Ultimate Shear Strength of Sand to Concrete Interface

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Abstract: One several studies have been performed by many researchers regarding laboratory interface testing. Interface tests were performed to determine the soil to structure shearing resistance angle (δ). This angle is used for the design of geotechnical structures such as friction piles, retaining walls, culverts, etc. Also, test results are useful for determination of parameters for constitutive modeling of interface response. Correlations between sand relative density, and corresponding friction angle (Ø), and interface shearing resistance angles (δ) are obtained. In addition, (δ) is represented as a function in (Ø). These relations are based on degree of interface roughness and particle shape of sand.

Two types of sand, and in addition one mix (50%-50%) of the two sand types, are investigated. The first type of sand is siliceous sand and has rounded to sub-rounded particles. The second type of sand is fragments of weathered igneous rock of granite and basalt. This type of sand has angular shaped particles. To form a surface representing the retaining structure, ordinary Portland concrete mix was made from locally available material (sand, ordinary Portland cement and potable water). The mix was then poured into a steel mold having 4 sides 59 mm long, and 19 mm high to fit into the shear box bottom half. In order to simulate a smooth surface of concrete, the mold was placed on to smooth plastic sheet, and then the paste is poured into the mold.

Interface tests have been performed on many types of soil-to-structure, soil-to-rock, and rock-to-rock interfaces. In this section, previous studies of soil-to-concrete and soil-to-steel interfaces are emphasized. The results of tests performed on both types of interfaces provide valuable insights into fundamental aspects of interface behavior.

Keywords: DSB, Portland cement, potable water, resistance

I. INTRODUCTION

Early systematic efforts to obtain data on the behaviour of soil-to-structure interfaces were carried out by Potyondy (1961), Clough and Duncan (1971) and Peterson et al. (1976). Their tests were performed using a slightly modified Direct Shear Box (DSB) in which a concrete specimen occupied one of the halves of the shear box. In most cases, the soil sample was prepared against a concrete specimen situated at the bottom. The tests were typically performed by first increasing the normal pressure to a desired value, then shearing the interface under constant normal stress to a maximum displacement of about 12.5 mm. They analyzed the influence of normal stress, interface roughness, and soil characteristics on interface behaviour, and developed a database of sand-to-concrete interface friction angles.

Direct shear box presents two important advantages: (i) wide availability and (ii) relatively simple test setup and sample preparation procedures. Consequently, it has been the common choice for interface testing in research and practice. Other applications of the direct shear box include testing interfaces such as soil to geomembrane, soil to geotextile, and geomembrane to geotextile. Commercial devices have been developed for larger interface areas of up to 305 by 305 mm (12 by 12 in.), and they can be used for soil-to-concrete testing.

Traditional DSB devices present several limitations. The maximum relative displacement that can be attained in a conventional direct shear box is limited; hence, the determination of the interface residual strength becomes difficult. In addition, end effects, induced by the presence of the rigid walls of the soil container, may introduce errors in the test results. Kishida and Uesugi (1986) and Fakharian and Evgin (1996) pointed out that the actual sliding displacement Δactual between the soil particles and the concrete cannot be directly measured in the direct shear box. The displacement Δmeasured between the soil box and the concrete specimen includes the sliding displacement at the interface, as well as the deformation Δdis of the sand mass due to distortion under the applied shear stresses.

II. EXPERIMENTAL WORK

MATERIAL

Two types of sand are used. The first type is siliceous sand and has rounded to sub-rounded particles. This type of sand in the present study is referred to as "Rounded sand". It is brought from a quarry besides the Ring Road Cairo-Suez road. The second type of sand is fragments of weathered igneous rock of granite and basalt and has angular shaped particles. This type of sand in the presented study is referred to as "Angular sand".

