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The Grading Effect of Coarse Sand on Consolidated Undrained Strength Behaviour of Sand Matrix Soils

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Abstract**: *In geotechnical engineering field, the behaviour of soil does rely much on the shear strength for design purpose. Previously, findings show that the change of grained size in soil will change the structure (microstructure) and behaviour of the soil; consequently, affected the strength. To date, limited study focused on the effect of grading on the behaviour of sand fine mixtures. This study aims to investigate the effect of coarse sand on undrained strength behaviour of sand matrix soils in comparison with clean sand. A series of test on reconstituted sand matrix soils had been carried out by conducting consolidated undrained (CU) triaxial test using GDS ELDYN® triaxial machine. Coarse sand (retain within 2.0 mm to 0.6 mm) was mixed with 0%, 10 %, 20%, 30%, and 40% of fine particles (kaolin) independently by weight to prepare reconstituted samples. Triaxial samples of 50 mm diameter and 100 mm height were prepared using wet tamping technique (5% of moisture content) with targeted relative density at 15% (loose state). Each reconstituted sample was sheared at two effective confining pressures of 100 kPa and 200 kPa, respectively. Results show that the gradation contributed to the behaviour of the sand matrix soils. Increasing percentage of coarse sand in sand matrix soils exhibited higher effective friction angle. Similar trends were also observed on the angularity effect on undrained shear strength parameters.***

Index Terms**: *Sand Matrix Soils, Coarse Sand, Consolidated Undrained, Cohesion, Friction Angles.***

I. INTRODUCTION

Cohesion, c and friction angle, ϕ, are two important parameters needed in shear strength analysis for design purposes such as in landslides, earth dams, landfill and road construction. Coulomb's law on shear strength was introduced by Coulomb. As mentioned by [1], the equation can be expressed as below:

$$s = c + p \tan \phi \tag{1}$$

where; s = shear strength, c = cohesion, p = compressive stress and ϕ = internal friction.

Shear strength analyses on consolidated drained (CD) or consolidated undrained (CU) test through triaxial machine have been used by past researchers to evaluate and investigate the soil response of the ground structures during and after construction. [2], [3], [4], and [5] have conducted a series of triaxial test on cohesive or cohesionless soil to investigate the behaviour of the soils in term of engineering characteristics. Particle shape is one of the factors that contributes to the soil shear strength. Research conducted by [1] revealed the effect of particle shape on shear strength as can be seen at Figure 1. In that figure, where S-Silt-I consists of angular shape particle while M-Silt-II is rounded, it shows that higher strength was measured at S-Silt-I compared to M-Silt-II. This finding was supported by [6] using silty sand samples. They showed that the shearing resistance was increased with the increase of angularity, which was contributed by rolling and sliding activities of the particle. In other words, the higher angularity of the particles, the higher load can be applied on the soil to resist the failure.

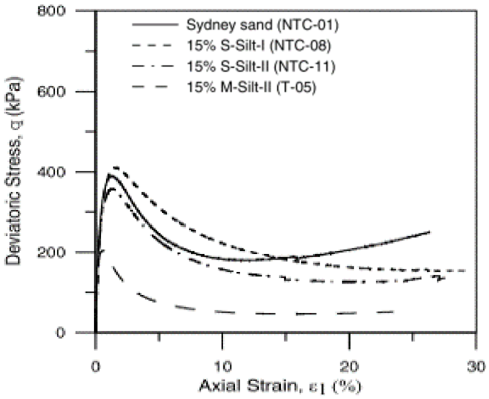

Figure 1. Graph of deviator stress versus axial strain on different angularity of soil particles [1]

. The addition of fines content on the sand matrix soils tend to increase or decrease the shear strength of the soils.

[7] conducted a test on a river sand matrix soils which consist of clean sand mixed with fines to observe the undrained shear strength of the soils. It shows that undrained shear strength decreased when the amount of fines increased until certain amount of fines was reached.

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However, the undrained shear strength increased back when an amount of fines increased. As reported by [7], the lowest value of undrained shear strength of sand matrix soils was measured at 25% of fines content.

The present of fines content affected to liquefaction in soils was unique as can be seen at Table 1. The results of undrained shear strength (which can be used as static liquefaction) show that the critical undrained shear strength of each liquefied soil did not occur at the same fines content due to some factors such as aging and cementation, soil type, particle shape, particle size distribution, and relative density of the soils. Although the results on the effect of fines content conducted by [7] and [8] have been achieved, the effect of the sizes of sand and the particle shape was found to contribute to the strength behaviour of the sand matrix soils.

