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Influence of Different Types of Soils on Soil-Geosynthetics Interaction Behavior

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Abstract—Interaction behavior of soil-geosynthetic system is of great importance in design and analysis of reinforced soil structures. Type of soil and geosynthetic influence the parameters describing the interaction. In general, interaction parameters of soil-geosynthetic system are generally determined by direct shear and pullout tests. This paper presents the influence of different types of soils and geosynthetics on the interaction behavior of soil-geosynthetics system using direct shear tests. Large scale direct shear tests were conducted for the purpose using four different types of cohesionless soils and two types of geosynthetics (woven and nonwoven). The results are presented and discussed in terms of peak shear resistance, interface friction angle and efficiency factors for different soils and geosynthetics. It is observed that the interface friction angle values are significantly affected with soil type and geosynthetic material. Efficiency factors are not affected with type of soil for a selected geosynthetic material. However, different efficiency factors for different geosynthetic materials are observed. For the range of materials tested at the 50 kPa normal stress the range of efficiency factors is 0.4-0.45.

Keywords—Geosynthetics, interaction behavior, direct shear test, efficiency factors

I. INTRODUCTION

The evaluation of soil-geosynthetic interaction parameters is very important for design and analysis of geosynthetic reinforced soil structures [1-4]. Increased applications of soil reinforcement structures can be attributed to a number of factors, including low cost, aesthetics, reliability, simple construction techniques, and the ability to adapt to different site conditions. However, the economic benefits have been often limited by the availability of good-quality granular soils. These materials have been preferred as backfill material due to their interface mobilisation and ability to prevent development of pore water pressures [2]. The interface friction angle and adhesion between a geosynthetic and soil are the primary and most contentious variables used in geosynthetic reinforcement structure design and stability analysis. Though the shear strength of the soil/geosynthetic interface has been investigated by conducting other tests, such as tilt-table tests [3, 5], the direct shear test is the most common testing method [6 - 11]. Modified direct shear tests are being generally performed to determine the interaction parameters like friction angle, adhesion coefficient and other design parameters for various interfaces within the design. The ASTM D5321 [12] standard on the test method is commonly followed for the purpose. The dimensions of typical direct shear test specimen are 300 × 300mm.

Most of the previous investigations have studied the interaction behavior of geosynthetics with good quality granular soils. In general, cohesionless soils are preferred as backfill or neighboring soil to the reinforcement for better performance. However, it is inevitable to adopt locally available soils, which may be of low quality cohesionless soils and/or cohesive soils for reinforcement applications under some practical situations. Hence, determining the soil-geosynthetic interaction parameters with cohesive soils and other cohesionless soils is essential for proper designing and efficient performance of reinforced soil structures under such special practical conditions. There have been very

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limited investigations on the interaction behavior of different types of soils and geosynthetics. Lopes et al. [3] and Hsieh et al. [13] have investigated the shear behavior of different types of soil and geosynthetics.

The objective of the paper is to investigate the influence of different types of soils on soil-geosynthetics interaction parameters using direct shear tests. For the purpose different cohesionless soils having different gradation curves, mean/effective particle sizes are selected along with different types of geosynthetics. The results are presented in terms of peak shear resistance, interface friction angles and efficiency factors, describing the influence of different types of soils and geosynthetics.

II. TEST EQUIPMENT AND PROCEDURES

A large direct shear test setup, with a shear box of size 300 mm × 300 mm × 150 mm height, as shown in Fig. 1 was used to evaluate the interaction behavior of the soil/geosynthetic systems. The direct shear tests on geotechnical materials (soil-soil) were conducted according to ASTM D3080 [14]. Modified direct shear tests on soil-geosynthetic specimens were conducted according to ASTM D5321 [12], in a manner similar to a direct shear test on geotechnical materials but with a modification. The modification is that the lower shear box of the conventional direct shear test setup was fitted with rigid wooden block. A wooden plank of dimensions 295 mm × 295 mm covered/clamped with geotextile was placed on the wooden block (Fig. 2). The use of similar rigid block was practiced by Lee and Manjunath [8] and Lopes and Silvano [15]. The lower box of direct shear test setup could able to move for 35 mm of total displacement during shearing.

