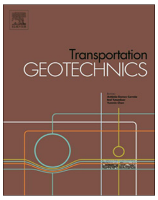
Transportation Geotechnics 2 (2015) 99–107

Contents lists available at ScienceDirect

Transportation Geotechnics

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



Performance assessment of geogrid-reinforced railroad ballast during cyclic loading

Syed Khaja Karimullah Hussaini [a], Buddhima Indraratna [b,*], Jayan S. Vinod [b]

[a] *Department of Civil and Environmental Engineering, Indian Institute of Technology Patna, Patna 800 013, Bihar, India*
[b] *Centre for Geomechanics and Railway Engineering, University of Wollongong, Wollongong City, NSW 2522, Australia*

ARTICLE INFO

Article history:
Received 18 August 2014
Revised 23 October 2014
Accepted 10 November 2014
Available online 23 November 2014

Keywords:
Ballast
Geogrid
Geogrid influence zone
Lateral spread
Particle breakage
Settlement

ABSTRACT

Recently, rail practitioners have resorted to the use of geogrids as a low-cost solution to stabilise ballast. In view of this, large-scale cyclic tests have been conducted on reinforced ballast using a modified process simulation test (MPST) apparatus at a loading frequency of 20 Hz, with geogrid placed at the subballast–ballast interface and within the ballast. Fresh latite basalt having a mean particle size of 35 mm and geogrids with different aperture sizes was used. The experimental results indicate that the geogrid arrests the lateral spreading of ballast, reduces the extent of permanent vertical settlement and minimises the particle breakage. However, the in track performance is shown to be influenced by the shear behaviour at the ballast–geogrid interface, wherein the extent of both lateral and vertical deformation reduce with the increase in shear strength at the ballast–geogrid interface. Moreover, the geogrid also helps in minimising the extent of differential track settlement that arises due to the difference in sleeper–ballast contact stress along the track length. The efficiency of geogrid is found to be identical at vertical stresses of 230 and 460 kPa. These test results highlight the role of geogrid in stabilising ballast, thus encouraging its use in railway applications.

Introduction

Railway ballast is a key component of a conventional railway track and it distributes the applied wheel load to the subgrade while maintaining the alignment. However, the cyclic load generated due to the passage of trains degrades and fouls the ballast which directly contributes to differential track settlement and track misalignment. To restore track alignment and to avoid derailment, the rail authorities are compelled to carry out frequent track maintenance. Often, the track maintenance operations disrupt traffic causing delays hence affecting productivity. For instance, the ballast related maintenance costs across Australia are substantial and estimated to be around 15 million dollars per annum in the state of NSW alone (Indraratna et al., 2013). It is well known that stability of a ballasted track structure is directly dependent on the performance of the ballast layer and this can be enhanced by reinforcing the track with geosynthetics.

Several researchers have established the role of geosynthetics in reducing the settlement of ballast under cyclic loading (e.g. Bathurst and Raymond, 1987; Matharu, 1994; Indraratna et al., 2007, 2010; Brown et al., 2007). Walls and Galbreath (1987) reported that the inclusion of geogrid facilitated an increase of the speed limit from 8 km/h to 56 km/h on a portion of track that earlier posed problems in terms of excessive track settlement. Indraratna et al. (2007) demonstrated that the inclusion of geosynthetics reduced the extent of both settlement and degradation of ballast. Shin et al. (2002) highlighted

---

[*] Corresponding author. Tel.: +61 2 4221 3046; fax: +61 2 4221 3238.
E-mail addresses: hussaini@iitp.ac.in (S.K.K. Hussaini), indra@uow.edu.au (B. Indraratna), vinod@uow.edu.au (J.S. Vinod).

http://dx.doi.org/10.1016/j.trgeo.2014.11.002
2214-3912/

Notation

A	geogrid aperture size	N	number of load cycles
BBI	ballast breakage index	z	distance above the subballast
D_{50}	mean particle size of ballast	α	interface efficiency factor
GIZ	geogrid influence zone	ε_a	axial strain
LSRI	lateral spread reduction index	ε_{ar}	axial strain ratio
MPST	modified process simulation test apparatus		

