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Effect of Plastic Fines on Undrained Behavior of Clayey Sands

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***Abstract*—**In recent years, the occurrence of several liquefactions in sandy soils containing various values of clay content has shown that in addition to silty sands, clayey sands are also susceptible to liquefaction. Therefore, it is necessary to investigate the properties of these soil compositions and their behavioral characteristics. This paper presents the effect of clay fines on the undrained shear strength of sands at various confining pressures. For this purpose, a series of unconsolidated undrained triaxial shear tests were carried out on clean sand and sand mixed with 5, 10, 15, 20, and 30 percent of clay fines. It was found that the presence of clay particle in sandy specimens change the dilative behavior to contraction. The result also showed that increasing the clay fines up to 10 percent causes to increase the potential for liquefaction, and decreases it at higher values fine content. These results reveal the important role of clay particles in changing the undrained strength of the sandy soil.

***Keywords*—**Clayey sand, liquefaction, triaxial test, undrained shear strength.

I. Introduction

LIQUEFACTION of sandy soils is one of the most important reasons for the destruction of earth structures and foundations. As the natural soils are not clean sand, most of the research was focused on the soils that containing fines. In the early years, it was thought that only clean sands are susceptible to liquefaction, hence for several years' great effort has been devoted to the study of the undrained behavior of clean sands. With the occurrence of new earthquakes, it was observed that sandy soils with fine content are susceptible to liquefaction phenomenon. One of the marvelous cases is related to the liquefied soils that containing a high content of clay particles on 22 June, 2002 in Changureh, Avaj-Iran earthquake. This earthquake, the magnitude of which was 6.4 Richter, in addition to causing damage to structures, led to liquefaction. Liquefaction in a field occurred as a sand boiling. After sampling, it was revealed that the soil contained 44 percent of clay content, but it underwent liquefaction [1].

This paper evaluates the liquefaction potential and undrained behavior of clayey sands with various clay content. For this purpose, a series of undrained triaxial tests were conducted on clayey sand specimens with 0 to 30% clay content. The specimens were consolidated at three different consolidation stresses. Finally, the interpretations of the results of the undrained shear strength were discussed, and focused on the steady state shear strength.

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II. Previous Research

Georgiannou et al. [2] performed a laboratory investigation into the behavior of sedimented clayey sand with clay content up to 30%. They concluded that for a given granular void ratio, as the clay content of clayey sands increases from 4.6 to 10% the undrained brittleness and strains to phase transformation also increase. They observed a reverse trend at clay fractions in excess of 20%.

Ovando-Shelley and Pérez [3] carried out undrained monotonic loading tests in a triaxial cell to examine the behavior of sand and kaolin mixtures with 3, 5, and 7% kaolin. They indicated that the small amount of added kaolin led to a reduction in peak deviator stresses and minimum strength. Also, the potential for generating of pore water pressure increases by increasing the amount of kaolin.

Bouferra and Shahrour [4] carried out a series of monotonic and cyclic triaxial tests on soil samples that were reconstituted by mixing an amount of kaolin and sand with five values of fine content (Fc=0, 5, 10, 15, and 20%). The results indicated that the increase in the fine content up to 15% reduces the dilatant tendency of the sand-clay mixture, and consequently reduces its resistance to liquefaction.

Abedi and Yasrobi [5] conducted a series of undrained monotonic triaxial compression tests on specimens of sand with variation in clay content from 0 to 30%. They indicated that, up to a threshold fine content, the instability increases with increase in the fine content, whereas with increasing fine content, above 10 to 15%, the instability decreases. They also found that increasing in fine content leads to a decrease in the peak strength of the specimens.

Papadopoulou and Tika [6] investigated the influence of fines plasticity on the undrained monotonic and cyclic triaxial behavior of sands containing plastic fines. They reported that the undrained shear strength decreases with increasing plasticity index up to a threshold value, above this value, the undrained shear strength increases with increasing the plasticity index of fines.