The normal load was applied through a loading yoke connected to a loading lever, counter-balanced by a dead weight. The shearing of the test specimen was done by a screw-advanced drive system, powered by a motor and gear system, maintaining a controlled constant rate of shear displacement. During shearing the lead screw pushes the shear box along with the lower half box, such that the load cell connected to the upper half of the box via the U-arm measures the shear resistance. Horizontal displacement is recorded by placing a linear variable differential transformer (LVDT) onto the front face of the shear box as shown in Fig. 1. During testing, data from the load cell and LVDT were recorded through data acquisition system.

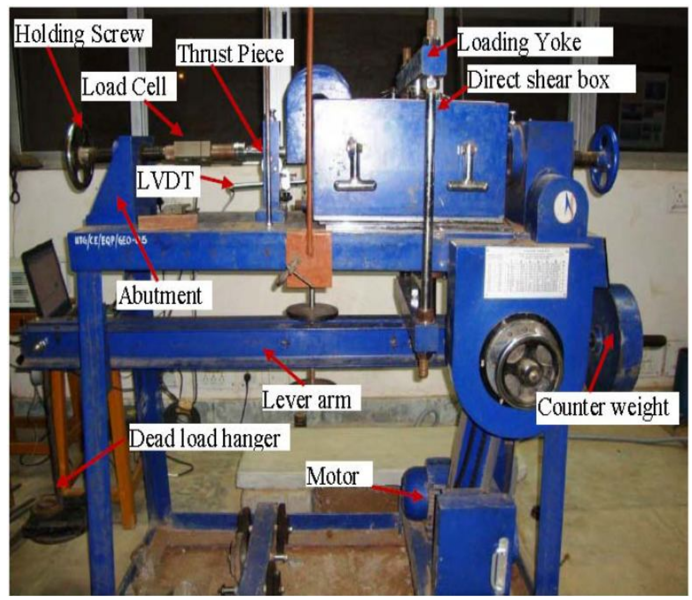

Fig. 1 Large direct shear box setup

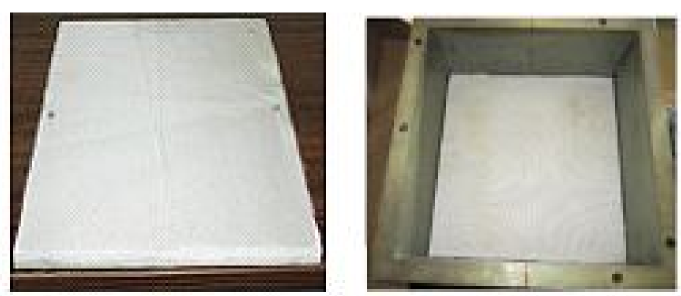

Fig. 2 Modification to the direct shear setup

III.MATERIALS USED

Soils

Four different types of cohesionless soils were used in the tests. Three different types of soil (soil 1, soil 2 and

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soil 3) are adopted and the fourth one is the mixture of the other three. The particle size distributions, as per ASTM D6913 [17], of the four types of soils: soil 1, soil 2, soil 3 and soil 4 (mix of three soil), are shown in Fig. 3. Their physical properties such as maximum dry density, minimum dry density and specific gravity of soil were determined according to ASTM D4253 [18], ASTM D4254 [19] and ASTM D 0854 [20], respectively and are presented in Table 1. The specific gravity of sands was found to be 2.64. The coarser size sand, Soil 1 (D_{50}=1.5 mm), has minimum and maximum unit weight values as 14.8 and 16.6 kN/m^3 respectively, and soil particle diameter values ranging from 1 to 2 mm. The finer size sand, Soil 3 (D_{50}=0.22mm), has minimum and maximum unit weight values of 14.6 and 16.7kN/m^3 respectively, and soil particle diameters values range from 0.09 to 0.5 mm. All the soils are classified as poorly graded sands (SP) according to unified soil classification system [21]. Microscopic views of the different grades of soils are shown in Fig. 4. From the figure it can be seen that the sand particles are of round/sub angular shape and surface is smooth.

