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An Experimental Study on Geogrid with Geotextile Effects Aimed to Improve Clayey Soil

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ABSTRACT

The increase of shear strength in soil, reinforced with the geogrid (*alternate reinforcer*), is resulted from an increase of modulus of soil hardness, and also from the tensile strength of reinnforcer. The shear strength of contact surface in soil appears due to both the friction strength against the contact surface, and the passive strength formed in front of the elements of the geogrid system. In the clay reinforced with a geogrid, the resistance of the contact surface is low; therefore, contact surface rupture occurs before the tensile strength reaches the ultimate limit. Also, the geogrid is almost ineffective in limiting particles movement and creating passive resistance in clay, due to a big difference in the sizes of geogrid opening (a perture) comparing to clay grains. In this research, we tried to examine the effect of geotextile layers around the geogrid aimed to improve the soil-geogrid interaction in different drainage conditions by means of triaxle (UU) and (CD) trials on a large scale. Experiments were carried out, based on non-reinforced samples, geogrid-reinforced samples and geocomposite reinforced samples. The results of the experiments showed that the geotextile layers around the geogrid in the clay reinforcements not only effectively improved the interaction of contact surface, where the stresses are concentrated on the geogrid, but enhanced the shear strength parameters, the consolidation and drainage processes, as well. Radiographic results taken from fractal samples indicated that the rupture plate gets a reflection state in the reinforcing elements at the location of geocomposite configurations only, relative to the reinforcing elements. Meanwhile, the geogrid layers did not have any impact on the changes of rupture surface situation.

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1. INTRODUCTION

Since the past decades, soil reinforcement method has been mostly applied with coarse grained material, as a backfill material. But, recently, applying fine grained material containing lower quality is inevitable due to local accessibility and the economy [1]. On the whole, depending on the soil in the contact surface with the geogrid; it is possible either of the following mechanism appears [2]:

1. All the stresses that concentrated on the reinforcing element as a tensile stress almost established in only coarse grained soil which has an appropriate interaction with reinforcement element. Therefore, in this case, the reinforced soil strength is limited due to the tensile strength of geogrid.
2. In the event of a soil slide on the geogrid, resulted in from lower strength of soil contact surface-geogrid in the clayey, and saturated soils, in particular; consequently, an improper interaction of soil-geogrid and poor resistibility of the adjacent soil are appeared. In this condition, the reinforcer will act like a surface that functionally remains unused in a soil mass, in such case this mechanism of rupture is so called direct shear mode in the contact surface which it happens before the whole tensile strength concentrated in the geogrid [3]. For this very reason, mainly, there is not any reinforcement plan with a suitable performance aimed for the clayey and fine

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grained soils. Therefore, the objectives of this research paper, including installation of geotextile layers at the two sides of geogrid are defined, firstly for improvement of the interaction condition in the contact surface of soil-geogrid, by means of geotextile, and secondly for assessment of the soil strength enhancement.

The probability of this improvement will be much higher when we realize that the most shearing stresses that are released from around the reinforcement, are promptly reduced, proportionally to the development of materials application process [4]. Additionally, as clay particles penetrate the geotextial pores because of the low stress strength; it is mostly employed for the reinforcement of clay [5].

Therefore, it seems if the geotextile layers are employed around the reinforcement elements in the low quality backfills, the interaction conditions will be remarkably improved and led to the concentration of stresses into the surface of geogrid as the high shear stresses, appeared around the contact surface.

Furthermore, it will be feasible to study various drainage conditions by means of triaxial tests including the behaviour assessment and strength parameters [6]. Therefore, triaxial tests in the states: UU and CD were employed in this research work. So far, it is worth to mention, most research works have been performed for the purpose of assessment of interaction of soil-geotextile contact surface in non-cohesive gravel and sand masses; while, at the contrast less researches have been carried out on the cohesive soils.

2.MATERIALS AND METHODS

The soil used in this research is of Kaolinite clay type. The characteristics of this soil are provided in Table 1 defined according to the relevant ASTM standard, and it is referred to as class: clay of low plasticity (CL). This soil is based on unified soil classification system (USCS) having considered the soil distribution aggregates and the test results of Atterberg limits.

