Geotextiles and Geomembranes 46 (2018) 384–395

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

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

# Interfacial properties of Geocell-reinforced granular soils

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ARTICLE INFO

*Keywords:*
Geosynthetics
Geocell
Granular materials
Interface
Direct shear test
Soil grains size

ABSTRACT

To provide an accurate response of Geocells under pull-out conditions such as what happened in retained backfills, interfacial characteristics of Geocell-backfill are required. A series of direct shear tests was carried out to investigate influence of soil physical properties on interfacial properties of Geocell-reinforced granular soils. Variable parameters encompass poorly graded coarse-grained soils with different medium particles sizes (3, 6 and 12 mm), different normal stresses (100, 200 and 300 kPa) and different relative densities (50 and 70%). To compare the developed strength of the shear plane, in unreinforced and Geocell-reinforced statuses, shear characteristics mobilized at the shear plane including friction angle, dilation angle and apparent cohesion have been evaluated. The results indicated improvement of the interface's shear strength characteristics due to the presence of Geocell. The shear strength in the Geocell-soil interface was increased by increasing the medium grain size and relative density of the soil. From the obtained results, for coarse aggregates (cell aspect ratio-ratio of Geocell's cells diameter (b) to the medium grains size ($D_{50}$)- smaller than 8.5), Geocell reinforcement was two times, at least, more successful than compaction effort, in improving shear characteristics of the unreinforced medium dense fill materials. It has been recommended using Geocells in environments with low normal stress and coarse aggregates. Furthermore, the results clarify that Geocell with cell aspect ratio equal to 4, has the best performance in improvement of interface's shear strength.

## 1. Introduction

In the last two decades, due to its cost savings, ease of construction and ability to improve the visual appearance, Geocell-reinforced soil has been significantly exploited in geotechnical engineering to improve the bearing capacity of footings (Tanyu et al., 2013; Tavakoli Mehrjardi et al., 2012, 2013; Dash and Chandra, 2013; Chen et al., 2013; Huang, 2014; Song et al., 2014; Han and Thakur, 2014; Moghaddas Tafreshi et al., 2015; Biabani et al., 2016; Hegde et al., 2016; Thakur et al., 2016; Hegde and Sitharam, 2017). Anchorage and/or tensioned membrane effects are the key mechanisms of Geocells for reinforced slopes, earth walls and roadway applications, constraining lateral and vertical embankments deformations. In other hand, Geocell-soil interface plays an important role for design and performance of the reinforced soil structures. Leshchinsky and Ling (2013) conducted a series of embankment model tests with different configurations of Geocell placement and loaded monotonically and cyclically to investigate the effectiveness of Geocell confinement on substructure integrity. The tests and numerical simulations demonstrate that Geocell confinement effectively increased stiffness and strength of a gravel embankment while reducing vertical settlement and lateral spreading. Additionally, the parametric study shows that the use of Geocell provides a composite mattressing effect that distributes subgrade stress more uniformly than without reinforcement, increasing bearing capacity and reducing settlement, especially on soft foundations.

Although, over recent years, many researchers have investigated shear properties of soil–geosynthetic interfaces (Silvano and Lopes, 2005; Liu et al., 2009; Anubhav and Basudhar, 2010; Khoury et al., 2011; Vieira et al., 2013; Ferreira et al., 2015; Hatami and Esmaili, 2015), there are limited studies on the shear charactristics of Geocell-soil interface. In fact, most of the research have been carried out by triaxial tests to investigate the shear strength of Geocell-soil composite (Bathurst and Karpurapu, 1993; Rajagopal et al., 1999; Shen, 2005; Chen et al., 2013; Wang et al., 2008; Manju and Madhavi Latha, 2013).

Bathurst and Karpurapu (1993) reported the results of large scale triaxial compression tests, carried out on Geocell-soil composite and unreinforced samples. The results illustrated stiffening effect and increasing strength imparted to the soil by the enhanced confinement effect. Moreover, comparison of reinforced and unreinforced samples showed that the peak friction angle of the soil infill and that of the composite were the same. However, by using Geocell inclusions in the soil sample, the apparent cohesion was increased substantially to 156–190 kPa, depending on the available confining pressure. Also, Rajagopal et al. (1999), Chen et al. (2013) and Shen (2005) performed

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https://doi.org/10.1016/j.geotexmem.2018.03.002
Received 3 August 2017; Received in revised form 15 January 2018; Accepted 4 March 2018

triaxial compression tests on granular soils to investigate the overall performance of the composite. It was observed that the soil developed cohesive strength resulting from the confinement by the Geocell, and the magnitude of the cohesive strength, unlike the friction angle of the composite, varied with the properties of the Geocell. Chen et al. (2013) used different shapes of cells such as circular, rectangular and hexagonal to construct Geocells. They found out that the circular shape was most effective in increasing the apparent cohesion. Wang et al. (2008) conducted a large-scale direct shear on Geocell reinforced soils. It was concluded that Geocell reinforcement results in an increase of 2.44 times in cohesion, and the tests with the Geocell and the cement stabilization result in an increase of 10 times in cohesion compared with the unreinforced soil. However, the friction angle does not change markedly. Manju and Madhavi Latha (2013) carried out direct shear tests to investigate the interface shear properties of sand-Geocell interface. Two different geonets with high contrast in tensile strength properties and aperture size were used to fabricate Geocells. Results showed that the inclusion of Geocells imparts cohesion to the sand and slight variation in friction angle. Also, it was concluded that the tensile stiffness of Geocell material plays significant role in governing the interface friction characteristics of Geocell reinforced sand, apart from the pocket size of cells. In this regard, Zhang et al. (2006) concluded that inclusion of Geocell reinforcement increases both apparent cohesion and the angle of internal friction of the backfill.

