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Effect of Particle Size of Sand on the Interface Shear Behavior of Sand and Non-woven Geotextile

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Abstract

Soil-geosynthetic interface is the weakest zone for shear failure. It is influenced by size, shape, density and water content of sand. It is also influenced by the properties of geosynthetic such as texture and structure. This paper explores the influence of the size of sand on the behavior of sand-geotextile interface. Three types of sands namely coarse, medium and fine sand and non-woven geotextile were used in this study. Several interface direct shear tests on these materials were performed using a direct shear box modified for interface testing. The test results depict that the peak interfacial friction angles between the sand particles and geosynthetic material (geotextile) depend on the relative size of sand particles. The interfacial friction angle for fine sand is higher than that of the coarse sand with the non-woven geotextile. Interfacial strength efficiency of fine sand is 19.45% greater than that of coarse sand and is 11.38% greater than that of medium sand for the same type of geosynthetic material. Interfacial friction angle between sand and non-woven geotextile is 0.70 to 0.90 times of sand to sand friction angle for dry condition.

Keywords: Size of sand, interfacial friction angle, sand-geotextile interface, direct shear test.

INTRODUCTION

The use of geotextile-reinforced soil systems has extremely been increased for essential earth structures. Thus, it is important to understand the behavior of geotextile and reinforced soil interface. The walls and slopes reinforced with geosynthetic are considered to be an advanced technology in geotechnical engineering. The application of reinforced slopes establishes the most cost-effective solution in highway projects now a days. The inclusions of geosynthetic within the soil help improving the performance of potential planes of weakness against failures [1]. A good understanding of the interfacial friction characteristics may provide great assistance for the effective and safe design of reinforced soil structure. To understand and determine the interfacial friction characteristics, direct shear tests, pull-out tests, in-soil tensile tests and ramp tests are usually used [2]. Among the tests, the direct shear test is the most common method [3, 4]. The interface behavior is influenced by a combined effect of surface textures and deformability of the geotextiles. It is also influenced by the index properties of soils [5]. Furthermore, the interlocking between sand and geotextiles depends upon the size of sand and also upon its morphology [6]. It is observed that higher interfacial shear strength is achieved when mean particle size (D_{50}) of sand properly matches with asperity size of interfacing material. It is also noted that normal stress affects the interface interaction mechanisms. When normal stress is less than 50 kPa, interlocking and friction develop at a superficial level. However, when normal stress is more than 50 kPa, interlocking and friction develop at a

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matrix level [6]. The interfacial behavior of cement treatment on soil to non-woven geotextile interface is also a matter of interest to many researchers. The study at microscopic level of the interface depicts that the interfacial soil-geotextile shear strength is extremely reliant on the size distribution of soil particle and particularly, on its fine content [7].

As discussed earlier, the interface shear strength can be obtained either by tilt table test or by direct shear test [8]. Usually, tilt table tests are preferable at extremely low stress level (<10 kPa) whereas direct shear test is preferable for higher stress level (from 50 to 500 k Pa). It is observed that direct shear tests at extremely low stress level do not provide reliable results due to mechanical difficulties. Moreover, the boundary conditions of tilt table test and direct shear tests are differ. Tilt table test is controlled by force whereas direct shear test is controlled by displacement. In the case of tilt table test, one can obtain the peak strength but not the residual strength while in the case of direct shear test, the soil specimen is restrained and remains stable when the peak strength is reached [9]. Considering the conditions and facilities, in the present study, the conventional-sized direct shear test box is used to understand the interfacial behavior of sand-geotextile.

Nevertheless, precise approximation of interfacial shear strength by using the laboratory studies has not yet been given sufficient importance so far in the literature. Still today, approximate and empirical correlations are used to perform the designs compromising the accuracy. In the present study, several laboratory experiments were carried out with fine, medium and coarse sands and non-woven geotextiles in a modified direct shear box to understand the influence of the size of sand on interfacial shear behavior. The aims of this research are as follows: (i) to study the influence of particle size of sand on the behavior of sand-geotextile interface, (ii) to compare the interfacial behavior of three different sizes of sand with non-woven geotextile and (iii) to find a correlation between interfacial friction angle for sand and non-woven geotextile with sand-sand friction angle.

