JES, Vol. 52, No. 1, Jan 2024 DOI: 10.21608/JESAUN.2023.221832.1243 Part A: Civil Engineering

Journal of
Engineering Sciences
Faculty of Engineering
Assiut University
مجلة
العلوم الهندسية
كلية الهندسة
جامعة أسيوط
journal homepage: http://jesaun.journals.ekb.eg

Shear Strength Behavior for Reinforced Soil with Geosynthetic at Different Inclination Angles

Received 9 July 2023; Revised 3 November 2023; Accepted 3 November 2023

Ahmed M. ELHanafy[1]

Keywords
Direct Shear Box, Reinforced Sand, Geosynthetics, Shear Strength Improvement

Abstract

The interaction between soil and geosynthetic reinforcement is important for the design and performance of reinforced soil structures. This interaction can be very complex depending on the type, properties of the reinforcement and orientation for these geosynthetic into a reinforced soil. The interaction mechanism for different orientation of these geosynthetic still doesn't study accurately. This paper investigates the interaction mechanism for reinforced sand with different geosynthetics types at different inclination angles. The strength parameters of soil geogrid interface were obtained from direct shear tests. These investigations were conducted with the aim of characterizing the shear strength of reinforced soil composite. Two types of geosynthetic, Woven geotextile and Biaxial geogrid were selected to insert into sand. Laboratory testing programs were performed in shear box device, square box with 100 mm in length was used and the reinforcement layer was placed in different inclination angles. The first angle is perpendicular to the failure surface 90. the second angle of reinforced was inclined with 45. to the failure surface and the third angle of reinforced was horizontally parallel to the failure surface. All tests were conducted with three vertical loads of 17.95, 27.95 and 37.95 kg. Three parameters were studied according to the relative density of sand, inclination angle of geosynthetics in shear box and type of geosynthetics reinforcement layer. The test results reveal that the sand reinforced with biaxial geogrid achieved the highest value of shear strength enhancement. The maximum shear strength improvement occurred at inclination angle 90 to the failure plan when reinforced by biaxial geogrid and Woven geotextile.

1. Introduction

Soil reinforcement techniques are adopted to enhance the performance of earth structures like reinforced walls, soft ground improvement, roads and railways embankments, slope stabilization and foundations etc. Any geosynthetic material employed as reinforcement has the main task of resisting

---

[1] Researcher, Construction Research Institute, National Water Research Center, Cairo, Egypt

https://doi.org/10.21608/JESAUN.2023.221832.1243

applied stresses or preventing unacceptable deformations in reinforced geotechnical structures. In this process, the geosynthetic acts as tensioned member to the composite material (soil and backfill material) and restrain tensile deformations by mobilizing tensile load in geosynthetic and to stop the soil from sliding over the geosynthetic or pulling out the soil by providing bond resistance, adhesion, interlocking or confinement and thus maintains the stability of the soil mass [1–3]. Geosynthetics are primarily used to absorb the tensile stress developed in a soil mass. Consequently, a critical zone is created between soil and geosynthetic surface which is called soil-geosynthetic interface. The shear behaviour of this interface has significant importance where the soil mass has a potential to be failed along the interface. The interface characteristics depend on both the type of reinforcement and backfill material. Various types of geosynthetic materials have been used for soil reinforcement including geotextiles (woven and nonwoven), geogrids and geocells. Whatever the reinforcement and backfill materials are used for the design of a reinforced soil structure, the interaction properties of soil-reinforcement interface play an important role. The direct shear and pullout tests are widely used methods to study quantitatively these interaction mechanisms. The use of geosynthetic reinforcement in soil is one of the most effective techniques in the last decade being used in the maintenance, construction, and rehabilitation of engineering structures such as slopes and embankments laid on soft soil [4]. The design, modeling, and performance of reinforced soil structures depend on how soil and geosynthetic materials interact. The soil's physical and mechanical properties, the geogrid reinforcement, and the interactions these materials all play a role in this interaction process. Today's there is different types of geosynthetic (woven and non-woven geotextile, geocomposite, geogrid and geocell, etc.) are used to strengthen the soil. Geosynthetic increase the shear strength by providing interlocking and enhancing tensile strength of soil [5,6]. Geosynthetic reinforcement effectively enhanced the soil stiffness, cohesion, and shear strength of cohesive soil. Also, the improvement in soil strength depends on the types of Geosynthetic [7].

The important of employing the coefficient of interaction or interface efficiency has been explode by numbers of researchers. interface efficiency is used to determine the effective length of the reinforcement need outside the critical slip plane for reinforced slopes and mechanical stabilized earth walls as a fundamental design parameter in Geosynthetic reinforced soil structures [8,9]. The coefficient of interaction is defined as the ratio of shear strength of reinforced soil to unreinforced soil at the same overburden pressures [10]. Direct simple shear testing or inclined plan tests have been used in numerous studies to better understand the shear strength behavior of reinforced soil. The boundary conditions, stress routes, and failure mechanisms applied to the specimen vary significantly depending on the test method. [11] provides a thorough analysis of the benefits and restrictions associated with these testing. Many researchers have looked at interface shear strength. [12] used the modified and conventional method (DST) to examine the interface shear strength characteristics of biaxial and triaxial geogrid-reinforced construction and demolition aggregates. Triaxial geogrids with higher stiffness provide higher interface shear strength qualities when using the DST method. [13] discussed the aggregate geogrid interface's strength metrics from direct shear and pullout testing. It was concluded that the geogrid's interaction coefficient was 0.56, 0.45, and 0.33 for surcharge loads of 5, 10, and 20 feet, respectively. [14] contrasted the outcomes of inclined plane tests and horizontal reinforcement in direct shear tests. [15] looked at the interface shear strength of materials used to cover landfills in inclined plane experiments. It was concluded that the direct shear tests with horizontal reinforcement typically yield slightly higher interface parameters than testing on an inclined plane. With the reinforcement layer positioned parallel to the failure plane caused for the shear box, certain research in the literature [16 ,17] provide laboratory test findings. Other studies

[18] position the reinforcing layer perpendicular to the failure plane or rotate it. According to [19], two methods can replicate the interaction between reinforced soil and geogrid materials. The first method, friction at the contact is mobilized in the latter, it can be simulated in a lab setting to determine the soil-geogrid interface's strength parameters. Tensile loads in the geogrid are mobilized as part of the second process. The two-difference interaction process in geosynthetic reinforced soil is shown in figure 1.