Table 1. Liquefied soils observed from earthquake incident

Researchers	Earthquake Incident	Year	Liquefied soils
[9]	Loma Prieta, United States	1989	Silty sand consists of 13 % clay content and 40 % non-plastic silt
[10]	Peloponnese, Greece	2008	Non-plastic fines content of 30 %
[11]	Tohoku, Japan	2011	Percentage of fines content less than 25 %
[12]	Emilia, Italy	2015	Sand with an amount of clay content less than 10 %
[13]	Gorkha Earthquake, Nepal	2015	Percentage fines content varies from 0.6 % to 2.9 %

Therefore, to understand the effect of sizes and shape of sand in sand matrix soils in term of undrained shear strength behaviour, different sources of sand were used compared to [8]. Thus, specific objectives have been set: (1) to determine basic properties of each sand matrix soils sample; and (2) to analyse the effect of coarse sand on the undrained shear strength characteristics of sand matrix soils.

II. LABORATORY TEST

A. Basic Test

In order to investigate the effect of coarse sand on undrained shear strength behaviour in sand matrix soils, basic tests (particle size distribution, particle density, maximum void ratio, and minimum void ratio) on sand matrix soils were conducted before triaxial test was carried out. The basic tests were performed in accordance with BS 1377-2: 1990 and test procedure used by [14].

B. Isotropically Consolidated Undrained Test

A Johor mining sand is divided to three groups of sizes known as coarse sand, medium sand, and fine sand. To achieve the aims of this research, only one group of coarse sand (size retain 2.00 mm to 0.6 mm) was mixed with percentages of 0%, 10%, 20%, 30%, and 40% of kaolin by dry mass to form reconstituted sand matrix soils samples as tabulated in Table 2. Figure 2 shows the coarse sand and kaolin from Kaolin (M) Sdn. Bhd., Selangor, Malaysia used in this research.

Table 2. Basic properties of sand matrix soils

Sand Matrix Soils	Sample Code	Percentage by weight (%)	
		Sand	Kaolin
Sand	SAND	100	0
Coarse Sand	S100K0 - C	100	0
Coarse Sand + Kaolin	S90K10 - C	90	10
	S80K20 - C	80	20
	S70K30 - C	70	30
	S60K40 - C	60	40

(a) Coarse sand

(a) Kaolin

Figure 2. Materials used to reconstituted of sand matrix soils

Non-homogeneous samples were one of the factors that affected the results of soil liquefaction resistance as stated by [15]. Hence, the moist tamping techniques [4], [16], [17], [18], [19], [20], [21], [22] and [23] that consist of 5% of moisture content to form homogeneous, easy-to-control target density, and to prevent the segregation of the samples, were applied.

Each sample, including original sand (SAND), was prepared in split mould placed on the 50 mm diameter of triaxial pedestal. The height of the reconstituted samples was fixed to 100 mm. Rubber membrane was put into the split mould, and using a vacuum to suck the air trapped between inner face of mould and outer face of rubber membrane to keep the consistency diameter of samples at 50 mm.

Five layers, with each layer thickness of 20 mm, were formed using moist tamping technique with target relative density of 15% which represented loose state of sand matrix soil samples. The test procedure was based on BS1377 8:1990 and was provided by GDS Instrument through [24]. Figure 3 shows the reconstituted sample prepared on the triaxial pedestal.

