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Modelling of geocell-reinforced subballast subjected to cyclic loading

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ABSTRACT

This paper presents the experimental and numerical studies of geocell-reinforced subballast subjected to cyclic loading. A series of laboratory experiments were conducted using a large-scale prismoidal triaxial apparatus that was subjected to relatively low confining pressures of $\sigma'_3 = 10–30$ kPa and a frequency of $f = 10$ Hz. Numerical simulations were performed using the commercial finite element package ABAQUS in three dimensions to realistically model cellular confinement, and to study the effectiveness of geocell reinforcement on subballast. A cyclic loading with a periodic and positive full-sine waveform was adopted to model the geocell-reinforced subballast, which is similar to the load carried out in the laboratory. The results of numerical modelling agreed well with the experimental data, and showed that geocell could effectively decrease the lateral and axial deformations of the reinforced subballast. The numerical model was also validated by the field data, and the results were found to be in good agreement, indicating that the proposed model was able to capture the load-deformation behaviour of geocell-reinforced subballast under cyclic loading. A parametric study was also carried out to evaluate the effect of the subballast strength and geocell stiffness on the mobilized tensile strength in the geocell mattress. It was found that the maximum mobilized tensile stress occurs on the subballast with the lowest degree of stiffness. Also the results revealed that lateral displacement decreased further by increasing geocell stiffness, and geocell with a relatively low stiffness performs very well compared to the geocell with a higher stiffness.

1. Introduction

Railway networks are one of the major transport systems used for carrying passengers, and transporting freight and bulk commodities between major mines and ports in many countries worldwide. Considering an acceptable ride quality, relatively low cost, and growing demand from industry and commuters, railways have become more popular than other modes of transportation. Nevertheless, the sustainable development of rail infrastructure requires a significant amount of cost associated with track maintenance and rehabilitation of track substructure (Indraratna et al., 2013). However, to compete with other transportation modes and meet the ever growing demand for public and freight transport, the railway industry will face challenges to improve the track operational efficiency and decrease maintenance and infrastructure costs. The foundation of a conventional ballasted track consists of granular material layers that help to transmit and distribute the induced cyclic load to the underlying subgrade at an acceptable or controlled stress level (Suiker et al., 2005; Selig and Waters, 1994). To date, reinforcing track substructure using a planar reinforcement is commonly deployed as it has been proven to reduce the axial and lateral deformation of ballast and subballast layers, and to improve the stability of track substructure under cyclic train loading (Ngo et al., 2014; Indraratna et al., 2011a,b; Kwon and Tutumluer, 2009; Atalar et al., 2001). Past studies have shown that cellular reinforcement can provide much better lateral confinement to infill granular soils than planar reinforcements (Indraratna et al., 2015; Hegde and Sitharam, 2015; Huang et al.,

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2011; Han et al., 2011). The performance of geocell mattress in stabilizing different types of infill soils subjected to monotonic loading has been investigated in several studies (Biabani and Indraratna, 2015; Wang et al., 2013; Tafreshi and Dawson, 2012; Yang et al., 2010; Pokharel et al., 2010; Saride et al., 2009). A summary of research outcomes of selected past studies is given in Table 1. In addition, there are a few studies available, which have investigated the performance of granular material in plane-strain condition (Radampola et al., 2008; Wanatowski et al., 2008; Radampola, 2006; Peters et al., 1988). However, understanding the performance of geocell reinforcement under cyclic loading is the key requirement, which is needed for its design and application in ballasted rail tracks.

The development of a numerical model is inevitable in order to establish proper design guidelines based on safety and economic considerations. Considering the computational effects involved, a two-dimensional (2D) model often become more popular than a three-dimensional (3D) model for plane strain conditions (Hegde and Sitharam, 2013; Mehdipour et al., 2013; Yu and Sloan, 1997). An equivalent composite approach has often been used to model

Table 1
Summary of research outcomes of previous studies.