III. Tested Materials

In this article, tested materials contained two types of soil: (1) 161 Firoozkooh sand and (2) kaolin. The physical properties are given in Table I. Tested specimens were a mixture of sand with 0, 5, 10, 15, 20, and 30% clay fine content, Fc. The clay and sand materials were mixed completely to form a homogeneous mixture. The particle size distribution of the materials is given in Fig. 1.

TABLE I
MECHANICAL PROPERTIES OF SOILS USED

Soil	Specific Gravity, G_s	Min Void ratio, e_{min}	Max Void ratio, e_{max}	Uniformity Coefficient, C_u	Gradation Coefficient, C_z	Liquid Limit, LL (%)	Plastic Limit, PL (%)	Plasticity index, PI (%)
Sand	2.658	0.59	0.91	1.9	0.89	-	-	-
Kaolin	2.589	-	-	-	-	48	27	21

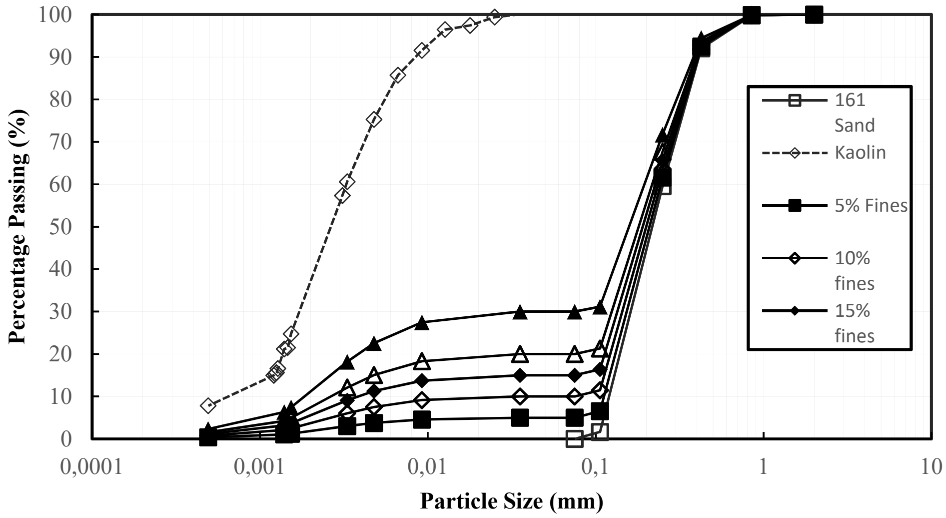

Fig. 1 Grain size distribution curve of materials

TABLE II
TEST PROPERTIES

Test	Effective consolidation stress, σ'$_3$ (kPa)	Fine content, Fc (%)	Void ratio after consolidation, e_f	Steady Sate Undrained Shear Strength, q_{ss} (kPa)	Steady Sate Mean Effective stress, p'_{ss} (kPa)	Peak Undrained Shear Strength, q_{peak} (kPa)
S-1	100	0	0.806	190	145	190
S-2	150	0	0.801	240	180	240
S-3	200	0	0.799	285	216	285
SF5-1	100	5	0.801	18	15	66
SF5-2	150	5	0.794	39	29	93
SF5-3	200	5	0.788	59	49	118
SF10-1	100	10	0.774	1	1	32
SF10-2	150	10	0.761	2	3	62
SF10-3	200	10	0.751	7	9	87
SF15-1	100	15	0.706	4	4	33
SF15-2	150	15	0.686	15	12	62
SF15-3	200	15	0.676	20	17	82
SF20-1	100	20	0.640	22	18	36
SF20-2	150	20	0.624	44	32	68
SF20-3	200	20	0.612	62	46	89
SF30-1	100	30	0.598	41	28	49
SF30-2	150	30	0.592	66	56	68
SF30-3	200	30	0.574	85	63	97