2. 1. Materials Properties

The geosynthetic studied was a reinforcement geocomposite consisting of geogrid in middle and two geotextile layers on both sides of geogrid. Table 1 summarises some characteristics of geocomposite, with indication of the corresponding test methods. Kaolinite was used as the clay soil for the testing program. The index properties of the clay and sand were determined according to the appropriate ASTM standards and are summarized in Table 2. According to unified soil classification system (USCS) the clay was classified as inorganic clay of low plasticity (CL). Figure 1 illustrates the particle size distribution of the soil.

TABLE 1. Engineering properties of geosynthetic

Geotextile	Test Method	Value
Mass per unit area (g m^{-2})	EN ISO 9864	262 (±14)
Thickness (mm)	EN ISO 9863-1	2.37 (±0.10)
Tensile strength (kN/m)	EN ISO 10319	12.00 (±1.20)
Elongation at maximum load[a] (%)	EN ISO 10319	56.4 (±2.5)
Geogrid		
Longitudinal rib width (mm)	-	6
Transverse rib Width (mm)	-	5
Tensile strength (kN/m)	EN ISO 10319	22
ε max[a] (%)	EN ISO 10319	10.3

[a] machine direction of production

TABLE 2. Properties and classification of the fine soil

Kaolinite clay	Test method	Value
Liquid limit (%)	ASTM D4318	46
Plastic limit (%)	ASTM D4318	26.3
Plasticity index (%)	ASTM D4318	19.7
Optimum moisture content (%)	ASTM D698	22.4
Maximum dry density (g/m^3)	ASTM D698	1.62

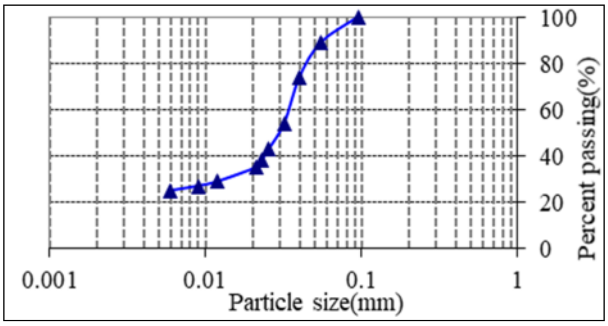

Figure 1. Particle size distribution of the fine soil

2. 2. Characterisation Tests

For calculating the shear strength parameters in different reinforcement mode, were used UU triaxle test compliant with ASTM D2850 - 03a (2007) and CD compliant with ASTM D7181 - 11 standards (Table 3). The common methods of preparing large scale samples for unconsolidated undrained triaxle test are: Dry method, moist method, dry pluviation, wet pluviation [7]. Among these, the moist tamping method allows for specimen preparation with arbitrary relative density and achieves sufficient homogeneity through the application of different compaction efforts on each layer; thus, compacting each layer to the same density [8]. Considering the characteristics of these methods, the moist tamping method was selected for large-scale triaxle soil specimen preparation in this study. All samples were thoroughly mixed with optimum moisture content.

TABLE 3. Summary of the test program

Reinforcement Mode	N. of Layers	Position*	Type of Test	W	D (mm)	H (mm)
Without Reinforcement	-	-	UU CD	Opt Sat	152.5	305
Reinforced with Geogrid	1	H/2	UU CD	Opt Sat	152.5	305
	2	H/3	UU CD	Opt Sat	152.5	305
	3	H/4	UU CD	Opt Sat	152.5	305
Reinforced with Geocomposite	1	H/2	UU CD	Opt Sat	152.5	305
	2	H/3	UU CD	Opt Sat	152.5	305
	3	H/4	UU CD	Opt Sat	152.5	305

* From the top of the specimen

They were then sitting in a curing tank with the same moisture content for at least 24 h before specimen making. The clay soil samples were poured layer-by-layer (five layers) into cylindrical steel moulds. Then, the clay soil samples were compacted such that all layers had the same specific density, and the surfaces of each layer were scratched to ensure better bonding with the next layer. The degree of compaction of each layer was 95%, and reinforcements layers were embedded at suitable heights. For CD tests, samples were saturated before applying the vertical stress, with back- pressure compatible with σ_3. After completion the saturation process, the isotropic consolidation procedure was applied with the specimen drainage valves open; the full consolidation was take 24 h during testing.

All triaxle specimens were prepared similarly and the reinforcement in reinforced soil specimens has not any contact with the membrane. Figure 2 shows the position of reinforcement in different samples.

