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Effect of Silt Presence on Shear Strength Parameters of Unsaturated Sandy Soils

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***Abstract*—**Direct shear test is widely used in soil mechanics experiment to determine the shear strength parameters of granular soils. For analysis of soil stability problems such as bearing capacity, slope stability and lateral pressure on soil retaining structures, the shear strength parameters must be known well. In the present study, shear strength parameters are determined in silty-sand mixtures. Direct shear tests are performed on 161 Firoozkooh sand with different silt content at a relative density of 70% in three vertical stress of 100, 150, and 200 kPa. Wet tamping method is used for soil sample preparation, and the results include diagrams of shear stress versus shear deformation and sample height changes against shear deformation. Accordingly, in different silt percent, the shear strength parameters of the soil such as internal friction angle and dilation angle are calculated and compared. According to the results, when the sample contains up to 10% silt, peak shear strength and internal friction angle have an upward trend. However, if the sample contains 10% to 50% of silt a downward trend is seen in peak shear strength and internal friction angle.

***Keywords*—**Shear strength parameters, direct shear test, silty sand, shear stress, shear deformation.

I. Introduction

In many geotechnical problems, direct shear tests are used to evaluate the shear strength parameters of soil materials for obtaining design parameters. The direct shear test has been used in geotechnical engineering over the last 50 years due to its simplicity and repeatability. This direct shear test is applied to the sand to determine the friction angle, the dilatation angle or the shear strength of the sand.

Shear strength and dilatation behavior of sandy soils was investigated by various researchers. Salgado et al. [1] examined the results of the triaxial test to reach the critical and maximum friction angle of clean sand and the maximum silty sand, they found that increasing the percentage of silt to in clean sand, leads to a significant increase in the shear strength parameter and soil dilatation. It was also observed that in small strains, the stiffness decreases and the critical state strength and maximum resistance increase. Huang et al. [2] investigated the effect of silt content on undrained resistance of Taiwan's sand by performing a triaxial cyclic test. Ragogupta [3] tested the effect of non-plastic fine content on loose sand behavior. The results showed that the internal friction angle decreases by adding fine grained soil due to the compressibility of fine grains. Xiao et al. [4], by analyzing the existed experimental data, presented an analytical relationship for study the effect of the silts on the resistance and dilation properties of Ottawa sand. The model presented by Xiao et al. [4] has a good agreement with the experiments result of Salgado et al. [1]. Yusufpour and Hamidi [5] also investigated the fine content effect on the shear strength and dilatation properties of Babolsar sand by using a direct shear apparatus in saturated state; they found that the overall behavior of the samples depends on their sand structure.

In the present study, a series of direct shear tests were carried out on 161 Firoozkooh sand mixtures with different percentages of silt (0.10, 30.50) at a relative density of 70% and in three vertical stress of 50, 100, 200 kPa. The main purpose of the study is to determine the effect of silt content on shear strength parameters and the dilatation angle of unsaturated silty sand under static loading.

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II. Material Properties

In this study, 161 Firoozkooh sand and Firouzkooh silt were used make samples. This sand has a golden-yellow color and it is subangular according to the chromembin table [6]. Based on laboratory observations (using electron microscopy, Fig. 1), this sand has approximately 60% angular and 40% rounded. Firoozkoh silt, in appearance, is powder-shaped and angular. The purpose of this material selection is the availability of the materials and its strength break down during loading. As well as the minerals present in this soil are not readily reactive and not dissolved in the water. The particle size distribution curves of tested sand and silt material are obtained from the sieve and the hydrometric test on this soil is shown in Fig. 2. In this research, the selected sand and silt material are categorized as SP and ML were used according to the Unified soil classification, respectively [7].

III. Test Procedure and Apparatus

A. Sample Preparation

There are several methods for sample preparation in sandy soil, which can be described as moist tamping and dry pouring are recognized as two common methods. In this paper, the sample was carried out using moist tamping method. Since in this study, the wet tamping method used to sample preparation, 5% moisture content was used [8]. Therefore, experiments are carried out under unsaturated conditions.