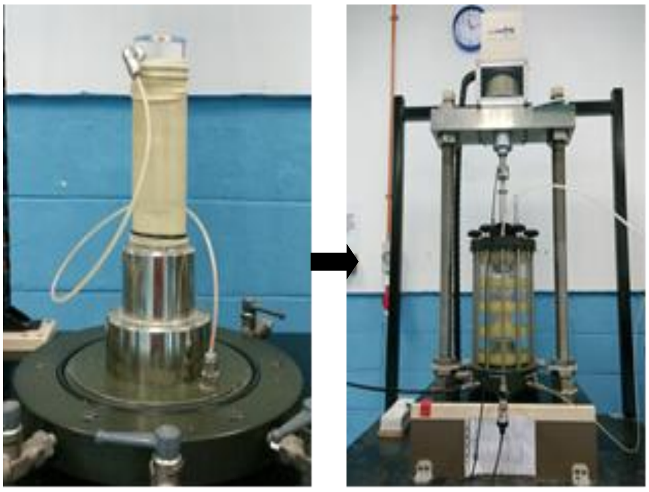


Figure 3. Reconstituted cylindrical sample on triaxial pedestal

De-aired water was used to all cylindrical samples for saturation stage. This was suggested by [5] and [24] to achieve full saturation for each sample. As the GDS machine operated, complete with automatic control of back pressure and compressed air (for cell pressure), automatic saturation was applied with the different pressure of 10 kPa between cell pressure and back pressure was maintained continuously until fully saturated samples was achieved. Comparable with saturation technique by increasing back pressure, this technique (automatic saturation) as stated by [25] can avoid the cyclic changes in effective stress of the samples. To check whether full saturation had been reached, a B-check stage was introduced, by which it can be fully saturated when the value of B-check reached 0.95 and above [24]. For this research, the applied back-pressure was 190 kPa for fully saturated condition of sand matrix soils. At this condition, the cell pressure and back pressure values were kept static before consolidation stage performed. Two values of effective consolidation pressure, σ’ were applied, 100 kPa and 200 kPa, for analysis purposes. Undrained condition was kept similar to all samples. In order to achieve 100 kPa of effective consolidation pressure, the back pressure recorded at saturation stage was maintained while the cell pressure was increased until the different pressure between it them had reached 100 kPa. The same procedure was applied to 200 kPa effective consolidation pressure. Static triaxial test was carried out by isotropically consolidated undrained for all samples. Each sample was sheared under undrained condition at 100 kPa and 200 kPa of effective consolidation pressure. An increment of approximately 0.1 mm/min of axial strain was applied to all samples until 25% axial strain was reached. Through literature review, the small axial strain rate was applied to allow pore pressure changes to equalize throughout the sample [5]. All measured data were automatically logged to computer.

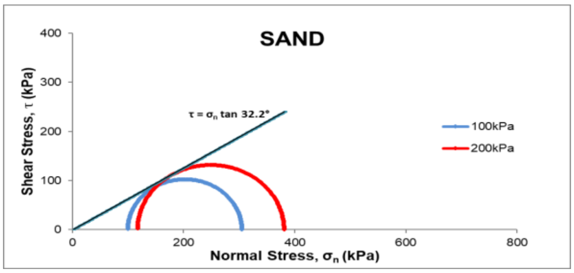
III. RESULTS AND DISCUSSIONS

Table 3 tabulates basic properties of sand matrix soils tested. It shows that, as coarse sand decreased, the gradation (based on USCS) of sand matrix soils changed from poorly graded sand (SP) to silty sand (SM). The initial transition was observed between S90K10-C to S80K20-C which consists of 10% and 20% of fines content, respectively. Coefficient of uniformity, Cu increased when the percentage of coarse sand decreased. Similar trend was observed for particle density, ρs. The shape of mining sand used was classified as sub-angular to angular.

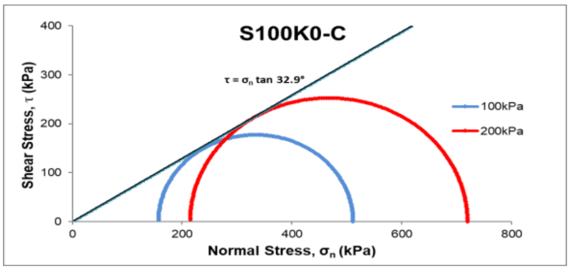
The effect of coarse sand in sand matrix soils on consolidated undrained strength was investigated over five different sand matrix soils and pure sand on the same materials. The results were analysed from undrained triaxial test under 100 kPa and 200 kPa effective consolidation stress. The various undrained shear strength on Mohr-Coulomb failure envelope of sand matrix soils are shown in Fig. 4. From Figure 4, it shows that the shear strength of coarse sand (S100K0-C) presented higher effective friction angle, ϕ’ compared to pure sand (SAND).

