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Scale Effects of Direct Shear Box on Behavior of Geogrid-Sand Interface

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Abstract: Direct shear test is one of the simplest and most economical tests to measure shear strength parameters of dry or saturated sandy soil as well as soil-geogrid interaction parameters. In the current study the effects of specimen size and density on soil-geogrid interaction parameters employing shear boxes of 6 × 6 cm, 10 × 10 cm and 30 × 30 cm have been investigated. Results show that increasing specimen size of unreinforced sand with constant density results in a decrease in angle of friction which has been attributed to reduced confinement effect using larger shear boxes. The rate of reduction in angle of friction is increased by increasing soil density and using geogrid as reinforcement.

Key words: Direct shear box, geogrid, shear strength, specimen size, direct shear test.

1. Introduction

During the last decades there has been a considerable increase in the use of reinforced soil structures as a solution for civil engineering problems such as bearing capacity, slope stability and lateral pressure on earth retaining structures. Interaction between soil matrix and geosynthetic is one of the major issues in design of reinforced-soil structures which depends on soil type, geosynthetic type, size of specimen and scale factor of test. Direct shear test is one of the most common tests used to determine the soil-geosynthetic interaction parameters. Previous researches [1, 2] studied the effects of box size on shear strength in unreinforced soils. Direct shear tests on unreinforced sand samples showed that soil strength parameters were affected by the test scale. Parsons [1] presented test results for crushed quartz and Ottawa uniform sand which showed that larger shear boxes produced lower values of friction angle. Using three different size shear boxes 60 × 60 mm, 100 × 120 mm, and 120 × 200 mm, with soils prepared in a loose state, test results showed that the friction angles decreased slightly with increasing box size. Tests were done with very small normal stresses to obtain the failure envelopes (1.5 to 9.8 kPa) that such low normal stresses in conventional direct shear machines would be unlikely. Based on studies, the angles of friction obtained from tests on crushed quartz varied from 30.7° to 31.5°, whereas in uniform sand these values ranged from 28.5° to 31.0°. Both sets of data are presented in Fig. 1.

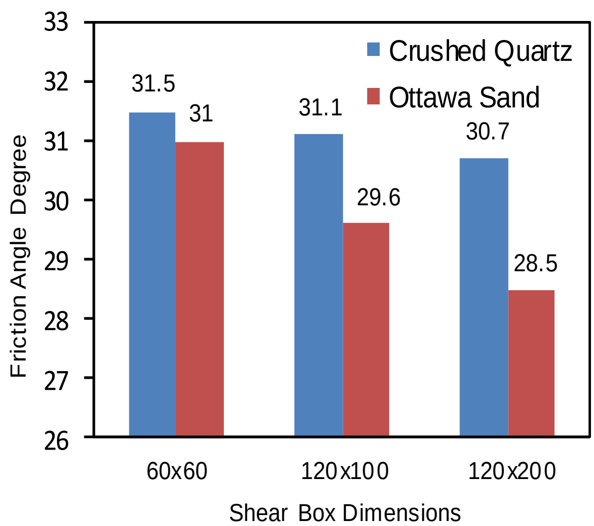

Fig. 1 Effect of shear box size of crushed quartz and Ottawa sand (after Parsons [1]).

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Cerato and Lutenegger [3] tested a range of sands' varying densities and angularities, using different size shear boxes to determine the scale effects. The test results showed that the friction angles of soils were most affected by specimen size. Wu et al. [4] showed that specimen size and specimen shape have some effects on the shear zone and shear bands development in dense Toyoura sand such as deformation properties and peak frictional angle. According to ASTM D 3080, the direct shear box test has several particle-size to box-size requirements when preparing specimens to be tested. It is recommended that the minimum specimen width should not be less than ten times the maximum particle-size diameter and the minimum initial specimen thickness should not be less than six times the maximum particle diameter. In shear boxes, the particles larger than the above mentioned size must be removed leading to a difference in grain-size distribution. Since the amounts of these particles typically depend on the box size, the results of shear tests with different box sizes are not comparative. In the present study, appropriate soil grain-size distribution compatible with all box sizes is used resulting in a constant soil grading.

