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The Effect of Scale Direct Shear Test on the Strength Parameters of Clayey Sand in Isfahan City, Iran

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Abstract: The direct shear test measures shear strength parameters of soils and other particulate materials. In this study the effects of box size on the strength parameters of soil is studied in Isfahan city area. The soil samples are classified as SC according to the unified soil classification system. The samples were well graded with dry density ranges in the between 1.67 and 1.82 g cm^{-3}. The tests on the shear strength properties of SC soils were carried out by using large, medium and small scale direct shear equipment with shear box dimensions of 60, 100 and 300 mm. The undistributed samples, having almost the same properties, were tested in three square shear boxes of varying sizes. Forty five sets (each set with three samples) of direct shear tests at a constant rate of 1 mm min^{-1} were performed to study the influence size of the shear boxes and soil density on the strength parameters. The results show the effect of scale on the test. The large and medium scale direct shear produces a higher cohesion and lower friction angle compared with the results of the small-scale direct shear test. The tests indicate that the friction angle and cohesion increase when soil density in each of the three boxes increases. Therefore, these observations suggest that strength parameters are controlled by the scaling effect and physical properties of the soil. The present study also shows the relationship between the shear strength parameters of small and large scale direct shear tests.

Key words: Direct shear test, friction angle, cohesion, clayey sand, scale effects

INTRODUCTION

The testing of soils by applying a shear load has resulted in a worldwide revival of interest over the last few decades. In geotechnical engineering, the engineering properties of soil layers must be known to the required depths. Engineering properties can be determined by means of tests carried out in the field and laboratory (Bowles, 1997). Different shear tests are used in soil mechanics to measure the mechanical properties of soils. Direct shear tests are favored by many geotechnical engineers because of their simplicity and repeatability (Zhou *et al*., 2009). This test is one of the experiments that are used to determine the shear strength of soil for more than 50 years (Cerato and Lutenegger, 2006). First time, Coulomb (1976) used the direct shear test with different materials including wood blocks to determine the equation used to express shear stress as a function of normal stress and friction angle. The direct shear test was not used for testing the shear strength of soils until the early 1800's when Alexandre Collin studied slop stability (Skempton and Collin, 1949). A historical account of the engineering application of direct shear testing is provided by Matthews (1988). Today this test has been widely used to measure the shear strength of soils (Maaitah and Allah-Mahadin, 2004; Liu *et al*., 2005; Monkul and Ozden, 2007; Pakbaz *et al*., 2008; Wu *et al*., 2008; Shafiee *et al*., 2008; Härtl and Ooi, 2008; Yan, 2009). The specimen size or scale effects on direct shear test were, first time, discussed by Parsons (1936). He presented test results for crushed quartz and clean uniform sand. It was showed that a larger shear box produced lower values of friction angle. Few researchers investigated the influence of specimen size and scale effects shear box testing on the friction angle and cohesion. It was seen that size and scale shear box (length, width and height) affected both the resulting strength parameters (Cerato and Lutenegger, 2006; Simoni and Houlsby, 2006; Wang *et al*., 2008; Bareither *et al*., 2008; Liu *et al*., 2009; Zhou *et al*., 2009). Previous studies have shown that different shear strength parameters can be obtained in direct shear test, using different size shear boxes (Parsons, 1936; Cerato and Lutenegger, 2006; Bareither *et al*., 2008; Wu *et al*., 2008).

Isfahan is one of the most important historical cities of Iran; therefore, the construction in this city is importance. The soil samples used in this study was taken

