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Use of cellular confinement for improved railway performance on soft subgrades

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A B S T R A C T

Due to extensive right-of-way, railroads are inevitably subject to poor subgrade conditions and interrupted service for significant maintenance due to excessive deformations and loss of track geometry. Geocell confinement presents itself as a possible solution for improving performance of ballasted railroad embankments over weak subgrade. To investigate the efficacy of geocell confinement on ballasted railway embankments, a set of well-instrumented, large-scale cyclic plate loading tests and numerical simulations were performed on geocell-confined ballast overlaying a weak subgrade material. The agreement of results from tests and simulations served as a basis for simulating practical track geometry and performance for various geocell configurations and subgrades using three-dimensional (3D) finite element (FE) analyses. The study showed that geocell reinforcement significantly decreased track settlement, decreased subgrade deformations with lower and uniform distribution of vertical stresses on subgrade and inhibited lateral deformation and serviceability under cyclic loading. These results demonstrate that geocell confinement can be an effective alternative to subsurface improvement or shorter maintenance cycles, particularly on weak subgrades.

1. Background

Cellular confinement, or geocell, is a three-dimensional (3D) honeycombed shaped geosynthetic used to increase the strength and modulus of the cohesionless soils through a mechanism of confinement. In cohesionless soils, such as sands or gravels, shear strength and modulus are generally low under small confining pressures, but can be increased using additional confinement offered by a geocell structure under small deformations. Geocell is more effective for soil confinement than other types of geosynthetics (e.g., geogrid or geotextile through interlocking or friction), making it the subject of extensive study as the complex interdependence of geometry, soil strength and loading mechanism make its composite behavior difficult to quantify.

The US Army Corps of Engineers first investigated cellular confinement as a construction concept to economically improve mobility for roads across soft ground (Webster and Alford, 1978) and concluded cellular confinement, initially done with aluminum, increased soil strength under loading. The soil was compacted in the cellular grids and test traffic was applied over the soil to test the effectiveness of geocell confinement. The enhanced confining effects of geocell on aggregate materials were later observed through use of large-diameter triaxial tests, demonstrating notable increases in strength (Bathurst and Karpurapu, 1993). Similar triaxial tests have demonstrated increased strength of granular soils with geocell confinement (Biabani et al., 2016a), some electing to analyze its effects as an apparent cohesion for simplicity (Rajagopal et al., 1999). However, the geocell increases the strength of granular materials through enhanced confinement effects, which also stiffens the reinforced composite through a "mattress" effect (Zhou and Wen, 2008; Hegde, 2017), especially beneficial over soft soil (Biswas and Krishna, 2017). Geocell reinforcement has demonstrated increased strength and reduced deformation over a variety of adverse soil conditions; however its implementation is limited due to lack of comprehensive design methods (Yuu et al., 2008; Hegde, 2017).

Geocells are usually shipped in folded form and are spread during installation to form a honeycomb like structure with pockets (cells) into which soil is added and compacted. The three-dimensional shape of the cells (each pocket) provides the confinement effects to the soil by surrounding it thus creating a stiff structure that prevents lateral movement of material, consequently increasing soil strength (Koerner, 2012). This system has demonstrated effectiveness in increasing the

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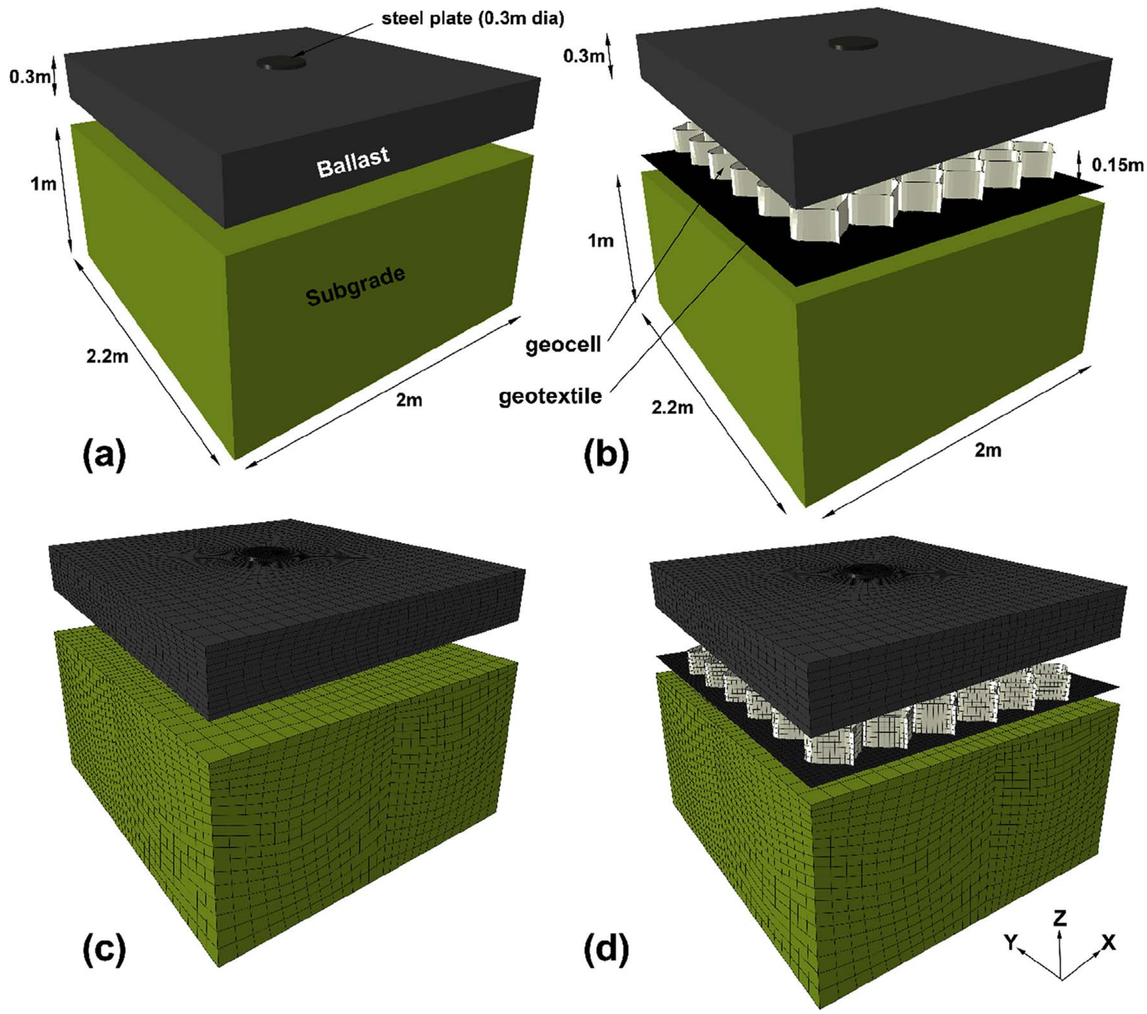