MATERIALS USED

In this study, three types of sands were used. These sands were collected from the same river and separated according to ASTM D422 [10]. They are coarse sand (CS: particle size 4.75 mm-2 mm), medium sand (MS: particle size 2 mm-0.425 mm) and fine sand (FS: particle size 0.425 mm-0.075 mm). The sands are classified as poorly graded sands as per Unified Soil Classification System. Figure 1 shows the photographs of sand used in the present study. The grain size distribution of these sands are depicted in Figure 2. Properties of three different sizes of sands are represented in Table 1. A sample of commercially available non-woven geotextile of polypropylene monofilament was selected for current study. The specifications and engineering properties are presented in Table 2. Laboratory tests such as determination of mass per unit area, determination of thickness, strip tensile strength test, grab tensile strength test, elongation test for strip, elongation test for grab, determination of vertical and horizontal permeability, CBR puncture test were conducted to obtain the properties of the geotextile (GT) sample.

Table 1. Properties of three different sizes of sand used in the laboratory experiment.

Property	Coarse Sand (CS)	Medium Sand (MS)	Fine Sand (FS)
D_{10}	2.02	0.45	0.13
D_{30}	2.5	0.50	0.17
D_{50}	2.9	0.55	0.20
D_{60}	3.3	0.60	0.24
Coefficient of uniformity (C_u)	1.63	1.33	1.84
Coefficient of curvature (C_c)	0.94	0.83	0.93
Maximum dry density (gm/cm^3)	1.69	1.64	1.60
Minimum dry density (gm/cm^3)	1.56	1.51	1.40

Figure 1. Fine, medium and coarse sands used in the direct shear test.

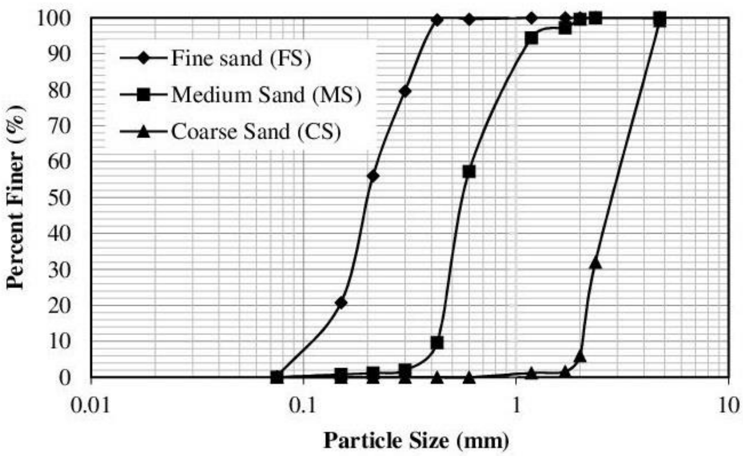


Figure 2. Grain size distribution of sands used in the laboratory experiment.

Table 2. Properties of geotextile used for the laboratory experiment.

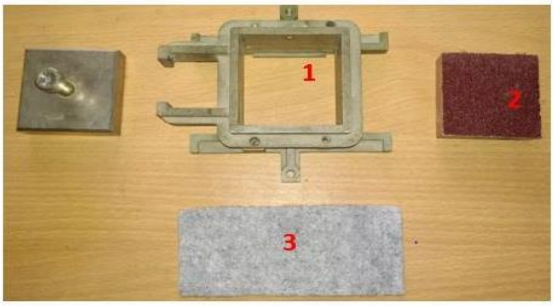
Property	Test standard	Unit	Test Value Geotextile
Mass per unit area	ASTM D 5261 [11]	gm/m^2	445
Thickness	ASTM D 5199 [12]	mm	3.75
Strip tensile strength	ASTM D 5035 [13]	kN/m	40.14 (machine direction)
			36.37 (X-machine direction)
Strip elongation	ASTM D 5035 [13]	%	107.92 (machine direction)
			117.17 (X-machine direction)
Grab tensile strength	ASTM D 4632 [14]	N	2604.9 (machine direction)
			2306.6(X-machine direction)
Grab elongation	ASTM D 4632 [14]	%	127.87 (machine direction)
			119.72 (X-machine direction)
CBR puncher resistance	ASTM D 6241 [15]	N	4690.26
Effective opening size	ASTM D 4757 [16]	mm	< 0.075
Horizontal permeability (under 2 kN/m^2 load)	ASTM D 4491 [17]	m/sec	0.59×10^{-3}
Vertical permeability (under 2 kN/m^2 load)	ASTM D 4491 [17]	m/sec	2.96×10^{-3}