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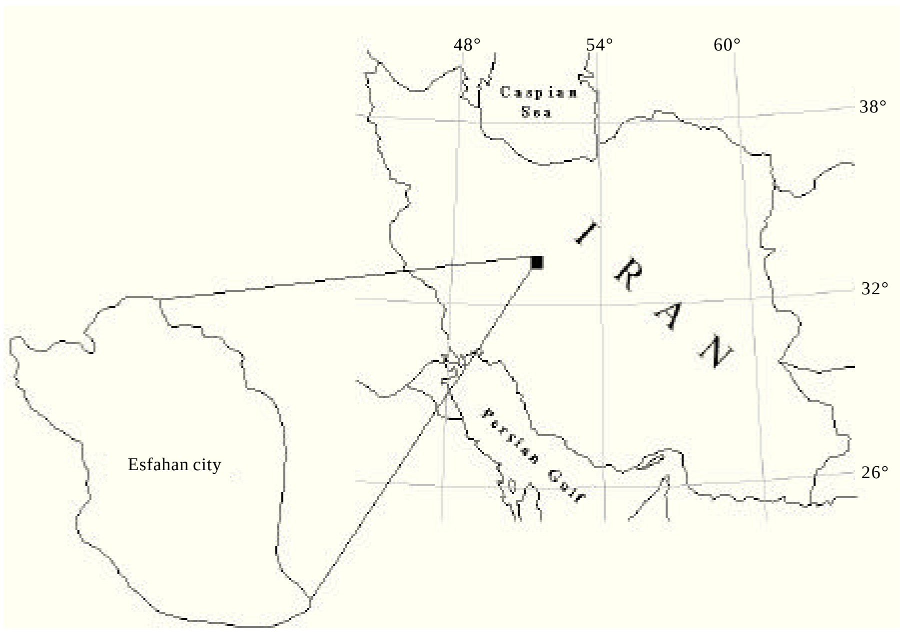

Fig. 1: Map of Iran and location of study area

from downtown of the Isfahan city area central Iran (Fig. 1). These samples are classified as SC according to the unified soil classification system. In this study, the experiments on the clayey sands have been studied in detail to explore the influence of the shear box on the friction angle and cohesion. In this study, the tests on the shear strength properties of SC soils were carried out by using large, medium and small scale direct shear equipment with shear box dimensions of 60, 100 and 300 mm. Earlier studies have also performed similar direct shear test with different size shear boxes in different countries (Parsons, 1936; Cerato and Lutenegger, 2006; Bareither *et al*., 2008; Wu *et al*., 2008).

MATERIALS AND METHODS

Clayey sand: Tests were conducted on 45 naturally occurring soils having almost the same geologic origins. The soils were obtained from borrow pits in natural ground. The soils used in this investigation were characterized using grain-size, density, moisture content, liquid limit, plastic limit and plasticity index according to ASTM Standard test methods (ASTM, 2009).

The soil samples classified according to Unified Soil Classification System (USCS). Grain-size analyses were performed in general accordance to ASTM D 422-63 Standard test method for particle-size analysis of soils. The particle size distribution curves for the sample soils are shown in Fig. 2. These soils could be classified as SC according to the USCS (ASTM D2487-06E01). Soils used in the tests were well graded and the maximum and minimum dry density of the soils was 1.67 and 1.82 g cm^{-3}. Table 1 shows that the other physical properties also exhibit considerable variation:

Moisture content (W%) = 5.6 to 8.3
Liquid Limit (LL) = 22 to 33
Plastic Limit (PL) = 17 to 23
Plasticity Index (PI) = 5 to 14

Direct shear test: Soil strength is the resistance to mass deformation developed from a combination of particle rolling, sliding and crushing. It is reduced by any pore pressure that exists or develops during particle movement. This resistance to deformation is the shear strength of the soil as opposed to the compressive or tensile strength of other engineering materials (Bowles, 1997). The oldest method for investigating the shearing resistance (e.g., cohesion and internal friction angle) of soils is the direct-shear test (Terzaghi *et al*., 1996). The direct shear test is used to estimate the shear strength of a laterally confined sample when breaking along a prefixed horizontal plane (Oyanguren *et al*., 2008). According to ASTM D 3080-04, the direct shear box test has several particle size to box-size requirements when preparing specimens for testing. It is recommended that the minimum specimen width should not be less than ten times the maximum particle-size diameter and the minimum

