on the stress-strain behaviour of unreinforced and reinforced subballast were examined. The influences of normal stress (σ_n), relative density (D_R), and the shearing displacement rate (S_R) were studied. The results showed that the shear strength of the subballast–geogrid interface was significantly higher than that of the subballast–geomembrane interface. These results also showed that the reinforced subballast with a higher density provided enhanced performance over a wide range of relative densities. The results also indicated that the shear strength was significantly affected by the shearing rate.

1. Introduction

In the view of rapid urbanization, an increasing demand for appropriate ground improvement techniques is inevitable, in order to construct road and rail infrastructure over subgrade deposits with low shear strength. Unlike conventional rigid reinforcement such as steel and timber, flexible geosynthetics have shown a promising approach to improve the performance of granular media placed over weak and soft subgrade (Woodward et al., 2007; Bergado et al., 1993; Haeri et al., 2000). Planar geosynthetics (i.e. geogrid, geotextile) have been effectively utilized to reduce excessive settlement and lateral displacement of relatively soft subgrade soils (Murthy et al., 1993; Stark et al., 1996; Koerner, 1998; Dash et al., 2001; Arulrajah et al., 2014; Al-Qadi et al., 2011; Ezzein and Bathurst, 2012; Palmeira, 2009) and that of ballast (Indraratna et al., 2006; Fatahi and Khabbaz, 2011; Indraratna and Nimbalkar, 2013). Despite these advances, only limited studies have examined the influence of the size and shape of geogrid apertures on the performance of ballast (Brown et al., 2007; Indraratna et al., 2012). Moreover, no comprehensive study on investigating the influence of these parameters on the behaviour of rail subballast has yet been reported.

One of the most important design parameters that needs to be known accurately is the shearing resistance between the aggregates and the geocell material. Due to difficulties associated in determining the interface coefficient, a conservative value of 2/3 of soil friction angle is generally used (Indraratna and Nimbalkar, 2013; Leshchinsky and Ling, 2013). However, the interface friction angle is influenced by several factors such as the normal stress (σ_n), the shearing displacement rate (S_R), the relative density (D_R), and type of geosynthetic (i.e., variations in the size and shape of the aperture and the type of material). In this regard, conducting large-scale direct shear testing to evaluate the interface friction angle between subballast and the geocell membrane was considered blatantly advantageous (Jewell and Wroth, 1987; Swan et al., 1991; Anubhav and Basudhar, 2010), given the immense benefits to the rail industry, as many rail organisations worldwide are now looking at effective ways of stabilising subballast.

It is important to note that the potential use of geocells to stabilise the overlying ballast layer has often been regarded with deep scepticism or even considered detrimental from a track maintenance point of view. In other words, removing spent ballast from the track and replenishing it with fresh ballast is not convenient if a

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http://dx.doi.org/10.1016/j.geotexmem.2015.04.002
0266-1144/

geocell mattress interferes with the automated track maintenance (ballast cleaning) machinery. In this context, Australian rail organisations have now made attempts to use geocells and other methods of stabilisation to improve the subballast that rarely requires maintenance, unlike the overlying degrading ballast. This study was the result of applied research undertaken within the Cooperative Research Centre for Rail Innovation in collaboration with rail organisations in the state of New South Wales, namely ARTC and Sydney Trains.

In the field, only a small confining pressure (hence normal stress) exerted by the ballast shoulder ($\sigma_3' \leq 30$ kPa), is usually available (Indraratna et al., 2015). The shearing rate may differ in a railway embankment, which is subjected to varied cyclic stress levels, depending on the train speeds. Moreover, to maximise the benefit of reinforcement in the field, the infill soil needs to be compacted to an optimum density. However, under a typical rail environment, this optimum density is not always achieved. The interface shear strength is also governed by geosynthetic characteristics such as the percentage of open area (OA). Therefore, a comprehensive study of the effects of normal stress, shearing rate, relative density, and OA on the shear strength is both timely and imperative.

To design geocell-stabilized rail tracks, it is imperative to determine the frictional interaction between the aggregates and the geocell membrane in both lateral and vertical directions. However, given the highly random nature of particle orientations within the subballast assembly, it is anticipated that the angle of shearing resistance between the aggregates and the membrane could be isotropic, assuming that the membrane texture usually uniform.

