Influence of Grain Sizes on Undrained Strength of Sand Mixtures

Bakhtiar Affandy Othman, Aminaton Marto, Faizal Pakir, Amir Zaki Salikin

Abstract*: Sand is known as the main material in land reclamation works to develop and widen an area. It is important for the Geotechnical Engineer to ensure the sand used can accommodate the burden imposed from the structures to be built on it. Previous researchers have conducted studies on the strength of sand, whether focusing on the sand itself or with the presence of fines. However, the study of sand grain size effects in sand mixtures in affecting sand behavior is extremely limited. The sizes and angularity of the sand particle are believed to contribute to the behavior of sand mixtures soil. Hence, the study to investigate the effect of sand grain size on sand mixtures in term of undrained strength is being carried out. The sand was sieved to coarse sand, medium sand and fine sand then each size was mixed with kaolin at 0 %, 20 % and 40 %. The undrained strength was obtained from triaxial test on undrained condition. As a result, it is found that the maximum deviator stress, q_{max} increases with the decrease of fines (kaolin) content. On the other hand, at the same fines content, increased of sand size leads to the increased of q_{max}, which means the increased of undrained shear strength. In addition, the angular shape of sand particle was thought to contribute to the high value of undrained shear strength for the sand mixtures.

***Index Terms*: Shear strength, kaolin, coarse sand, medium sand, fine sand.**

I. INTRODUCTION

Sand in natural condition may have an amount of fines, whether as plasticity fines or non-plasticity fines or both. For many years, research related to the effects of fines content in sand fine mixtures was found well studied. In the past 5 years, studies on engineering behaviour of sand composed of various amount of fines have been conducted by [1], [2], [3], [4], [5], [6] and [7]. Loss of shear strength may lead to liquefaction phenomenon in granular soils. Shear strength of granular soils may decreased or increased with the presence of fines. This behaviour was proven by [8], in which they showed that the strength of mixtures reduced with increases of silt from 0 % to 30 %, then the strength increases thereafter. This transition is known as a threshold value. However, [9] show the transition occurs between 20 % to 40 % of fines content. As reported by [10] on the characteristics of liquefied soils, natural liquefied soils occured at various fine content from 15 % to 70 % of fines. However, other factors as pointed out by [11] such as confining pressure, type of soil, relative density of soil, particle size and gradation of the soil, depositional environment, aging and cementation as well as historical environment need to be considered.

The relationship of fines content with minimum void ratio, e_{min} and maximum void ratio, e_{max} had been studied by [12]. As mentioned by [13], the value of e_{max} and e_{min} are influenced by the grain shape, as example, decreases of angularity will decreased the value of e_{max} and e_{min}. Research conducted by [14] stated that the engineering behaviour of soils is influenced by the shape of particles. It can be seen from the study done by [15] on various types of sand such as natural sand and crushed sand; they found that the critical state parameters, Γ increase with decreased of particle shape in term of roundness, R. [16] highlighted that the frictional strength is strongly influenced by particle shape; as an example, shearing resistance increases with increases of angularity of particles due to the decreases of ratio of rolling to sliding contacts.

[17] summarized some results from year 1968 to 1999 on the effects of particle size gradation on liquefaction resistance. From the research results, some researchers claim that mean grain size (D_{50}) of 1.0 mm to 0.1 mm causes decreasing in liquefaction resistance, while some researchers show that the D_{50} = 0.08 mm is more susceptible to liquefaction. Based on the research done by previous researcher, evaluation on field case histories of liquefaction potential for 50 years around the world have been figured out by [18]. From Figure 1, [18] concluded that about 78 % liquefaction out of 155 incidents occur when the mean grain size, D_{50} is lied between 0.113 mm to 0.338 mm. [17] show that there is no relationship can be concluded between the coefficient of uniformity, C_U and coefficient of curvature, C_C with the cyclic resistance. The results have been shown to be in agreement with [19].