For drawing Mohr circles, all triaxial test were performed with 1.5, 3 and 4.5 kg/cm^2 as σ_3. In all of the test, the shearing speeds were controlled by the axial

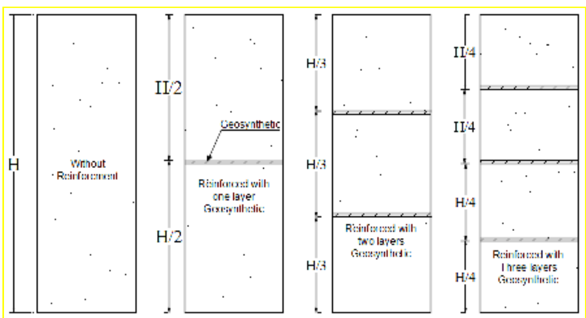

Figure 2. The arrangement of reinforcement in different samples

loading rates of 0.64 mm/min (UU) and 0.026 mm/min (CD). The triaxial test was terminated when the axial strain reached 20% or the stress reached the critical condition [9].

During testing, the shear stress, shear strain, consulidation, drainage, specimen failure shapes were investigated.

3. RESULTS AND DISCUSSIONS

In this section, the results of triaxle tests in (UU) and (CD) are discussed.

3. 1. Stress - Strain Diagrams

The stress-strain diagrams for cluster samples are shown in Figures 3-6 for the UU mode in various reinforcement states at confining pressures of 1.5, 3, and 4.5 bars, respectively. The first curve or the lowest curve in these graphs is for the non-reinforced clay and the subsequent curves are related to the 1, 2, and 3 layers of the geogrid. They all have a peak shear stress point, which indicates the failure of the contact surface of the geogrid before reaching the reinforce to its final tensile strength. The highest curves are related to the 1, 2, and 3 geogrid layers with geotextile (Geocomposites), which lack the maximum stress point, and the shear stresses even at the end of the experiments, the upward gradient with very low slope are shown. This behaviour reflects the mobilization of tensions at the reinforcement level and the use of geogrid tensile strength due to the improvement of the condition of the action which is because of the presence of geotextile. Comparison of the curves of samples arranged by geogrid layers with a curved pattern of samples arranged by geogrid layers enclosed with geotextile, is similarly observed, as expected. Furthermore, according to the predictions, the presence of geotextile around geogrid causes the enhancement of surface contact conditions and interaction of soil-geogrid, and consequently improves the shear strength of the soil. The existence of stress and strain effects in the geogrids covered by geotextile, as shown in Figure 7, is also an evident in this connection; meanwhile it is worth to mention, the geogrid which is extracted from a sample, reinforced by pure geogrid remains perfectly sound and free of any strain effects.

Another important point to be drawn from the graphs is the effect of the presence of geotextile layers around the geogrid on the increase of the gradient of the linear region and thus it is the increase of the soil elastic modulus.