TABLE 1
PHYSICAL PROPERTIES OF FOUR TYPES SOILS USED

Properties	Soil 1	Soil 2	Soil 3	Soil 4
Particle size range (mm)	1-2	0.5-1	0.09-0.5	0.09-2
G	2.64	2.64	2.64	2.64
D_{10} (mm)	1	0.4	0.16	0.12
D_{30} (mm)	1.2	0.46	0.2	0.27
D_{50}(mm)	1.5	0.5	0.22	0.49
D_{60} (mm)	1.6	0.51	0.25	0.57
C_u	1.6	1.27	1.56	4.75
C_c	0.9	1.03	1	1.86
Classification (USCS)	SP	SP	SP	SP
$\gamma_{d,\,max}$(kN/m^3)	16.6	16.3	16.7	18.1
$\gamma_{d,\,min}$ (kN/m^3)	14.8	14.5	14.6	15.8
ϕ at RD 70%	37.7°	34.8°	33.1°	35.5°

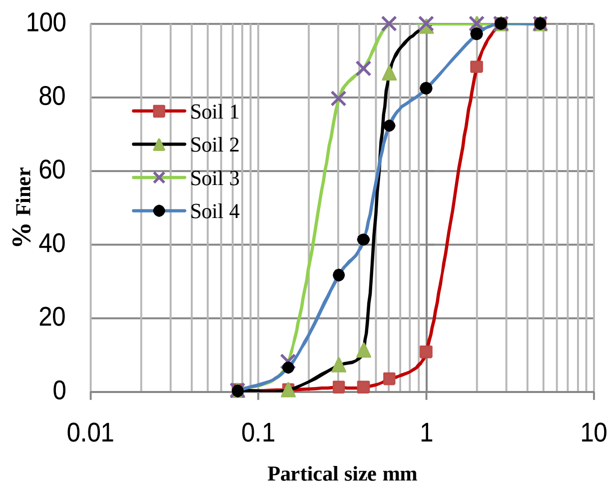

Fig. 3 Grain size distribution curves of soils used

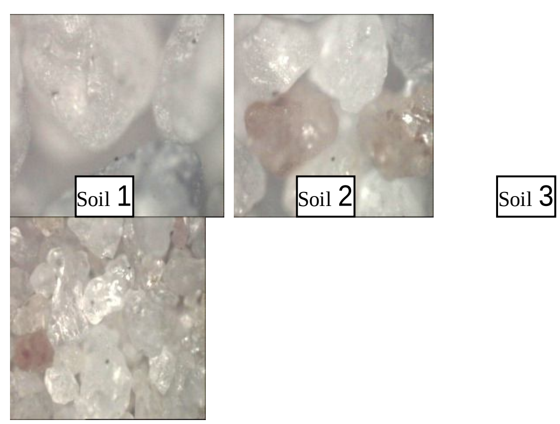

Fig. 4 Microscopic view of soil 1, soil 2 and soil 3

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Geosynthetics

Two types of geosynthetics, nonwoven geotextile (GT1) and woven geotextile (GT2), were used in the present study and are shown in Fig. 5. The tensile properties of geotextile specimens were determined as per ASTM D4595 [22] and mass per unit area of the materials were determined as per ASTM D5261 [23] and are presented in Table 2. Tensile load-strain response of GT1 and GT2 are as shown in Fig. 6. From Table 2 and Fig. 6 it can be observed that the two geosynthetic materials selected are having almost same tensile strength of about 39 kN/m but with different elongation at failure, unit mass and surface texture. GT1 has relatively rough texture than that of GT2.