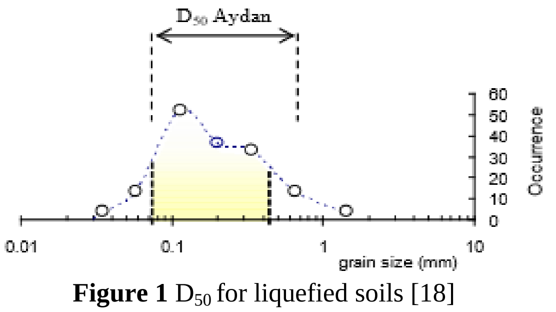

Figure 1 D_{50} for liquefied soils [18]

Revised Manuscript Received on July 10, 2019.

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Hence, based on the findings from the literature above, the research on effect of different sizes of sand particles in sand mixtures is still lacking. Existing results are also not conclusive. Therefore, this paper reports some results of a study on investigating the influence of different sizes of sand in sand mixtures in terms of effect to undrained shear strength. Further results could be used to provide as an indicator on liquefaction resistance of sand mixtures. The GDS ELDYN® triaxial machine was used to carried out the main test (undrained triaxial test).

II. METHODOLOGY

A. Basic Properties

Tropical sand used in this study was obtained from a river at Johor Bahru, Malaysia which widely used as construction material. Kaolin as fines content was bought from Kaolin (M) Sdn. Bhd., Selangor which located approximately 300 km from Johor Bahru. As mentioned by [20], this kaolin is characterized with white colour and have a maximum dry density, ρ_d = 1.64 Mg/m^3, optimum moisture content, w_{opt} = 18 %, specific gravity, G_s range from 2.60 to 2.66, and liquid limit and plastic limit of 42 % and 21 %, respectively. [3] reported the same kaolin used in this research as reconstituted of sand mixtures is classified as intermediate plasticity silt (MI), according to United Soil Classification System (USCS). As reported before by [21], the tropical sand soil is classified as poorly graded (SP) with mean diameter, D_{50} = 0.47 mm, C_C = 0.86 and C_U = 2.14. Particle density, ρ_s of the sand is 2.63 Mg/m^3. Figure 2 illustrates the particle size distribution (PSD) of sand and kaolin used in this research.

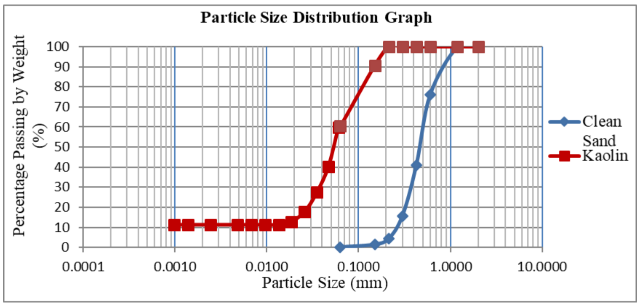

Figure 2 PSD of sand and kaolin in the current research [21]

Table 1 shows the compositional characteristics of reconstituted samples of various sizes of sand in sand mixtures. Through sieving, clean sands were separated into three different sizes range for coarse sand, medium sand and fine sand. Samples with three (3) different fines content for each sizes of sand were prepared for basic and isotropically consolidated undrained triaxial tests.

Table 1 Sand and kaolin composition in sand mixtures

Soils Type	Code	Percentage by weight (%)	
		Sand	Kaolin
Sand (Coarse)	S100K0 -C	100	0
Sand (Coarse) + Kaolin	S80K20 -C	80	20
	S60K40 -C	60	40
Sand (Medium)	S100K0 -M	100	0
Sand (Medium) + Kaolin	S80K20 -M	80	20
	S60K40 -M	60	40
Sand (Fine)	S100K0 -F	100	0
Sand (Fine) + Kaolin	S80K20 -F	80	20
	S60K40 -F	60	40