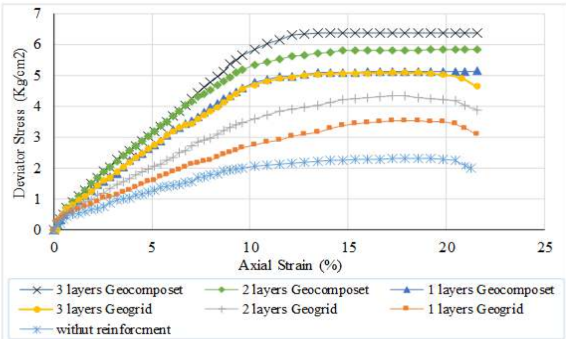

Figure 3. Stress-strain diagrams at confining pressure σ_3=1.5, UU mode

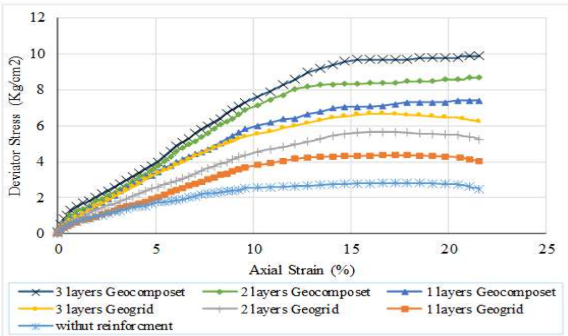

Figure 4. Stress-strain diagrams at confining pressure σ_3=3, UU mode

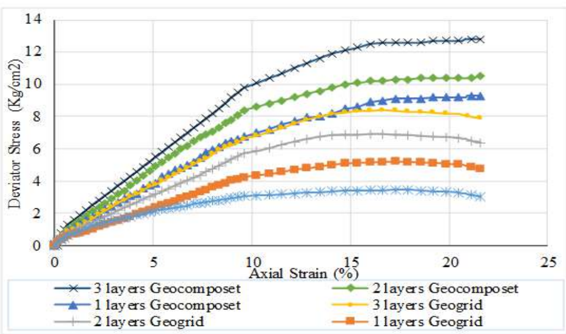

Figure 5. Stress-strain diagrams at confining pressure σ_3=4.5, UU mode

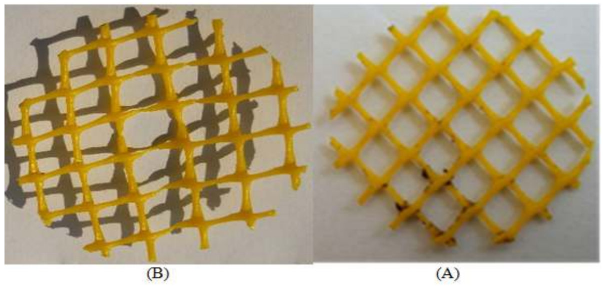

Figure 6. (A): Geogrid extracted from a geogrid reinforced sample (B): Geogrid extracted from Geocomposite reinforced sample

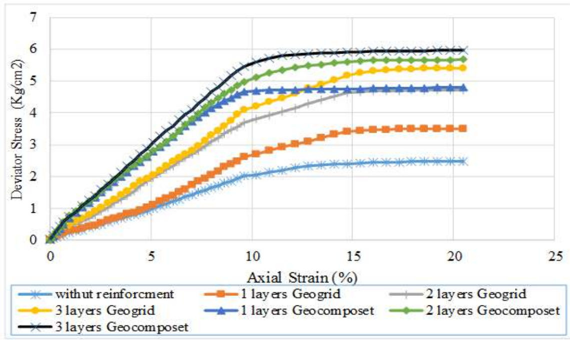

Figure 7. Stress-strain diagrams at confining pressure σ_3=1.5, CD mode

This is consistent with the results of Carlos, et al. (23), who evaluated the geocomposite-reinforced sample through a triaxle test.

Based on the comparison of the graphs concerning different confining pressures; in general, like the report [10] on clay soil reinforced with geotextile presented by Noorzad and Mirmoradi [11], we found that by increasing the confining pressure, the tolerance of stresses increases by the samples, under different reinforced conditions. But, it is interesting to know, this increase in geocomposite-reinforced samples is higher, in other words, the specimens merely reinforced with geogrid do not show much sensitivity to the increase of lateral tension, which is due to both the absence of friction and the sufficient interaction between soil and geogrid.

The rate of stress increase that can be tolerated by a reinforced sample (reinforced with one geogrid layer covered with geotextile (geocomposite) relative to a merely geogrid-reinforced sample for confining pressure at about 1.5 kg/cm^2 it is about 44.5%; and for confining pressure at about 4.5 kg/cm^2 it is about 71%. Considering the stress-strain diagrams for the clay sample in various conditions of reinforcement and in the mode of (CD) are presented in Figures 8, 9 and 10. Perhaps, a question would be set forth why the final stresses differ in the same side pressures for the different states of reinforcement in the (UU) and (CD) situations, but it should be noted that test (UU) has been conducted on the samples in the optimum humidity mode, while clay samples have been saturated before the test (CD) during the post-pressure application process; so the sample behaviour, in each of the reinforcement states, should be compared to that of the sample in other reinforcement states, besides that in the same drainage conditions.

By observing these diagrams, the effectiveness of geotextile layers on the improvement of the soil-geogrid interaction is clearly evident in the conditions of sample saturation and being the drainage valves open. It is noteworthy to mention that none of the samples showed a maximum shear stress point, unlike the UU; even at the end of the experiments the shear stresses increase at the very low gradient. This behavior represents a gradual cut in the fracture surface. Liu et al. [12] precisely reported the same behavior with direct cutting experiments on clay-geogrid samples. Thus, an increse in the stress strength of a sample reinforced with geogrid layer, covered with geotextile (geocomposite) relative to the increase of a sample reinforced with geogrid only, respectively are at about 1.5 kg/cm^2, 36.5%, and 4.5kg/cm^2 65% for the confining pressures.