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It is brought from 6th of October City and sieved on sieve No. 4.75. Figures (1) and (2) show the grading and shape of both sands. To form a surface representing the retaining structure ordinary Portland concrete mix was made from locally available material (sand, ordinary Portland cement and potable water).
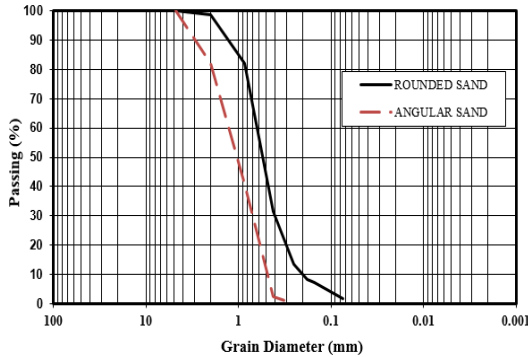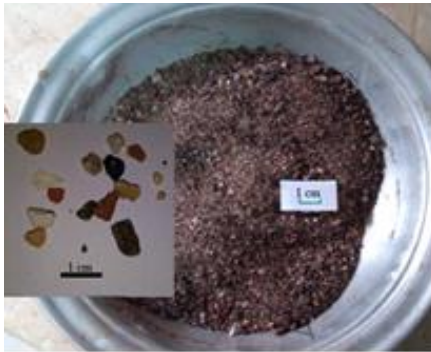

Fig. 1.Rounded sand.

Fig. 2.Angular sand .

The mix was then poured into a steel mould having 4 sides 59 mm long, and 19 mm high to fit into the shear box bottom half.

Maximum and minimum dry density determinations were performed according to ECP 202-2001. From the grain size distribution curves of both rounded and angular sands shown in Figure (1) and (2), the index parameters (Cu, Cc, ρmax, ρmin) are tabulated in Table (1).

Table- 1: Physical Index parameters values of the used sand.

Parameter	Rounded sand	Angular sand
% finer 4.75 mm	100	100
% finer 0.075 mm	1.6	0.00
% finer 0.002 mm	-	-
Uniformity coefficient, Cu	3.1	3.00
Coefficient of curvature, Cc	1.35	0.65
Classification according to (ASTM	SP	SP

D2487)		
ρ max (gm/cm3)	1.81	1.94
ρ min (gm/cm3)	1.54	1.58

ANGULARITY AND MINERAL COMPOSITION

Angularity refers to the sharpness of the corners or curvature of edges of the grains. Geologically, during transportation, the grain edges become more rounded, the sizes of particles are reduced and the shapes are modified by splintering of chips along planes of weakness.

Experimental studies indicated that the roundness (or angularity) is related to the degree of abrasion or wear suffered by the particles. It should therefore be related to the type and length of transportation or reworking and have considerable geological significance. It is regrettable that accurate method of measuring roundness (or angularity) has not been developed yet.

Several studies describe angularity qualitatively as it is defined in the ASTM specifications D 2488, the angularity of sand-size particles is easiest to measure by matching the outlines of individual particles with photographs of two sets of standard sand particles, each set having different sphericity Figure (4). The visual angularity / roundness scale contains six classes, very angular, angular, subangular, sub rounded, rounded, and well-rounded. (Powers, 1953). Calculations of angularity of the used materials are tabulated in Table (2). Figure 3: Outlines of six roundness classes of sand-size particles having high and low sphericity. (After M.C. Powers, 1953).
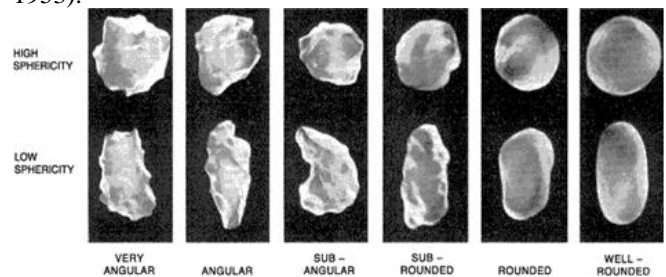

Fig. 3.Shapes classification of sand particles sand.

Table- 2: Physical Index parameters values of the used sand.

Sand type	Mineral composition		Angularity ratio	
Rounded sand	100%	Quartz	15%	Well rounded
			85%	Sub - rounded
Angular sand	25%	Quartz	10%	Sub - rounded
			90%	Well rounded
	75%	Rock fragments and weathered Basalt	20%	Angular
			80%	Very angular

A PANalytical X-Ray diffraction equipment is used to determine the mineral composition of both types of sand. Tests was carried out in central laboratories sector, the Egyptian Mineral Resources authority.