TABLE 2
PROPERTIES OF GEOSYNTHETICS USED IN STUDY

Properties	Non woven geotextile (GT1)	Woven geotextile (GT2)
Mass per unit area (g/m^2)	698	250.4
Tensile strength (kN/m)	38.8	39.2
Elongation at break (%)	22.8	39.13

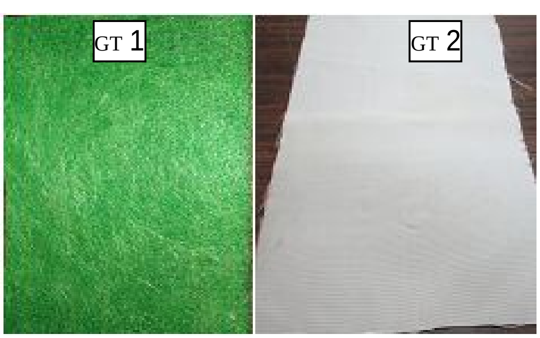

Fig. 5 Geosynthetics used in study

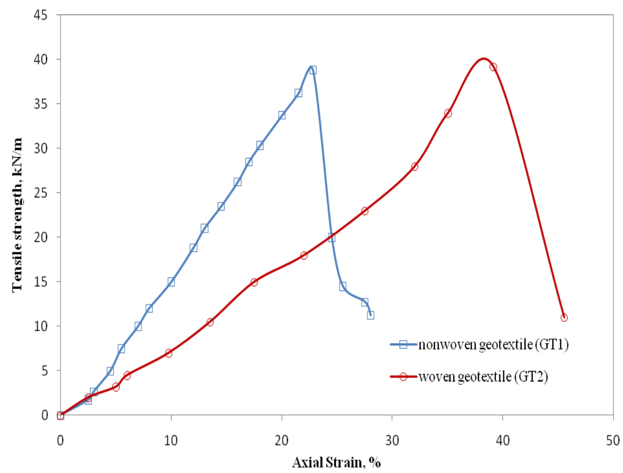

Fig. 6 Tensile load-strain behavior of GT1 and GT2

IV. TEST RESULTS AND DISCUSSION

A series of direct shear tests, according to ASTM D3080 [14] and ASTM D5321 [12], were performed in the study using four types of granular soils and two types of geotextiles. All the soil specimens were prepared at 70 % relative density (RD=70%) using sand raining method. The height of fall required to achieve required relative density was determined by trail tests. The samples collected, while preparing the samples, showed about ± 3% variations in the unit weights. All the tests were conducted under same displacement rate of 4.567 mm/min and at normal stress of 50 kPa.

Results obtained from direct shear tests on four soils and modified shear tests on four different soils with non-woven geotextile (GT1) are shown in Figs. 7a – 7d. The peak shear resistance occurred at the shear displacement of 3-6 mm and 6-10 mm for unreinforced and reinforced specimens respectively. From the Fig. 7 (a, b, c and d) it is observed that soil-soil peak shear stress are 32.09 kPa, 28.36 kPa, 26.88 kPa and 29.24 kPa for unreinforced soil 1(D_{50}=1.5 mm), soil 2(D_{50}=0.5 mm), soil 3(D_{50}=0.22 mm) and soil 4(D_{50}=0.49 mm) respectively. The corresponding soil-geosynthetic (GT1) peak shear stresses are 16.75 kPa, 15.57 kPa, 14.67 kPa and 15.97 kPa respectively for four different soils, in order. From these peak stress values it can be noted that the response follows more or less increasing trend with mean particle

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size of soil (D_{50}). Figure 8 clearly provides the comparison all modified direct shear test results for four different soils with non-woven geotextile (GT1).