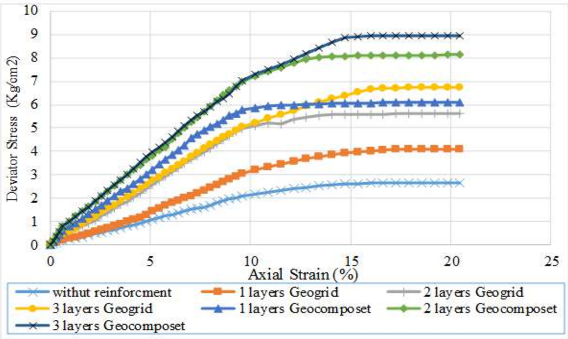

Figure 8. Stress-strain diagrams at confining pressure σ_3=3, CD mode

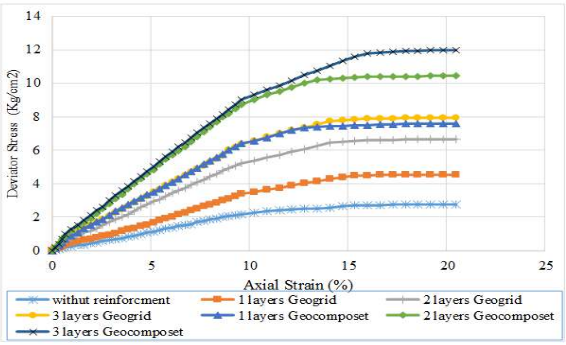

Figure 9. Stress-strain diagrams at confining pressure σ_3=4.5, CD mode

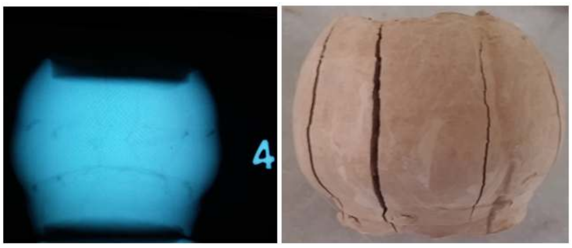

Figure 10. the reinforced sample with one layer of geogrid

3. 2. Shear Strength Parameters

The values of the internal friction angle (φ) and adhesion (C) presented in Tables 4 and 5, respectively for the modes (UU) and (CD). As Shin [13] reported for the shear strength of the reinforced soil at the contact surface is due to the formation of frictional resistance between the reinforcement and the soil, as well as due to the elastic resistance (passive) developed among the cross-sectional elements of geogrid; therefore, both factors, and the latter in particular, have an effect on the internal friction angle of the soil [14, 15].

The increase in the internal friction angle in UU mode for a sample reinforced with 1, 2, and 3 layers of geogrid covered with geotextile (geocomposite) are equal to 72.8, 53.6 and 43%, respectively compared to a sample reinforced with geogrid only. One of the reasons for this noticeable distinction is due to the variable sizes of the geogrid openings compared to the sizes of the clay grains. In general, the geogrid must limit the movement of soil granules in order to increase the friction resistance of the contact points of mobilized gravel due to which the resistance of the soil system is improved. But, the geogrid is almost ineffective in limiting particles motion, due to the fineness of clay grains. However, being the geotextile

TABLE 4. Shear resistance parameters in (UU) mode

Reinforcement mode	N.of Layers	C (kg/cm^2)	Φ (degree)
Without Reinforcement	-	0.74	9.05
Reinforced with Geogrid	1	1.08	12.9
	2	1.14	17.7
	3	1.18	21.04
Reinforced with Geocomposite	1	1.13	22.3
	2	1.04	27.2
	3	0.99	30.1

TABLE 5. Shear resistance parameters in (UU) mode

Reinforcement mode	N. of Layers	C (kg/cm^2)	Φ(degree)
Without Reinforcement	-	1.13	2.6
Reinforced with Geogrid	1	1.31	8.4
	2	1.47	13.9
	3	1.56	17.1
Reinforced with Geocomposite	1	1.21	18.5
	2	1.03	26.3
	3	0.88	29.5

layers at the soil-geogrid interface leads to improvement in their interaction, consequently the stresses, induced are mobilized in the form of tensile stresses at the reinforcing surface. This prevents the use of unused geogrid capacity in the soil, and significantly improves both the mechanical properties and shear strength parameters of clay soil.