The equipment model named "X'Pert PRO" with Monochromator, Cu-radiation (λ= 1.542 &) at 45 K.V., 35 M.A. and scanning speed 0.03 o/sec. were used. The reflection peak between $2\theta = 2^o$ to 60°, corresponding spacing (d, Å) and relative intensities (I/Io) were obtained. The mineral composition of both sands revealed by x-ray analysis Figures (4) and (5) for both rounded and angular sand respectively is as follows:

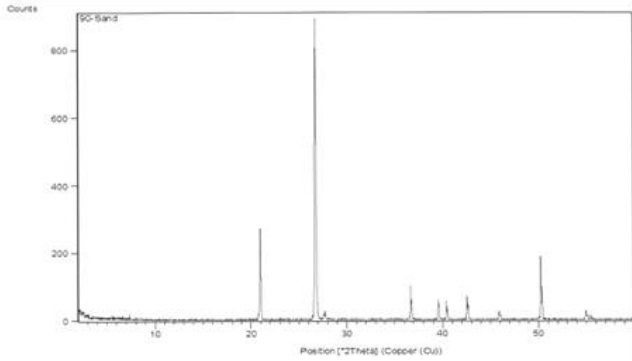(a) The rounded sand composed mainly of quartz mineral "100% silicon Oxid – Si O2".

Fig. 4.X-ray analysis for rounded.

b) The angular sand composed mainly of 75% quartz mineral and 25% anorthite "CaAI2Si2O8".
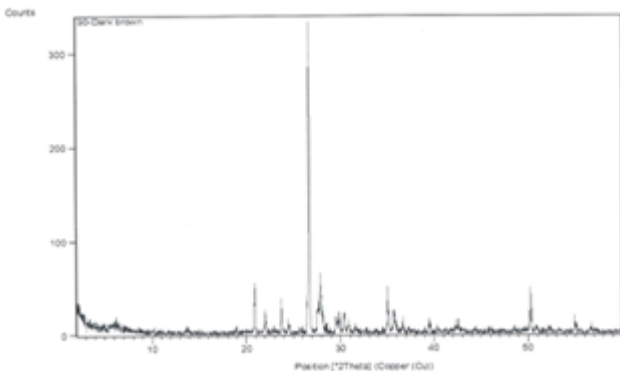

Fig. 5. X-ray analysis for angular sand.

DETERMINATION OF THE DRY DENSITIES OF SAND SPACIEMENS

Suitable preparation of samples is very important to have reliable measurements that lead to accurate results. In order to prepare samples at different relative densities, values of maximum and minimum dry densities for sand types (rounded, angular and 50%-50% rounded/angular) were first determined according to ECP 202-2001. Minimum dry density is determined using the same mould for the maximum dry density determination.

The diameter of the mould equals 152.2 mm and its height equals 155.4 mm. The soil was poured through a funnel opening. The opening had rounded shape that had larger diameter = 17.3 cm, while the smaller diameter = 14 mm inserted into the mould. The pouring operation had to be in slow continuous circular motion. In addition, the bottom of the funnel tube had to be maintained above the surface of the sand in the mould by 25 mm. The mould was slightly overfilled then it was leveled using a flat steel bar in one direction. Then the mould was weighed and the minimum dry

density was calculated knowing the volume and the weight of the mould.

Afterwards maximum dry density was determined using compaction by vibration method for dry sand. The steps of the procedure were as follows:
- After filling the mould with dry sand, it was attached to a vibrating machine.
- A surcharge was placed on the top of the mould then it was vibrated at a certain frequency for 8 min.
- The mould was unfastened to measure the accuracy settlement in the sand height inside the mould in several directions. The average was taken to know the new volume of the sand after being compacted by vibration, Fig. 6.

Fig. 6.Mould used to determine maximum and minimum dry densities.