EXPERIMENTAL PROGRAM

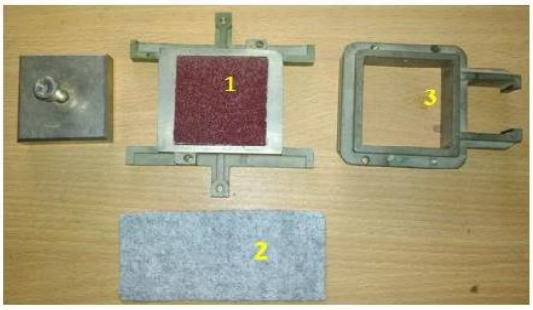
Following ASTM D 3080 [18], direct simple shear test was carried out to determine the individual friction angles of three sands of different sizes (CS, MS, FS). Initially, direct shear tests of sand alone were carried out to comprehend the shearing response of different types of sands by finding sand to sand friction angles. The equipment consisting of a square box of internal dimensions 6 cm × 6 cm was used for the direct shear test. Several tests were conducted with three normal stresses of 0.51

kg/cm², 1.02 kg/cm² and 1.53 kg/cm² for all types of sands. For geosynthetic interface testing, ASTM D 5321 [19] suggests to use a shear box with the following minimum dimensions: greater of 300 mm and 15 times the D_{85} of the coarse soil or at least five times the maximum opening size (in plan) of the geosynthetic. These guidelines are based on the requirement for testing the most combinations of geosynthetic and sandy soils. Studies by O'Rourke et al. [20], Palmeira [21] and Takasumi et al. [22] presented that apparatus size does not influence significantly the friction angles for cohesionless sands with ratios of mean particle size to length of the box that are in the range of 50-300. A smaller shear box (6 cm × 6 cm) was taken and a wooden block was placed in the lower half of the shear box. To prevent the stretching of the geotextile sample along the smooth surface of the wooden block, a sand paper was fixed on it. Then, a previously cut geotextile sample was clamped on the lower half of shear box and assembled properly by inserting pins. The photographs of the modified shear box are shown in Figure 3.

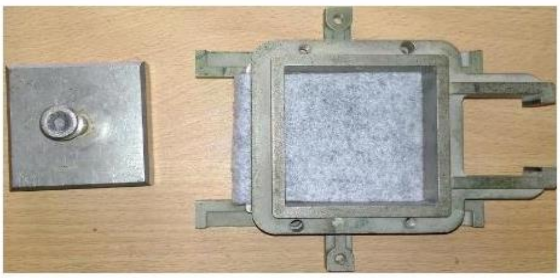
A fixed weight of sand was placed over the geotextile in the upper half of the shear box and compacted to achieve the desired relative density of 70% which corresponds to dry density of 1.69 gm/cm³, 1.64 gm/cm³ and 1.60 gm/cm³ for coarse sand, medium sand and fine sand, respectively. Then, placing the grid plate and top plate, the shear box was placed in the loading frame diligently. The soil sample was at dry condition, so no excess pore water pressure was generated. The displacement rate of 1 mm/min was applied under three normal stresses (0.51 kg/cm², 1.02 kg/cm², 1.53 kg/cm²). As the lower half of the shear box was fully covered with geotextiles, area correction was not taken into consideration.



Components of modified shear box: (1) 6 cm × 6 cm shear box; (2) Wooden block with sandpaper; (3) Geotextile



(1) Wooden block placed in lower half of shear box; (2) Geotextile; (3) Upper half of shear box.



Modified shear box of which lower half is clamped with geotextile.

Shear box loading frame

Figure 3. Assembly of the modified shear box used in the current study.

FINE SAND-GEOTEXTILE INTERFACE BEHAVIOR

A series of direct shear tests were performed using fine, medium and coarse sands with geotextile to comprehend the effect of the size of sand on their interfacial behavior. When conventional direct test and interface direct test were conducted using fine sand, it was noticed that the peak shear stress for sand alone was much higher and peak shear stress for interface direct test was a bit flat (Figure 4).

When the relationship between peak shear stress and normal stress was plotted, it was found to be a straight line passing through the origin (for both the cases); however, the slopes were different. The sand to sand friction angle for fine sand was 34.29º and the sand to geotextile interface friction angle was 29.73º (Figure 5). When the geotextile was introduced as reinforcement in sand, the interfacial friction angle gets reduced than the sand to sand friction angle and thus, the interfacial zone turns into the weakest zone for failure.