In this paper, direct shear test is utilized to investigate the soil-reinforcement interaction. Various box sizes, surcharges, soil densities are considered. Tests are conducted for three types of geogrids.

2. Characteristics of Specimens

2.1 Shear Box Size

Three shear boxes with different sizes of 6 × 6 cm, 10 × 10 cm and 30 × 30 cm are used.

2.2 Sand Properties

In this investigation Firoozkooh sand was selected. The physical characteristics, shear strength parameters and placement conditions of this soil are determined according to appropriate ASTM standards. Results from tests are summarized in Table 1 and Fig. 2.

Table 1 Sand characteristics.

USCS	SP
D10 (mm)	0.35
D30 (mm)	0.56
D60 (mm)	0.73
Uniformity coefficient	2.1
Coefficient of curvature	1.23
OMC (%)	9.8
MDD (g/cm^3)	1.67

USCS: Unified Soil Classification System;
OMC: Optimum Moisture Content;
MDD: Max. Dry Density.

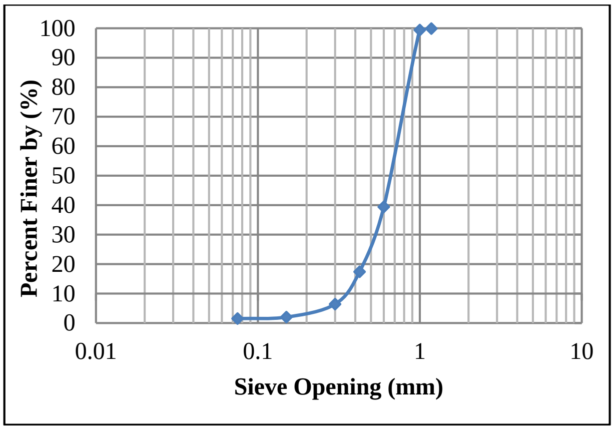

Fig. 2 Grain-size distribution for the sands used in this investigation.

According to USCS sand was classified as SP.

2.3 Reinforcement

In order to investigate scale effect on reinforced soil three types of geogrid have been used as shown in Fig. 3. Table 2 shows properties of the geogrid.

The aperture size of the geogrid should be compatible with box size. In the case of 6 × 6 cm box size it is not allowable to use geogrid with aperture size greater than type A and therefore in order to gain

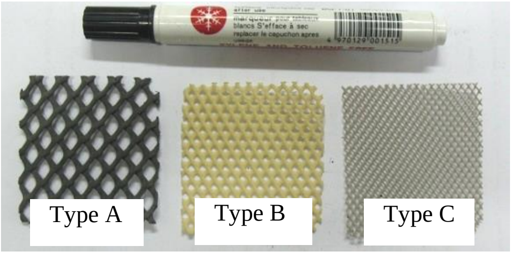

Fig. 3 Three types of geogrid (A, B and C).

Table 2 Properties of geogrid.

Geogrid type	Tensile strength (kN/m)	Thickness (mm)	Aperture size (mm)
A	2.6	1.4	4.2
B	2.4	1.2	2.5
C	1.5	0.7	1.2

comparable results the maximum aperture size corresponds to geogrid type A.

3. Test Conditions

All specimens are tested in dry condition with different dry densities. The maximum dry density and optimum moisture content of the soil are 1.67 g/cm^3 and 10%, respectively. In order to assess the effect of soil density on shear strength parameters, densities of 100, 95 and 90 percent of the maximum dry density are utilized. Therefore, specimens with densities of 1.67, 1.58 and 1.5 g/cm^3 are tested. The normal stresses of 100, 200 and 300 kPa are exerted on the specimens. Test velocity for all specimens is the same and equal to 1 mm/min.