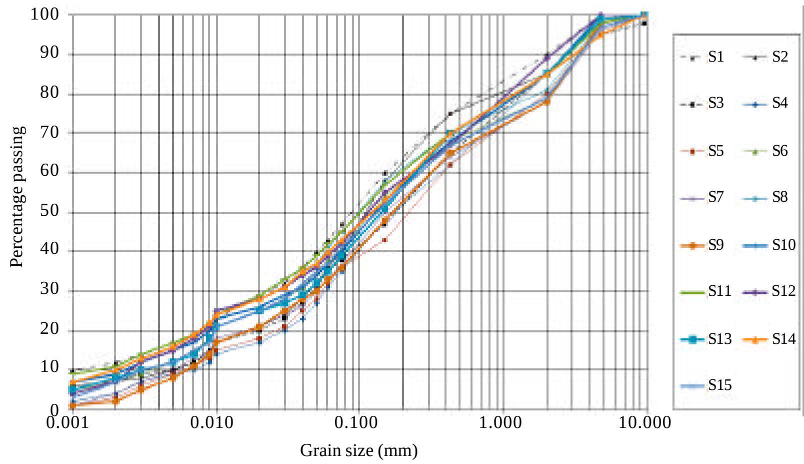

Fig. 2: Grain-size distribution for the soils used in this study

Table 1: Physical properties of tested samples

Sample No.	Percent fine (<75 µ) (%)	Percent sand (0.075-4.75 mm) (%)	Density γ_b (g cm^{-3})	Moisture content (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	USCS
S1	47	53	1.91	7.3	28	18	10	SC
S2	40	59	1.82	6.5	32	20	12	SC
S3	38	57	1.90	7.0	29	18	11	SC
S4	35	65	1.78	5.6	26	19	7	SC
S5	36	61	1.95	7.4	32	23	9	SC
S6	41	57	1.88	7.9	28	17	11	SC
S7	37	59	1.85	8.3	31	19	12	SC
S8	45	53	1.82	7.1	22	17	5	SC
S9	36	62	1.80	6.2	33	19	14	SC
S10	40	60	1.79	7.4	31	21	10	SC
S11	45	53	1.88	7.6	29	21	8	SC
S12	42	58	1.92	8.2	31	18	13	SC
S13	39	60	1.84	8.2	30	21	9	SC
S14	43	52	1.91	7.5	31	20	11	SC
S15	41	56	1.94	8.1	28	20	8	SC

USCS: Unified soil classification system, SC: Clayey sand

initial specimen thickness should not be less than six times the maximum particle diameter. It should be mentioned that, the ASTM D 3080-04 standard test method for direct shear tests of soils stipulates the apparatus size to be at least ten times the size of the largest particle size and the horizontal dimension of the apparatus to be at least twice the vertical dimension. Research on the particle-size to box-size requirement is becoming quite popular. For example, Taylor and Leps (1938) performed comparative large shear box (305×305 mm) versus Shear box (76×76 mm) on the oven-dried Ottawa sand. They observed that friction angle measured in the small shear box was 0.5° larger, on average, than friction angle measured in the large box. Ingold (1982) concludes that the friction angle obtained from a 60×60 mm shear area was 2-3° higher than that obtained from a 300×300 mm shear area. Jewell and Wroth (1987) suggested a ratio of shear box length to average particle size in the range of 50 to 300. It is very important to prevent the soil sample moisture content losing during the shear test. Therefore, the direct shear box was wrapped with nylon stretch film and covered with moisturized cloth after placing the sample in the direct shear machine. Three different sizes of shear boxes were used. The movement of the lower shear box in the horizontal direction is controlled by a set of gears which are mobilized by an electric motor. The size of the shear box can influence the test results. The test results from the Cerato and Lutenegger (2006) studies showed that there is a scale effect present in direct shear tests. They observed that small particle-size to box-size ratios provided a smaller friction angle. They also showed that not only the relative size of the particle to the box but also the relative density affected the friction angle. The friction angles difference corresponding to peak strength measured in small-scale and large-scale direct shear box were reported by Bareither *et al*. (2008) ranges between 4 to 2° for sand backfill. Zhou *et al*. (2009) presented the ASTM recommended box size in fact may result in shear band reaching the box boundaries and smaller particle/box ratio may either decrease or increase the bulk friction. The test results of Toyoura sand presented by Wu *et al*. (2008), showed the lower friction angle value for large scale shear box.

The friction angle and cohesion play a major role in design of many engineering structures in soil, such as foundations, slopes stability and other structures. The direct shear test one of tests is used to determination these parameters. This research project lasted more than six months, from October 2009 to March 2010. The undistributed samples, having almost the same properties, were obtained from borrow pits in center of Isfahan city.