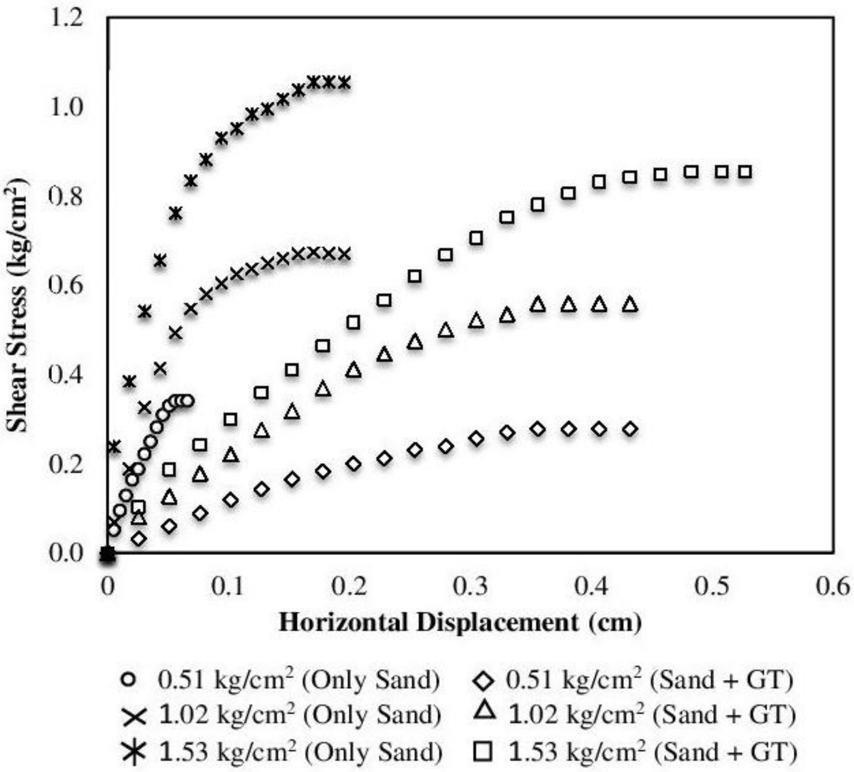


Figure 4. Evolution of shear stress with the horizontal displacement for fine sand.

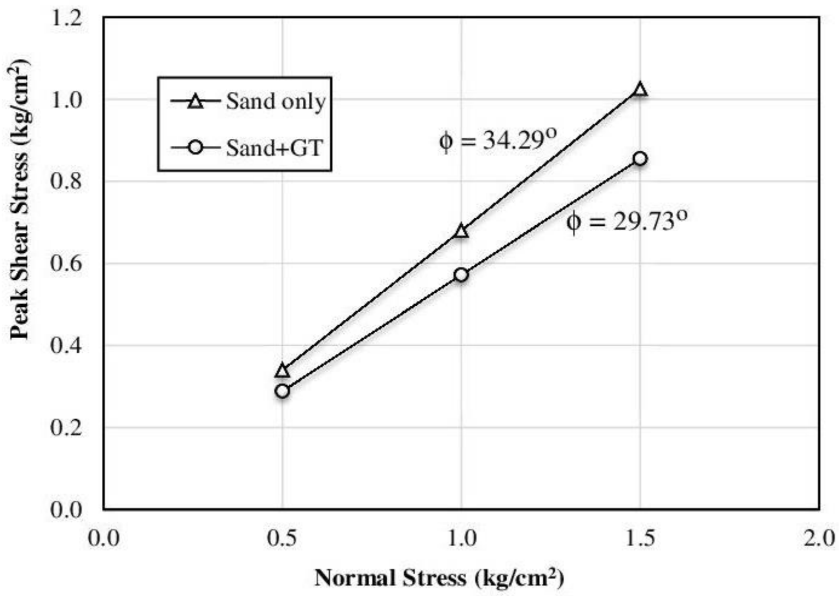


Figure 5. Relationship between the peak shear stress and the applied normal stress for fine sand.

MEDIUM SAND-GEOTEXTILE INTERFACE BEHAVIOR

When conventional direct test and interface direct test were conducted using medium sand (Figure 6), it was noticed that the peak shear stress for sand alone was higher and peak shear stress for interface direct test was a bit flat. It indicates that shear parameters also get reduced when geotextile is used in the interface direct shear test (same as fine sand).