4. Specimen Preparation

According to their density, specimens are placed in the boxes and compacted in different number of layers. The required weight of the soil is calculated according to box volume and the maximum dry density of the soil. The desired density is gained by adjusting compaction energy or number of layers by trial and error. Specimens with densities of 1.5, 1.58 and 1.67 g/cm^3 are compacted in 4, 6 and 8 layers, respectively. The layers should be placed in a way that none of their boundaries coincide with the shear plane unless a special goal is set. Since the aim of this investigation is to place the geogrid in the shear plane, the layer under the geogrid is set in a way that the boundaries coincide with shear plane as shown in Fig. 4.

5. Result

5.1 Effect of Box Size on Internal Friction Angle of Unreinforced Sand

Fig. 5 shows the effect of box size on internal friction angle. As can be seen increase in box size is followed by decrease in internal friction angle for different densities. In loose sands (density of 1.5 g/cm^3) the angles of internal friction attained from specimens with dimensions of 6 × 6 cm and 10 × 10 cm were 35.4° and 33.3°, respectively showing a decrease of 2.1° (6%), while in compact samples (density of 1.58 g/cm^3) a decrease of 3.4° (9%) and in dense samples (density of 1.67 g/cm^3) a decrease of 4.5° (11%) in angle of internal friction are obtained. The maximum shear stresses and also maximum internal friction angle correspond to the small boxes. This is due to the rigid wall restrictions and movement limitations. Since in larger shear boxes there is more space between soil particles and the rigid wall, the particles can easily move on each other resulting in a reduction in internal friction angle.

Studies on different soil samples with different grain sizes and different shear box dimensions [2] showed that the changes in internal friction angle predominantly depend on box sizes and grain-size distribution of sample. Box sizes affect the internal friction angle up to 10°. Fig. 6 shows the effect of increase in box size at different densities on internal friction angle of unreinforced sand.

As shown in Fig. 6 at different densities, there is not a significant difference in the internal friction angle achieved from samples with dimensions of 10 × 10 cm and 30 × 30 cm. On the other hand, according to requirements of ASTM D 3080 specification for the box size and the particle size, one can conclude that a box with dimensions of 10 × 10 cm is appropriate for soil investigation purposes. Therefore, using larger boxes has no considerable effect on parameters of shear strength.

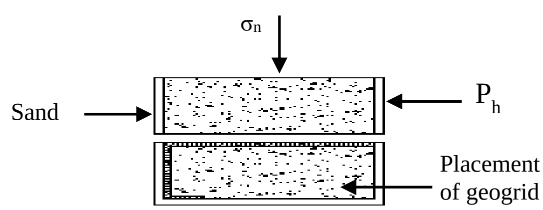

Fig. 4 Placement of geogrid layer in direct shear box test.