The cylindrical sand mixtures samples (50 mm diameter and 100 mm height) were prepared on the triaxial pedestal using 5 layers with the thickness of 20 mm per layer. Relative density of 15 % (loose state) was prepared on all sand mixtures sample. Previous researchers have developed and utilized various techniques for preparing samples for laboratory testing. The effective techniques to prepare the high quality of sample close to the natural condition are important especially in triaxial testing. The grain structure arrangement remains the most influence factors that influenced the stress-strain behaviour of the sample prepared [22]. Various techniques such as moist tamping, dry or moist pluviation, air pluviation and dry funnel deposition on sample preparations of sandy soil on triaxial test to measure soil behaviour have been presented by previous researchers (examples; [23]; [24]; [22]; [5]; [25]). Moist or wet tamping technique is the most popular technique applied for sample preparation as used by past researchers such as [26]; [27]; [28]; [29]. Through this technique, the homogeneous of the sample can be produced ([17]; [25]; [30]). Due to that, moist tamping with 5 % moisture content was applied to each samples of sand matrix soils in this study. Isotropically consolidated undrained triaxial test was conducted according to [31].

Figure 3 shows the setting up of the samples on GDS ELDYN® triaxial machine. This machine has the ability to conduct a test up to 10 kN of vertical load and 5 Hz frequency for cyclic test.

Figure 3 Samples setup on triaxial machine

The cell was filled with de-aired water as a medium to provide the confining pressure [32], controlled by compressed air pressure. In saturation stage, when the B value is equal or more than 0.95, the sample is considered as fully saturated. After fully saturated condition achieved, 100 kPa effective consolidation pressure were applied to each sample types. After consolidation stage completed, the shearing with shear strain rate of 0.1 mm/min was applied until maximum strain reached 25 %.

In order to observe the particle shape of sand and kaolin in sand mixtures, Scanning Electron Microscope (SEM) was applied which provided by Microscopy Laboratory, Universiti Tun Hussein Onn Malaysia, Johor. Figure 4 illustrates the setting up of SEM machine.

Figure 4 JEOL (JSM-6380LA) series of SEM machine

III. RESULTS AND DISCUSSION

A. Microscopic Characteristics of Sand and Kaolin

SEM image of coarse, medium and fine sand are shown in Figure 5, 6 and 7, respectively. Based on the roundness, R introduced by [33], all three sand sizes have sub-angular shape. In general, when the particle sizes decrease, the surface area increased. This sub-angular shape contributed to higher shear strength compared to the rounded and well-rounded particles. As mentioned by [34], larger surface area leading to increase interaction to other particles. On the other hand, it can be said that, when saturated condition reached, the fine sand matrix soils tend to highly surrounded by water molecules compared to medium and coarse sand mixtures.