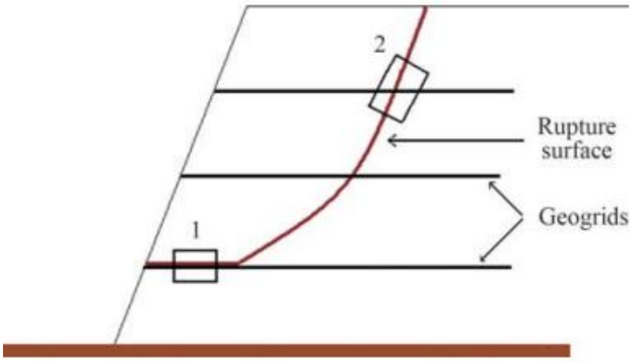


Figure 1: Mechanisms of soil-geogrid interaction interface shear and reinforcing tension.

In the first mechanism, the interface resistance is mobilized by the sliding of the topsoil mass in relation to the geogrid while the geogrid stays attached to the lower portion of the enveloping soil. In this mechanism, direct shear testing using a geogrid that is horizontally positioned in a shear test apparatus can be used to determine the interface strength parameters (C and θ). The potential failure surface intercepting the geogrid results in the second interaction mechanism. Direct shear tests on soil samples with reinforcement angled in reference to the horizontal shear surface can produce a laboratory simulation. The failure surface's intercept point is where the geogrid is under its most tension. In this method, the tension reinforcement absorbs the shear loads at the soil-geogrid interface. The direct shear test using inclined reinforced soil is shown in figure 2.

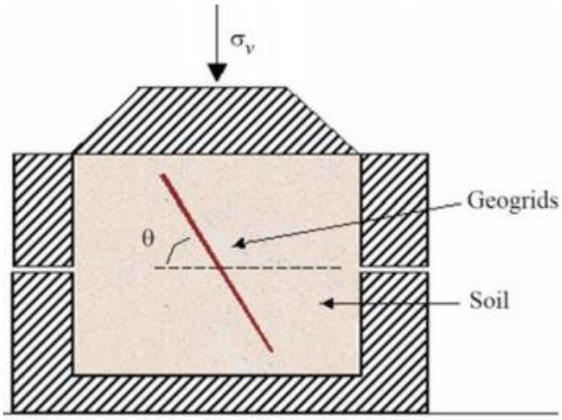


Figure 2: - Direct shear testing with inclined reinforcement

The role of geogrids in reinforced slopes is to overcome the soil's low tensile stress resistance. The geogrid becomes tensioned when the failure surface intercepts it, which stabilizes the reinforced soil mass. The angle (θ), which varies from its initial value of (θ_i) to its final value of (θ_f) at the conclusion of the shearing process, has a substantial impact on the soil geogrid resistance. As shown in figure 3, this variation in (θ) will rely on the degree of angular distortions and the thickness of the shearing zone.

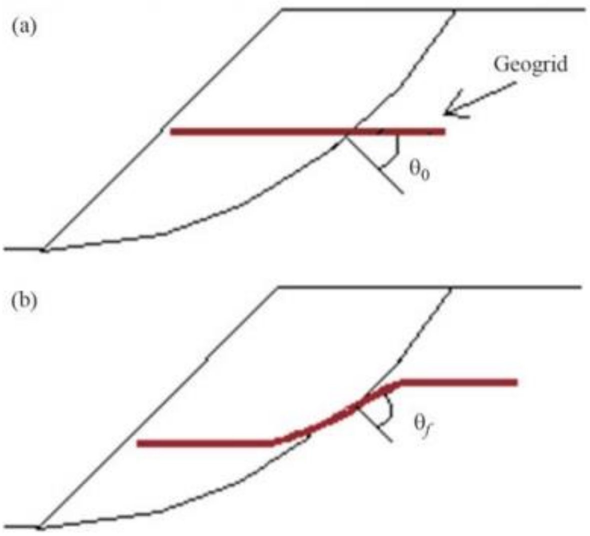


Figure 3: Behavior for reinforced in the shear zone. initial state (a) and distorted state (b), respectively.

To characterize the behavior of the composite material when the soil and the reinforcement are sheared, the reinforcement layer was placed at three different inclination angles in this study. The first angle was 90 degrees perpendicular to the failure surface, the second angle was rotated 45 degrees to the failure surface, and the third angle was horizontal and parallel to the failure plane. The main aim of this study is determining the shear strength improvement factor for inclined geosynthetic reinforced soil composite for two types of geosynthetic. This research was useful in determine the most advantageous arrangement of the geogrid for construction projects on reinforced slopes and vertical filter with geotextile behind retaining walls. Also, this research is permitted to clearly define the soil region that is not deformed during the direct simple shear test.

2. Material Used

2.1. Granular Soil

Egyptian local sand was used to gather clean, siliceous sand that had been air-dried. Two geosynthetic materials' contact behavior was assessed using sand. The physical characteristics of the sand were examined in the lab before the interface direct simple shear tests were carried out. According to ASTM D421 [20]. The sieve analysis for sand sample was obtained. The results are shown in figure 4. The unified soil classification system [USCS] shows that the sand is medium to coarse sand, traces of small gravel, trace of silt. According to ASTM D1557-09) (2009), D 698) (2010), [21 and 22], Table 1 shows the index properties of the tested sand (Optimum Moisture Content and Dry density for sand were obtained from Modified Proctor Test). Sand has a water content of 12%.

2.2 Geosynthetic Specimens

The used Geosynthetic consist of two samples. The first one from Woven geotextile type Hate C 00.52. The second one from Biaxial geogrid type Hate (23.142 GR) as shown in figure 5 (a, b). These materials have strong elasticity and stretch tension along with good resistance to heat, vibration, acid, and alkali.