III. TESTING PROGRAM

A total of 36 direct shear box tests are performed to evaluate relations between internal shearing resistance angle, interface shearing resistance angle and relative density for three sand types (rounded, angular and 50%-50% rounded/angular) against concrete surface. Testing program is indicated in Table (3).

Direct shear tests with a 60 mm square box were performed to determine both the internal and the interface peak shearing resistance angles at a rate of horizontal displacement of 0.4 mm/min. Different values of relative densities of sands (Dr = 50 and 90%) were tested. Three normal stresses were used: 100, 200 and 300 kPa so that linear shear strength envelopes are plotted.

IV. TEST RESULTS

Two main factors in this section that are focused upon in the analysis of direct shear box results. These factors are: angularity of particles and relative density of sand. These factors are of great importance in studying the shear behaviour of both sand/sand and sand/concrete-interfaces.

EFFECT OF ANGULARITY

Angular sand has higher shear strength than the other two types of sand in both internal and interface tests. This is due to higher interlocking between the sand particles. On the other hand, rounded sand has lower shear strength than the two other types of sand, Figures (6 to 14) and Table (4).
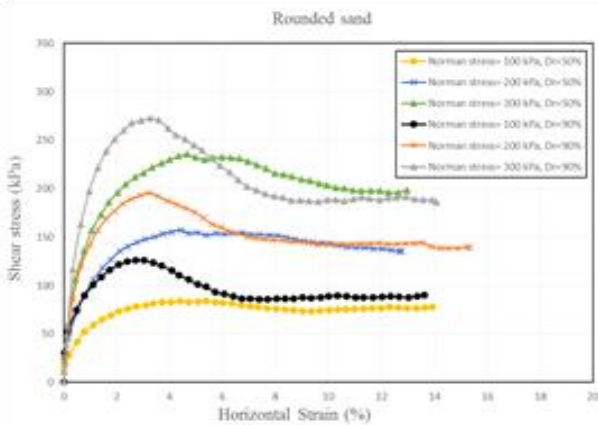
EFFECT OF RELATIVE DENSITY

From the test results the effect of the relative density of sand is as follows:
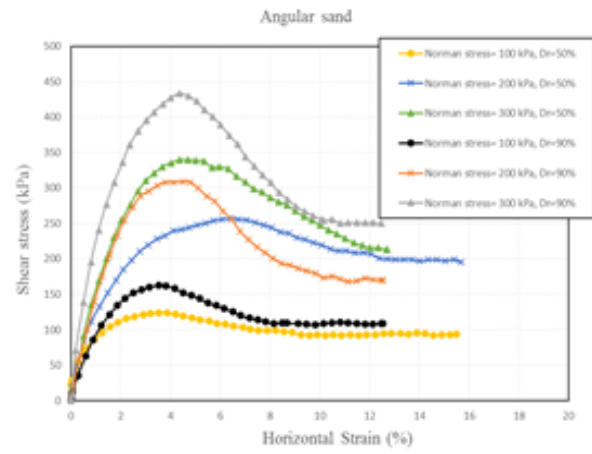
As the relative density of the sand increases both the internal and interface shearing resistance angles increase

**Table- 3: Experimental program and result sand.**

Direct shear box		Dr %	Normal stress(kPa)	No. of DSB tests	□ peak	δ peak	Result
Top half	**Bottom half**						
Rounded sand	Rounded Sand	50	100, 200, 300	3	yes	-	□ = f(Dr)
Rounded sand	Rounded Sand	90	100, 200, 300	3	yes	-	□ = f(Dr)
Angular sand	Angular sand	50	100, 200, 300	3	yes	-	□ = f(Dr)
Angular sand	Angular sand	90	100, 200, 300	3	yes	-	□ = f(Dr)
50%-50% rounded-angular	50%-50% rounded-angular	50	100, 200, 300	3	yes	-	□ = f(Dr)
50%-50% rounded-angular	50%-50% rounded-angular	90	100, 200, 300	3	yes	-	□ = f(Dr)
Rounded sand	Smooth concrete face	50	100, 200, 300	3	-	yes	δ = f(φ), δ = f(Dr)
Rounded sand	Smooth concrete face	90	100, 200, 300	3	-	yes	δ = f(φ), δ = f(Dr)
Angular sand	Smooth concrete face	50	100, 200, 300	3	-	yes	δ = f(φ), δ = f(Dr)
Angular sand	Smooth concrete face	90	100, 200, 300	3	-	yes	δ = f(φ), δ = f(Dr)
50%-50% rounded-angular	Smooth concrete face	50	100, 200, 300	3	-	yes	δ = f(φ), δ = f(Dr)
50%-50% rounded-angular	Smooth concrete face	90	100, 200, 300	3	-	yes	δ = f(φ), δ = f(Dr)

