

# Effect of Low Plastic Clay Quantity on Behavioral Characteristics of Loose Sand

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**Abstract**—After the Nigatta earthquake in Japan, in 1960, the liquefaction and its related hazards, moved to the thick of matter. Most of the research have been carried out on clean sands and silty sands so far, in order to study the effect of fine particles, confinement pressures, density and so on. However, because of this delusion that adhesiveness of clay prevents the liquefaction in sand, studies on clayey sands have not been taken seriously. However, several liquefactions happened in clayey sands in recent years, and lead to the necessity of more studies in this field. The studies which were carried out so far focused on high plastic clays. In this paper, the effect of low plasticity clays on the behavioral characteristics of sands is discussed. Thus, some triaxial tests were carried out on clean sands and clayey sands with different percentages of added clay. Specimens were compacted in various densities to study the effect of quantity of clay on various densities, too. Based on the findings, the amount of clay affects the behavior of sand greatly and leads to substantial changes in peak bearing capacity and steady state values.

**Keywords**—Liquefaction, clay, sand, triaxial, monotonic.

## I. INTRODUCTION

BEFORE the Nigatta earthquake (Japan, 1960) which resulted in huge amount of destruction and loss of property, sandy soils were not categorized as problematic soils. After the "liquefaction" and its resulting destructions had been defined, comprehensive studies began to be carried out. Most of those primary investigations focused on clean and silty sands [1]. Based on most of them, it was concluded that by adding some silt or non-plastic fines to sandy soil, its liquefaction potential rises. However, this increasing resumes until a threshold amount, and further addition of fines decreases the liquefaction potential [2]-[4]. Furthermore, other studies dealt with confining pressure [5] or the effect of layered systems on the behavior of clean sand & the sand containing fines [6].

Almost all of previous studies targeted silts or other non-plastic fines and use of fine plastic materials was not a matter of importance. The delusion was claiming that because of the plastic property of clay particles, sand grains were attached together and thus the liquefaction potential was decreased. But some liquefaction took place in clayey sands and lead to more investigations in recent years, in this field.

Based on their findings, adding some clay to sandy soil greatly affects its behavioral characteristics [7], [8]. In the present paper, the results of a study are being presented, in which by adding low plastic clay to sand, the behavioral characteristics of clayey sand (using different percentages of

added clay), using triaxial monotonic test apparatus were investigated.

## II. SPECIFICATIONS OF TESTS

The apparatus of tests was a monotonic loading one, and the tests were conducted in undrained consolidated mode. The load applying approach was a strain-controlled method (0.5 mm/min), and the effective confining pressures equal to 100 Kpa were applied in all tests.

### A. Material Properties and Specimen Preparation Method

The sandy materials used in tests were a kind of milled silicate-sand of Firouz-Kooh (#161). The mechanical properties are as follows (Table I):

TABLE I  
FIROUZ-KOOH SANDY MATERIAL PROPERTIES

Sand Catag.	$G_s$	$e_{max}$	$e_{min}$	F %	K (cm/sec)
161	2.66	0.928	0.583	0	0.0125

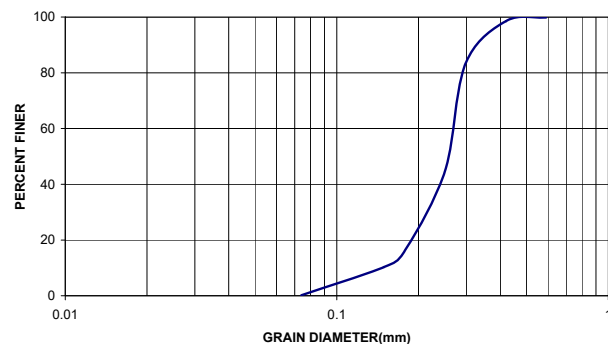


Fig. 1 Particle- size distribution of sand (161)

The properties of clayey materials (passed through sieve #200) are tabulated in Table II:

TABLE II  
PROPERTIES OF CLAY MATERIALS

Clay collected from:	$G_s$	LL	PL	PI
Daroongar (Mashhad)	2.64	28	17	11

In order to prepare the specimens, "wet tamping method" was used. In this method after the clayey material were dried in the oven, screened through a # 200 sieve and then mixed with sandy materials, resulted in a homogenous mixture; followed by 5% of water added to the mixture. Then based on

the desired density, the mixture compacted within six layers in a cylindrical specimen test container (100 x 50 mm).