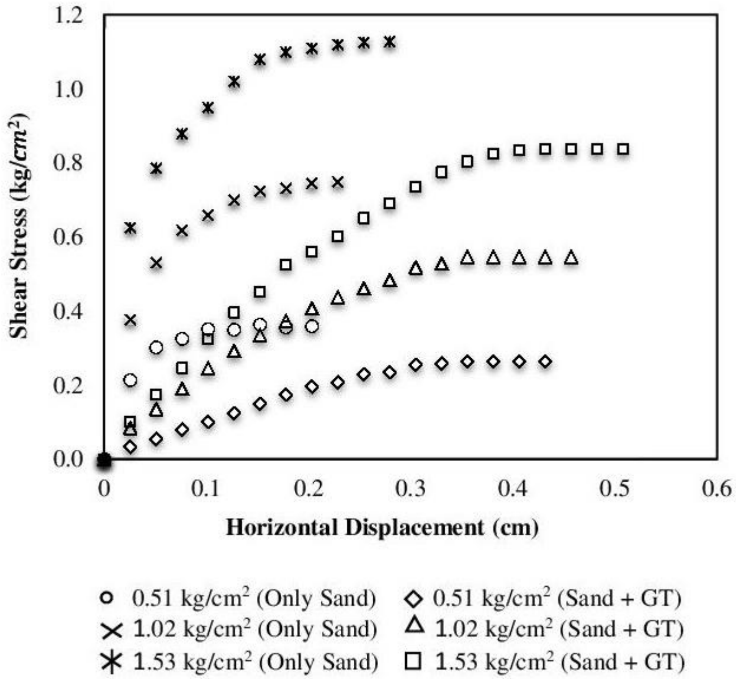


Figure 6. Evolution of shear stress with the horizontal displacement for medium sand.

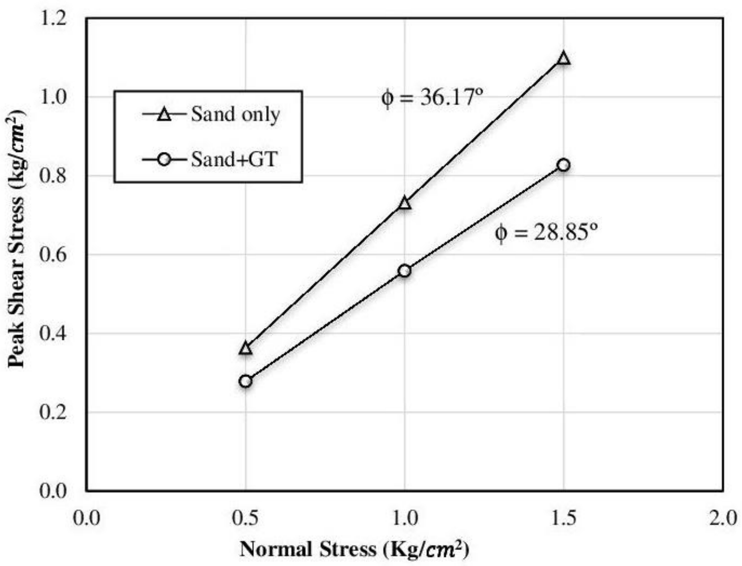


Figure 7. Relationship between the peak shear stress and the applied normal stress for medium sand.

When the relationship between the peak shear stress and normal stress was plotted (Figure 7), it was found to be a straight line passing through the origin (for both the cases) but the slopes were different. The sand to sand friction angle for medium sand was 36.17º and the sand to geotextile interface friction angle was 28.85º. Figure 7 shows that sand to sand friction angle for medium sand is 36.17º which is greater than that of fine sand. It also shows that the interface friction angle for medium sand is smaller than that of fine sand.

COARSE SAND-GEOTEXTILE INTERFACE BEHAVIOR

When conventional direct test and interface direct test were conducted using coarse sands (Figure 8), it was observed that the peak shear stress for coarse sand alone was higher and peak shear stress for interface direct test was a bit flat. It indicates that shear parameters also get reduced when geotextile is used in the interface direct shear test. Similar behavior is also noted for fine and medium sand.

When the relationship between the peak shear stress and normal stress was plotted (Figure 9), it was found to be a straight line passing through the origin (for both the cases) but the slopes became different. The sand to sand friction angle for coarse sand was found to be 37.93º and the sand to geotextile interface friction angle was 26.61º. Sand to sand friction angle for coarse sand is 37.93º which is greater than that of fine and medium sand. It also shows that the interface friction angle for coarse sand is the smallest one.