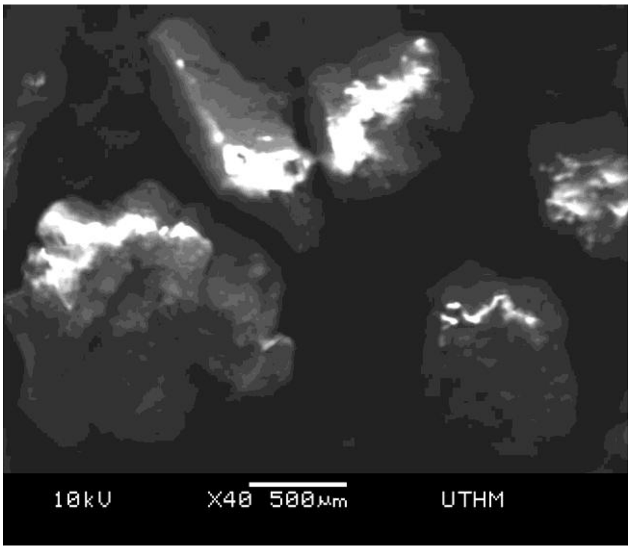

Figure 5 SEM image for coarse sand

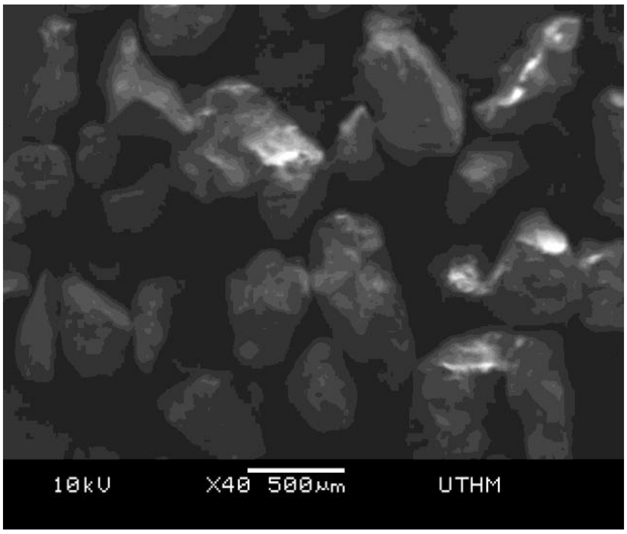

Figure 6 SEM image for medium sand

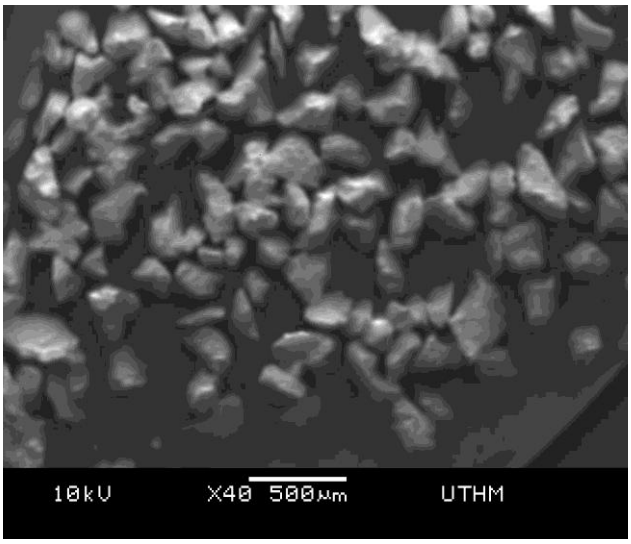

Figure 7 SEM image for fine sand

B. Particle Size Distribution (PSD)

Figures 9, 10 and 11 show the particle size distribution for coarse, medium and fine sand mixtures, respectively. According to the Figure 9, mean grain size, D_{50} of coarse sand mixtures ranges from 0.72 to 1.10. It could be calculated from Figures 10 and 11, D_{50} ranges from 0.28 to 0.36 and 0.11 to 0.19, respectively. Based on this result, it can be deduced that D_{50} increases with decreases of fine content, and generally it can be said that the D_{50} decreases with decreases of sand particle size. From Figure 9, using Unified Soil Classification System (USCS), the coarse sand mixtures, S100K0-C is classified as poorly graded (SP) sand while S80K20-C and S60K40-C are classified as silty sand (SM). The coefficient of uniformity, C_U are 1.7, 46 and 90; and coefficient of curvature, C_C are 0.9, 17 and 0.5 respectively for S100K0-C, S80K20-C and S60K40-C.

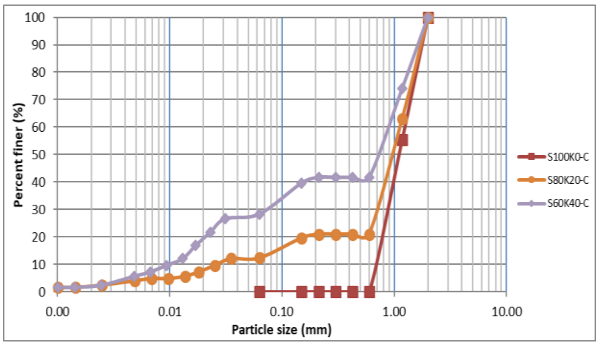

Figure 9 PSD of coarse sand mixtures.