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Fig. 1 Microscopic image of tested Firoozkooh sand

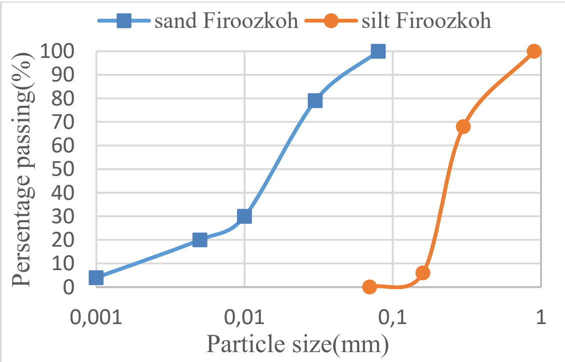

Fig. 2 Particle size distribution curves of tested materials

B. Direct Shear Test

Fig. 3 shows the general schematic of the automatic direct shear apparatus used. Horizontal loading rate in all specimens is 1 mm / min. The samples were subjected to three vertical stress of 50, 100, and 200 kPa under shearing. All experiments were carried out to a strain rate of 15% to observe the soil behavior in high strains.

IV. Result and Discussion

A total of 12 direct shear tests were conducted to investigate the effect of different silt content on behavior of shear strength parameters and dilatation of sand. Maximum shear strength and friction angle of specimens were calculated. Fig. 4 shows the shear stress variations with shear deformation in different percentages of silt for a density of 70% in vertical stress of 50,100, and 200 kPa.

Fig. 3 Digital direct shear apparatus in IKIU lab

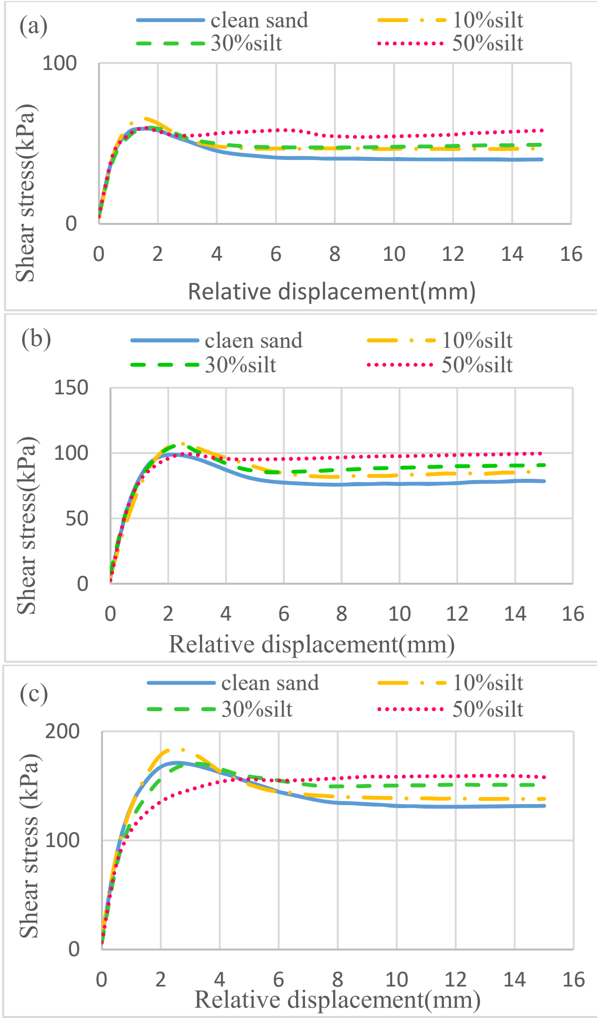

Fig. 4 Shear Stress versus relative displacement curves of silty sand samples under vertical stress; (a) 50 kPa; (b) 100 kPa; (c) 200 kPa

According to Fig. 5, the shear strength of the sand mixture is increased by increasing the percentage of shear compared to the clean sand up to 10% and then. Fig. 6 shows the volumetric behavior of the samples. In this figure, the soil behavior is dependent on the sand structure that shows the dilatation process.