2. Experimental procedure

2.1. Materials

The granular medium used in this study was locally available crushed basalt from a quarry near Wollongong, NSW, Australia. Particle size distribution adopted for rail subballast was within the range specified by the rail industry (Fig. 1). The specimens were oven-dried prior to their use. Three types of geosynthetics (Fig. 2) were used to reinforce the subballast: (i) geomembrane (GC1 and GC2), (ii) triaxial geogrid with triangular opening (GG1), and (iii) biaxial geogrid (GG2, GG3 and GG4). Four types of geogrid and two types of geomembrane were selected to examine the influence of open area (OA%) on the interface shear strength. The physical and mechanical properties of these geosynthetics are summarised in Table 1.

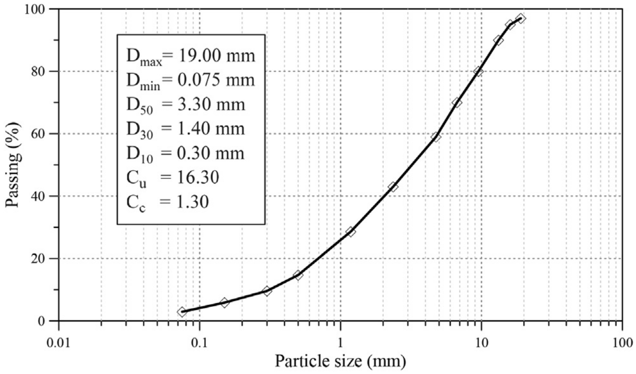

Fig. 1. Particle size distribution used in current study.

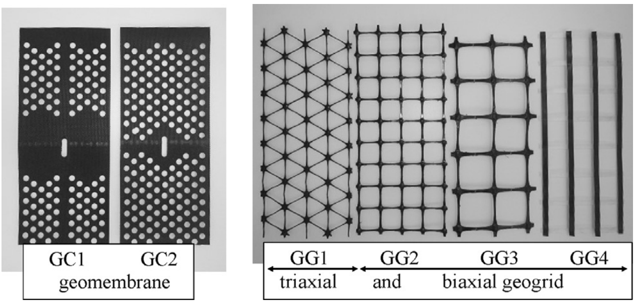

Fig. 2. Different types of geosynthetic used in large-scale direct shear.

2.2. Test setup

Laboratory investigations were conducted using a large-scale direct shear box which consisted of two square units (300 × 300 mm). The lower box (90 mm in height) was free to displace under the fixed upper box (100 mm in height) as shown in Fig. 3. The displacement of the lower box was controlled by an electric motor with a set of gears. A predetermined amount of granular material was placed inside the shear box and compacted in several layers to achieve the desired density that was representative of field conditions ($\rho = 2100$ kg/m^3). For the reinforced subballast, two layers of geomembrane having the dimensions of 150 × 300 mm or one layer of biaxial and triaxial geogrid (300 × 300 mm) were placed at the interface of upper and lower boxes, along the shearing direction (Fig. 3). Two ends of the geosynthetics were clamped at the front edge of the lower shear box using several clamping blocks, and the top half of the shear box was then filled with subballast, as shown in Fig 3. In order to simulate a realistic track environment (i.e. less confining pressure), the experiments were conducted at relatively low normal stress that varied from 1 to 45 kPa.

A total of 60 tests, including 45 reinforced and 15 unreinforced specimens under different normal stresses were conducted using the large-scale direct shear apparatus, as summarised in Table 2. In particular, 12 tests with different relative densities (i.e. $D_R = 40, 50, 60, 70, 77, 85\%$) were conducted. In addition, the influence of the shearing rate was analysed by varying the shearing rate (i.e. $S_R = 1, 2, 4, 8, 12$ mm/min) for unreinforced and reinforced subballast with GC1 at selected relative density (D_R) of about 77% and at a normal stress of $\sigma_n = 20.5$ kPa. The type of geomembrane GC1 was selected, because it is used in the manufacture of geocell mattresses (Indraratna et al., 2015). For the remaining investigations, the specimens were compacted in a dry condition to a relative density (D_R) of about 77% and sheared at a constant shearing rate of 1 mm/min (ASTM D5321-2012). Shearing continued during these experiments until a maximum horizontal strain (ε_h) of 10% was reached. Shear force, vertical and horizontal displacements were recorded by three mechanical gauges.

3. Results and discussion

3.1. Interface shear characteristics stress ratios

The stress ratio (τ/σ_n) and normal strain (ε_n) are plotted against the horizontal strain (ε_h) as shown in Fig. 4(a and b). Higher stress ratios occurred at low normal stress, and this is in accordance with earlier studies as the τ/σ_n ratio represents the apparent friction angle of granular materials (Suiker et al., 2005; Indraratna et al., 2011). The stress ratio (τ/σ_n) showed a non-linear variation with the horizontal strain (ε_h) as shown in Fig. 4a (i) and 4b (i). The peak