

Frictional properties between geocells filled with granular material

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Abstract

The parameters concerning the interaction between geocell and granular materials is required for the design of many geotechnical structures. With this in mind, a series of experiments using simple direct shear tests are conducted in order to understand the frictional properties between geocells filled with granular materials. The 54 test samples are prepared by filling the geocell with granular materials having three different gradations. These samples are tested at three different relative densities under three different normal stress levels. As a result, it was observed that interface resistance between the geocells filled with granular material is found to be generally greater than in the samples without geocells. Additionally, these samples with geocells are found to be stiffer; this is due to the fact that the samples with geocell gained more cohesion because geocells confined the grains within a restricted volume.

Keywords: geocell, granular material, interface interaction, normal stress, shear stress.

Introduction

Soil improvement methods have become increasingly important in recent years due to the very high costs of deep foundation systems. A recent soil improvement method involves strengthening the engineering properties of the soil with the usage of geocell. Such a soil improvement method with geocell-reinforced soil is now being used in several geotechnical designs; some of these are reinforced slopes, earth walls, roadway applications, and embankments. In these geotechnical applications, interfacial friction properties of composite systems, which consist of geo-synthetics and soils, are dominant parameters for the design. In the past decade, an examination of the literature reveals work the focus on the shear properties of soil-geosynthetic and soil-construction materials interfaces (Brown et al., 2007; Oh and Shin et al., 2007; Liu et al., 2009; Anubhav and Basudhar, 2010; Khoury et al., 2011; Vieira et al., 2013; Cuelho et al., 2014; Ferreira et al., 2015; Hatami and Esmaili, 2015; Çanakçı et al., 2015, Góngora and Palmeira, 2016; Kayadelen et al., 2018; Takegawa et al., 2019; Altay et al., 2019).

Many papers have also been produced through the practice of triaxial tests to determine the shear strength of geocell-soil samples (Dash et al., 2007; Zhou and Wen, 2008; Chen et al., 2013; Wang et al., 2008; Manju and Madhavi Latha, 2013; Leshchinsky and Ling, 2013). As a result of these studies, it can be observed that the shear strengths increase significantly using geocell in soil samples. Moreover, many researchers have investigated the bearing capacity of footings with geocell-reinforced soil (Latha et al., 2006; Latha and Murthy, 2007; Dash et al., 2007; Sitharam et al., 2007; Wang et al., 2008; Moghaddas Tafreshi and Dawson, 2010; Yang et al., 2012; Tavakoli Mehrjardi et al., 2012; Tanyu et al., 2013; Dash and Chandra, 2013; Chen et al., 2013; Huang, 2014; Song et al., 2014; Han and Thakur, 2014; Moghaddas Tafreshi et al., 2015; Avesani Neto et al., 2015; Aboobacker et al., 2015; Biabani et al., 2016; Kumar and Saride, 2016; Sireesh et al., 2016; Hegde et al., 2016; Thakur et al., 2016; Mehrjardi et al., 2019). Last of all, through the studies performed on the bearing capacity of shallow foundations using reinforced soil with geocell, it was established that the bearing capacity of soil increases with the use of geocell.

Wang et al., (2008) carried out comprehensive experiments to understand the effects of geocell on geotechnical parameters of soil such as cohesion and internal friction angle. According to their results, there was an increase by a factor of 2.24 in the cohesion, and there was no significant change in the internal friction angle. Other researchers, Chen et al., (2013), for example, undertook to determine the effect of different types of geocells on the strength of soil, basing their study on circular, rectangular and hexagonal shapes. These studies showed that the strengths are noteworthy and increased in all types of geocells according to the unreinforced condition. In addition, Chen et al., (2013) emphasized that the highest strength was obtained in the circular geocells.

Zhang et al., (2006) conducted a series of experiments to determine the interaction between geocell and sandy soil. In the experiments, they examined the changes in the internal frictional angle and cohesion values. They determined that the internal friction angle and the cohesion value increased in geocell reinforced sandy soils.

Manju and Madhavi Latha (2013) completed experiments to examine the strength parameters in the interface of sandy soils with geocell. In these experiments, the geocells which have two different tensile strength were used. Their results pointed to an increase in the cohesion of sandy soils by using geocell, and they also stated that there was a slight increase in the internal friction angles of sandy soils.

The influence of soil properties on the interfacial properties of Geocell-reinforced granular soils was investigated by Mehrjardi and Motarjemi (2018). Using poorly graded coarse-grained soils with different medium-sized particle (3, 6 and 12 mm), different normal stress levels (100, 200 and 300 kPa), and different relative densities (50% and 70%), they detected and evaluated shear characteristics mobilized at the shear plane including friction angle, dilation angle and apparent cohesion. It was observed that the shear strength in the geocell-soil interface rises by increasing the medium grain size and relative density of the soil.

Considering all the studies given here, it is clear that the process of geocell strengthening of the soil has been focused on how the frictional properties change. In addressing this aim, direct shear tests were generally performed on soils with different type of geocells. The direct shear test box sizes that were used also differ according to the studies. Even though the dimensions are different, it is still apparent that the results are compatible, and the trends are generally positive with the usage of geocell in terms of geotechnics.

When the studies are examined as a group, the majority of them concern the improvement of the sandy soil with geocell. However, studies on the interface and interaction between the granular material and geocell are very limited. For this reason, this study chooses to investigate the interfacial friction characteristics and the behavior between geocell blocks filled with sand and gravel. The main study objective is to identify general trends in such a structure. All research observations can contribute to this subject, even if the data obtained in the laboratory within the framework also have some limitations. Here, experiments are conducted on three different gradations (1-2 mm, 2-5 mm, 5-10 mm) with three different relative densities (30%, 50%, 70%) under three different normal stress levels (43 kPa, 86 kPa, 172 kPa). First, the direct shear experiments are carried out on the granular material without geocell. Then, the experiments with geocell are performed to observe the interface interaction between granular materials and geocell.