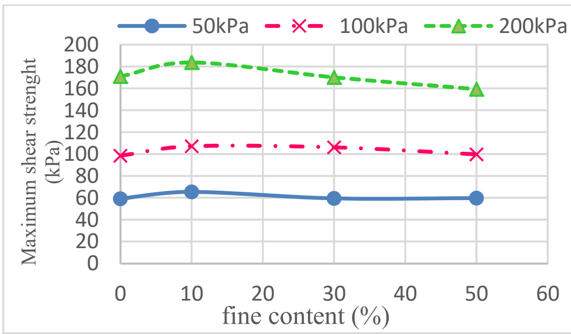

Fig. 5 Maximum shear strength versus the fine content in three vertical stress of 50, 100, and 200 kPa

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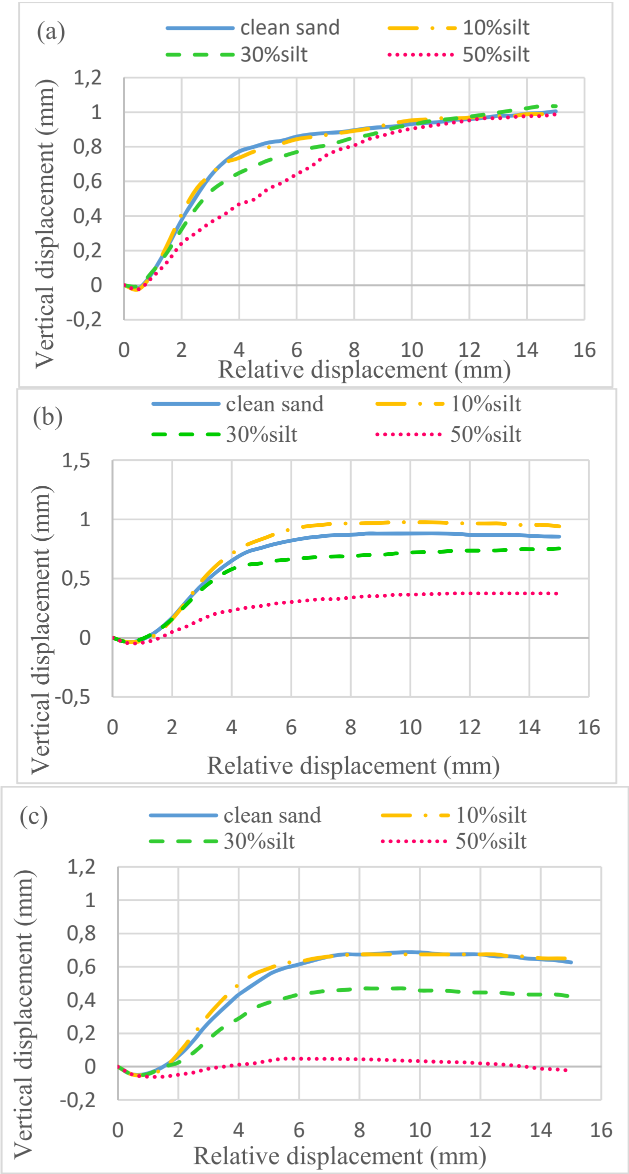

Fig. 6 Vertical displacement versus relative displacement curves of silty sand samples under three vertical stress; (a) 50 kPa; (b) 100 kPa (c) 200 kPa

Fig. 7 shows the variations of the friction angle in silty sand samples.

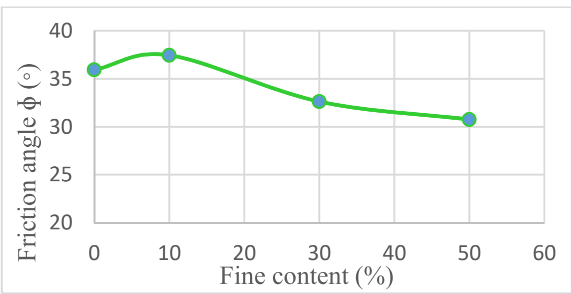

Fig. 7 Variations of friction angle versus fine content in three vertical stresses of 50, 100, and 200 kPa

The results of the experiments showed that by increasing the percentage of silt up to 10%, the internal friction angle increases then decreases. Fig. 8 is the results of Xiao et al. [4] studies. By comparing Fig. 7 with Fig. 8, it can be seen, in the present study and the results of Xiao et al. [4] that the samples contain up to 7% silt dilation angle have an upward trend and the samples contains 7% to 20% silt have a downward trend. The difference between these two studies is in peak internal friction angle. In the present study, peak internal friction angle is in the sample contains 10% silt, however in the study of Xiao et al. [4] peak internal friction angle is in the sample contains 7% silt. The present study is on 161 Firozkooh sand, but Xiao et al. [4] studied on Ottawa sand, so the soil characteristics (particle size distribution, particle shape and density) are different. Therefore, there is a good agreement between the result of the present study and the analytic relationship presented by Xiao et al. [4].