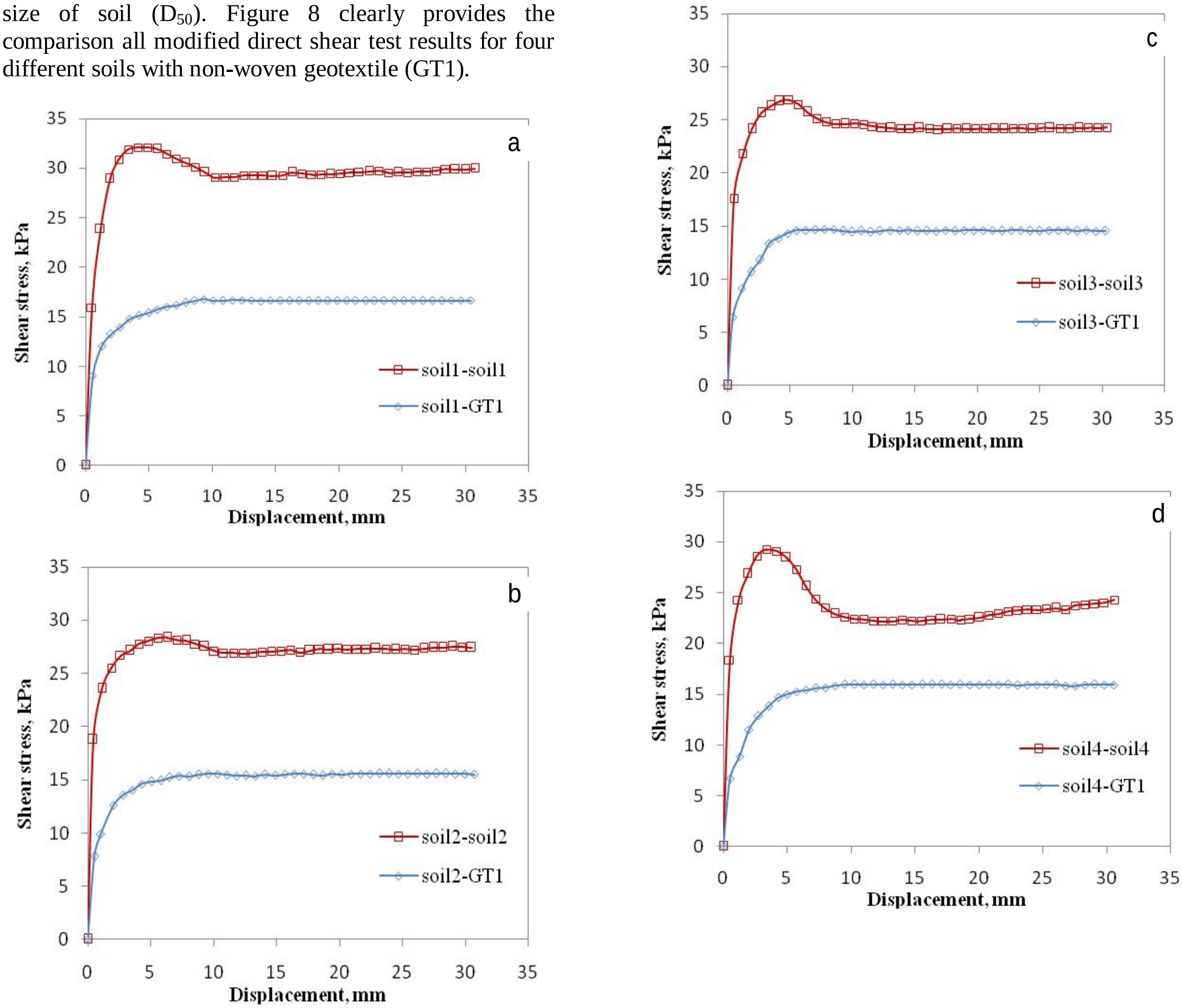

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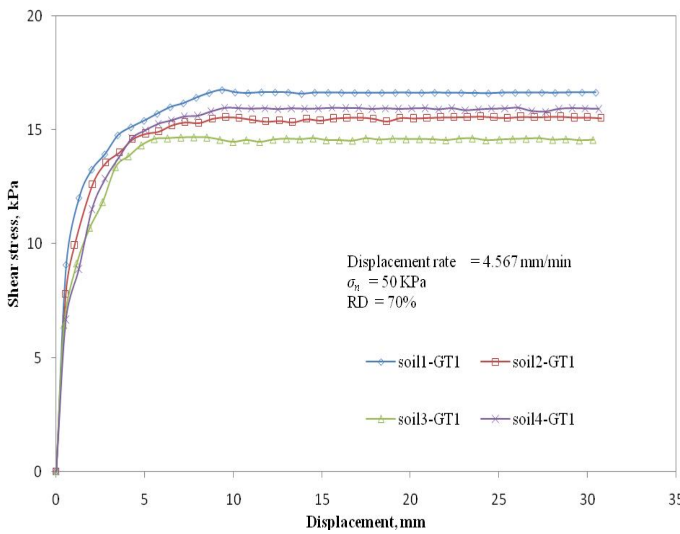
Fig. 7 Direct (soil-soil) and modified direct shear test