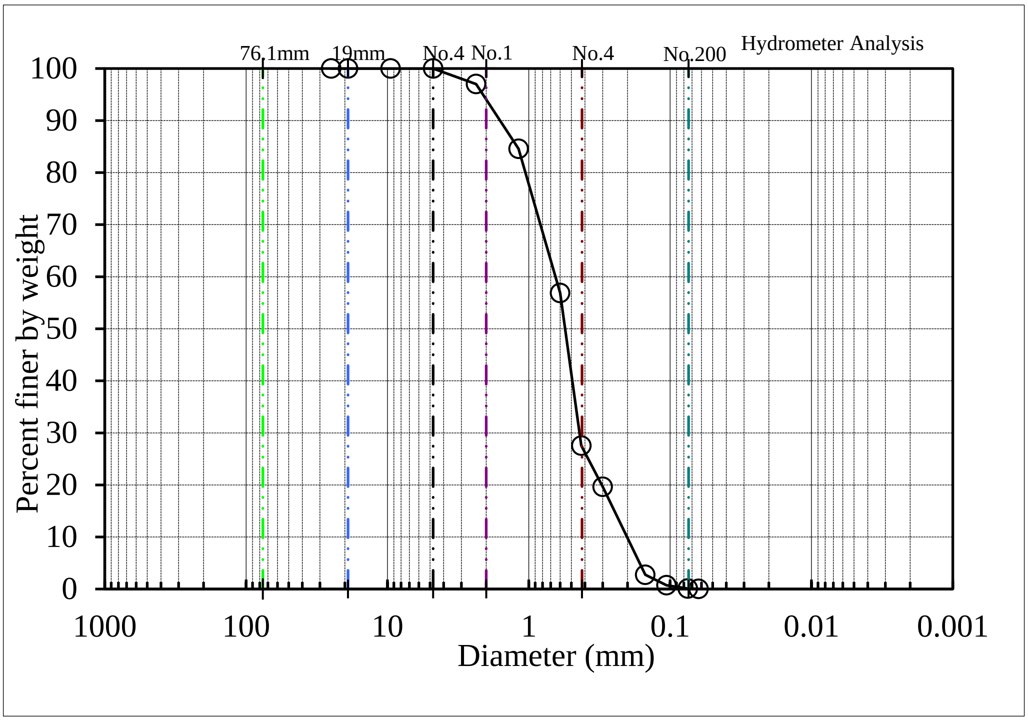


Figure 4 Grain Size Distribution Analysis for Sandy Soil

Table 1 Summary of geotechnical properties of the used sand

Property	Value	Property	Value
Specific gravity (Gs)	2.64	% of fine Gravel	2.40
% of Clay	0.00	Effective diameter (D_{10}) mm	0.202
% of Silt	0.10	30% passing diameter (D_{30}) mm	0.437
% of fine Sand	9.90	60% passing diameter (D_{60}) mm	0.647
% of medium Sand	48.00	Coefficient of uniformity (C_u)	3.20٣
% of coarse Sand	40.0	Coefficient of Curvature (C_c)	1.463

(a)Woven Geotextile type Hate (C00.52) (b) Biaxial Geogrid type Hate (23.142 GR)

Figure 5 (a, b) Geosynthetic specimen types used in the study

2.2.1 Woven Geotextile

The woven geotextile used in this study type [Hate C 00.52. Woven geotextile]. Hate C00.52 fabricated by Husker Company with technical specifications illustrated in table 2.

Table 2: Properties of hate C00.52 geotextile – According to manufacture specification.

Tensile strength in long direction.	26 kN/m
Tensile strength transversely direction.	25 kN/ m
Puncture force min.	2.7 kN
Unit Weight	120 g/m^2
Permeability	0.25 m/s

Wide width tensile strength test was performed on the specified [Hate C 00.52] geotextile samples according to ASTM D 6637, 2011 [23], in Geosynthetic Laboratory at Construction Research Institute (CRI). Three tests were performed on standard samples. The average value was illustrated in table 3. The tensile strength of woven geotextile from the laboratory test gives results near to manufacture specification.

Table 3: Properties of Wide Width Tensile Strength According to ASTM D 6637.

Tensile strength	25.19 kN/ m
Secant stiffness 0 to 3% (kN/m)	169.02 kN/m
Tensile Modulus	161.58 kN/ m
Secant stiffness 0 to 10% (kN/m)	170.689 kN/ m
Strain @ break (%)	18.2

2.2.1 Biaxial Geogrid sample

Hate (23.142 GR) was the biaxial geogrid employed in this study, produced by the Husker Company. Table 4 provides examples of the laboratory-reported tensile strength results.

Table 4: Properties of Wide Width Tensile Strength for two Geosynthetic Specimens

Property / Type of Geosynthetic	Thickness (mm)		Mass per Unit Area (g/m^2)		Max. Tensile Strength (L.D) & (T.D) kN/m		Opining Size (mm)
	Product Data	Test Result	Product Data	Test Result	L.D	T. D	L.D x T. D
Hate C00.52 (Houskar)	0.90	0.90	120	115	26.0	25.19	2.0 x 2.0
Hate (23.142 GR)	0.60	0.60	130	130	15.0	14.0	4.0 x 4.0

L.D: Longitudinal Direction, T.D: Transvers Direction

3. Experimental work

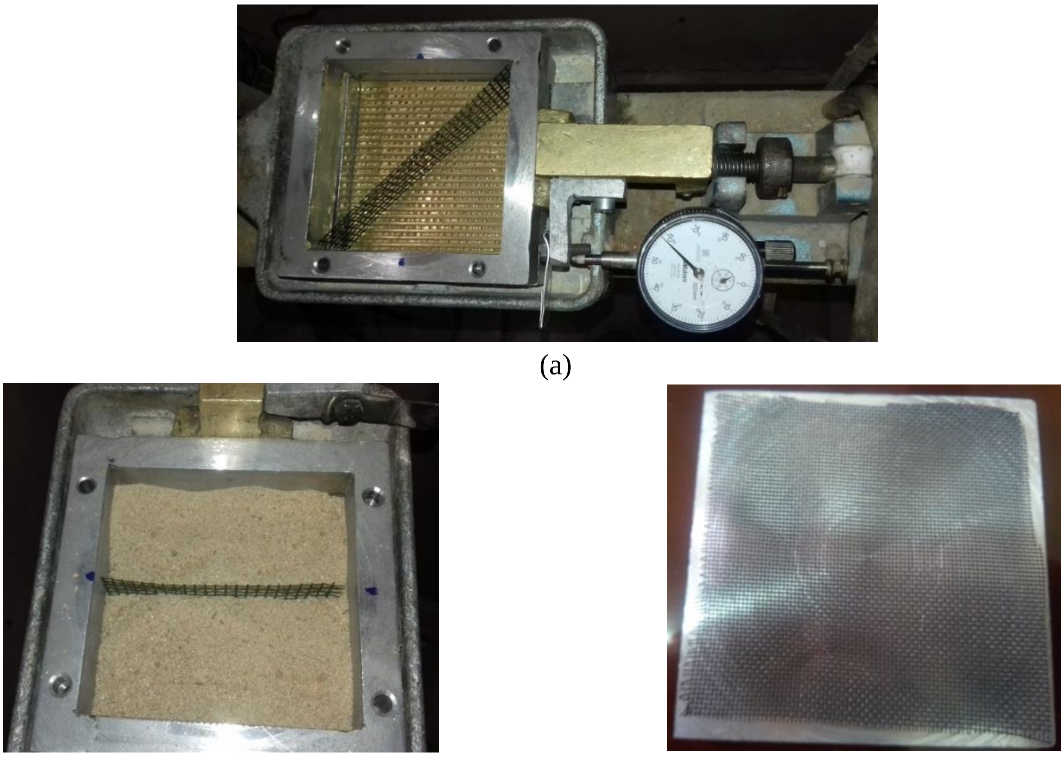
3.1 Experimental procedure

This study uses a small-scale direct shear box testing apparatus, as depicted in figure 6, which comprises of a fixed bottom box and a moving top shear box. In this study, a square box measuring 100 mm in length was used. A loading plate beneath the lower shear box transfers a vertical force to the backfill material. on top of the backfill in the upper shear box is a response plate. One load cell, two displacement transducers (one for measuring horizontal displacement and the other for measuring vertical displacement). The applied shear force was recorded.