Material type	Reinforcement type	Test specimen scale	Research methodology	Salient research outcomes	Limitations	Reference
Sand and clay	Geocell	900 × 900 × 600 L × W × H (mm)	Numerical simulation (FLAC^{3D}).	1) The geometry of the geocell has a significant impact on the load carrying capacity and reducing the settlement of the soil bed. 2) The results revealed that having three layers of planar geogrids can be led to provide optimum performance improvement.	Monotonic loading only, hence cannot interpret cyclic loading behaviour.	Saride et al. (2009)
Clayey sand and soft clay	Geocell	50,000 × 25,000 W × H (mm) 1000 and 2000 mm Geocell height	Experimental and numerical investigation of geocell supported embankment (GEOFEM)	1) Locally available material can be used as infill material in the absence of granular material. 2) Performance of the reinforced embankment was significantly improved by increasing the aspect ratios (optimum aspect ratio of 1.0)	(1) Monotonic loading (2) Equivalent composite model (i.e. soil and geocell are integrated as one material)	Latha and Rajagopal (2007)
Sand	Geocell and planar geogrid	900 × 900 × 600 L × W × H (mm)	Experimental results and numerical investigation on the bearing capacity of square footings.	1) Geocell reinforcement was found to be more effective than other types of reinforcement. 2) Numerical results confirmed that by transferring the footing load to deeper depth, stress and strain underneath of the footing will be markedly reduced.	1) Monotonic loading 2) The mobilised stress over the geocell was not investigated.	Latha and Somwanshi (2009)
Gravel	Geocell	1524 × 610 × 546 L × W × H (mm)	Numerical modelling of behaviour of railway ballasted structure with geocell confinement	1) Providing geocell reinforcement significantly reduced vertical deformation, particularly for material with lower quality. 2) Geocell reinforcement successfully arrested lateral spreading along the slope of the railroad substructure.	1) Confining pressure assumed constant during the entire simulation. 2) Diamond shaped geocell pockets, which are different to actual geocell configuration.	Leshchinsky and Ling (2013a,b)
Aggregate and sand	Geocell	1000 × 840 × 1000 L × W × H (mm) Geocell$_{\text{thickness}}$ = 100, 150 mm	Numerical modelling for geocell-reinforced unpaved roads (FLAC^{3D}).	1) A three-dimensional mechanistic–empirical (M–E) model for geocell-reinforced unpaved roads was developed. 2) A compaction-induced residual stress in the base layer was determined using the hysteretic k_0-loading model.	1) Confining pressure remains constant during the entire simulation. 2) Diamond shaped geocell pockets for simplicity	Yang et al. (2013)
Sand and clay	Geocell and geogrid	450 × 450 × 600 L × W × H (mm)	Numerical modelling of geocell-reinforced sand (FLAC^{3D}).	1) Tensile strength had a significant impact on footing strength, compared to other reinforcement properties. 2) Performance of the foundation was improved further by proving additional planar geogrid.	Monotonic loading only.	Hegde and Sitharam (2014); (2015)
Gravel	Geogrid	300 × 200 × 400 D × W × H (mm)	Numerical modelling of ballast and geogrid interaction in pullout testing (DEM).	1) It was found that pullout force to be greater for the clumps than for the spheres. 2) Much more localised deformation of the geogrid observed as result of stronger grid-particle interlock.	Geocells not used.	Ferellec and McDowell (2012)
Gravel	Geogrid	700 × 300 × 450 L × W × H (mm)	Numerical modelling of geogrid-reinforced ballast under cyclic loading (DEM).	1) settlement of ballast decreased significantly due to geogrid. 2) The optimum location for the geogrid was found to be at 100 mm above the base (confined test) and 50 mm from the subballast (unconfined test).	1) Geocells were not used. 2) Limited number of cycles.	Chen et al. (2012)
Sand	Geocell	480 × 380 × 100 L × W × H (mm)	Numerical modelling of geocell-reinforced sand (FLAC^{3D}).	1) Bearing capacity of the foundation increased significantly due to geocell reinforcement. 2) Maximum displacement and tension were found to be close to the bottom of the geocell pocket.	1) Study is limited to a single geocell pocket. 2) Monotonic loading.	Han et al. (2008)
Sand	Geocell	2000 × 2000 × 700 L × W × H (mm)	Experimental results of rubber–soil mixture and geocell under repeated loading.	1) The optimum embedded depth of first layer of geocell and vertical spacing of geocell layers were about 0.2 times of loading plate diameter. 2) The maximum and plastic deformation increased by increasing number of load cycles.	1) Limited number of cycles.	Moghaddas Tafreshi et al. (2014)