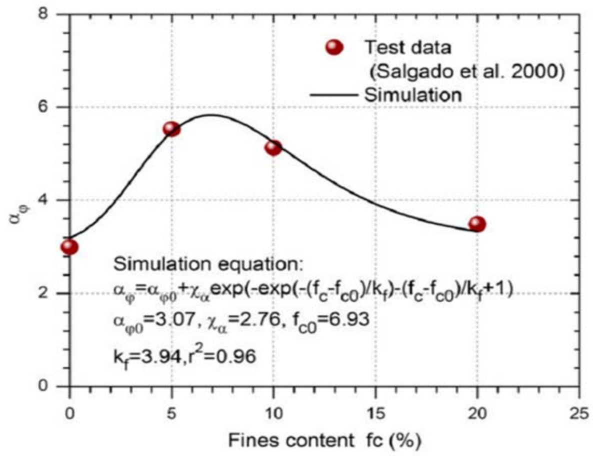

Fig. 8 Variation of α_Ψ versus fine content (Xiao et al. (2014) [4])

Soil deformation is often accompanied by variations in volume. Loose sand tends to contract and reduce volumes, and compact sand can be only deformation when the volume is slightly larger and looser. This phenomenon is called dilatation. The exact estimation of the dilatation angle as an effective geotechnical parameter of soil reinforcement and design the retaining wall is necessary that not paying attention to it may cause undesirable economic and structural constraints. The two measurements of vertical deformation (v) were averaged and related to the shear displacement (u) to calculate the rate of dilation (dv/du). Assuming that the horizontal plane in the shear box is a zero extension line, the angle of dilation can then be deduced from the Mohr's circle of strain increments as in (1):

$$tan\psi = \frac{d\varepsilon_{yy}}{d\gamma_{yx}} = \frac{d_v}{d_u} \quad (1)$$

where ε_{yy} and Y_{yx} are the vertical compressive strain and shear strain. Fig. 9 shows the curve of the variation dilation versus the percentage of silt in three vertical stresses of 50, 100 and 200 kPa.

The obtained results indicate that the amount of dilation in the mixture is increased by increasing the percentage of silt up to 10% and decreases. Due to the fact that the soil samples in the present study were made with moist tamping method of 5% moisture content, the samples were unsaturated. Comparing of the results of this study with studies by Salgado et al. [1], which was carried out by drained triaxial tests on Ottawa sand, there is a good similarity, therefore it can be concluded that the addition of a limited moisture content (5%) in the moist tamping method in the present study did not have a significant effect on the general behavior of the variations in the dilation angle on silty sand, although more precise comment and complete review on this subject will need to perform tests in complete draining condition.

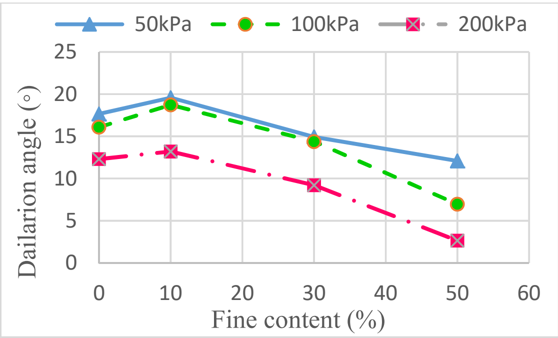

Fig. 9 Variation of dilatancy angle versus fine content for three vertical stresses 50,100 and 200 kPa

V. Conclusion

In this study, 12 direct shear tests were performed to determine the effect of silt content on shear strength behavior of sand under different vertical stresses. The specimens were prepared with different silt content (10, 30, 50) and compacted in a density of 70%. The sandy soil samples were tested under three vertical stress 50,100,200 kPa and, the following results were obtained:

- The general behavior of the samples is dependent on the sand structure.
- An increase in the percentage of silt in mixtures containing 10% silt compared to a mixture of 0% silt increases the amount of dilation. However, thereafter, with an increase in silt in mixtures containing from 30% to 50%, the decrease in the amount of dilatation was observed, also by decreasing the vertical stress, the dilation angle increases.
- The peak shear strength and internal friction angle of sandy samples increased by an increase in silt content up to 10%, and then decreases with increasing amount of silt.

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