On top of the lower box, a steel rigid base was erected, on which the geosynthetic specimens were mounted (Figure 7a, b, and c). The specimen was then secured to the front edge of the base plate with the aid of two steel clamping blocks and four aligned bolts. When using pure sand, the upper shear box was filled by letting the sand fall from a height while being sieved twice. The sand layer in the upper shear box was 20 mm tall. Before filling the shear box with sand, water was added to the soil samples. Soil was packed into the upper box in three steps using the same amount of compaction force. As a result, the backfill soil's density was almost constant. The three vertical loads used for the direct simple shear tests were 17.95, 27.95, and 37.95 kg. In each test, the stress was applied, and the vertical displacement was recorded. Only after the vertical movement had stabilized the shear load was applied. The normal load remained constant throughout the shearing operation. For each test, the shearing speed was held constant at 0.5 mm/min.

The same procedure was repeated for all types of geosynthetics. Fourteen different tests were performed during this investigation. Table 5 indicated the program details tests which done in this research.

Figure 6 Direct Shear Box Device used in the research



(a)

(b) (a)

Figure 7 Different inclination angles for Geosynthetic used in Direct Shear Box
(a =45°, b =90°, c =0°) on the direction of movement

3.1 Experimental program

The main experimental program consisted of total of fourteen tests of direct simple shear test. It’s divided into three series, S1 and S2. in addition to the control test S0 for the sand without any reinforcements. Table (5) shows the experimental program configuration.

Table 5 experimental program configuration for two Geosynthetic Specimens

Test Series	Type of Geosynthetic	Dr. %	Reinforcement Inclination Angle in Direct Simple Shear	Type of soil	No. of tests
S_0	Non	40 & 60	None	Sand	2
S_1	Biaxial Geogrid	40 & 60	0	Sand	6
			45		
			90		
S_2	Woven Geotextile	40 & 60	0	Sand	6
			45		
			90		

S: Series tested number *Dr. %: Relative Density*

4. Results and Discussion

4.1 Interface Shear Strength

Under many types of structures, the shear strength of a soil-geosynthetic interface is essential parameter, particularly in a slope stability studies where the slip surface runs down the geosynthetic. A series of direct simple shear tests were performed to obtain the shear strength characteristics of the different types of geosynthetic interfaces. Figures 8 and 9 represents the normal and shear stress relationship for (S_0 and S_1), sand with relative density 40% and 60%. Reinforced with biaxial geogrid interfaces using three constant vertical load 17.95, 27.95 and 37.95 kg.

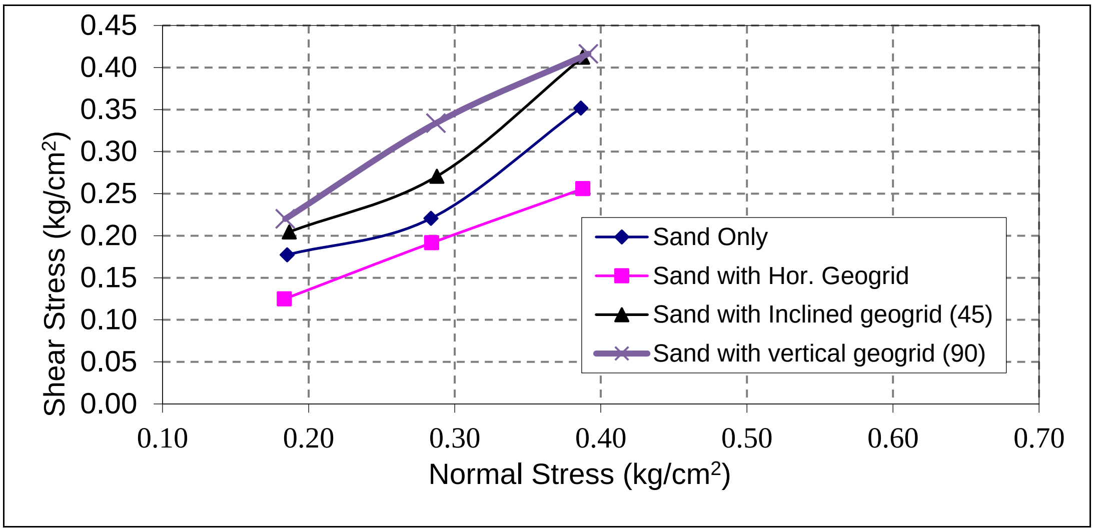


Figure 8 Normal and shear stress relationship at Dr. = 40 % for Biaxial Geogrid

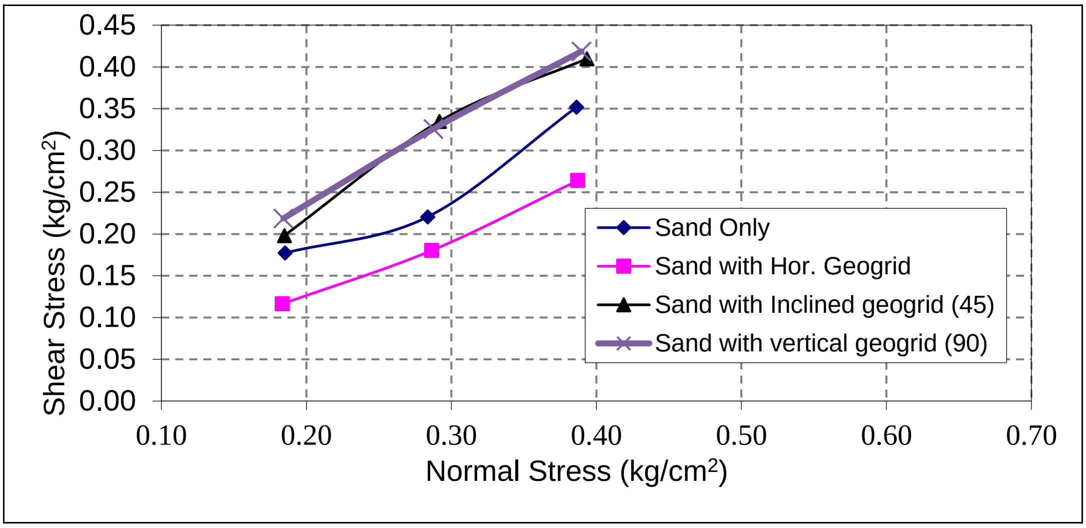


Figure 9 Normal and shear stress relationship at Dr. = 60 % for Biaxial Geogrid.