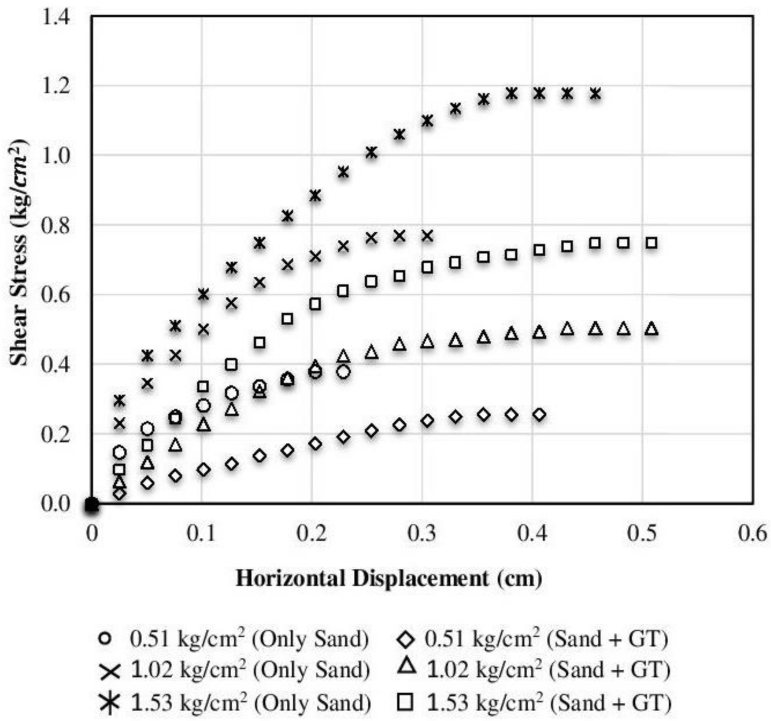


Figure 8. Evolution of shear stress with the horizontal displacement for coarse sand.

COMPARISON OF FRICTION ANGLES BETWEEN SAND-SAND AND SAND-GEOTEXTILE INTERFACE

When the peak shear stresses of conventional direct shear tests are plotted against the applied normal stresses in a single plot, straight line is obtained passing through the origin. Figure 10 shows that the sand to sand friction angle is the highest for coarse sand and the lowest for fine sand as one can expect. The value of friction angle for coarse sand is 37.93º, medium sand is 36.17º and fine sand is 34.29º. Again, when the peak shear stresses of interface direct shear tests are plotted against the applied normal stresses in a single plot, straight line is obtained passing through the origin also (Figure 11). However, the value of sand to geotextile interface is smaller than that of sand to sand interface regardless of the size of sand. Figure 11 shows that the interfacial friction angle is the highest for fine sands and the lowest for coarse sand, which is just in the reverse order of test results when only sand is considered in the direct shear test. The value of friction angle for coarse sand is 26.61°, medium sand is 28.85° and that for fine sand is 29.73°.

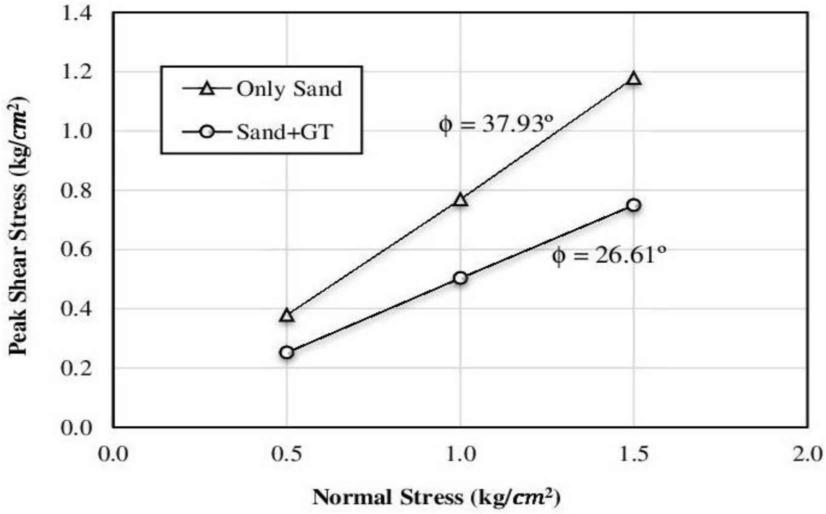


Figure 9. Relationship between the peak shear stress and the applied normal stress for coarse sand.