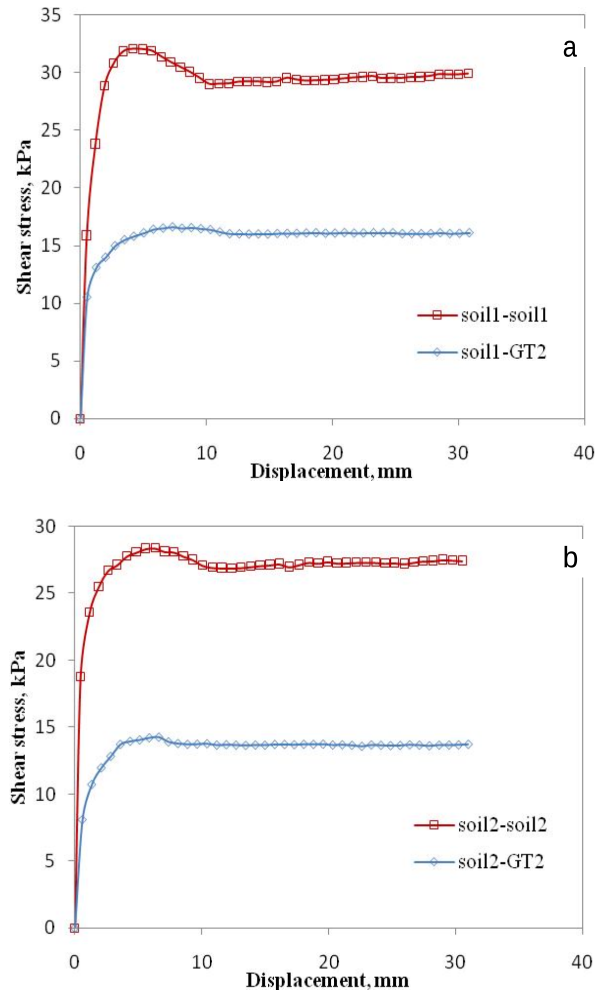


(soil-GT) results of all soils with GT1

Fig. 8 Modified direct shear test results for all soils with GT1

Figure 9 and 10 presents the results similar to Fig. 7 and 8, respectively, but with woven geotextile (GT2). In this case, soil-geosynthetic (GT2) peak shear stress for different soils: soil 1(D_{50}=1.5 mm), soil 2(D_{50}=0.5 mm), soil 3(D_{50}=0.22 mm) and soil 4(D_{50}=0.49 mm) are 16.62 kPa, 14.27 kPa, 13.3 kPa and 15.04 kPa respectively. These peak stress values are lower than that of non-woven geotextile (GT1) case. This implies that non-woven geotextile facilitated good interaction with neighboring soil which may be attributed to its texture. However, for the case of coarser size soil (soil1) the difference between the peak shear stress values for both GT1 and GT2 is not very significant, which is attributed to the larger mean particle size (D_{50}=1.5 mm).

In general, for both GT1 and GT2, there is an increase in soil/geosynthetics interface shear stress with effective particle size of the soil (D_{50}). But, in spite of having slightly lower D_{50}, soil 4 (D_{50}=0.49 mm) exhibited 2% and 5.2% higher peak shear stress, for GT1 and GT2 respectively, than that of soil 2 (D_{50}=0.5 mm). This may be attributed to the relatively flat gradation curve of soil 4 than that of soil 2 as shown in Fig. 3.