Fig. 8. Shear stress versus horizontal displacement curves for angular sand.
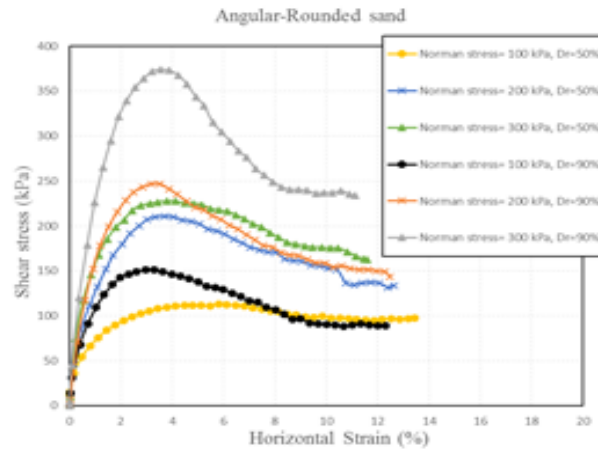
Fig. 9. Shear stress versus horizontal displacement curves for angular-rounded sand.
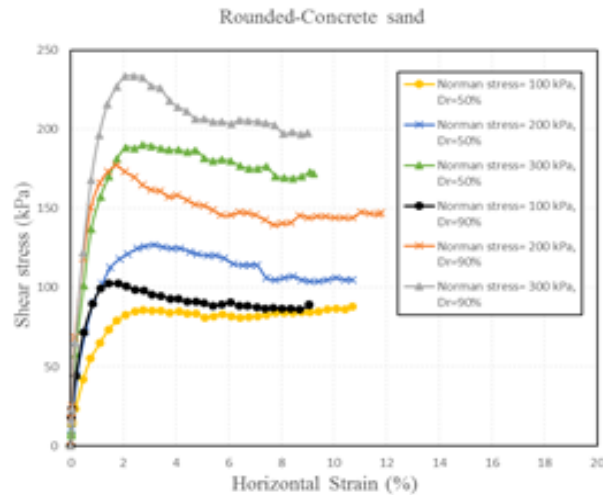

Fig. 7. Shear stress versus horizontal displacement curves for rounded sand.

Fig. 10. Shear stress versus horizontal displacement curves for rounded-concrete sand.
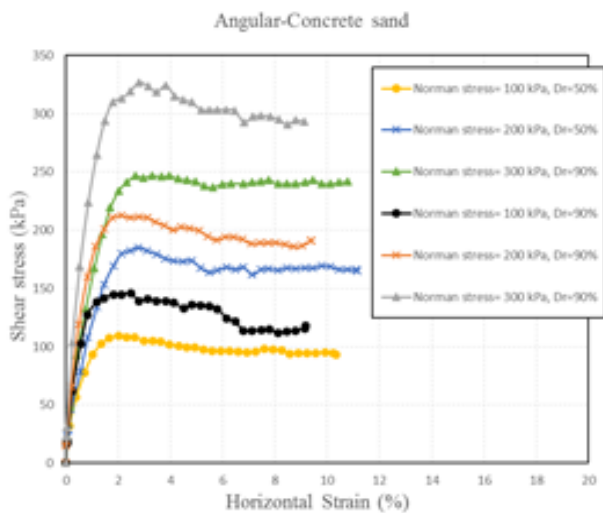
Fig. 11. Shear stress versus horizontal displacement curves for angular-concrete sand.
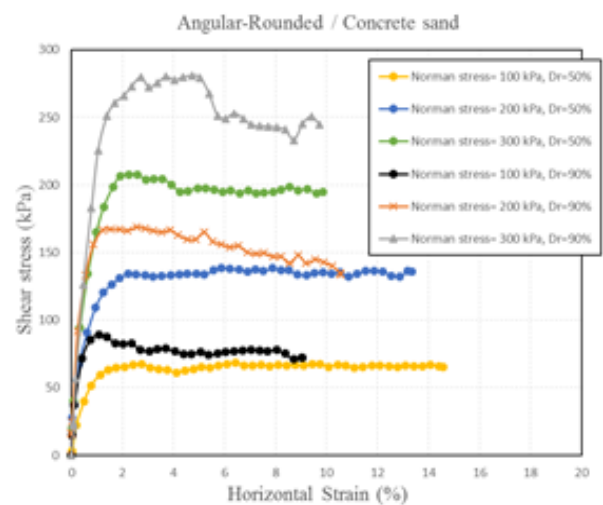