The specimens were prepared in two different specific dry unit weights. The loose one ( $D_r = 27\%$ ,  $\gamma_d = 1.45 \frac{gr}{cm^3}$ ), and the dense one ( $D_r = 45\%$ ,  $\gamma_d = 1.5 \frac{gr}{cm^3}$ ). Then for each one, different percentages of added clay equal to 0, 5, 10, and 15 were added. Leaving the little effect of clays  $G_s$  on the void ratio, almost all the specimens are prepared in the same void ratio. More of the specimens' specifications are as shown in Table III.

TABLE III

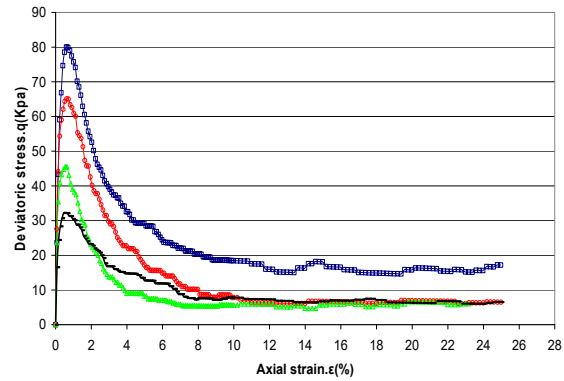
$e_0$ POROSITY RATIO BEFORE CONSOLIDATION			
$(\gamma_d = 1.45 \frac{gr}{cm^3})$	$e_0$	$(\gamma_d = 1.5 \frac{gr}{cm^3})$	$e_0$
Clean sand	0.834	Clean sand	0.773
5% added clay	0.828	5% added clay	0.767
10% added clay	0.828	10% added clay	0.767
15% added clay	0.828	15% added clay	0.767

### III. RESULTS OF THE TESTS

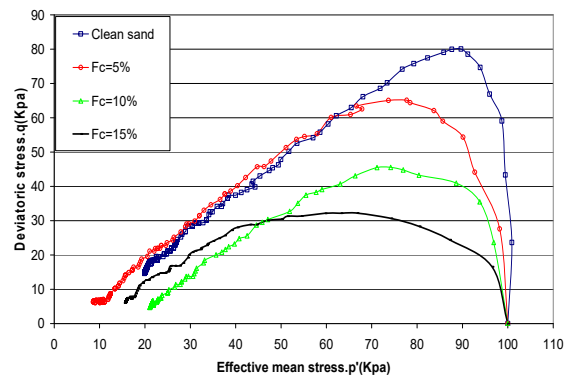
The results of tests are presented in Fig. 2 for clean sand, and its combination with 5, 10, and finally 15 percent of added clay respectively ( $\gamma_d = 1.45 \frac{gr}{cm^3}$ ). As it is apparent, by adding some clay to sand, the behavior of the sand changes significantly. Based on Figs. 2 (a) and (b), strain softening behavior is apparent for clean sand, yet by adding 5% percentages of clay materials, the value of steady state strength falls about 60% in comparison to clean sand, nevertheless no significant change happens for peak strength (only 18 percent). By further values of added clay (10% and 15%) a substantial decrease occurs for peak strength values (45%-60% decrease). Note, in spite of 5%-15% change in the quantity of clay materials, no significant loss takes place in values of steady-state strengths. Furthermore, by taking a look at paths of stress (Fig. 2 (b)), it can be easily understood that adding 5% of clayey materials does not change path greatly. However, the addition of 10% does. The changes in pore water pressure (Fig. 2 (c)) shows a trend which declares an approximate relationship between clay amount and pore water pressure increase. Influence of fines content on the response of sand-clay mixtures in ( $\gamma_d = 1.5 \frac{gr}{cm^3}$ ) is shown in Fig. 3.