Experimental setup and program

The experimental set-up used in this study was reconstructed by modifying the standard shear box test setup. The shear rings, which can be placed inside the standard shear test cell, were re-designed and manufactured to obtain a bigger ring than the standard version. The cross-section of the rings was 116*116 mm, and the height of ring was 60 mm (Figure 1). Geocell used in these experiments is made of HDPE (High-Density Polyethylene). The original geocell was cut and re-fixed, enabling it to be placed in the shear box ring for this laboratory work and allowing new geocell dimensions to be

delineated. The geocell's pocket size was 60 mm * 60 mm and its height was 30 mm. The material properties of geocell are given in Table 1. The geocell designed for this study is then placed inside the shear box's ring and the granular material is placed in the cell with certain relative densities. Granular material placed with geocell is shown in Figure 2.

Table 1. Material Properties of Geocell. (Self-Elaboration).

	Units	Values
Welding distance	cm	6
Nominal cell length/width (L/W)	cm	3.5/4.5
Cell area	cm ²	15.75
Cell height	cm	3
Thickness	mm	1.5
Tensile strength	kN/m	20

The granular material used in this experimental study was taken from İskenderun Gulf. In preparation, experiments were performed on oven-dried granular material samples in the Soil Mechanics Laboratory of Osmaniye Korkut Ata University, and the granular material was divided into three different gradations. The gradation curves for each one is given in Figure 3. The first group was (Group A) consisting of 1-2 mm grains. Second (Group B) and third (Group C) groups consisted of 2-5 mm and 5-10 mm grains, respectively (Figure 4). Before the shear tests, the physical parameters and gradation curves of granular material were obtained using standard experiments according to ASTM (American Society for Testing and Materials) for soil mechanics. The maximum and minimum dry unit weights are given in Table 2.

Table 2. Minimum and maximum dry densities of granular materials. (Self-Elaboration).

Group	Minimum Dry Unit Weight (gr/cm ³)	Maximum Dry Unit Weight (gr/cm ³)
1-2 mm (A)	1.38	1.56
2-5 mm (B)	1.46	1.63
5-10 mm (C)	1.49	1.68

Figure 1. Test set-up. (Self-Elaboration).



Figure 2. Geocell placed in shear rings with granular material. (Self-Elaboration).



As can be seen from Figure 3, the particle size distribution of group A soil is coarse sand, and its specific gravity is 2.70. Group B and group C are fine and medium gravel, respectively. Their specific gravities are 2.63 for group B and 2.71 for group C. Group A soil has been classified as poorly graded clean sand (SP) and Groups B and C have been classified as poorly graded gravel (GP) according to ASTM D 6913-04.

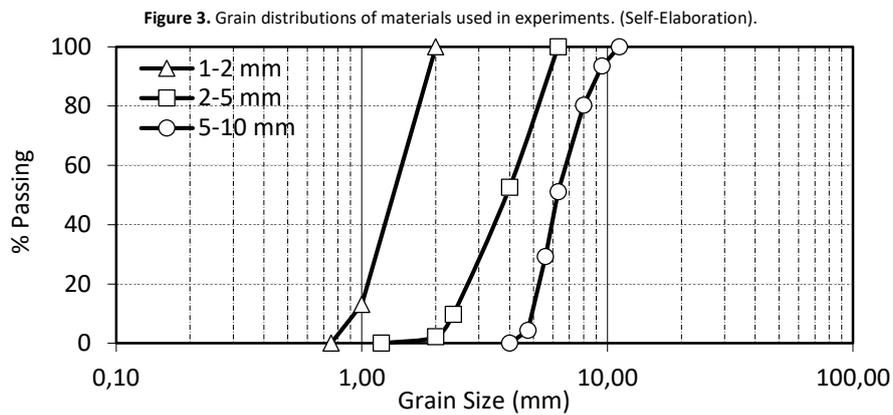
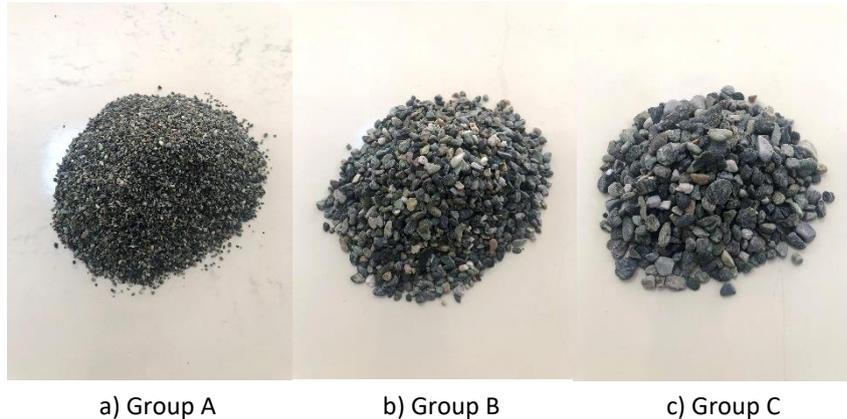


Figure 4. Granular materials having different gradations a) 1-2 mm, b) 2-5 mm, c) 5-10 mm. (Self-Elaboration).



54 shear tests were conducted to understand the interfacial friction characteristics and behavior between geocell blocks filled with granular material, the measurements made according to the ASTM D3080-04 (Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions). Different grain size distributions were used under three different normal stress levels (43 kPa, 86 kPa and 172 kPa). In addition, the effects of the relative densities (30%, 50% and 70%) on the interface properties between two geocell layers filled with granular material was investigated and recorded.

Results and discussion

Effect of normal stress

This study primarily concentrates on the interfacial behavior of two geocell units filled with granular material. The three gradation compositions are constituted by sieving granular material into 1-2 mm, 2-5 mm, and 5-10 mm grain sizes. The samples were prepared in three different relative densities 30%, 50% and 70 %, respectively. Both the samples with and without geocell were sheared under three levels of normal stress ($\sigma_n=43$ kPa, $\sigma_n=86$ kPa, $\sigma_n=172$ kPa).