As a whole, in the load support applications, surface characteristics of the Geocells play an important role in deciding its performance. Generally, Geocell possesses a unique cup shaped texture on its surface. These textures are responsible for the roughness of the surface. The surface roughness is responsible for the interface friction between the material and the soil. Higher the surface roughness results in higher interface friction (Hedge, 2017). Taking into account the scarcity of studies on the characteristics of Geocell-soil interface, a series of large direct shear test have been carried out to investigate the interactive parameters of Geocell-soil composite on the interface's shear strength with respect to the backfill aggregate size. The specific aims of this study are:

- To investigate and to compare effects of the soil's physical properties such as aggregate size and relative density on the characteristics of Geocell-soil interface,
- To compare the shear strength of treated (Geocell-reinforced) and untreated (unreinforced) samples,
- To evaluate the residual shear strength developed at the shear plane of either treated (Geocell-reinforced) and untreated (unreinforced) samples,
- To compare the effectiveness of Geocell reinforcement and compaction effort in enhancement of the interface's shear characteristics.

## 2. Test materials

In the current study, coarse-grained soils as well as Geocell reinforcement have been used as test materials which are explained in details as following.

### 2.1. Soils

Three types of uniformly graded soils as fill materials with the medium grain size ($D_{50}$) of 3, 6 and 12 mm were considered. The properties of these materials, which are classified as SP and GP in the Unified Soil Classification System (ASTM D2487-11), are summarized in Table 1. Also, the grading of backfill materials is graphically illustrated in Fig. 1. It should be mentioned that these materials can be used in railroad as ballast and in retaining walls as fill materials.

**Table 1**
Properties of all three soils used in the tests.

| Properties | Sand, S3 | Gravel, G6 | Gravel, G12 |
|---|---|---|---|
| Unified Soil Classification System | SP | GP | GP |
| mean grain size, $D_{50}$ (mm) | 3 | 6 | 12 |
| coefficient of uniformity, $C_u$ | 1.47 | 1.41 | 1.49 |
| coefficient of curvature, $C_c$ | 0.94 | 0.95 | 1.11 |
| specific gravity, $G_s$ (ASTM D854-14) | 2.69 | 2.65 | 2.61 |
| maximum dry unit weight (kN/m$^3$) (ASTM D4253–16) | 16 | 15.6 | 15.6 |
| minimum dry unit weight (kN/m$^3$) (ASTM D4254–16) | 14.5 | 14.3 | 14 |
| Porosity at $D_r$ = 50% | 0.72 | 0.75 | 0.76 |
| Porosity at $D_r$ = 70% | 0.69 | 0.72 | 0.73 |
| Moisture content (%) | 0 | 0 | 0 |

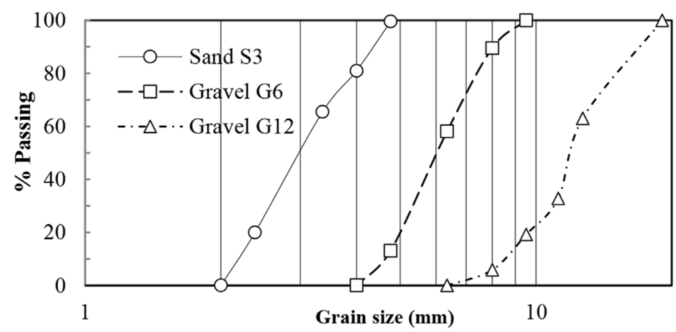


**Fig. 1.** Grain size distribution curves for sand and gravel used in the tests.

### 2.2. Geocells

Geocells were made of a tape of Heat Bonded Nonwoven geotextile (HBNW) which bonded to a neighboring tape, at regular intervals of distance, in order to form a “honeycomb” arrangement. The Geocells used in the tests has the pocket size and height of 55 mm × 55 mm and 50 mm, respectively. The characteristics of the Geocell used in this study are summarized in Table 2. It should be mentioned that, with respect to the soil grading size (poor-graded fine to medium aggregates), the tensile strength of the textile material (13 kN/m) is selected to satisfy scaling rules.

## 3. Test procedures

### 3.1. Test setup

The main part of the test was samples preparation in the box of the direct shear test. To do so, firstly, the required weight for each kind of the fill materials was calculated with respect to its relative density and physical properties (see Table 1) and also, based on the volume of large-scale direct shear box to infill the shear box. Then the fill, at its air-dried water content (moisture content equal to 0%), was poured into the mold in three finished layers of about 54 mm-lift thickness. Layers were compacted by a light compacting hammer to reach the target layer

**Table 2**
Technical characteristics of the Geocell.

| Properties | Unit | Value |
|---|---|---|
| Cell area | mm$^2$ | 55 × 55 |
| Cell height | mm | 50 |
| Mass per unit area[a] | g/m$^2$ | 470 |
| Ultimate tensile strength[b] | kN/m | 13 |
| Axial strain at failure[b] | % | 55 |

[a] Geocell area is plan area of expanded honeycomb structure.
[b] Geocell values apply to the geotextile used to make the web.