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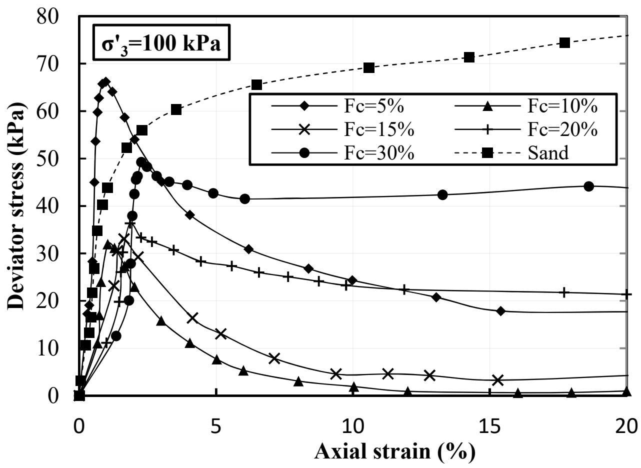

Fig. 2 Stress-strain curve for clean sand and clayey sand specimens at various values of fine content under 100 kPa consolidation stress

IV. Experimental Program

The experimental program included 18 undrained triaxial tests for various fine content and confining pressures. All of the triaxial tests were performed on specimens of 70 mm diameter and 140 mm height. The specimens were prepared by the moist placement method at a water content of 5-6% [7]. All of the specimens were made with the same specific weight of 14.35 kN/m^3 which represents a loose state for soils.

The saturation procedure was done using CO_2 percolation. Specimens shall be considered to be saturated if the value of B is equal to or greater than 0.95. The consolidation phase was carried out under effective consolidation stresses of 100, 150, and 200 kPa. The specimens were subjected to undrained compression loading at a constant strain rate of 0.5 mm/min that produced approximate equalization of pore pressures throughout the specimen at failure. Details of undrained triaxial tests are presented in Table II.

V. Results and Discussion

Figs. 2 and 3 represent the stress-strain and pore water pressure curves of clean sand and clayey sands specimens at various values of fine clay content, respectively. In Fig. 2, the deviator stress values for clean sand correspond to the secondary axis on the right side of the graph.

It can be observed that the presence of clay particles altered the undrained behavior. The clean sand sample has exhibited dilative behavior, so that the pore pressure has increased in lower strains because of the contraction of the sand grains through the small void space between the sand grains (ε<1.5%), and with increasing the axial strain, due to the dilatory behavior of the sand particle, the pore pressure has decreased. By comparing the undrained behavior of the clean sand with the clayey sand specimens, it is observed that the presence of the clay particles has changed the soil's behavior from dilation to contraction. The high compressibility of clay particles is the reason of the change in soil behavior [8]. In the clayey sand specimen, deviator stress reached a peak strength and followed by a drop in strength and reached to a constant value at large strains.

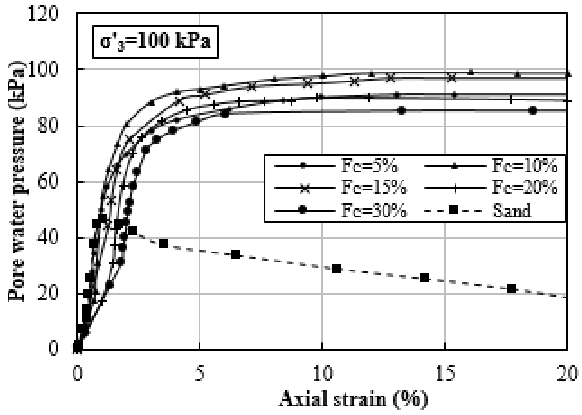

Fig. 3 Pore water pressure curve for clean sand and clayey sand specimens at various values of fine content under 100 kPa consolidation stress

As can be seen from Fig. 3, the amount of the clay particles changes the potential for generating excess pore pressures during undrained loading. The excess pore water pressure increased by increasing the fine content up to a threshold value, and followed by a decrease at higher values of Fc. The specimens containing 10% fine content, had the highest value of the pore water pressure. In this mixture, the clay particles tend to accumulate at contact points of sand particles, that Gratchev et al. [9] called them "*clay bridges*", which have very low resistance. The excess pore water pressure for specimens containing 10% fines reached to a value of 99 kPa under a consolidation stress of 100 kPa that indicates an unstable structure formed in the soil. Consequently, such a structure is very close to the occurrence of full liquefaction behavior (deviator stress value is close to 0). Further increase in clay content reduces the void ratio, and consequently, increases greater resistance to liquefaction.