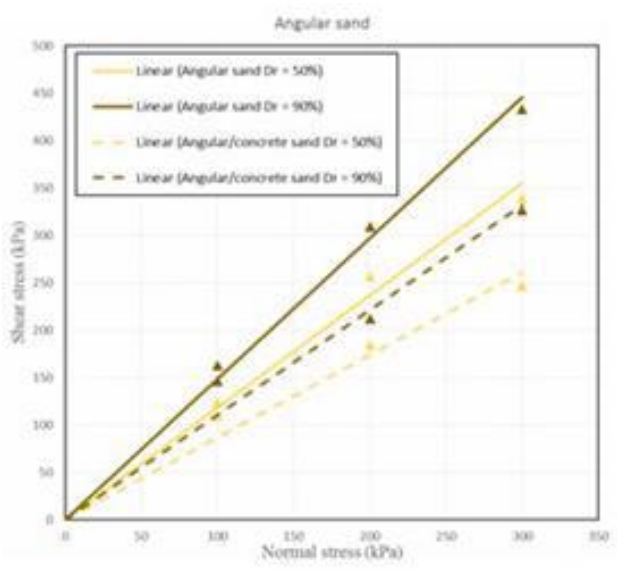**Fig. 12. Shear stress versus horizontal displacement curves for angular-rounded/concrete sand.**

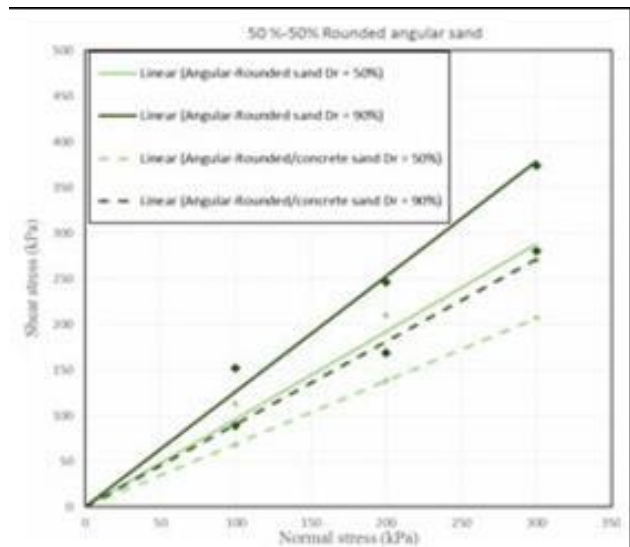**Fig. 13. Failure envelope of angular sand.**

Fig. 14. Failure envelope of rounded/angular sand.

Table- 4: Summary of all test results

Sand type	Dr %	$\phi^{\bullet}$ Degree	$\delta^{\bullet\bullet}$ Degree	Ratio δ/ϕ
Rounded sand	50%	38.2	32.5	0.85
	90%	43.6	40.7	0.93
Angular sand	50%	49.8	41	0.82
	90%	56	48	0.86
50%-50% Rounded/Angular sand	50%	43.8	34	0.78
	90%	51.6	42.14	0.82

The displacement softening behaviour is clear in internal and interface tests in case of testing dense sand. Thus, at high relative density (Dr = 90%), the peak is more pronounced. On the other hand, at low relative density (Dr = 50%) no peak is observed,.