Similar trend with coarse sand mixtures was observed for soil classification of medium sand mixtures and fine sand mixtures (Figure 10 and Figure 11). For medium sand mixtures, C_U lies between 1.6 and 30.0, while C_C lies between 0.9 and 7.1. For fine sand mixtures, C_U ranges from 2.2 to 13.0 and C_C ranges from 1.3 to 3.7

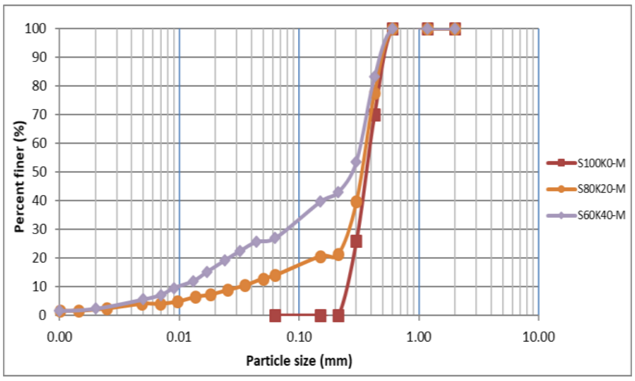

Figure 10 PSD of medium sand mixtures.

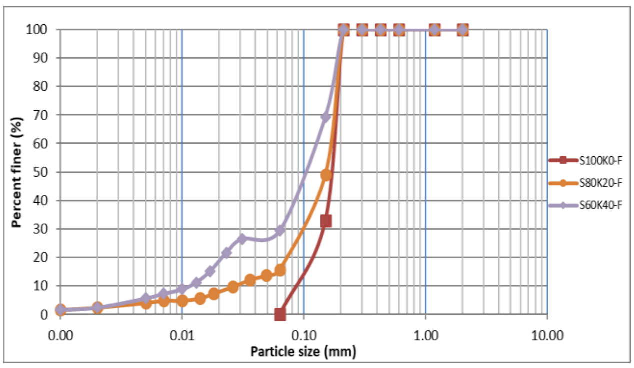

Figure 11 PSD of fine sand mixtures.

C. Isotropically Consolidated Undrained Triaxial Compression Test (CU)

A series of CU tests were conducted to the various sizes of sand mixed with different percentage of fines. Figures 12, 13 and 14 show the deviator stress-strain relationships of coarse, medium and fine sand mixtures, respectively. As can be seen from Figure 12, the maximum deviator stress, q_{max} of coarse sand mixtures decreases with increases of fine content. The q_{max} has occurred at strain of 19.62 % (q_{max} = 354 kPa), 24.83 % (q_{max} = 232 kPa) and 24.78 % (q_{max} = 180 kPa) for sample S100K0-C, S80K20-C and S60K40-C, respectively. The addition of fines to the sand increased the strain at failure.

Similar trend was observed on medium sand mixtures, however the value of q_{max} was decreased to 305 kPa, 202 kPa and 129 kPa for samples S100K0-M, S80K20-M and S60K40-M, respectively. Reverse behaviour occurred at fine sand mixtures at transition from 20 % to 40 % of fine content. The q_{max} measured was decreased from 218 kPa (S100K0-F) to 133 kPa (S80K20-F). However, q_{max} increases to 139 kPa for sample S60K40-F.

Results show that the q_{max} decreased with increased of fines content, and at certain value shows a reversible result. This kind of outcome is expected, as also reported by [9]. There is a concept of 'threshold' value. In the case of coarse and medium sand mixtures, it is found that no threshold value occurred until 40 % of fines. Threshold condition can be explained as where the transition condition of fines particle filling the voids between sand particles and become a dominant particle than sand (exceeds the void between sand grain). From the results, it can be inferred that for fine sand matrix soils the threshold value occurred between 20 % of fines and 40 % of fines. Since it was not observed, more percentage of fines needs to be added to coarse and medium sand to determine the threshold values