Figures 5-13 indicate direct shear test results of the granular material samples with and without geocell having different gradations and relative densities under the three normal stress levels. The data from the figures exhibit the traditional stress-strain curves. The curves begin to slightly decrease after the maximum shear stresses are reached. When the curves for various samples with and without geocell are compared, it can be easily seen that the curves of samples with geocell are generally positioned above the other curves. The reason for this increase is based on the interpretation that the stress deformation graphs are shifted upward by the addition of the resistance of the geocell edges to the friction between the grains in the samples without geocell. Also, geocells allow the soil grains to move together, causing more resistance as these grains slide over each other. It is reasonable to say that geocell causes an increase in the stress-strain curves roughly in the range of 15% to 20%. When similar experiments in the literature are examined, it can also be seen that the results obtained from the experiments using the larger-sized shear rings are comparable to those in this study. Peak values of interfacial resistances are similar to each other in the experiments both with geocell and without geocell for the same normal stress levels and relative densities.

In Figure 5. When $Dr=30\%$ and normal stress $\sigma_n=43$ kPa, the peak values of shear stress for soil group A with and without geocell conditions are near 40 kPa. In the same graph, the other peak values of curves for normal stresses $\sigma_n=86$ kPa and $\sigma_n=172$ kPa are near 70 kPa and 140 kPa, respectively. At the highest normal stress, $\sigma_n=172$ kPa the difference in peak values between the samples with and without geocell are more evident. The next Figures 6 and 7 show that the increase in relative density of soil results with the equal peak values between the conditions with and without geocell. In Figure 7, note that when $Dr=70\%$ for each three normal stress level, the peak values of the curves with and without geocell samples are equal. This equality also can be seen clearly when the gradation changes. In Figures 8-10, when the soil sample B, which has a gradation of 2-5 mm, is measured at each normal stress level, the curves of samples with and without geocell have almost the same peak values of shear stress.

Figure 5. Shear Stress vs Shear Displacement of 1 mm-2 mm gradation under different normal stresses when $Dr=30\%$. (Self-Elaboration).

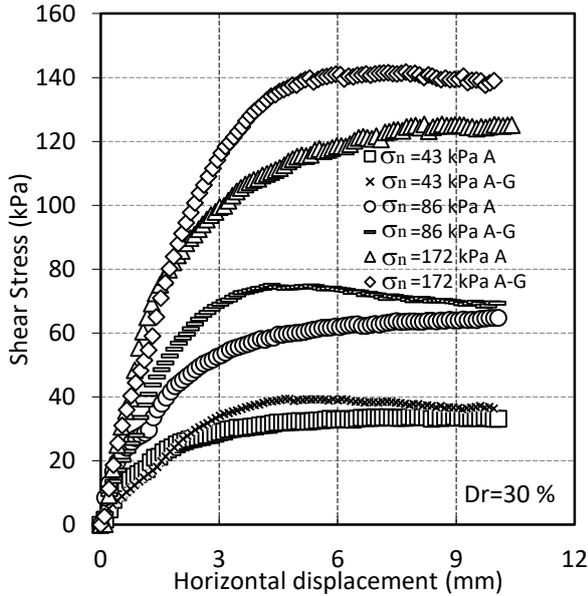


Figure 6. Shear Stress vs Shear Displacement of 1 mm-2 mm gradation under different normal stresses when $Dr=50\%$. (Self-Elaboration).

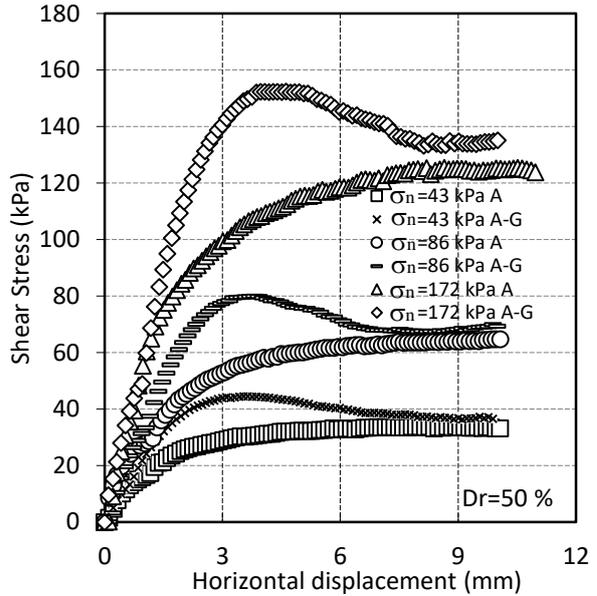


Figure 7. Shear Stress vs Shear Displacement of 1 mm-2 mm gradation under different normal stresses when $Dr=70\%$. (Self-Elaboration).

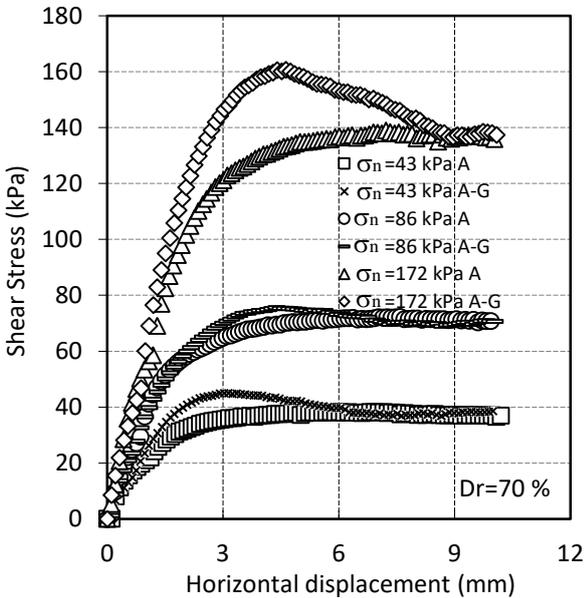


Figure 8. Shear Stress vs Shear Displacement of 2 mm-5 mm gradation under different normal stresses when $Dr=30\%$. (Self-Elaboration).