From figures 8 and 9, it was noted that the reinforced sand with horizontal Biaxial geogrid (parallel to the direction of tension) resulted to decrease in shear stress values about the sand without reinforcement. While the reinforcement with Biaxial geogrid at inclined angles 45° and 90 ° on the tension direction, increase the shear stress values with various ratios ranged from 24.08% to 18.25% and from 23.04% to 21.19% at relative density 40 and 60% respectively. Therefore, these ratios decreased with increase the relative density for sand. In addition, it was noted that the same shear stress values were recorded at the normal stress equal 0.30 kg/cm^{2} ^{for} sand reinforced with Biaxial geogrid at inclined angles 45° and 90° at relative density 60 %. These results can be attributed to interlocking between soil and reinforcement through the apertures of the geogrid which caused to the increase the shear strength as loads applied, and an efficient anchoring effect is achieved. Figures 10 and 11 represents the normal and shear stress relationship for (S_0 and S_2), sand with relative density 40 and 60 %, reinforced with woven geotextile interfaces using three constant vertical load 17.95, 27.95 and 37.95 kg.

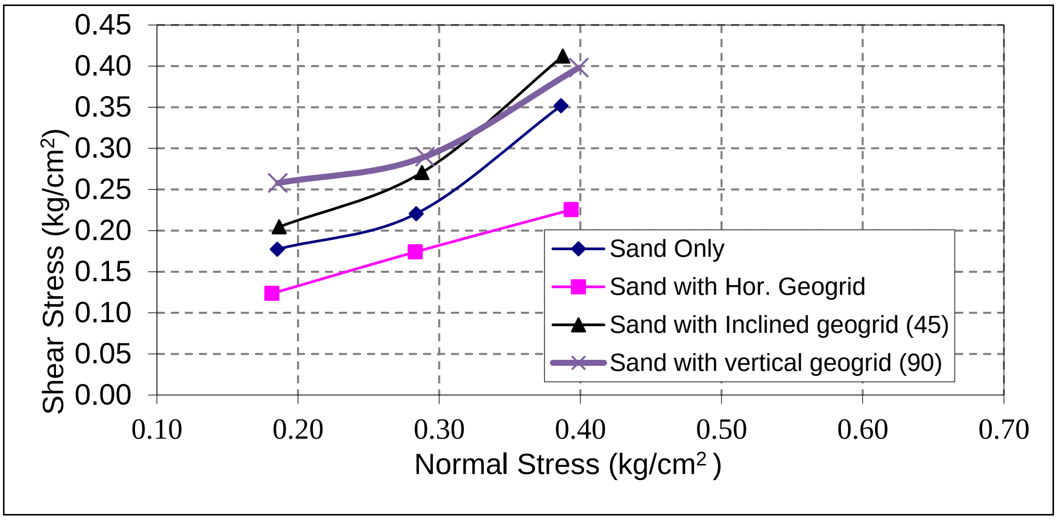


Figure 10 Normal and shear stress relationship at Dr. = 40 % for Woven Geotextile

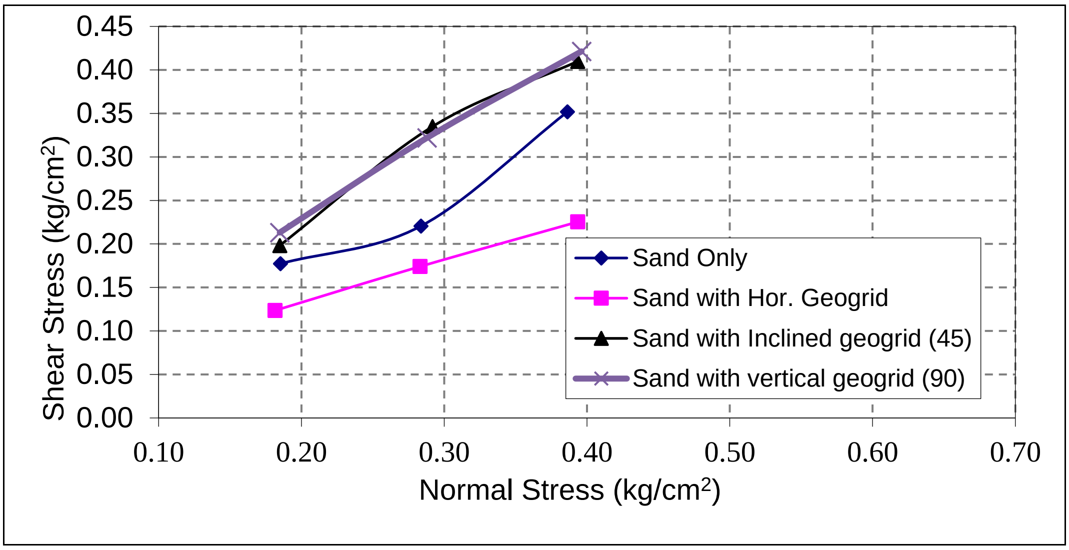


Figure 11 Normal and shear stress relationship at Dr. = 60 % for Woven Geotextile.

From figures 10 and 11, it was noted that the reinforced sand with horizontal Woven Geotextile (parallel to the direction of tension) resulted to decrease in shear stress values about the sand without reinforcement. While the reinforcement with Woven Geotextile at inclined angles 45° and 90 ° on the tension direction, increase the shear stress values with various ratios ranged from 45.65% to 13.13 % and from 20.33% to 19.76% at relative density 40 and 60% respectively. Therefore, these ratios decreased with increasing the relative density for sand. This can be attributed to the increase in normal stress, the geosynthetics materials deform as a reinforced material starts to bear the loads. The test findings demonstrate that, the interface shear strength is not linear against the normal stresses. In addition, the test results show that rather than the kind of geosynthetics, the relationship between shear stress and relative density is mostly dependent on the type of backfill. Moreover, it can be shown that there is no evidence of displacement softening behavior at geotextile interfaces, hence the relationship can be described as hyperbolic in nature.

4.2 Shear Strength Improvement

The shear strength improvement index was employed in this study to indicate the shear strength of the soil improved after the addition of geosynthetic. The shear strength at the geosynthetic reinforced soil composites divided by the soil's shear strength under the same overburden conditions which used to define this index. The literature has established similar associations as the (Interface Efficiency) [15,18]. Improvement in shear strength for granular soil is defined as:

$$C_i = \frac{\tan \delta_a}{\tan \phi},$$

Where C_i is the improvement in shear strength, δa represents the friction angle of composite geosynthetic reinforced soil, and φ represents the friction angle of sand. Table 6 indicates the results for the improvement factor in shear strength. Depending on the type of geosynthetic, the reinforced sand's shear strength enhancement ranged from 1.167 to 1.821 for biaxial geogrid at two used relative densities 40% and 60%. While the reinforced sand's shear strength enhancement ranged from 1.167 to 1.337 for woven geotextile at two used relative densities 40% and 60%.