In this study, three different size shear boxes were used. The first square shear box (small box) had a width of 60 mm and a depth of 20 mm (aspect ratio, H/L = 0.34). The samples were sheared at a constant rate of 1 mm min^{-1}. In this test program 15 sets of direct shear tests with three increasing normal stresses (1, 2 and 3 kg cm^{-2}) were performed using a dead-weight system. The second square shear box (medium box) had a width of 100 mm and a depth of 30 mm (aspect ratio, H/L = 0.3). The samples were sheared at a constant rate of 1 mm min^{-1}. In this test program 15 sets of direct shear tests were performed. The third square shear box (large box) had a width of 300 mm and a depth of 100 mm (H/L = 0.34). Also in this box, fifteen tests were performed with the different normal stresses using dead-weight.

RESULTS

The size of the shearing device can influence the direct shear test results. Generally, the boundary effect and device friction are more significant for a smaller shear box. A total of forty five tests were performed on the soil samples. The results are summarized and discussed in this section. It is well known that the failure of a granular mass can usually be adequately described by the Mohr-Coulomb failure criterion (Lambe and Whitman 1979). The friction angle and cohesion were determined either as a regression best fit to each test series over the normal stress range and by calculating these parameters for each test.

In this study, direct shear tests were performed in three different size shear boxes. The friction angle and cohesion for each sample soil as a function of box size is shown in Fig. 3 and 4. As these Fig. 3 and 4show by increasing the box size, the friction angle decreases and cohesion also increases in most cases. Also Fig. 3 and 4 show the range in friction angle for small, medium and large box is from 27.6 to 33 and 24.6 to 30.7 and 23.1 to 29.4, respectively. Also the range in cohesion