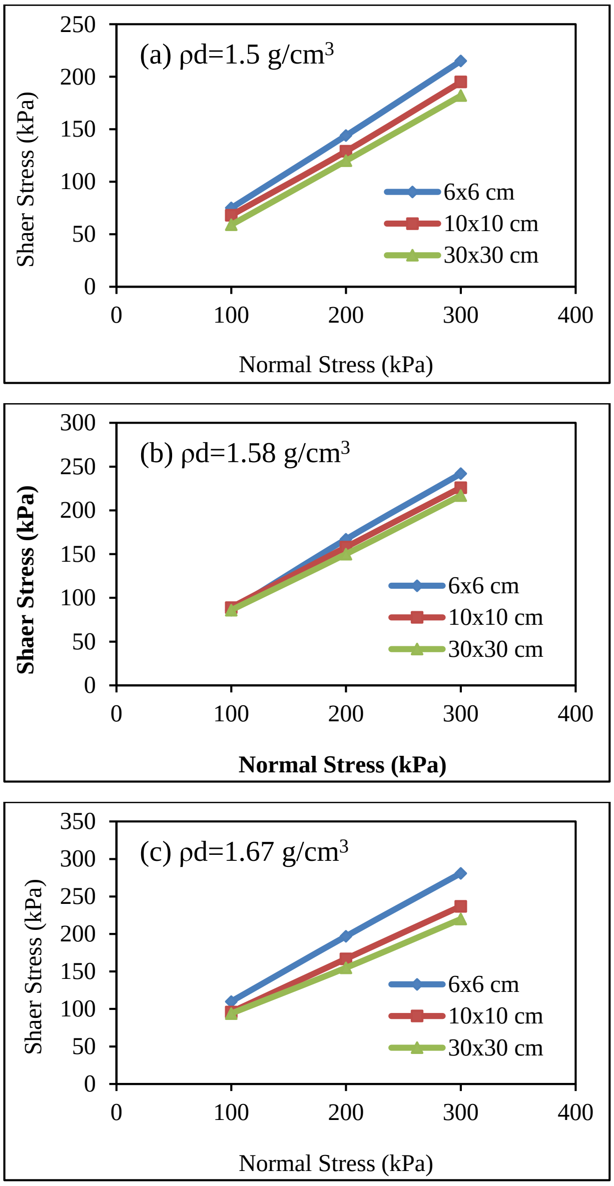

Fig. 5 Effect of increasing box size at different densities on the shear stress-normal stress relationship. (a) Loose sand, (b) compact sand, (c) dense sand.

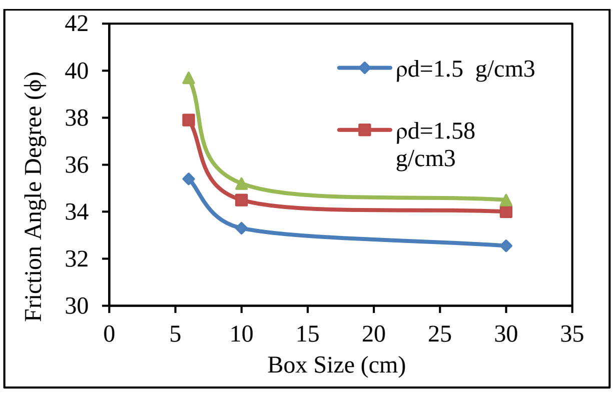

Fig. 6 Effect of box size at different densities on internal friction angle of unreinforced sand.

5.2 Effect of Density on Internal Friction Angle of Reinforced Sand

Table 3 provides a summary of results presenting effect of box size and specimen density on the internal friction angle of unreinforced and geogrid-reinforced soil samples (geogrid types A, B and C). As shown in Table 3, in unreinforced sand, by increasing density the internal friction angle increases which leads to increase in interlocking of particles. Consequently more energy is required to overcome the interlocking force; The smaller the box size is, the higher the value of internal friction angle will be. By increasing density from 1.5 to 1.67 g/cm^3 in shear boxes with dimensions of 6 × 6 cm, 10 × 10 cm and 30 × 30 cm the value of internal friction angle increases about 12%, 6% and 6%, respectively.

As shown in Table 3, soil reinforcement will result in increase of friction between soil particles and geogrid. In specimens with dimensions of 6 × 6 cm, by increasing the soil density from 1.5 to 1.67 g/cm^3 the value of friction angle increases from 36° to 42° in a sample reinforced with geogrid type A showing an increase of 17%. This value varies from 34° to 38° in a shear box with dimensions of 10 × 10 cm, and from 35° to 38° in a specimen with dimensions of 30 × 30 cm showing an increase of 11.5% and 8.5%, respectively. In both geogrids type A and B reinforced soil samples there is almost similar rate of increase in friction angle between soil and geogrid, while in geogrid type C reinforced soil specimens the rate of increase in friction

Table 3 Effect of density on internal friction angle of unreinforced and reinforced sand.