Table 6 Improvement in shear strength (C_i) at maximum shear stress.

Geosynthetic Type	Dr. %	Inclination Angle	C_i
Biaxial Geogrid	40	45	1.185
		90	1.609
Woven Geotextile		45	1.185
		90	1.337
Biaxial Geogrid	60	45	1.167
		90	1.821
Woven Geotextile		45	1.167
		90	1.325

The biaxial geogrid has been observed to be the most efficient in increasing the shear strength due to the high tensile strength, which resulted in higher interface friction resistance. Moreover, it was noted that the biaxial geogrid reinforcing layer with an inclination angle of (90 ^{o}) to the failure plan improved the shear strength more than angle (45 ^{o}) to the failure plan. These test results from the current study agree with the results reported by [19] and [25]. In addition, the height of the specimen's center shows the most shearing. However, there is no distortion in the upper or lower region, only translation. It should be noted that all these results have limitations in simulating for all conditions in a reinforced soil structure. Among various reinforcing materials, Geosynthetics types, inclination angles, overburden stress values and their applications are important parameters to estimate the coefficient of improvement.

4.3 Shear Stress-Displacement Relationship

Shear stress-horizontal displacement curves were created to assess the frictional behavior of the geosynthetic reinforced soil composite. Shear displacement divided by the length of the shear box (100 mm), expressed as a percentage, is horizontal displacement. Shear stress-displacement relationships for sand with angled Biaxial geogrid interfaces are shown in Figures 12 and 13, respectively. for 17.95, 27.95, and 37.95 kPa constant normal stresses.

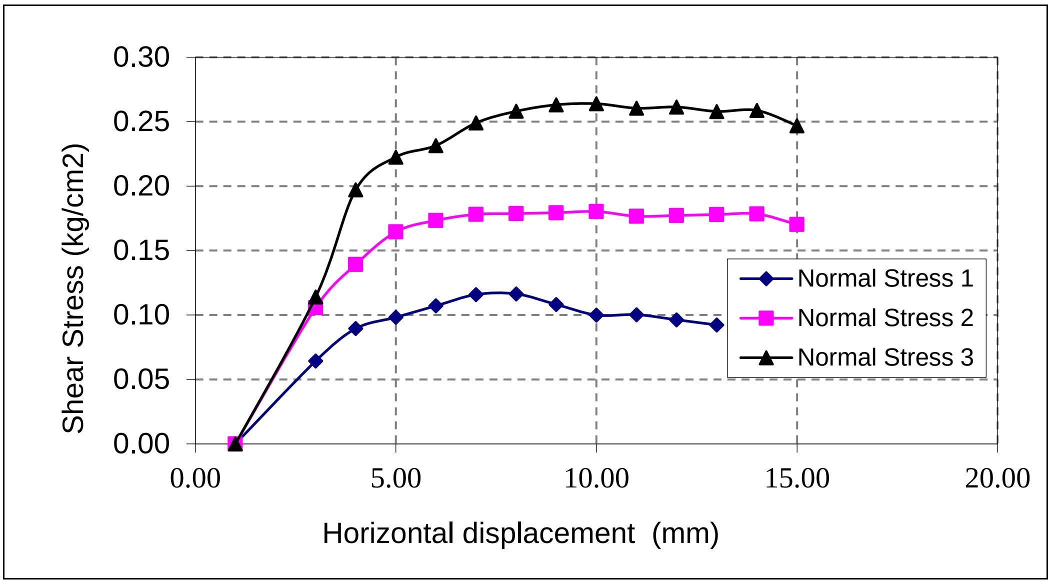


Figure 12 Shear Stress - Horizontal Displacement Relationship
(S1-0°) at Dr. = 60 % for Biaxial geogrid.

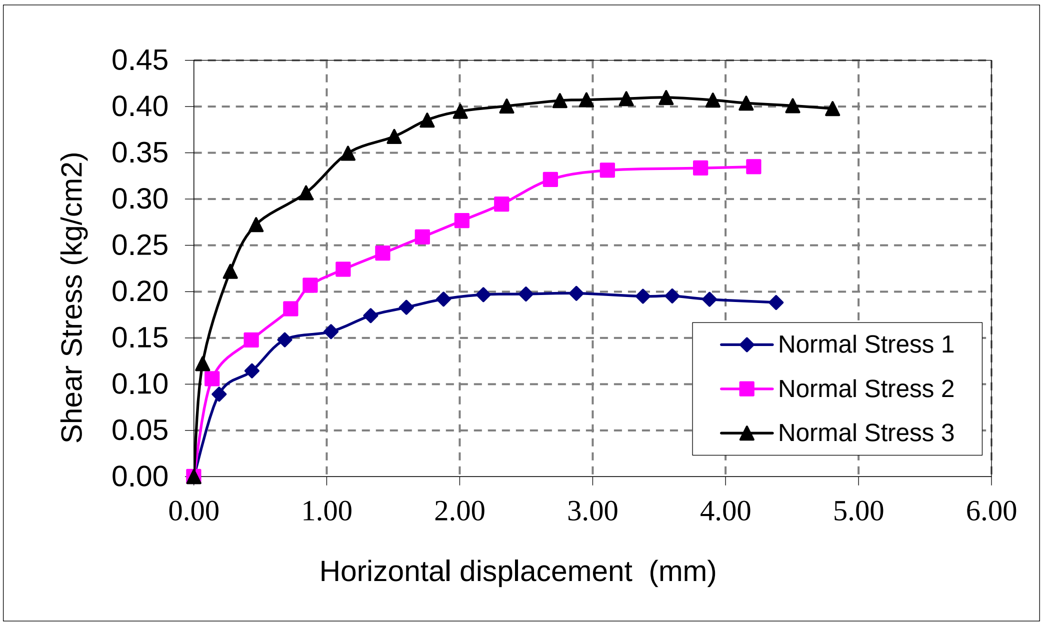


Figure 13 Shear Stress - Horizontal Displacement Relationship
(S1- 45°) at Dr. = 60 % for Biaxial geogrid.

It can be observed that the vertical confining stress marginally increases the geogrids' displacements in the shearing zone. Figures 13 and 15 make this clearly. As a result, larger levels of normal stress are anticipated to result in higher tensile stresses in the geogrid. Figure 14 and 15 represents shear stress-displacement relationship between sandy with horizontal and inclined Woven geotextile interfaces respectively at normal stresses of 17.95, 27.95 and 37.95 kPa.