Fig. 1. Details of plate loading tests and respective (a) Unreinforced, (b) Reinforced models geometry and mesh for respective (c) Unreinforced and (d) Reinforced models.

strength of soil, particularly cohesionless soil, reducing deformations under monotonic and cyclic loading (Leshchinsky, 2011; Biabani et al., 2016b; Thakur et al., 2016; Pokharel et al., 2017). Large scale triaxial tests conducted on geocell-reinforced sub-ballast subjected to cyclic loading showed that the increased confinement reduced the vertical and volumetric strains in the sub-ballast. Benefits of using geocell was noticeably higher at the low confining pressures at higher frequency of loading (Indraratna et al., 2015).

Numerical modelling of geocell has been a notable challenge due to its complex, three-dimensional honeycomb structure. Hegde and Sitharam (2015) modelled the 3D honeycomb shape of the geocells using Finite Element (FE) analysis and found that reinforcements were effective in distributing loading to a wider area and to a relatively shallow depth as compared to unreinforced soil and geogrid-reinforced soil. Han et al. (2008) carried out mechanistic analysis of a geocell-reinforced gravel base over soft subgrade under a vertical loading using the finite difference method, demonstrating that geocell confinement improved load-bearing behavior. Leshchinsky and Ling (2013a; 2013b) performed laboratory and numerical analyses of railway ballast embankments reinforced with geocell under monotonic and cyclic loading conditions, demonstrating improved load-carrying capacity and inhibited lateral displacements for ballast embankments. Numerical models and experiments both showed geocell confinement minimized settlement under both cyclic and monotonic loads. However, damage was noted at the seams of the geocells used in these tests (Leshchinsky and Ling 2013a,b) under higher loading – a by-product of the manufacturing process. In the tests outlined within this study, no significant damage (tearing, rupture) was noted at the seams.

Ballast performs many important functions for railroad performance, including resisting vertical, lateral and longitudinal forces, absorbing energy and reducing vibrations, providing adequate drainage, and distributing the load from the railroad to acceptable levels for the subgrade (Selig and Waters, 1994). Due to the repeated loads incurred over many cycles, rearrangement and degradation of ballast occurs. This results in ballast fouling and loss of geometry due to lateral spreading of the ballast (Lackenby et al., 2007). The degradation of ballast causes reduced frictional strength and increased lateral spreading which is regarded as the primary cause of loss of track geometry and causes higher track maintenance cost. Geocell reinforcement has been used in various geotechnical applications and has shown improvement in performance but studies of geocell reinforcement in railway embankments are limited (Indraratna et al., 2015). Geocells have shown to improve the settlement behavior of soil due to increased strength and stiffness of the reinforced mattress (Zhou and Wen, 2008), resulting in lower displacements and wider distribution of loading (Yang et al., 2010) causing lower shear stresses at the subgrade interface (Giroud and Han, 2004). In full-scale railway testing, geocell resulted in sustained track geometry stemming from reduced settlement and lateral spreading (Raymond, 2001). Insight into the performance improvements stemming from geocell reinforcement of ballasted railway embankment overlying weak subgrades is limited. However, numerical simulations based on physical experiments are a useful means for investigating design considerations pertaining to geocell-reinforced railway embankments in a controlled manner without the