As seen from Figs. 2 and 3, the fine content affects the undrained shear strength of soil. Fig. 4 shows the variation of the steady state strength of the specimens against the fine content increase. The steady state strength decreases with increasing fine content up to a threshold value, and follows by an increasing trend at higher values of Fc. In mixture with Fc=10%, the steady state strength has the lowest value.

Fig. 5 illustrates the steady state line for various soil mixtures. It can be seen that as the clay content increases, the steady state line moves downward. Naeini and Baziar [10] described this phenomenon as the function of fine particles analogous a lubricant among sand particles in silty sand specimens. It can be stated that, in all FC, liquefaction potential of clayey sands is higher than clean sands.

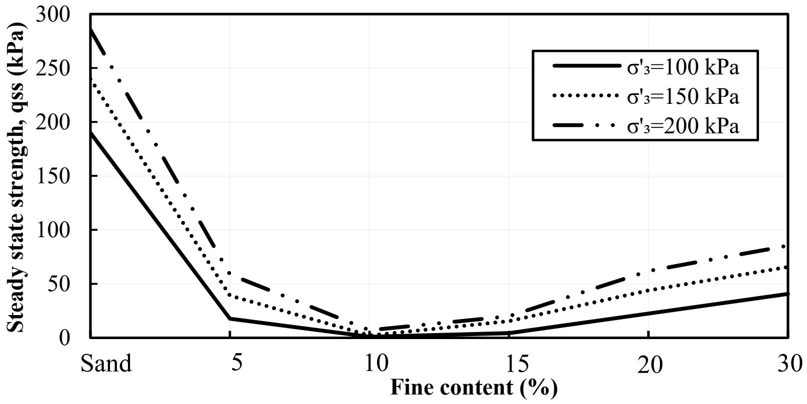

Fig. 4 Variation of the steady state strength with increase in the fine content

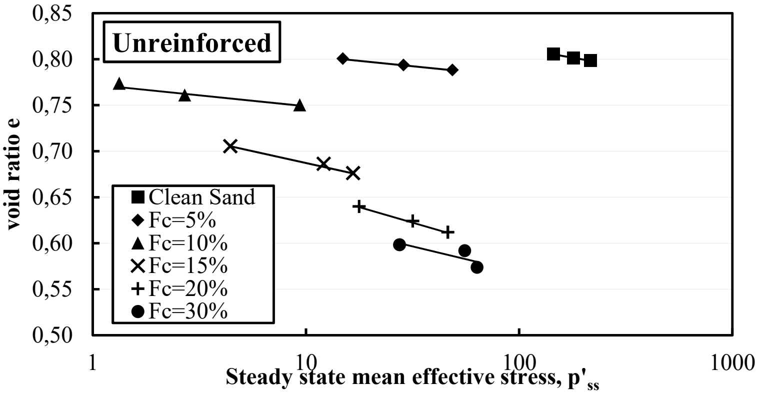

Fig. 5 Steady state lines for various sand-clay mixtures

VI. Summary and Conclusion

The effect of clay fines in sandy soils was investigated by performing a series of undrained triaxial shear test on specimens containing 0 to 30% clay content. The following conclusions were drawn:

- The presence of clay particle changes the dilative behavior of clean sand specimens to contraction. This phenomenon increases the liquefaction potential.
- Increasing the clay content up to 10% reduces the steady state strength and increases the shear strength in a higher value of clay content.
- By increasing the clay content value, the location of steady state line transfers. The steady state lines are moved downward with increasing the clay content.

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