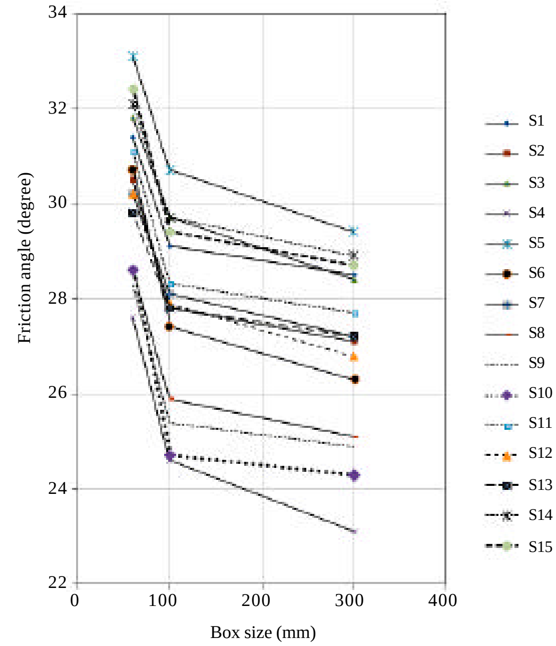

Fig. 3: Influence of box size on friction angle

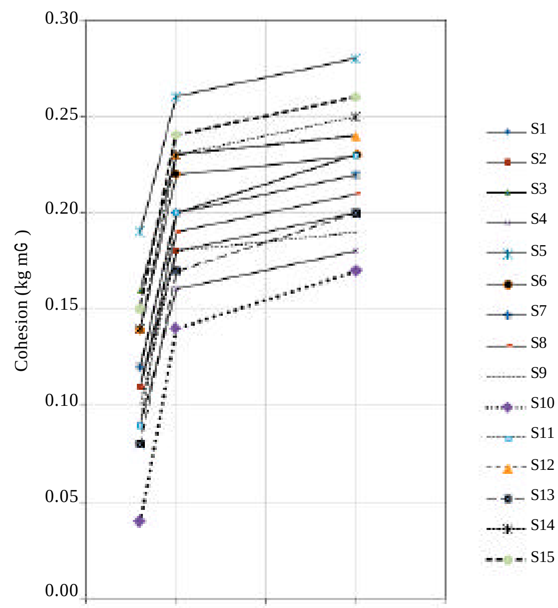

Fig. 4: Influence of box size on Cohesion

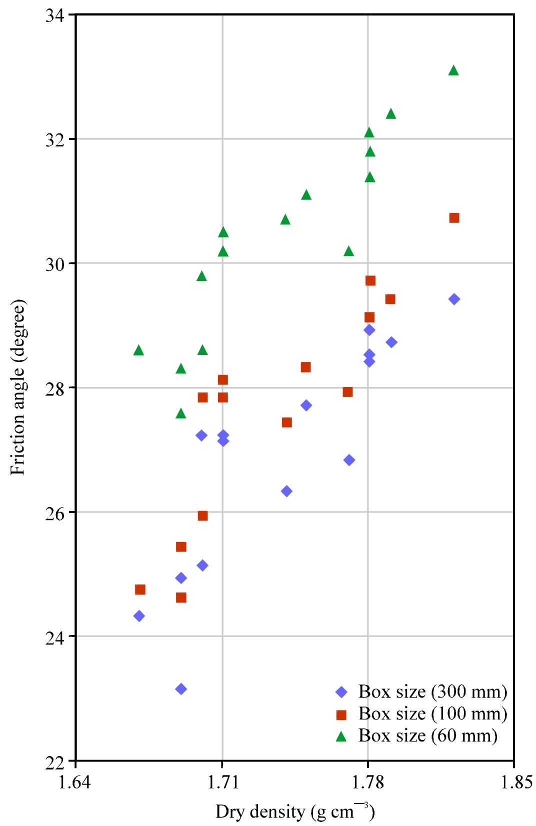

Fig. 5: Influence of density on friction angle

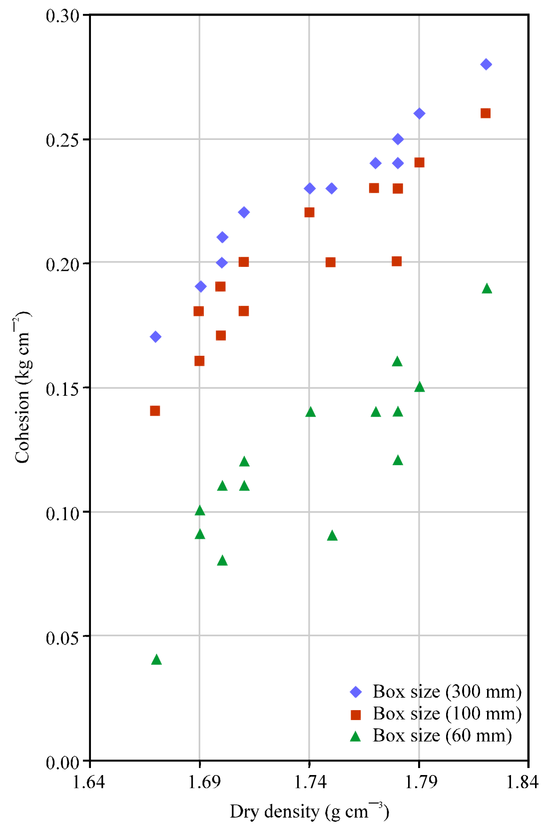

Fig. 6: Influence of density on cohesion

for small, medium and large box is from 0.04 to 0.19 and 0.14 to 0.26 and 0.17 to 0.28, respectively. It can be argued that the friction angle obtained from the smallest shear box (60 mm), show higher friction angles and lower cohesion in soils tested and also the results of the largest shear box (300 mm) show higher cohesion and lower friction angles in soils tested. The friction angles obtained from the two larger boxes (100 and 300 mm boxes) are almost similar.

Density factor affecting the strength parameter: This study evaluated the effect one of physical characteristics (density) on the strength parameters of clayey sand from Isfahan. Density, friction angle and cohesion were determined for 15 samples. The tests results also show that the friction angle and cohesion increase with increasing density in each of the three boxes (Fig. 5, 6). The test results in this study show that there is a scale effect present in direct shear tests. These results help to explain the previous finding that investigated scale effects in direct shear boxes.