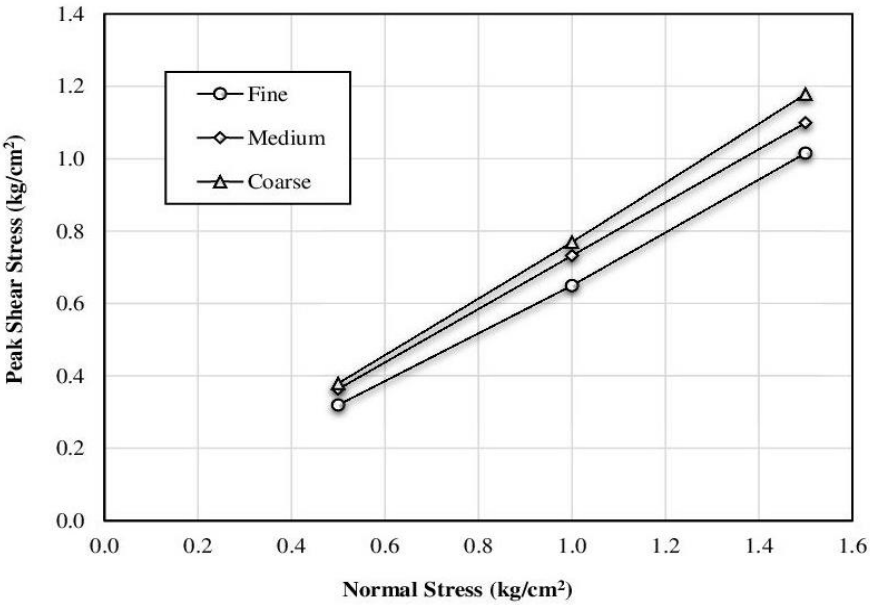


Figure 10. Comparison of relationships between the peak shear stress and the applied normal stress considering sand only.

INTERFACIAL STRENGTH EFFICIENCY

As sand was used for the study, contact efficiency ratio between sand and geotextile can be defined for friction angle only. The interfacial strength efficiency ratio (for friction angle) can be defined by equation (1) as follows:

$$R_{tam\phi} = \frac{\tan \phi_{\text{int}\, er}}{\tan \phi} \quad (1)$$

Here, $\phi_{\text{int}\, er}$ = Interfacial Friction angle and ϕ = friction angle.

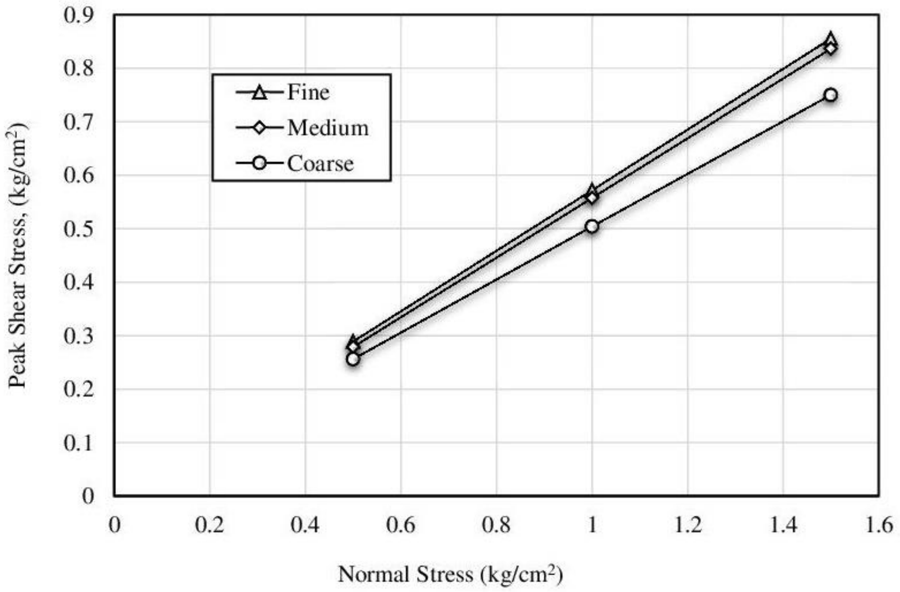


Figure 11. Comparison of relationships between the peak shear stress and the applied normal stress considering sand-geotextile interface.

The result shows that the interfacial strength efficiency is the highest for fine sand with the geotextile and it was 83.93%. The lowest value was found for coarse sand with geotextile and it was 64.28%. Interfacial strength efficiency of fine sand is 19.45% and 11.38% greater than that of coarse and medium sand, respectively.

RELATIONSHIP BETWEEN FRICTION ANGLE (ϕ) AND INTERFACIAL FRICTION ANGLE ($\phi_{\text{int}\,er}$)

A simple relationship between sand to sand friction angle (ϕ) and sand-geotextile interfacial friction angle ($\phi_{\text{int}\,er}$) was established for all three types of sands. The relationships are expressed by equations (2), (3) and (4) for coarse, medium and fine sand respectively.

$$\phi_{\text{int}\,er} = 0.702\phi \quad (2)$$

$$\phi_{\text{int}\,er} = 0.798\phi \quad (3)$$

$$\phi_{\text{int}\,er} = 0.867\phi \quad (4)$$

So, it can be generalized that interfacial friction angle for sand and non-woven geotextile, $\phi_{\text{int}\,er}$ = (0.70 to 0.90) ϕ

CONCLUSIONS

This paper investigated the effect of particle size of sands on interfacial shear strength of sand and geotextile (GT) by direct shear tests. Using a modified shear test apparatus, interface shear tests were conducted using coarse sand, medium sand and fine sand subjected to different normal stresses.