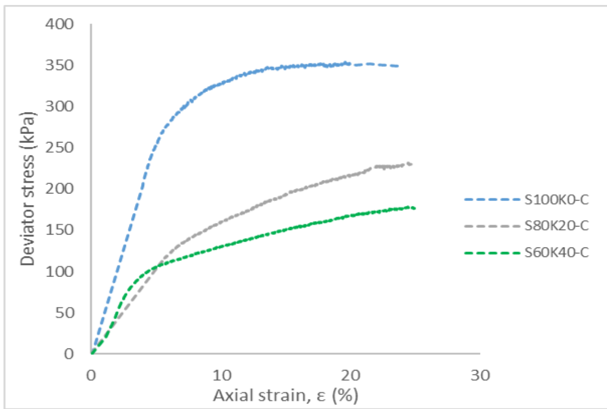

Figure 12 Deviator stress versus axial strain of coarse sand mixtures

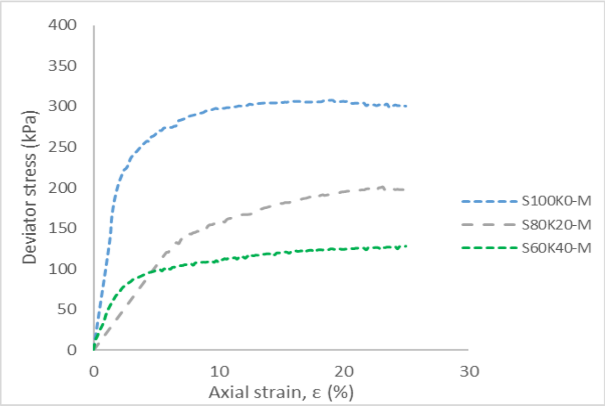

Figure 13 Deviator stress versus axial strain of medium sand mixtures

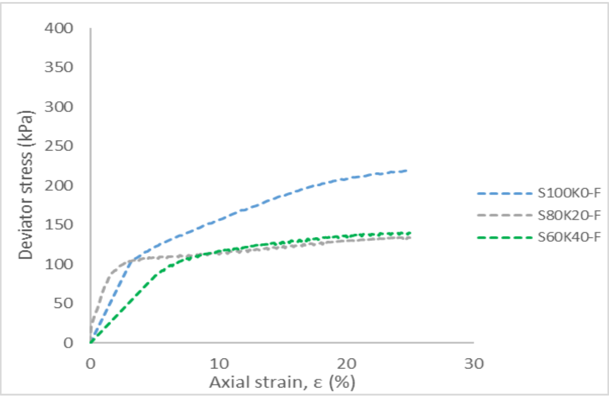

Figure 14 Deviator stress versus axial strain of fine sand mixtures

IV. CONCLUSION

(1) Mean grain size, D_{50} increases with decreases of fine content, and generally the D_{50} decreases with decreases of particle size of sand. The coarse, medium and fine sands used have sub-angular shape.

(2) Maximum deviator stress, q_{max} increases with decreases of fines content. At the same fines content, the increase of size of sand leads to the increase of maximum deviator stress, or can be said as the undrained shear strength.

(3) Maximum deviator stress, q_{max} of 354 kPa was observed as the highest at S100K0-C, while S100K0-M and S100K0-F were observed at 305 kPa and 218 kPa, respectively. Without fines content, q_{max} increases with the grain size.

(4) Maximum deviator stress, q_{max} was observed to occur at the strain between 19 % and 25 % for all sand mixtures. The addition of fines increases the strain at failure.

Threshold value had occurred between 20% and 40% of fines content for fine sand mixtures but it was not observed for coarse and medium sand mixtures for up to 40% fines content.

ACKNOWLEDGMENT

This research is collaboration between researchers from Malaysia-Japan International Institute of Technology (MJIIT), UTMKL and researchers from Research Centre of Soft Soil (RECESS), UTHM, Batu Pahat Johor through financial support by FRGS, Ref.: R.J130000.7822.4F849 and TIER 1 Grant Vot. H234, respectively. Thank you to Ministry of Higher Education (MOHE), Malaysia for that financial support and MJIIT, UTM for the financial assistance given.

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