Comparison of large, medium and small scale direct shear test: Large direct shear test (300×300 mm) on the undisturbed soil is costly, difficultly and time consuming. Therefore, these tests on the small projects are not feasible usually. A comparison of friction angles and cohesions of large and small direct shear boxes are presented in Fig. 7 and 8. The test data of small, medium and large scale shear boxes were investigated. To distinguish relationship between scale size direct shear and shear strength parameters of clayey sand regulation analysis was conducted. There are a highly significant relationship between friction angle of small and large shear box ($R^2 = 0.9218$), as well as cohesion obtained from small and large scale direct shear test results ($R^2 = 0.7968$). So, we can use the results of small scale direct shear box equations to find shear strength parameters for large direct shear box.

Comparison of results: The results from this study show that there is a scale effect present in direct shear tests and that the strength parameters depend on the density. The friction angles and cohesion obtained from the small scale tests were also compared to those from the large and medium scale tests to determine if statistically significant differences existed between the friction angles and cohesion measured in small scale and another scale tests. The medium and large scale direct shear box test show a higher cohesion and lower friction angle compared with

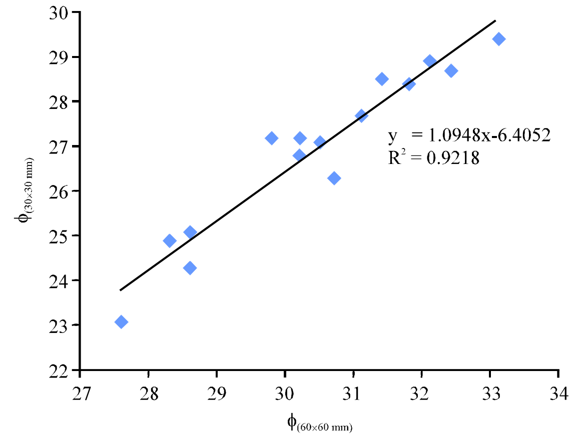

Fig. 7: Relationship between friction angles of large and small direct shear boxes

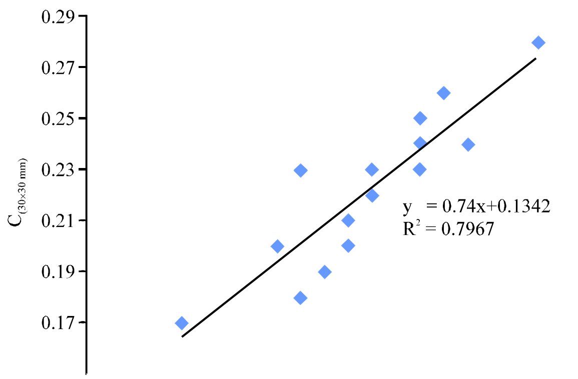

Fig. 8: Relationship between cohesion of large and small direct shear boxes

the results of the small-scale direct shear test results. Parsons (1936) showed that a larger shear box produced lower values of friction angle. Cerato and Lutenegger (2006) performed direct shear tests on five sands at varying densities in 60, 102 and 305 mm square shear boxes. They proposed the friction angle was seen to increase with increasing relative density in each of the three boxes and that the constant volume (residual) friction angle decreased or remained constant, with increasing box size depending on the type of sand and the relative density. Friction angles measured in this study differed by no more than 4.5° and in most cases differed by less than 3.5°. Previous studies conducted by Cerato and Lutenegger (2006), Bareither *et al.* (2008) and Zhou *et al.* (2009) and also the results on clayey sand reported in this study have shown that different shear strength parameters can be obtained in direct shear test, using different size shear boxes.

CONCLUSIONS

Forty five samples of clayey sand, having almost the same properties, were tested in three square shear boxes of varying sizes. The results show that the friction angles and cohesion were most affected by shear box size. The direct shear tests show that the friction angle and cohesion can be dependent on shear box size. The medium and large scale direct shear box test, having almost the same results, show a higher cohesion and lower friction angle compared with the results of the small-scale direct shear test results. A good relation exists between large scale and small scale direct shear test. The following equations for large and small scale direct shear are obtained.

$$\text{Friction angle: } \phi_{(300\times300)} = 1.0948\ \phi_{(60\times60)} - 6.4052\ (R^2 = 0.9218) \quad (1)$$

$$\text{Cohesion: } C_{(300\times300)} = 0.74\ C_{(60\times60)} + 0.1342\ (R^2 = 0.7968) \quad (2)$$

The friction angle and cohesion show an increase with increasing density in each of the three boxes.

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