The difference in the internal peak shearing resistance angles of angular sand from its loosest to its densest state is 6.2 degrees. For rounded sand this difference is 5.4 degrees and for 50%-50% (rounded/angular) sand is 7.8 degrees. However, for interface tests this difference is about 7, 8.2 and 8.1 degrees, respectively, Table (4). This shows that the peak interface shearing resistance angle is more influenced by changing the relative density of sand.

V. OBSERVATIONS REGARDING STRESS – DISPLACEMENT CURVE

Stress-displacement curves reveal the following observations:

In general, the peak shear strength is mobilized at small displacements as follows:

(1) In sand/sand tests: For rounded sand, the displacement ranges from 3.3% to 4.16 %, For angular sand, this displacement ranges from 5 % to 6.6 %. For 50%-50% (rounded/angular) sand, this displacement ranges from 3.3 % to 5 %.

(2) In interface tests: For rounded sand, the displacement ranges from 1.66 % to 2.5%. For angular sand, this displacement ranges from 1.66 % to 3.3 %. For 50%-50% (rounded/angular) sand, this displacement ranges from 1.666 % to 3.3 %.

(3) From the above-mentioned results, it is found that the displacement at which peak shear strength is mobilized is smaller for the tests of rounded sand compared with that in the case of angular sand.

VI. COMPARSION BETWEEN THE RESULTS AND THE EGYPTAIN CODE RECOMMENDATIONS

The Egyptian code CP 202-2001 gives the following values for the ultimate internal shearing resistance angles based on the sand relative density value as follows, Table 5:

Table- 5: f angle from E.C. 202-2001 and from present study

Relative density	φ (ultimate angle)	
	EC 202-2001	Present study
Loose sand	30 - 32	---
Medium dense sand	32 - 36	Rounded sand : 38 Angular sand : 50 Rounded-angular sand : 44
Dense sand	36 - 40	36 - 40
Very dense sand	> 40	Rounded sand : 43.6 Angular sand : 56 Rounded-angular sand : 51.6

It is noticed that the Egyptian Code of Practice, ECP 202-2001 gives lower values of the ultimate internal shearing resistance angles compared with that in the present study. The values of the angles in the present study are higher than the upper limit of the ECP values by 2-3.6 degrees for rounded sand, by 14-16 degrees for angular sand and by 8-11.6 degrees for 50%-50% (rounded-angular) sand.

The Egyptian code of practice gives the following values for the ultimate interface shearing resistance angles:

For interfaces between gravity retaining wall and fine to medium sand: = 24-29 degrees for rounded sand, = 29-31 degrees for 50%-50% (rounded-angular) sand, and = 35 degrees for angular sand.

In this paper, in case of rounded sand = 38.2 degrees, angular sand = 49.8 and 50%-50% (rounded-angular) sand and = 43.8.

It is noticed that the Egyptian Code of Practice has more conservative values of $(d/f = 0.7)$ than its values in the present study $(d/f = 0.82)$.

VII. CONCLUSIONS

(1) The relative density of the sand is an important factor that has to be considered in studying the shear strength of both soil and soil to concrete interface.

(2) The shape of the sand particles is an effective parameter affecting the shear behavior of sand.

(3) In general, internal shearing resistance angle f and the interface shearing resistance angle d for angular-shaped sand particles are larger than those for rounded-shaped sand particles.

(4) Direct shear box is a convenient device for interface testing.

(5) Relations are established between and f according to shape of sand particles and degree of roughness of the interface surface.

(6) Linear relations between relative density of the sand and both internal and interface shearing resistance angles are found to be herein the most convenient relation.

(7) Interface shearing resistance angle d is less influenced by changing relative density values than internal shearing resistance angle f.

(8) Shearing resistance angles (internal and interface angles) of rounded sand are more influenced by changing the relative density values than angular sand.

(9) Relative density almost has the same impact on the interface shearing resistance angles in the case of rounded and angular sand.

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