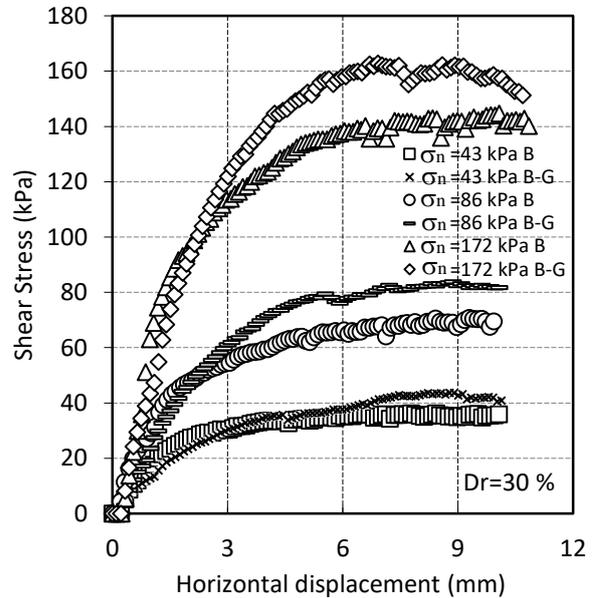


Figure 9. Shear Stress vs Shear Displacement of 2 mm-5 mm gradation under different normal stresses when $Dr=50\%$. (Self-Elaboration).

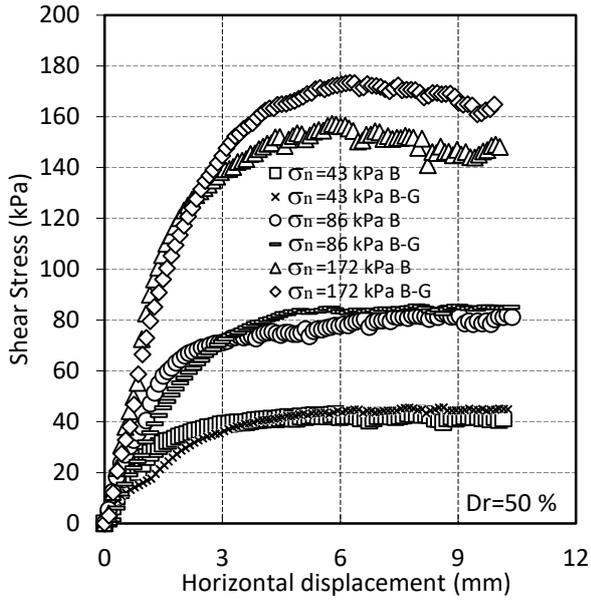


Figure 10. Shear Stress vs Shear Displacement of 2 mm-5 mm gradation under different normal stresses when $Dr=70\%$. (Self-Elaboration).

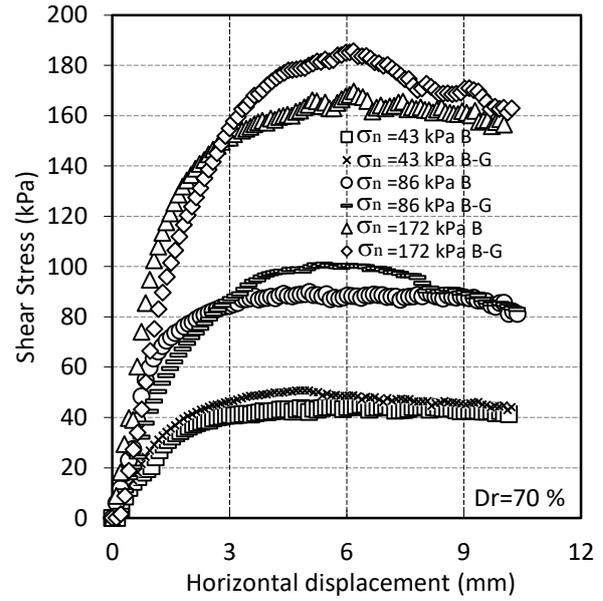


Figure 11. Shear Stress vs Shear Displacement of 5 mm-10 mm gradation under different normal stresses when $Dr=30\%$. (Self-Elaboration).

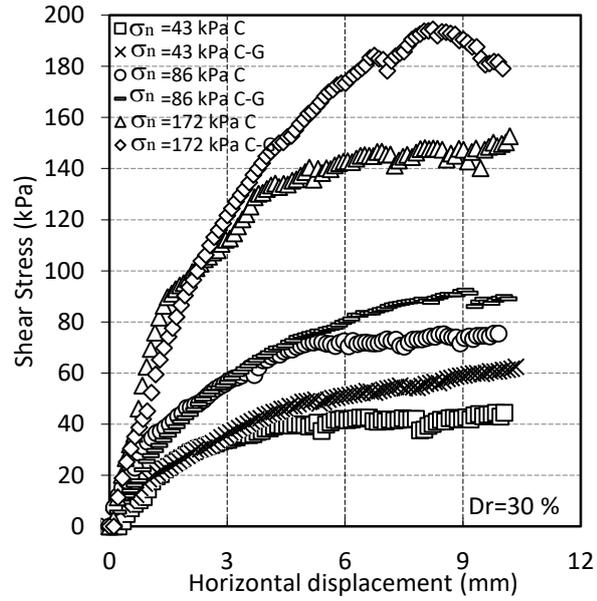


Figure 12. Shear Stress vs Shear Displacement of 5 mm-10 mm gradation under different normal stresses when $Dr=50\%$. (Self-Elaboration).