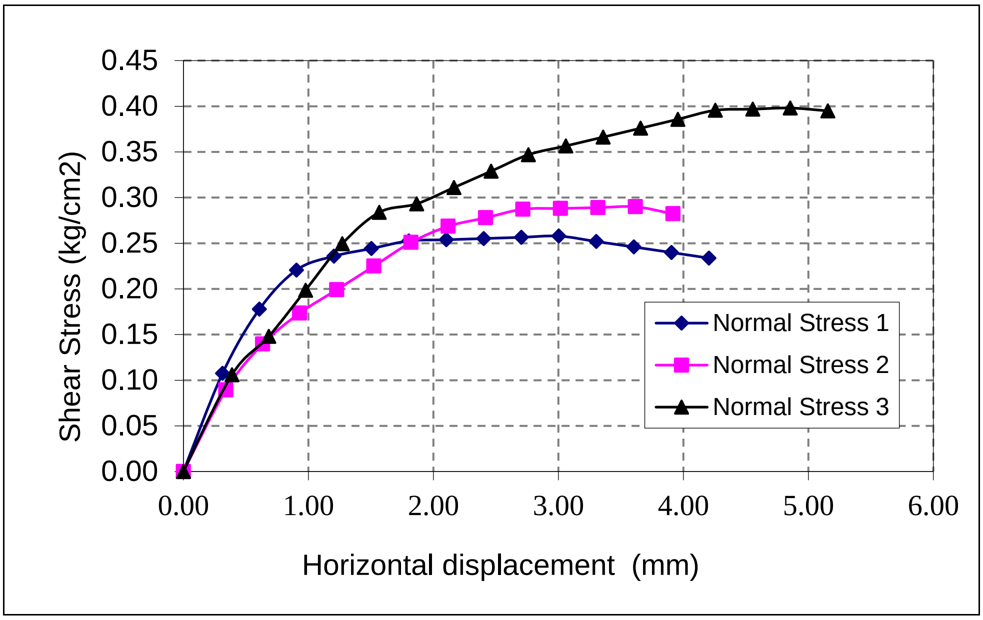


Figure 14 Shear Stress - Horizontal Displacement Relationship
(S2-90°) at Dr. = 40 % for Woven Geotextile.

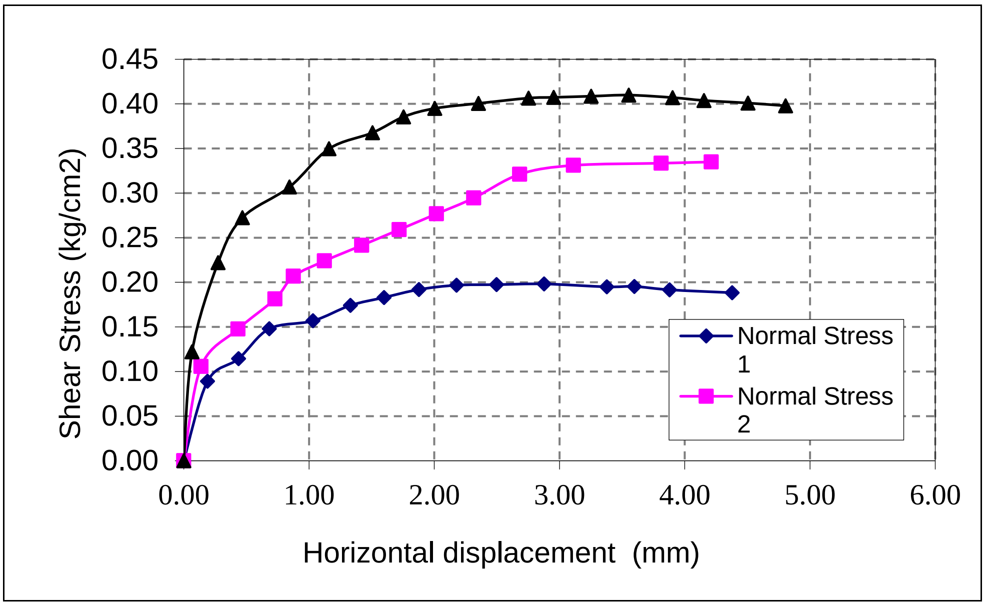


Figure 15 Shear Stress - Horizontal Displacement Relationship
(S1-45°) at Dr. = 60 % for Woven Geotextile.

The test findings show that the type of geosynthetics has a significant impact on the relationship between shear stress and relative displacement.

4.3. Dilatancy Angle Behaviour

According to test results, a specific interface's dilatancy behavior is consistent under any typical stress. Thus, the soil-geosynthetic interfaces' vertical versus shear displacement curves at 37.95 kPa applied normal stress were used for comparison. The contacts with the sand backfill material exhibit both contractive and dilative character. Because dilation is necessary for the shearing and rearranging of angular particles, it suggests that there is some degree of particle rolling and interlocking at sand/geosynthetic interfaces. It is important to note that for geogrid interfaces with sand, the value of maximum vertical displacement decreases as the percent open area of the geogrid increases for the same states of normal stress. Additionally, for lower normal stresses, the quantity of dilation is greater and at higher normal stresses, it is relatively less. For sand geosynthetic interfaces, the dilation with shearing indicates the presence of some degree of particle rolling and interlocking as dilation is required for the shearing and rearrangement of angular particles. For geogrid interfaces with sand, it is interesting to note that the value of maximum vertical displacement reduces with the increase of the percent open area of geogrid for a particular normal stress. And the amount of dilation is seen higher at lower normal stresses and comparatively less at higher normal stresses. The practical application of the current test results can be applied in reinforced slopes with different types of Geosynthetic and drainage systems behind the keystone walls, Gabions wall, Geocell walls.

5. Conclusions

To determine the impact of various factors on the frictional behavior of geosynthetic reinforced soil composite, direct shear box experiments were conducted. Two different types of granular soil, samples with two different relative densities, one type of shear box, and two different types of geosynthetic materials were considered during the experiments. The following findings can be summarized as:

1- When compared to reinforced soil, inclination angle (θ) was found to have a significant impact on the soil geogrid shear strength.
2- The reinforced sand with both biaxial geogrid and woven geotextile layer with an inclination angle 90^o to the failure plan increased the shear strength more than inclination with angle 45° to the failure plan.
3- The reinforced sand with biaxial geogrid led to increase the shear strength for soil mass larger than the reinforced with woven geosynthetic.

These results cannot be generalized and must be confirmed for various types of geosynthetic-soil composites because the behavior of geosynthetic reinforced soil composites depends on unique geosynthetic and soil parameters.