Box size (cm)	Density (g/cm^3)	Geogrid type			
		No.	A	B	C
	1.5	35.4	36	36	35
6 × 6	1.58	37.9	39	42	39
	1.67	39.7	42	43	41
	1.5	33.3	34	34	33
10 × 10	1.58	34.5	37	38	34
	1.67	35.2	38	39	36
	1.5	32.6	35	34	33
30 × 30	1.58	34	37	37	34
	1.67	34.5	38	38	36

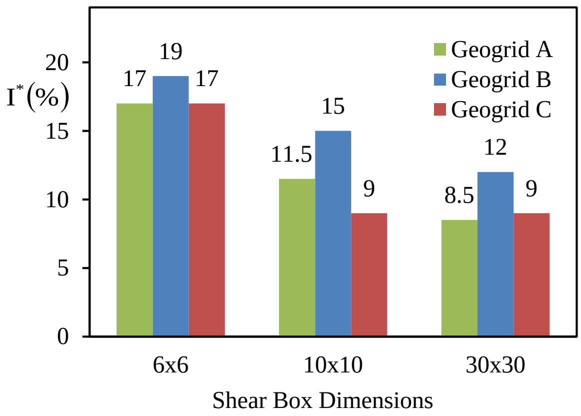

Fig. 7 Difference of dense and loose sands friction angles.

angle has been slightly dropped. This could be because of less interaction between soil particles at very fine geogrid apertures. Mentioned data are presented in Fig. 7. Calculated from Eq. (1):

$$I^* = \left(\frac{\phi_{dense} - \phi_{loose}}{\phi_{loose}}\right) \times 100 \tag{1}$$

6. Discussion on Results

As mentioned in the previous section, geogrids types A, B and C are applied to reinforce sand. The shear strength of soil samples reinforced with geogrid predominantly depends on interaction between soil particles, frictional resistance, interlocking between soil particles, the roughness of geogrid surface and transverse members. Table 4 shows the effect of specimen dimensions on angles of friction between sand and geogrids. As can be seen in the case of small size boxes that is the boxes with dimensions of 6 × 6 cm and 10 × 10 cm, the angle of friction between soil particles and geogrid type B is greater than geogrid type A. However, in a large box that is the box with dimensions of 30 × 30 cm this value is equal or even slightly smaller.

The strength of the specimen equipped with geogrid B is more than the same soil equipped with the geogrid A. This is due to shape of this geogrid which involves more roughness and transverse members. However, in geogrid type B which consists of smaller apertures than geogrid type A, there is less internal interaction between the soil particles. Therefore, in loose sand the interlocking of soil is very low at the apertures of

Table 4 Effect of geogrid types on angle of friction at different densities.

Density (gr/cm^3)	Box size (cm)	Geogrid type			
		No.	A	B	C
1.5	6 × 6	35.4	36	36	35
	10 × 10	33.3	34	34	33
	30 × 30	32.6	35	34	33
1.58	6 × 6	37.9	39	42	39
	10 × 10	34.5	37	38	34
	30 × 30	34	37	37	34
1.67	6 × 6	39.7	42	43	41
	10 × 10	35.2	38	39	36
	30 × 30	34.5	38	38	36