that most beneficial effect of reinforcement in reducing settlement was obtained when a layer of geogrid and geotextiles was placed at the interface of the subgrade and subballast layer. Raymond and Ismail (2003) reported, based on the physical model studies, that the optimum position of the geogrid within the ballast layer to be 125 mm below the sleeper soffit. On the other hand, the recent studies by Indraratna et al. (2013) concluded that the optimum geogrid placement location to be 65 mm above the subballast–ballast interface. The basic mechanism behind the improvement in track performance due to geogrid is primarily the particle interlocking that restricts the lateral flow of particles, hence enhancing track stability (e.g. Giroud and Han, 2004; Brown et al., 2007). Indraratna et al. (2012) have shown that particle interlocking and the associated shear strength at the ballast–geogrid interface are a function of the geogrid aperture size (A). They have recommended the optimum value of A/D_{50} (the ratio of geogrid aperture size to the mean particle size of ballast) as 1.2 to maximise the interface shear strength. However, the role of ballast–geogrid interface shear strength on the deformation and degradation aspects of ballast has not been explicitly studied in the past. Therefore, in this study, large-scale drained cyclic tests were carried out on geogrid-reinforced ballast using the modified process simulation test (MPST) apparatus to ascertain the benefits of geogrid on the performance of ballast, and thereby to confirm the role of particle interlocking at the ballast–geogrid interface on the overall track behaviour.

Laboratory investigations on geogrid-reinforced ballast

Test apparatus, materials and method of testing

The MPST apparatus used in this study has plan dimensions of 800 × 600 mm and can accommodate samples measuring 650 mm in height. The central portion of one of the side walls parallel to sleeper consists of a setup of five independent movable plates (numbered 1–5) each measuring 600 mm in width and 64 mm in height assembled along the depth (Fig. 1a). A small gap of 1 mm between the adjacent plates ensures the free lateral movement of each individual plate under the applied loading (Indraratna et al., 2013).

The test specimen comprised of a subballast layer of 150 mm at the bottom of the MPST apparatus overlain by a 325 mm thick layer of ballast compacted in three layers to a density of 1550 kg/m^3. Fresh latite basalt from Bombo quarry, NSW, Australia, with particle size distribution (PSD) conforming to AS 2758.7 (1997) was used in this study. The PSDs of ballast and subballast used in the study are shown in Fig. 1b. An assembly of sleeper and rail section, and crib ballast up to 150 mm thick was placed above the load-bearing ballast (Fig. 1c). To record the settlement of ballast upon cyclic loading, settlement plates were installed at the subballast–ballast interface and at the sleeper-ballast interface. In the case of reinforced specimens, geogrid was placed at either (a) $z = 0$ mm or (b) $z = 65$ mm, where z is the distance above the subballast–ballast interface. The physical characteristics and the technical specifications of the geogrids used (labelled G1 to G4) are summarized in Table 1. The geogrids used in the study were chosen based on the ballast–geogrid interface shear strength obtained from direct shear testing (Indraratna et al., 2012). Fig. 1(d) shows a picture of the geogrid used in the study.

In a typical track under operating conditions, the lateral spread of ballast is essentially in the outward direction (parallel to ties) with almost a zero lateral movement at the track centreline. Similarly, the plane strain conditions exist in the direction parallel to rails (Hussaini, 2013; Indraratna et al., 2013). A dynamic vertical stress of 460 kPa was applied onto the test specimen by means of a dynamic actuator and a lateral confining pressure of 10 kPa was applied onto the side wall with five movable plates. The other three walls of the MPST apparatus were held fixed and only the modified side wall was allowed to move laterally, in accordance with the track conditions as described earlier (Fig. 1e; Hussaini, 2013; Indraratna et al., 2013). Tests were conducted at a loading frequency of 20 Hz and up to 250,000 load cycles. A higher loading frequency of 20 Hz was selected in this current study to establish the deformation and the degradation behaviour of ballast at an enhanced train speed of about 150 km/h (for an axle spacing of 2.02 m). The assessment of ballast performance at such a high loading frequency is particularly important as the railway organisations worldwide are scheduling to upgrade/built the tracks to carry high-speed trains. The lateral movement of the individual plates was recorded continuously by the potentiometers connected to a data acquisition system. The electronic potentiometers used for recording the lateral movement of the plates were calibrated prior to each test. The tests were halted at selected number of load cycles (i.e. $N = 1$; 100; 1000; 3000; 5000; 10,000; 30,000; 50,000; 100,000 and 200,000) to record the readings from the settlement plates. The ballast specimen was sieved at the end of each test to evaluate the change in gradation and to quantify the breakage of particles.