Conclusions are pointed out from the experimental results and presented as follows:

- The particle size distribution of sand significantly affects the soil-geotextile interfacial behavior.
- When geotextile is introduced as reinforcement in sand, the interfacial friction angle gets reduced compared to the sand to sand friction angle and thus, interfacial zone converts into the weakest zone for shear failure.

- The interfacial friction angle for fine sand is higher than that of medium and coarse sand with the non-woven geotextile.
- Interfacial friction angle for sand and non-woven geotextile (ϕ_{inter}) was found to be approximately (0.70 to 0.90) times of sand to sand friction angle (ϕ).
- Interfacial strength efficiency of fine sand is 19.45% and 11.38% greater than that of coarse and medium sand, respectively.

REFERENCES

1. Yetimoglu T, Salbas O. A study on shear strength of sands reinforced with randomly distributed discrete fibers. Geotextiles and Geomembranes. 2003; 21(2):103–10p.
2. Palmeira EM. Soil-geosynthetic interaction: Modelling and analysis. Geotextiles and Geomembranes. 2009; 27(5):368–90p.
3. Lee KM, Manjunath VR. Soil-geotextile interface friction by direct shear tests. Canadian Geotechnical Journal. 2000; 37(1): 238-52p.
4. Anubhav, Basudhar PK. Interface behavior of woven geotextile with rounded and angular particle sand. Journal of Materials in Civil Engineering. 2013; 25(12):1970–74p.
5. Tuna SC, Altun S. Mechanical behaviour of sand-geotextile interface. Scientia Iranica, 2012; 19(4): 1044–51p.
6. Vangla P, Gali ML. Effect of particle size of sand and surface asperities of reinforcement on their interface shear behaviour. Geotextiles and Geomembranes. 2016; 44(3): 254–68p.
7. Ebadi M, Habibagahi G, Hataf N. Effect of cement treatment on soil non-woven geotextile interface. Scientia Iranica. 2015; 22(1):69–80p.
8. ASTM D5321. Standard Test Method for Determining the Shear Strength of Soil-Geosynthetic and Geosynthetic-Geosynthetic Interfaces by Direct Shear. ASTM International, West Conshohocken, PA; 2017.
9. Wu W, Wick H, Ferstl F, et al. A tilt table device for testing geosynthetic interfaces in centrifuge. Geotextiles and Geomembranes. 2008; 26(1):31–38p.
10. ASTM D422. Standard Test Method for Particle-Size Analysis of Soils. ASTM International, West Conshohocken, PA; 1998.
11. ASTM D 5261. Standard Test Method for Measuring Mass per Unit Area of Geotextiles. ASTM International, West Conshohocken, PA; 1992.
12. ASTM D 5199. Standard Test Method for Measuring the Nominal Thickness of Geosynthetics. ASTM International, West Conshohocken, PA; 2001.
13. ASTM D 5035. Standard Breaking Force and Elongation of Textile Fabrics (Strip Method). ASTM International, West Conshohocken, PA; 2006.
14. ASTM D 4632. Standard Test Method for Grab Breaking Load and Elongation of Geotextile. ASTM International, West Conshohocken, PA; 2008.
15. ASTM D 6241. Standard Test Method for Static Puncture Strength of Geotextiles and Geotextile-Related Products Using a 50-mm Probe. ASTM International, West Conshohocken, PA; 2014.
16. ASTM D 4757. Standard Practice for Placarding Solvent Vapor Degreasers. ASTM International, West Conshohocken, PA; 1998.
17. ASTM D 4491. Standard Test Methods for Water Permeability of Geotextiles by Permittivity. ASTM International, West Conshohocken, PA; 1999.
18. ASTM D 3080. Standard Test Method for Direct Shear Test of Soil. ASTM International, West Conshohocken, PA; 2004.
19. ASTM D 5321. Standard Test Method for Determining the Shear Strength of Soil-Geosynthetic and Geosynthetic-Geosynthetic interfaces by direct Shear. ASTM International, West Conshohocken, PA; 2008.
20. Ouria A, Mahmoudi A. Laboratory and numerical modeling of strip footing on geotextile-reinforced sand with cement-treated interface. Geotextiles and Geomembranes. 2018; *46*(1): 29–39p.

21. Palmeira EM. Sixth Géotechnique symposium in print, discussion on ‘direct shear tests and reinforced sand. Géotech. 1988; 38(1):146–48.
22. Takasumi DL, Green KR, Holtz RD. Soil-geosynthetic interface strength characteristics: A review of state-of-the-art testing procedures. *Proc. Geosynthetics’91*; 1991, Industrial Fabrics Association International, St. Paul, MN, 1991, 87–100p.