The trend of changes in the adhesion rate concerning both (UU) and (CD) modes initially increases but then it begins to decrease. The adhesion obtained in a condition of the reinforcement with geogrid is likely due to a soil with soil contact in the geogrid openings, as well as due to the presence of a suction agent in a reinforced geocomposite sample. It is worth to mention; this is to more likely occur in the case of a (CD) saturation sample. Also, having observed the samples after the laboratory tests; it is simply visible that their geotextile fibres and clay particles are well penetrated each other, and consequently a very appropriate bond is formed at the contact surface.

The degrees of increase of the internal angle of friction in the (CD) state concerning a sample reinforced with 1, 2, and 3 layers of geogrid and covered with geotextile (geocomposite) are 120, 89, and 72%, respectively; comparing to a sample reinforced with geogrid only. Generally, a reduction of the increasing curviness in the amount of shear strength parameters, resulted in from an increase in the number of geocomposite layers, shows there is an optimal spacing between the reinforcing layers. It seems, this optimal spacing is dependent on the properties of clay soil and geocomposite, and also on the moisture content. Moreover, it is worth to mention, the geocomposite layers that are established in a clay embankment will not only increase the shear strength of the soil, but also can act as horizontal drainage layers to prevent cavernous water pressures, if the embankment is saturated.

3. 3. Consolidation and Drainage Parameters After the tests (CD Tests), the water volumes of the outlet resulted in from drainage and consolidation are measured and summarized in Table 6.

Based on the water volumes of the outlet resulted in from drainage and consolidation, it can be concluded that the existence of geogrid layers alone can be effective in improving the trend of consolidation and drainage, though it is insignificant. Furthermore, the geotextile layers around the reinforcement and the increase in the number of layers of geocomposite are also highly effective in consolidation and drainage, and to a great extent, facilitate the process of water outflow from clay samples. This appears to be directly related to the porosity generated by the reinforcer in the sample. However, an increase in the content percentage of the saturated moisture in the sample proves an increase in the quantity of porosity, as the sample, too, is reinforced with the geocoposite.

3. 4. Radiography Results After the experiments, samples were taken for radiography to check the rupture plate condition in the presence of geogrid and geocomposite. These images are prepared by means of X-ray tube for which SWSI technique, Kodak film (MX125), Factor 120, Kv=70, SFD= 0.8m, Ug= 0.025 and Exposure Time= 45s are employed relying on a full range of individual safety and environmental protection system.

Figure 11 refers to the sample reinforcement with a geogrid layer, and Figures 12 and 13, respectively, show the images of samples arranged with one and two layers of geocomposite. These images have been prepared after the samples are dried and the cracks are appeared after the test (UU). These images show that the rupture plate, due to only the geocomposite reinforcement, can have reflective or mirror state relative to the reinforcement elements, but with the geogrid layers there is not any effect in the changes of ruprture plate condition. The reason of which is the the geogrid capacity, that cannot limit the movement of soil particles. However, the geotextile layers setting at the soil-geogrid interface leads to improved interaction and increased friction resistance mobilized in the contact points of the grains

TABLE 6. Values of consolidation and drainage in (CD) mode

Reinforcement mode	N. of Layers	σ_3 (kg/cm^2)	Consolidation (cm^3)	Drainage (cm^3)
Without Reinforcement	-	σ_3=1.5	57.1	103.5
		σ_3=3	104.92	187.9
		σ_3=4.5	207.4	283.5
Reinforced with Geogrid	1	σ_3=1.5	179.53	295.5
		σ_3=3	250.9	394
		σ_3=4.5	298.9	412
	2	σ_3=1.5	222.7	320.2
		σ_3=3	229.4	401.5
		σ_3=4.5	334.6	457
	3	σ_3=1.5	232.4	339.5
		σ_3=3	269.6	456.3
		σ_3=4.5	375	526.6
Reinforced with Geocomposite	1	σ_3=1.5	278.5	527.4
		σ_3=3	341	736.7
		σ_3=4.5	514.7	741
	2	σ_3=1.5	427	716
		σ_3=3	561.3	941.6
		σ_3=4.5	703.6	1035
	3	σ_3=1.5	502.11	877.5
		σ_3=3	637.4	1179
		σ_3=4.5	873	1276

Figure 11. the reinforced sample with one layer of geocomposites

Figure 12. the reinforced sample with two layers of geocomposites

Figure 13. Behavior of Geogrid in different stages

4. CONCLISIONS

As the interaction between soil and reinforcer is insufficient, thereby it is taken that the main problem is with the clay reinforcement in soil. This can possibly be solved, by means of applying and installing the geotextile, either around or at the both sides of geogrid layer, adjacent to the contact surface of reinforcer (geogrid) or at the interface of soil and reinforcer.