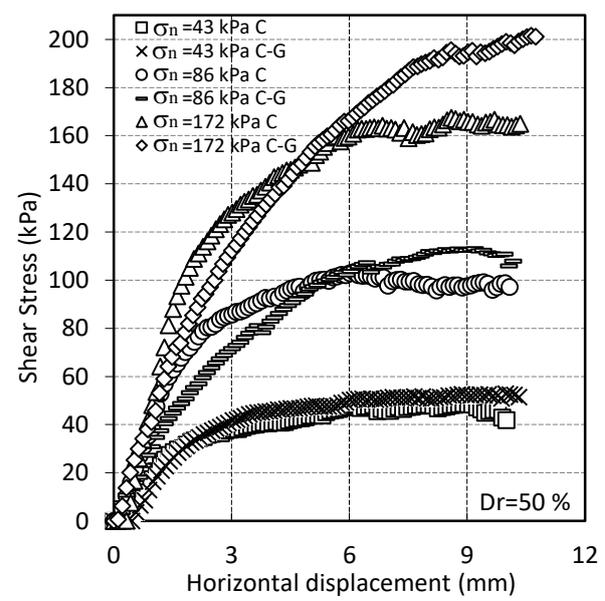
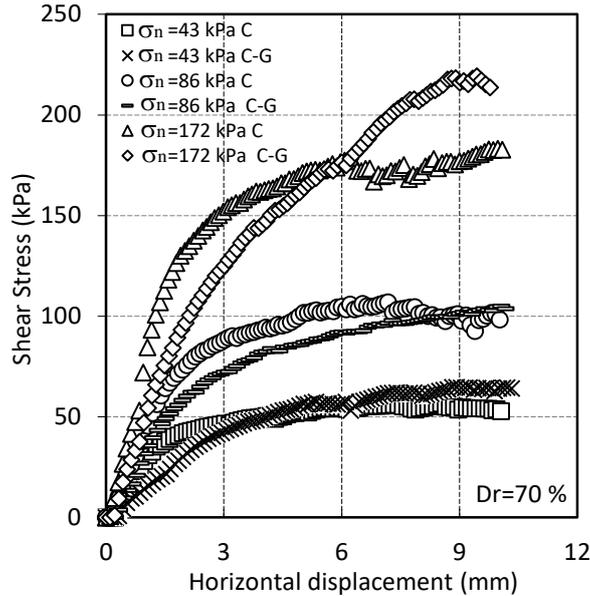


Figure 13. Shear Stress vs Shear Displacement of 5 mm-10 mm gradation under different normal stresses when Dr=70%. (Self-Elaboration).



Effect of gradation of soil

In this section, the effect of gradation on the interfacial behavior is presented; it is shown in Figures 14 through 22. When grain size increases, maximum shear stresses slightly increase in both experiments conducted with and without geocell. These increases become more apparent at the higher normal stress levels and in the samples with greater relative densities. This may result from the fact that the sample is a relatively round surface due to the granular material. On the contrary, if the grains were crushed stone which have sharper corners, the increases would be higher because it is obvious that the interlocking of the grains is weaker in round grained soils than it is when compared to crushed stone. In addition, when the grain size is increased, the deformations in which the samples reach maximum shear stress are greater. In other words, the stress deformation curves shift to the right as grain size increases. The increase in grain size also results in the highest shear stress values. For example, in Fig. 14 when Dr=30% and normal stress $\sigma_n = 43$ kPa, the highest shear stress is obtained for the curve of group C soil with geocell (C-G), which also has the biggest grain size distribution. When relative density increases, and the normal stress level remains at the same value of $\sigma_n = 43$ kPa (Figure 15 and 16), the highest shear stresses are similarly obtained for group C soil with geocell (C-G). The same phenomenon continues when the normal stress level increases (Figures 17-22). The highest shear stress measurement is obtained at approximately 220 kPa for C-G soil sample when $\sigma_n = 172$ kPa and Dr=70% in Figure 22.

Figure 14. Shear Stress vs Shear Displacement of different gradations when Dr=30% and $\sigma_n = 43$ kPa. (Self-Elaboration).

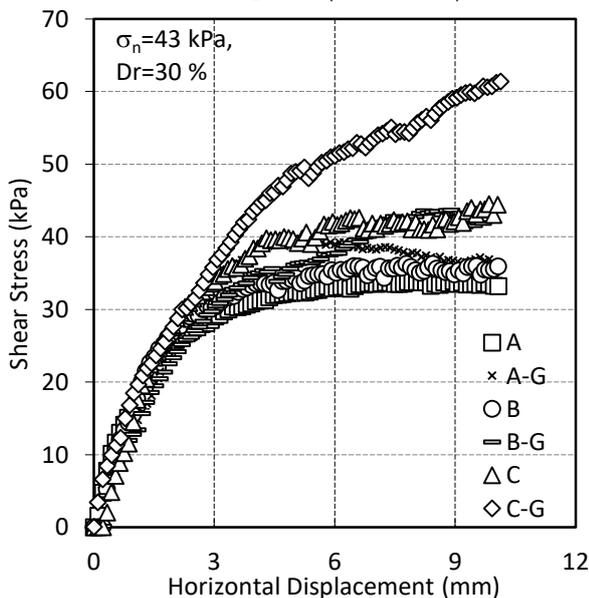


Figure 15. Shear Stress vs Shear Displacement of different gradations when Dr=50% and $\sigma_n = 43$ kPa. (Self-Elaboration).