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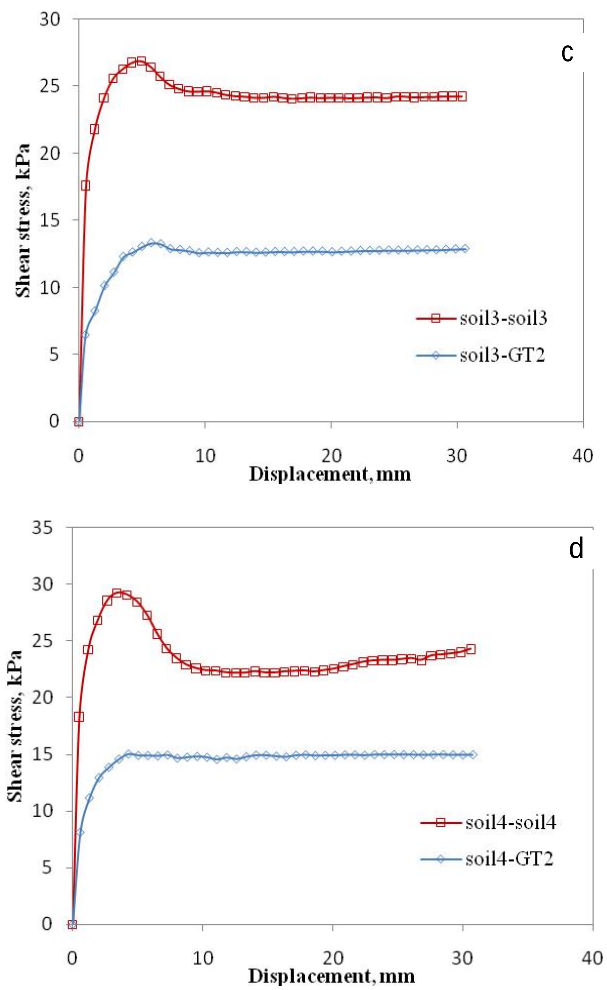

Fig. 9 Direct (soil-soil) and modified direct shear test (soil-GT) results of all soils with GT2

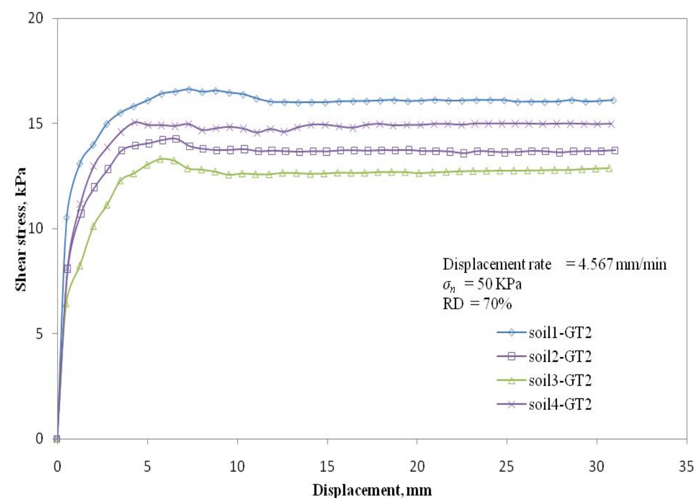

Fig. 10 Modified direct shear test results for all soils with GT2

Efficiency factors

From experimental data, friction angle (ϕ) for different soils and interfacial friction angle (δ_{GT}) for different soils with different geosynthetics are evaluated using peak shear stress values following Mohr-Coloumb principle as follows.

$\tau_p = c + \sigma_n \tan(\phi)$ and

$\tau_{pm} = c + \sigma_n \tan(\delta_{GT})$

Where, τ_p = Peak shear stress from direct shear test (soil-soil)

τ_{pm} = Peak shear stress from modified direct shear test (soil –Geosynthetic)

c = soil cohesion (c = 0 for granular soil)

σ_n = effective normal stress (= 50 kPa for all the tests)

ϕ = frictional angle of sand and

δ_{GT} = interfacial frictional angle between soil and geosynthetic

The friction efficiency factors (E_ϕ) are evaluated from the calculated values of ϕ and δ_{GT} using following equation:

$$E_\phi = (\tan \delta_{GT})/(\tan \phi)$$

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The internal friction angle (ϕ), interfacial friction angle (δ_{GT}) and efficiency factor (E_ϕ) evaluated for different soils with different geosynthetics are presented in Table 3.