For this purpose, the soil-geogrid-geocomposite shear parameters including chosion and angle of friction have been assessd, under different drainage conditions, by means of UU and CD triaxial tests on 6- inch speciemens. These samples are reinforced with the different layers of geogrid or geocomposite (geogrid placed between geotextile layers). Also, the values of consolidation and drainage are compared in the different conditions of reinforcement.

After analyzing the results of triaxial tests in different reinforcements and drainage conditions, the following results are obtained as briefly stated below:

1. Most portion of the geogrid strength remins untouched during the rupture of the contact surface in the sample, reinforced with geogrid.
2. The results of the tests show that as the geogrid covered with the geotextile layers, therefore the shear strength of the clayey soil is remarkably improved through increase of the interaction in the contact surface.
3. The increase of both porosity and saturation moisture rates is due to the geocomposite layers availability.
4. The application of geocomposite layers remarkably makes drainage and consolidation rates, as well as, the last moisture rate increase and reduce respectively, besides that they improvr friction strenght leading to increase of shear strenght rate.
5. Having visually inspected the surfaces of the specimen ruptures, after the tests performed it is seen that the clay particles penentrate the geotextile and consequently a good bond is set up on the contact surface. Furthermore, due to a shear stress reduction in the soil in where a distance is created from the reinforcer according to which these stresses are easily absorbed by the contace surface of clay-geotextile.
6. The results of photography, taken from the specimens ruptured, show that the rupture plate suffers reflection at the geocomposite reinforcer point relative to reinforcement elements and thereby the geogrid layers impact on the change of rupture plate situation is nill.

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An Experimental Study on Geogrid with Geotextile Effects Aimed to Improve Clayey Soil

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چکیده

افزایش مقاومت برشی خاک مسلح شده با ژئوگرید از دو عامل افزایش مدول خاک و مقاومت بالای مسلح‌کننده در کشش ناشی می‌شود. مقاومت کششی مسلح‌کننده در درون خاک حاصل از مقاومت اصطکاکی سطح تماس و ایجاد مقاومت پاسیو ایجاد شده در جلو المان‌های متقاطع عرضی ژئوگرید می‌باشد. در خاک رس مسلح شده با ژئوگرید، مقاومت سطح تماس پایین بوده و درنتیجه گسیختگی سطح تماس قبل از رسیدن مقاومت کششی مسلح‌کننده به حد نهائی رخ می‌دهد. همچنین به دلیل تفاوت فاحش بین اندازه چشمه‌های ژئوگرید در مقایسه با دانه‌های خاک رس، ژئوگرید در محدود نمودن حرکت ذرات و ایجاد مقاومت پاسیو در خاک رس تقریباً بی‌تأثیر است. در این پژوهش سعی شده تا با استفاده از آزمایش‌های سه‌محوری (UU) و (CD) **در مقیاس بزرگ**، اثر وجود لایه‌های ژئوتکستایل در اطراف ژئوگرید بر بهبود اندرکنش خاک- ژئوگرید در شرایط مختلف زهکشی بررسی شود. این آزمایش‌ها بروی نمونه‌های فاقد مسلح‌کننده، مسلح شده با لایه‌های ژئوگرید و مسلح شده با لایه‌های ژئوکامپوزیت انجام گرفت. نتایج مطالعات و آزمایش‌ها نشان داد که وجود لایه‌های ژئوتکستایل در اطراف ژئوگرید در تسلیح خاک رس به نحو مؤثری سبب بهبود اندرکنش سطح تماس و بسیج شدن تنش‌ها بروی ژئوگرید شده و نه‌تنها باعث ارتقاء پارامترهای مقاومت برشی می‌گردد، بلکه سبب بهبود فرایند تحکیم و زهکشی نیز می‌شود. نتایج پرتونگاری به عمل آمده از نمونه‌های گسیخته شده حاکی از آن بود که صفحه گسیختگی فقط در محل حضور مسلح‌کننده ژئوکامپوزیت، دچار انعکاس یا حالت Mirror نسب به المان مسلح‌کننده می‌شود و وجود لایه‌های ژئوگرید تأثیری بر تغییر وضعیت صفحه گسیختگی ندارد.

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