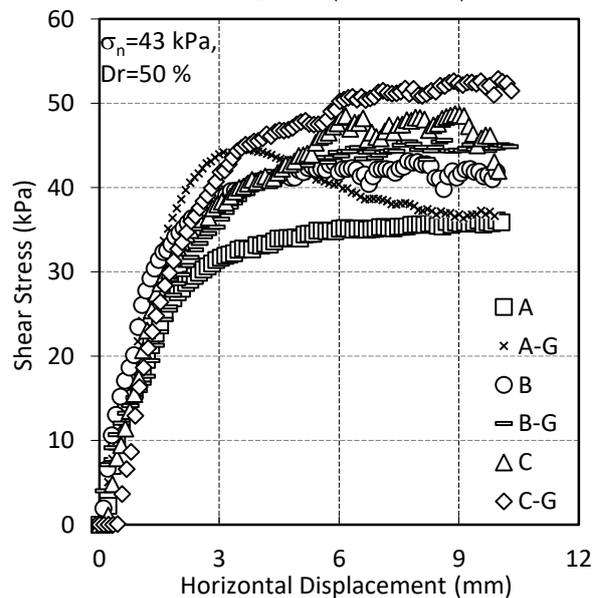
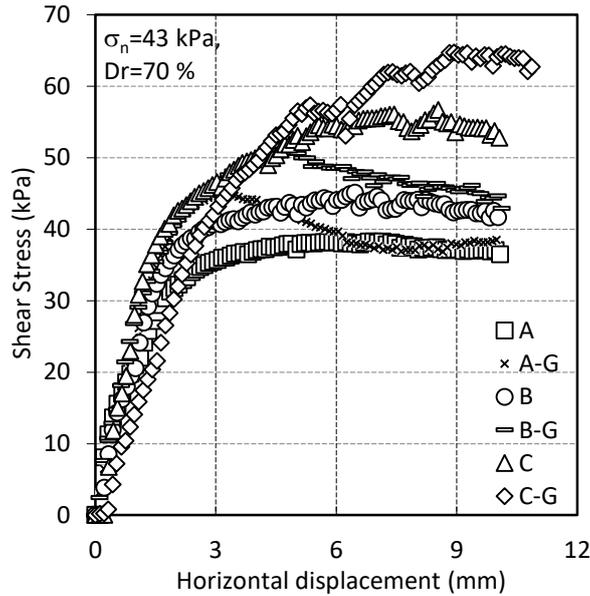


Figure 16. Shear Stress vs Shear Displacement of different gradations when $Dr=70\%$ and $\sigma_n=43$ kPa. (Self-Elaboration).



The strength envelopes, that is, the relationship of the maximum shear stress versus normal stress according to relative density, are presented in Figures 23-25. The envelopes shift upward, visibly rising in the inclination of the lines. Thus, it appears that the inclination of the envelopes is increased more noticeably when the geocell is used. This implies that the interface friction angle increased. The internal friction angle in the case of the samples without geocell varies from 32 to 43, while in the case of the samples with geocell, it ranges from 36 to 48 (Table 3). The other important point for the geocell reinforced soil is that there is an increase in the cohesion for all relative densities and grain size distribution even though the soil is cohesionless. The reason for this phenomenon is thought to be the compaction of geocell in the granular material, preventing lateral displacement and producing a reaction that holds the particles together. This effect is observed as cohesion under the direct shear test condition.

Figure 17. Shear Stress vs Shear Displacement of different gradations when $Dr=30\%$ and $\sigma_n=86$ kPa

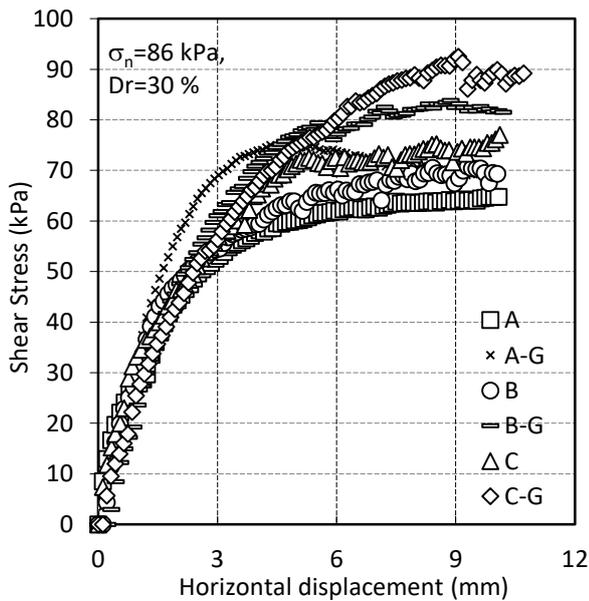


Figure 18. Shear Stress vs Shear Displacement of different gradations when $Dr=50\%$ and $\sigma_n=86$ kPa

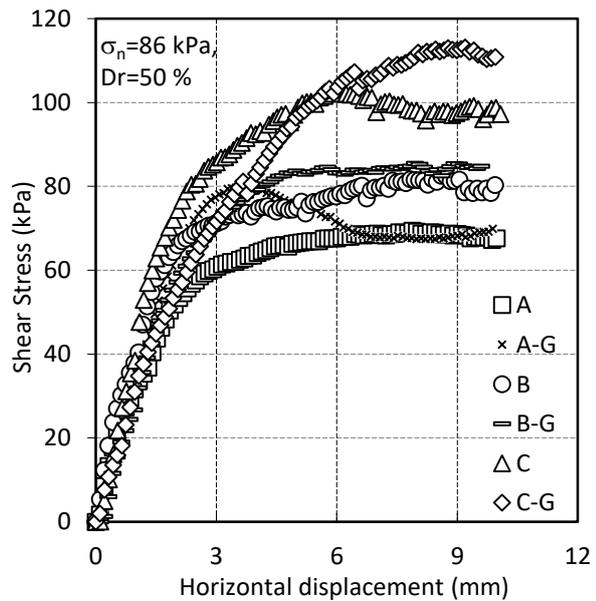
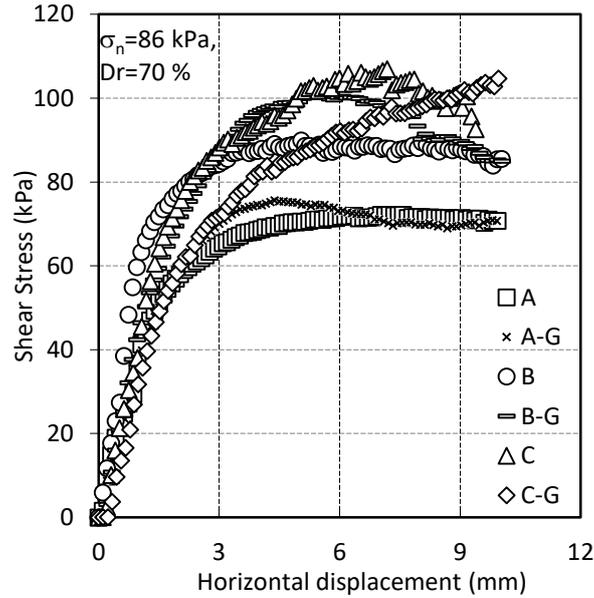


Figure 19. Shear Stress vs Shear Displacement of different gradations when $D_r=70\%$ and $\sigma_n=86$ kPa. (Self-Elaboration).