TABLE 3
INTERNAL FRICTION ANGLE (ϕ), INTERFACIAL FRICTION ANGLE (Δ_{GT}) AND EFFICIENCY FACTOR (E_ϕ) VALUES

Soil Type	ϕ(°)	Non woven geotextile (GT1)		Woven geotextile (GT2)	
		δ_{GT} (°)	E_ϕ=tan δ_{GT}/tan ϕ	δ_{GT} (°)	E_ϕ=tan δ_{GT}/tan ϕ
Soil1	37.7	18.5	0.43	18.3	0.42
Soil2	34.8	17.2	0.44	15.91	0.4
Soil3	33.1	16.35	0.45	14.9	0.41
Soil4	35.5	17.7	0.44	16.74	0.41

When comparing the results obtained for the two geosynthetics, a difference of approximately 1.09%, 8.1%, 9.73% and 5.73%, for different soils (soil1 to 4 in order) respectively, in interfacial friction angle (δ_{GT}) values is observed. The higher δ_{GT} values for non-woven geotextile (GT1) may be attributed to its rough texture relative to the smooth texture of woven geotextile (GT2). The surface roughness of nonwoven geotextile is responsible for the increasing resistance.

From the table it can also noted that soil 1 exhibited 7.55%, 13.14%, and 4.51% higher δ_{GT} values with GT1, when compared to δ_{GT} values for soil 2, 3, and 4 respectively. For GT2 these variations are 15.02%, 22.8%, and 9.3%. With this observation it can be stated that the type of soil has significant role on interface friction angle values. From the results reported here, it is also noted that the woven geotextile (GT2) results are more affected with soil variation, the range being 9 – 23% in comparison to 4 – 13 % for non woven geotextile (GT1).

Further, from all tests results, the lowest soil-geosynthetic interface friction angle value obtained was 14.9º, which corresponds to soil 3 (D_{50}=0.22)/geotextile GT2 (smoother surface), while the highest value was 18.5º, which corresponds to soil 1 (D_{50}=1.5)/geotextile GT1 (having the rougher surface). Therefore, the structure of the geosynthetic, soil particle size and also gradation of soil play a very important role in the soil-geosynthetic interface resistance.

However, in contrast to the discussion on the interfacial friction angles, variation in efficiency factors (E_ϕ) for different soils is not very significant for a selected geosynthetic material. The fact here is that the efficiency factors are representing the interfacial friction values of different types of soils normalised with the frictional angle values of the same soil. But different efficiency factors (E_ϕ) for different geosynthetics are observed from the values presented in Table 3. An average E_ϕ for non-woven geotextile (GT1) being 0.44 while the same for woven geotextile (GT2) it is 0.41.

V. CONCLUSIONS

Influence of different type of soils and geosynthetics on soil-geosynthetics interaction behavior is investigated by direct shear tests. Four different types of cohesionless soils adopted along with two different types of geosynthetic materials. The results are presented in terms peak shearing resistance, interface frictional angle, and efficiency factors. The main conclusions of the study are as follows: Type of soil has significant influence on the soil-geosynthetic interface friction angle which may be quantified in terms of mean particle size (D_{50}); Soil gradation also influence the soil/geosynthetics interfacial resistance, soil having relatively flatter gradation curve possesses higher interfacial resistance (soil 4). Geosynthetic structure has an important influence on the soil-geosynthetic interface friction angle; higher soil-geosynthetic interface friction angles are observed for coarser soil with rough textured geosynthetic material (Soil1-GT1). For the same geosynthetic material there was no significant variation in terms of efficiency factor for the range of different types of soils tested. A coarser soil didn't show substantial variation in interface friction angle or efficiency factor for the different geotextile materials tested. For other soils about 10% variation in

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the efficiency factors was observed between the two geosynthetic materials tested.

From the study it should be noted that the soil-geosynthetics interaction behavior is highly depended on the type of the geosynthetic material and the neighboring soils adopted. For the range of materials tested at the 50 kPa normal stress the range of efficiency factors is 0.4-0.45. Use of single normal stress of 50 kPa, only, is the limitation of the study.

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