Table 3. Basic properties of sand matrix soils

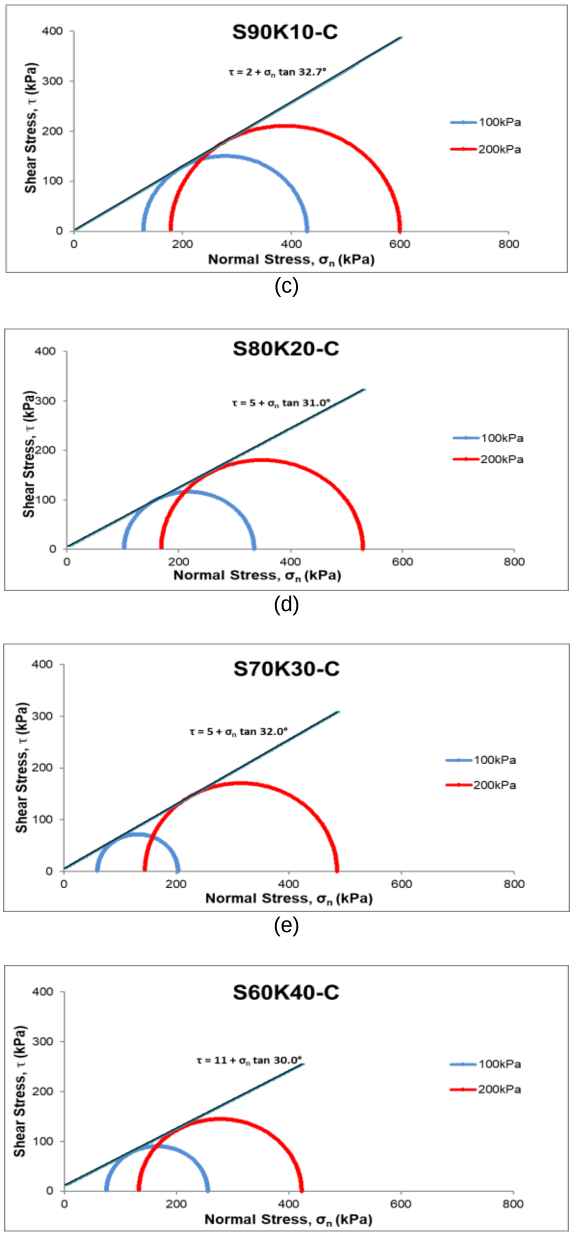
Sample Code	Density, ρ_s Mg/m^3	Gradation		USCS
		C_u	C_c	
SAND	2.63	2.14	0.86	SP
S100K0 - C	2.60	1.71	0.96	SP
S90K10 - C	2.61	7.67	3.71	SP
S80K20 - C	2.63	46.00	17.04	SM
S70K30 - C	2.62	73.33	1.36	SM
S60K40 - C	2.64	90.00	0.54	SM



(a)



(b)



(c)

(d)

(e)

(f)

Figure 4(a) – 4(f). Mohr-Coulomb failure criterion of sand matrix soils

According to Figure 4 and Table 4, effective cohesion, c' increased with increase of fine content, but effective friction angle, ϕ' decreased with increase of fines. In sand matrix soils (with present of fines content), the behaviour is due to the domination of fines content: increase of fines content will decrease the ability to prevent sliding and rolling of sand particles. SAND consist of three sizes of sand (coarse, medium, and fine), and it was measured by c' = 0 and ϕ' = 32.2° (ϕ' was less than that of S100K0-C, which is 32.9°). It can be seen, the value of c' for original sand and coarse sand (S100K0-C) was the same (c' = 0) as expected. A similar behaviour was reported by [8]. SAND shows a little bit lower friction angle compared with S100K0-C and S90K10-C; this was due to the contact between the particles. The present of medium and fine sand in SAND sample decreased the contact between the larger particles; hence, caused to decrease the ability to prevent sliding and rolling of particles compared to S100K0-C and S90K10-C samples. Although sample S90K10-C consists of fines particle, the small amount of fines content did not give significant effect to the value of effective friction angle.

Table 4. Effective cohesion and effective friction angle of sand matrix soils

Code	Effective cohesion, c' (kPa)	Effective friction angle, ϕ' (°)
SAND	0	32.2
S100K0-C	0	32.9
S90K10-C	2	32.7
S80K20-C	5	32.0
S70K30-C	5	30.0
S60K40-C	11	30.0

Since the fines content was similar to [8], comparison also can be made on c' and ϕ'. As reported by [8], c' was 0 kPa while ϕ' was 29.1° for river sand which reported has sub-angular shape. For comparison, in this SAND sample, similar value was observed on c' = 0 kPa; however 10% higher value of ϕ' was observed on mining sand. This condition is due to the different types of sand and particle shape [26] of each sample, whereby higher angularity resulted in higher ϕ'.

IV. CONCLUSIONS

The aim of this study is to investigate the effects of coarse sand on undrained shear strength behaviour of sand matrix soils. A series of experimental study on consolidated undrained triaxial test had been carried out and the results in term of Mohr-Coulomb failure envelope were used to analyse the behaviour of sand matrix soils. The following results are concluded.

a) The transition of soil classification of sand matrix soils occurred between 10% and 20% of fines content. The gradation of sand matrix soils changed from SP to SM with increase of fines, which shows the domination of fines on different undrained shear strength parameters.

b) The particle shapes affected the behaviour of sand matrix soils. Higher angularity of particles contributed to the higher effective friction angle. Higher percentage of coarse sand in sand matrix soils led to higher effective friction angle.

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