Regarding Table 3., there seems to be an increase in friction angle for various types of grain size distribution, shown as 1-2 mm, 2-5 mm and 5-10 mm. Regarding the friction angle, this increase is evident for all types of grain size distributions. The same phenomenon is observed for cohesion except for the grain size distribution of 5-10 mm. The aspect ratio is also given in Table 3., where it is defined as the ratio of geocell aperture size ($D_{geocell}$) to the average grain size of the soil samples (D_{50}) (Mehrzardi and Motarjemi, 2018). The most effective aspect ratio in this experimental study is measured at 4.8.

Figure 20. Shear Stress vs Shear Displacement of different gradations when $D_r=30\%$ and $\sigma_n=172$ kPa. (Self-Elaboration).

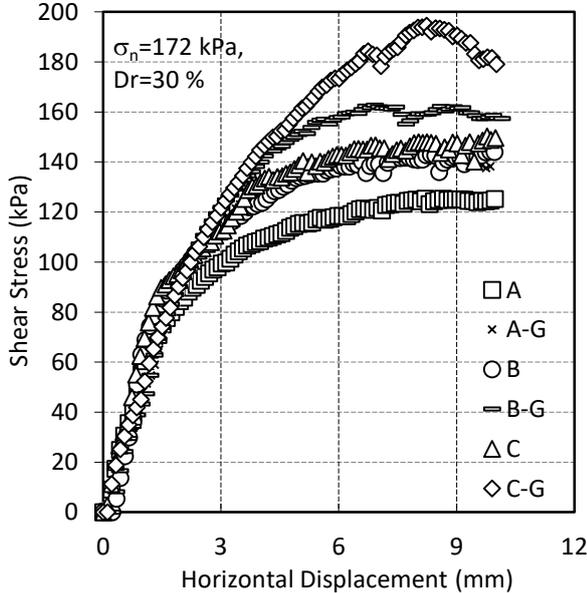


Figure 21. Shear Stress vs Shear Displacement of different gradations when $D_r=50\%$ and $\sigma_n=172$ kPa. (Self-Elaboration).

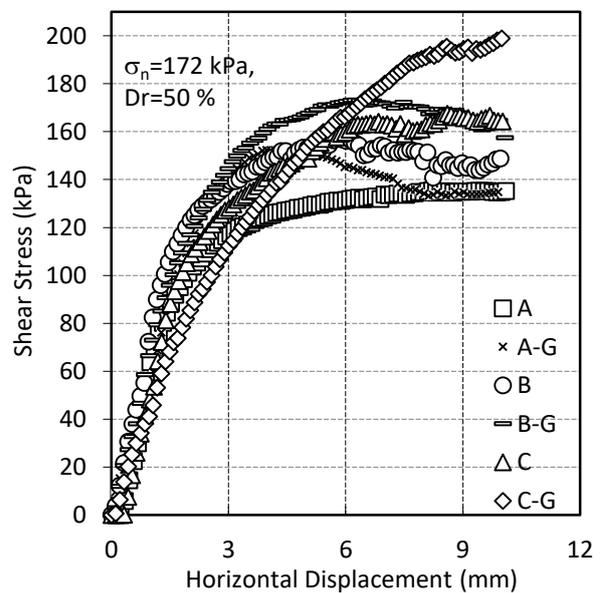


Figure 22. Shear Stress vs Shear Displacement of different gradations when $D_r=70\%$ and $\sigma_n=172$ kPa. (Self-Elaboration).

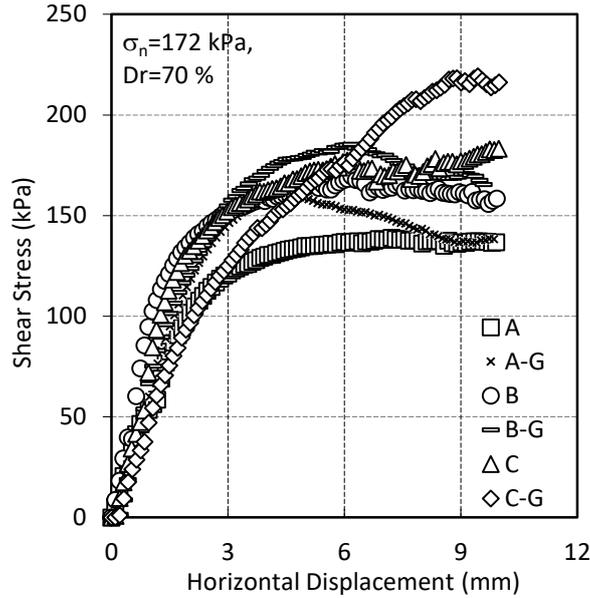


Table 3. Friction Angle of Granular Materials Under Different Relative Densities. (Self-Elaboration).

Group	Aspect Ratio	Friction Angle (Degree)		
	$D_{Geocell}/D_{50}$	$D_r=30\%$	$D_r=50\%$	$D_r=70\%$
1-2 mm (A)		33.0	35.1	35.5
2-5 mm (B)		37.0	40.7	41.9
5-10 mm (C)		37.3	41.5	43.1
1-2 mm (A-G)	20	36.0	41.0	40.4
2-5 mm (B-G)	7.5	40.7	42.0	43.8
5-10 mm (C-G)	4.8	45.0	46.5	47.8

A=Type A without geocell
 B=Type B without geocell
 C=Type C without geocell
 A-G=Type A with geocell
 B-G=Type B with geocell
 C-G=Type C with geocell

Another important behavior apparent from the test results is an increase in the stiffness of the granular material as it is reinforced by geocell. For all relative densities and grain sizes, the relation between shear stress and horizontal displacement is a gradual increase according to type, approaching a limit value; this is the typical behavior for the loose granular materials. But in the case of granular material with geocell, this graph passes through the peak value and then gradually decreases towards a limit value, revealing the behavior of dense granular material. Thus, it can be concluded that the granular materials gain an amount of cohesion and behave stiffer when reinforced by geocell. It can further be stated that due to the increase in rigidity (or elastic modulus) of granular material, less settlement can be expected under the same loads for the geocell applied case compared to the cases without geocell.