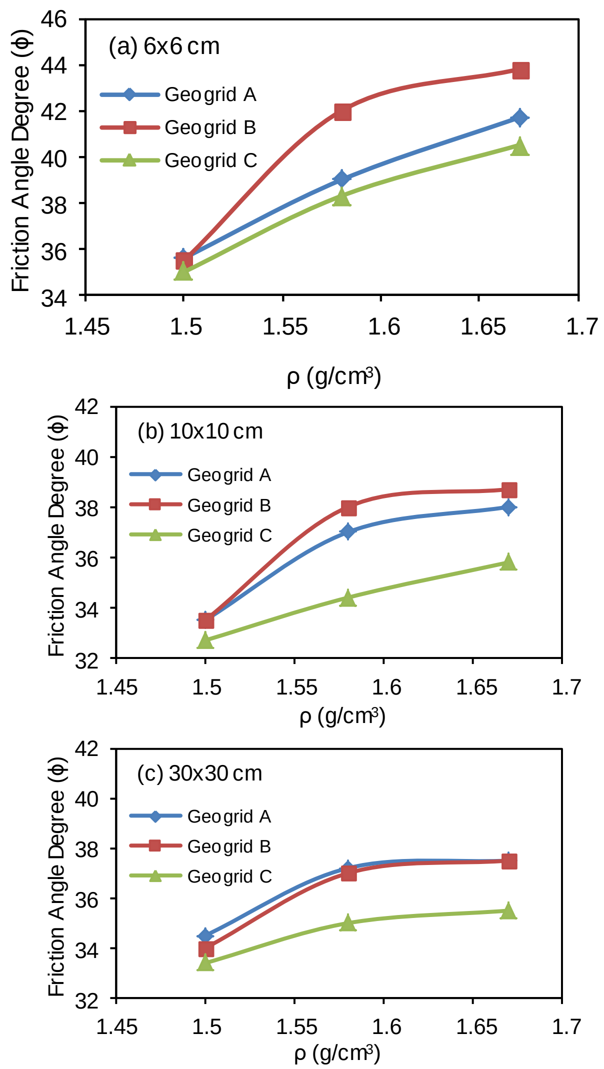

Fig. 8 Effects of density on angle of friction in soils reinforced with geogrid types A, B and C with specimen dimensions of (a) 6 × 6 cm, (b) 10 × 10 cm and (c) 30 × 30 cm.

geogrid. Thus, in loose sand there is no significant difference between the shear strength of sand reinforced with geogrid types A and B. The shear strength of loose sand reinforced with geogrid type B mainly depends on interaction between soil particles and roughness of geogrid surface. Another important issue is the interaction between soil and members of geogrid (longitudinal and transverse members).

By increasing soil density due to higher interaction between soil particles at geogrid apertures there is an increase in shear strength of both samples reinforced with geogrid types A and B. Because of more roughness of geogrid surface and transverse members in geogrid type B compared to geogrid type A, there is higher friction between soil particles and geogrid. This issue leads to greater shear strength in compact and dense sand specimens reinforced with geogrid type B compared to geogrid type A.

7. Conclusions

The most important conclusions obtained by conducting experiments on the sand soils are as follows:

(1) When the density is increased, the friction angle also rises up. This is due to the fact that more energy is required to overcome the interlocking force.

(2) Increasing soil density in small boxes leads to a considerable increase in internal angle of friction, while in large boxes this amount is not remarkable. This is because of less distance and movement space between soil particles and box wall and accordingly more developed shear stresses in small boxes.

(3) Sand reinforced with geogrid leads to an increase in friction angle. The value of increase directly depends on the roughness of geogrid surface, amounts of longitudinal and transverse members, size of apertures and density of the sand.

(4) By increasing density of sand specimens reinforced with geogrid at a constant size, the angle of friction between particles and geogrid increases. The increase in small-sized boxes is greater than in large boxes.

(5) In small boxes the angle of friction between sand particles and geogrid consisting of more members with larger apertures increases, while in large boxes there is an insignificant change in angle of friction.

(6) Soil density has a considerable effect on angle of friction of geogrid reinforced in dense sand, while no significant effect in loose sand.

(7) In large boxes, applying geogrid has no significant effect on sand resistance. This may be because of lacking of friction and interaction between sand particles and geogrid surface. In small boxes because of restrictions of shear box wall the angle of friction between soil particles and geogrid has a slight increase comparing to unreinforced sample at a same density and grain-size distribution.

Acknowledgements

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