References

1. Shukla SK Geosynthetics and their applications. Thomas Telford Publishing, London (2002).
2. Shukla SK, Yin JH (2006) Fundamentals of geosynthetic Engineering. Taylor and Francis, London.
3. Shukla SK (2012) Handbook of geosynthetic Engineering, 2nd edn. ICE Publishing, London
4. Wu H, Yao C, Li C, Miao M, Zhong Y, et al. (2020), “Review of application and innovation of geotextiles in geotechnical engineering”. Materials (Basel), V. (13) PP. (1-21).
5. Jewell RA. (1996), “Soil reinforcement with geotextiles”.
6. Koernel RM. (2005), “Design with geosynthetics”. 5th New Jersey, USA: Prentice Hall.
7. Waqas Hassan, Khalid Farooq, Hassan Mujtaba, Badee Alshameri, Arfan Shahzad, Muhammad Naqeeb Nawaz, Marc Azab. (2023), “Experimental investigation of mechanical behavior of Geosynthetic in different soil plasticity indexes”. Transportation Geotechnics, V 39
8. Koutsourais M, Sandri D, Swan R. (1998), “Soil interaction characteristics of geotextiles and geogrids”, Geosynthetics, V. 98, PP (739-744).

9. Tatlisoz N, Edit T, Benson C. (1998), “Interaction between reinforcing geosynthetics and soil-tire chip mixturres”, J Geotech Geoenviron Eng., V (124) pp (1109-1119).
10. Cowell MJ, Sprague CJ. (1993), “Comparison of pull-out performance of geogrids and Geotextile.”, Geosynthetics, V 93, PP (579-592).
11. Palmeira, E.M. (2009), “Soil-geosynthetic interaction: modeling and analysis”. Geotextile and Geomembranes, V. 27 (5), PP. (368–390).
12. Arulrajah, M. A. Rahman, J. Piratheepan, M. W. Bo, M. ASCE and M. A. Imteaz (2014), “Evaluation of Interface Shear Strength Properties of Geogrid-Reinforced Construction and Demolition Materials using a Modified Large- Scale Direct Shear Testing Apparatus”, Journal of Material of Civil Engineering ASCE. V. (26), PP. (974-982).
13. Bakeer, R.M., Sayed, S.M., Cates, B. & Subramanian, R. (1998), “pullout and shear tests on geogrid reinforced lightweight aggregate., Geotextiles and Geomembranes. V16 (2), PP. (119-133).
14. Wasti, Y. and Ozduzgun, Z.B. (2001), “Geomembrane-Geotextile interface shear properties as determined by inclined boar d and direct shear box tests”. Geotextiles and Geomembranes, V19 (1), PP. (45–57).
15. Pitanga, H.N., Gourc, J.p. and Vilar, O.M. (2009), “Interface shear strength of geosynthetics, evaluation and analysis of inclined plan tests”. Geotextiles and Geomembranes. V27 (6), PP. (435-446).
16. Takasumi DL, Green KR, Holtz R (1991), “Soil–geosynthetics interface strength characteristics” a review of state-of the-art testing procedures. In: proceedings of the geosynthetics’91 conference, Atlanta V (1), PP (87–100).
17. Tan SA, Chew SH, Wong WK (1998), “Sand–geotextile interface shear strength by torsional ring shear tests”. Geotextiles and Geomembranes, V16 (3), PP (299–328).
18. Choudhary AQ, Krishna AM (2016), “Experimental investigation of interface behaviour of different types of granular soil/geosynthetics”, Int J Geosynthetics Ground Eng. V2(1), PP (1–11).
19. Sayao ASFJ and Sieira ACCF (2012), “Evaluation of direct shear tests on geogrid reinforced soil”, Soils Rocks V35 (1), PP (65–74).
20. American Society for Testing and Materials (ASTM - D421) (2009), “Standard Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants” ASTM Book of Standards, Published in September.
21. American Society for Testing and Materials (ASTM D1557- 09) (2009), “Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft3 (2,700 kN-m/m3))” ASTM Book of Standards, Published in October.
22. American Society for Testing and Materials (ASTM - D698) (2010), “Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort” west Conshohocken, PA, USA: ASTM International.
23. American Society for Testing and Materials (ASTM D 6637, 2011). Standard Test Method for Determining Tensile Properties of Geogrids by the Multi-Rib Tensile Method.
24. Egyptian Code for Soil Mechanics and Design and Executing the Foundations, 2001, part 3 (202/3)
25. Jewell. R. A. and worth, C.P. (1987), “Direct Shear Test on reinforced sand”, Geotechniqe V 37 (1), PP (53:68).

سلوك مقاومة القص للتربة المسلحة بالمنسوجات الصناعية عند وضعها على زوايا قص مختلفة

<u>الملخص العربى</u>

إن دراسة آلية التفاعل بين التربة المسلحة والمنسوجات الصناعية مهم في مرحلة التصميم بالإضافة الي تقييم أداء التربة المسلحة تحت المنشآت مع الزمن. وهذا التفاعل يعتمد على نوع وخواص التسليح الصناعي المستخدم ووضعية هذه المنسوجات داخل التربة المسلحة. إن آلية هذا التفاعل يختلف باختلاف الأوضاع المختلفة للمنسوجات داخل التربة المسلحة وهذا التفاعل ما زال تحت البحث في العالم. في هذا البحث تم دراسة آلية تفاعل الرمال المسلحة مع أنواع مختلفة من المنسوجات الصناعية عند زوايا ميل مختلفة. أجريت هذه الدراسة بهدف تحديد خصائص مقاومة القص لمركب التربة المسلحة وتم الحصول على معاملات مقاومة القص للتربة من خلال اختبارات القص المباشر للتربة المسلحة. أجريت هذه الدراسة على تربة رملية ونوعين مختلفين من المنسوجات الصناعية؛ وتم إجراء الاختبارات على جهاز القص المباشر بأبعاد (١٠ x x10 2.5 (سم وبزوايا مختلفة داخل صندوق جهاز القص المباشر. الزاوية الأولي هي ٩٠ درجة والثانية ٤٥ درجة من مستوي سطح الانهيار والثالثة هي صفر درجة (أي أنها موازية لمستوي سطح الانهيار). وتمت هذه الاختبارات تحت ثلاثة أحمال عمودية مختلفة هي (١٧,٩٥و٢٧,٩٥ و٣٧,٩٥) كجم. وتم دراسة ثلاث معاملات مختلفة هي: -

١- الكثافة النسبية المستخدمة في الاختبار.
٢- زوايا وضع المنسوجات الصناعية داخل جهاز القص المباشر.
٣- نوع المنسوجات الصناعية المستخدمة.

أظهرت نتائج الاختبارات أن الرمال المسلحة بشبكة من المنسوجات الصناعية ثنائية المحور حققت قيم أعلى لمقاومة القص للتربة المسلحة. بالإضافة الي أن أقصى قيم لتحسين مقاومة القص للتربة المسلحة تم الحصول عليها عند استخدام زاوية ميل ٩٠ درجة على مستوي سطح الانهيار في حالتي استخدام شبكة من المنسوجات الصناعية ثنائية المحور ونسيج أرضي منسوج.