Figure 23. Linear Mohr-Coulomb failure envelopes of soil and between two geocell filled with soil of different gradation when $Dr=30\%$. (Self-Elaboration).

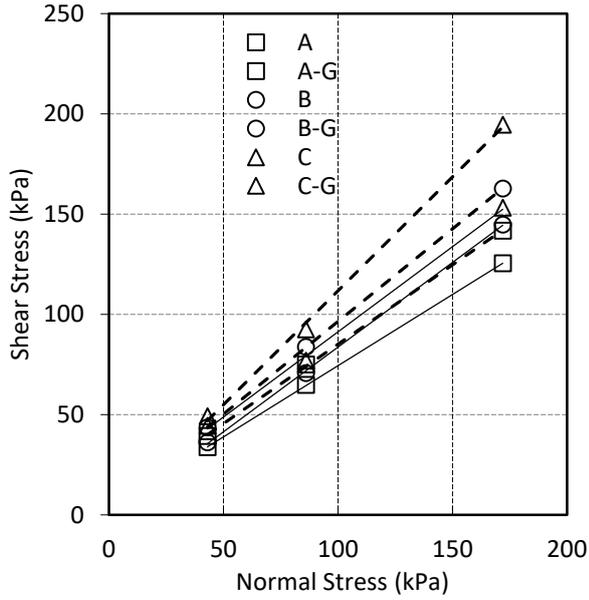


Figure 24. Linear Mohr-Coulomb failure envelopes of soil and between two geocell filled with soil of different gradation when $Dr=50\%$. (Self-Elaboration).

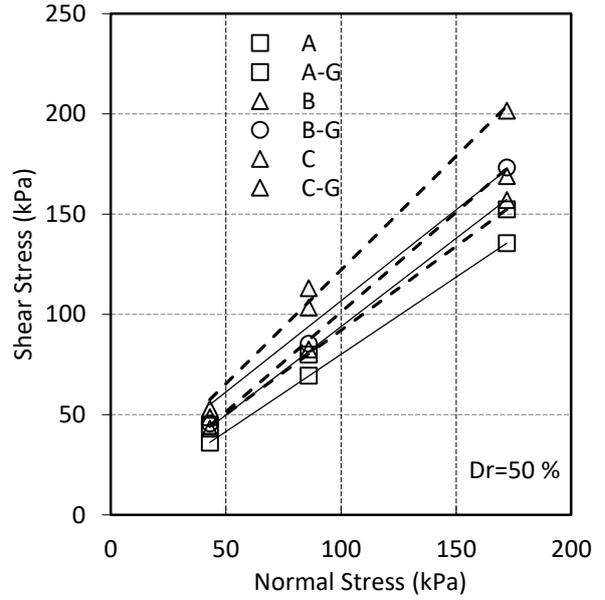
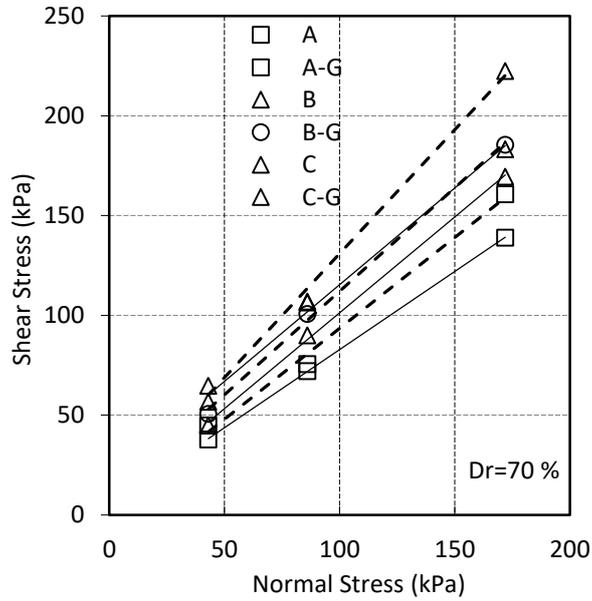


Figure 25. Linear Mohr-Coulomb failure envelopes of soil and between two geocell filled with soil of different gradation when $Dr=70\%$. (Self-Elaboration).



Experimental work on interface frictional behavior between two types of geocell filled with granular material is introduced in this study. This geo-mechanical fact must be utilized during the design process of geocell-reinforced soil structures, such as slopes, earth walls, roadway applications and embankments reinforced with geocell. For this purpose, 54 direct shear tests in total were carried out to obtain the measurements of the internal friction of granular material and interface friction between geocell filled with granular material. The findings from this article can be summarized as follows;

- As a result of the analysis of data obtained from experiments, the variation of interface resistance versus displacement behaves like the traditional load-displacement of granular material. As expected, normal stress plays an influential role in these experiments. When normal stress levels increase, the peak values of the interface resistance also increase.
- Due to the edge contact of the geocell, the interface resistance of the samples with geocell is demonstrated to be greater than those without geocell conditions. This results in an increase of approximately 15-20 % in peak values.
- The strength parameters (interface friction angle, cohesion effect) and stability of the samples with geocell are notably affirmed to be greater than those of samples without geocell. There can be an increase of 9 % in the interface between friction angles on average.
- The geocell offers little cohesion effect to grains due to the confinement of the grains within a limited volume.
- The samples with geocell behave with greater stability, owing to the increase in rigidity (or elastic modulus) of granular material even if it is loose, compared to the samples without geocell.
- With regards to the experiments conducted with the larger grain size, the interface resistance between two geocells filled with granular samples is higher. This effect is also more pronounced at a high relative density.

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