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A laboratory investigation to assess the functioning of railway ballast with and without geogrids

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ABSTRACT

Understanding the complex load transfer mechanism and the subsequent accumulation of deformation in ballast and subballast layers under repeated wheel loading is essential to design resilient rail tracks. Large-scale cyclic tests have been conducted on railroad ballast instrumented with optical based fibre Bragg grating (FBG) sensors, LVDTs, pressure plates and the settlement pegs to explore the role of geogrid and its interaction with ballast in improving the track performance. Latite basalt and geogrids with different aperture sizes were used for the investigations. The laboratory experimental results indicate that the geogrid inclusions enhance track performance by arresting the lateral spreading of ballast and thereby significantly reducing the extent of its vertical settlement. In contrast, the reinforcement of ballast with geogrid has only a marginal effect on reducing the settlement in the subballast layer. The results also show that geogrid minimises the amount of particle breakage, the effectiveness of which is governed by its placement position, with lowest breakage occurring when the geogrid is placed at a location 130 mm above the subballast. In addition, geogrids also reduce the extent of vertical stress in the subgrade soil. The laboratory test results establish beyond doubt the effectiveness of FBG sensing system in capturing the ballast movement under cyclic loading.

Introduction

The emergent requirement for better and efficient rail transport system both in terms of increased freight capacity and greater train speeds inherently place additional stresses on ballast. The repeated application of stress arising due to the passage of trains degrades and fouls the ballast which directly contributes to differential track settlement and track misalignment, thereby affecting the track stability and safety. In addition, the low in-situ confining pressure (i.e. 10–30 kPa) prompts the lateral spreading of ballast that further deteriorates the track condition (Baessler and Rucker, 2003; Selig and Waters, 1994). The recent study conducted by Dash and Shivadas (2012) also highlighted the lateral flow of ballast as one of the serious track problems. The practical implications of these track problems are to either impose speed restrictions on the affected track segments or to repair the concerned portions by replacing the ballast. However, the imposition of speed restrictions contradicts the very idea of introducing high-speed trains, and hence is not an acceptable solution. Moreover, repairing the tracks that involves ballast replacement and correcting the track alignment is a costly exercise that consumes millions of dollars every year worldwide. In this view, it is necessary to stabilise the ballasted rail tracks by means of geosynthetics so that they can carry high-speed trains without experiencing any major problem.

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Nomenclature

Notation

A_t	axle load in tons
BBI	ballast breakage index
C_m	the number of load cycles/MGT
C_{uf}	coefficient of uniformity (after the testing)
D_{50}	mean particle size of ballast
$D_{\max}$	maximum particle size of ballast
FBG	fibre Bragg grating
$LPSA$	large process simulation apparatus
N_a	the number of axles/load cycle
N	number of load cycles
PSD	particle size distribution
Z	distance above the subballast
e_f	void ratio
α, β	empirical constants
λ_b	Bragg wavelength
n_e	effective refractive index
Λ	grating period

In the recent past, several studies have described the cyclic behaviour of geosynthetic-reinforced ballast using the large-scale testing facilities (e.g. Bathurst and Raymond, 1987; Raymond and Bathurst, 1987; Nancey et al., 2002; Indraratna et al., 2006; Indraratna et al., 2012). Raymond and Bathurst (1987) commented that inclusion of a biaxial geogrid within the ballast layer lead to a decrease in permanent vertical deformations of up to 50% after 100,000 load cycles. Moreover, the number of load cycles required to cause a permanent vertical deformation of 50 mm increased by a factor of ten (10) when a geogrid was used. Bathurst and Raymond (1987) concluded that the effect of reinforcement in reducing the permanent deformations of ballast is more pronounced in the case of tracks laid on soils with a relatively low California Bearing Ratio (CBR) values. Similarly, Matharu (1994) has reported reductions in settlement when a geogrid was used in ballasted rail track. The field studies carried by Indraratna et al. (2010) also confirmed the effectiveness of geosynthetics in augmenting the track performance. The geogrid reinforcement of ballast also reduces the extent of particle breakage (Indraratna et al., 2006; Fernandes et al., 2008).

The aforementioned benefits of geogrid predominantly stem from the interlocking of ballast particles within the geogrid apertures. Therefore, any improvement in the deformation and degradation characteristics of ballast depends on the degree of ballast-geogrid interaction. Moreover, the effect of geogrid due to its planar geometry is expected to reduce with distance away from its placement location. Further, the internal deformations in ballast that occur as a result of train induced vibrations are yet to be studied in detail. Therefore, the current study was carried out on geogrid-reinforced ballast using the large-scale process simulation apparatus (LPSA) to gain insight into the interaction mechanism at ballast-geogrid interface and its implications on the track behaviour.

Large-scale laboratory tests on ballast with and without geogrids

Large-scale process simulation apparatus (LPSA)

The laboratory tests were conducted using a large-scale process simulation apparatus (LPSA) (Indraratna et al., 2013). It can simulate a section of track with plan dimensions of 800 mm long by 600 mm wide. The middle segment of one of the shorter side walls comprises of five independently movable plates (600 mm × 64 mm × 25.5 mm) assembled vertically with a small gap of 1 mm between each plate to allow their free lateral movement upon loading (Fig. 1a). The shorter dimension of the box (i.e. 600 mm) represents the centre-to-centre spacing between the sleepers whilst its longer dimension (i.e. 800 mm) represents the width of the loaded track (Indraratna et al., 2013). Test chambers of similar or smaller dimensions (having different side wall arrangements) were also successfully used in the past by several researchers (McDowell et al., 2004a,b; Chen, 2013) to study the role of geogrid on ballast behaviour.

Materials used and the testing methodology adopted

The test specimen comprised of a subballast layer of 150 mm at the bottom of the test chamber overlain by a 325 mm thick layer of ballast that was compacted in three layers using a vibrating plate to achieve a target field density of 1550 kg/m^3. To minimise particle breakage during vibration, a 5 mm thick rubber pad was placed underneath the vibrator. Fresh latite basalt from Bombo quarry, New South Wales, Australia was used for the laboratory investigations. The maximum and mean particle sizes ($D_{\max}$ and D_{50}) of ballast used in the study were 53 mm and 35 mm, respectively. The coefficient of uniformity, C_u of ballast was 1.87. The ballast specimens conformed to AS 2758.7, and also satisfied the revised recommendations proposed by Indraratna et al. (2004) that the value of C_u should range from 1.5 to 2.6 to possess sufficient strength and permeability. The void ratio (e) of ballast samples was 0.74. On the other hand, the maximum and mean particle sizes ($D_{\max}$ and D_{50}) of subballast were 19 mm and 0.5 mm, respectively. The coefficient of uniformity, C_u of subballast was 5. The particle size distribution (PSD) of both the ballast and the subballast used in this study is shown in Fig. 1(b). An assembly of sleeper (700 mm long) and rail section was placed above the load-bearing ballast and the space around the sleeper was filled with crib ballast up to 150 mm thick (Fig. 1a). All the samples were prepared in a similar manner except a layer of geogrid (G1–G4: Table 1) was placed at either (a) $z = 0$ mm or (b) $z = 65$ mm, where z is the distance above the subballast-ballast interface. Settlement pegs were installed at the subballast-ballast interface and at the sleeper-ballast interface to record the