As it's apparent, same trends followed here again. In stress-strain graph (Fig. 3 (a)), the behavior which corresponds to clean sand is somehow strain-softening after peak point, but after a temporary steady state (quasi-steady state), strain-hardening appears as a result of dilation in sand, thus strength increases. By adding 5% of clay materials, in contrast to previous looser specimens, the behavior significantly change. Under these new conditions, the strengths corresponding to steady and semi-steady states fall about 80% and 65%, respectively. As a result, after the peak value, the semi-steady state behavior alters to strain-softening behavior.

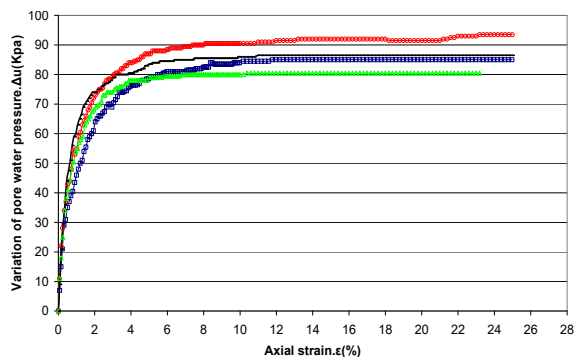
When values of added clay reach to 10% and 15%, the same trends appear here, as they appeared for ( $\gamma_d = 1.45 \frac{gr}{cm^3}$ ). It means the peak strength value drops about 70% in comparison to clean sand. Here again, in spite of the significant loss of peak values of strength, steady state bearing capacity for 10% and 15% of added clay specimens do not change significantly.



(a) Deviatoric stress against axial strain



(b) Plot of stress paths

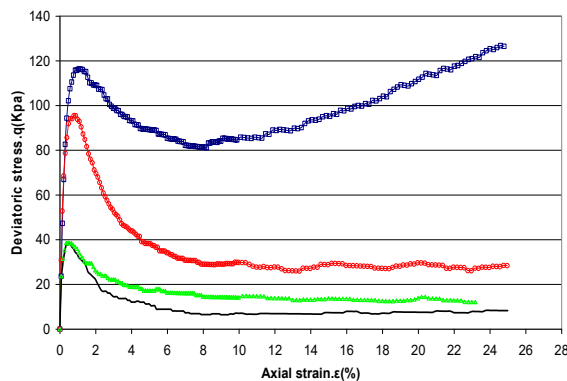


(c) Excess pore water against axial strain

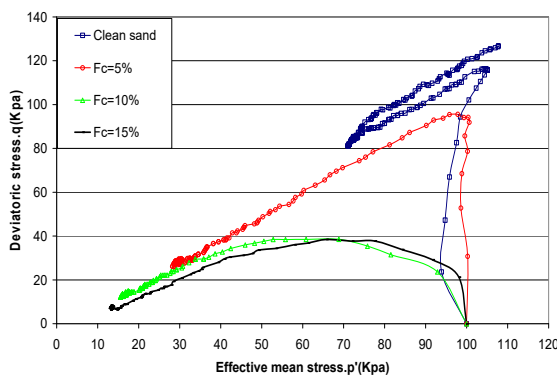
Fig. 2 Influence of fines content on the response of sand-clay mixtures ( $\gamma_d = 1.45 \frac{gr}{cm^3}$ )

In the graphs of path stress (Fig. 3 (b)) and pore water pressure changes (Fig. 3 (c)), one can obviously see the great

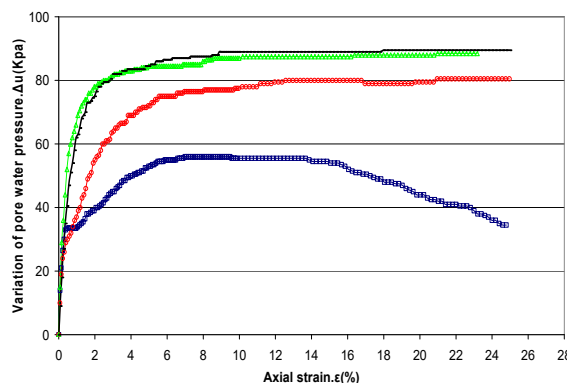
increase in amount of pore water pressures as a result of 5% of added clayey materials, alters the stress path substantially and strain-softening behavior comes into play.



(a) Deviatoric stress against axial strain



(b) Plot of stress paths



(c) Excess pore water against axial strain

Fig. 3 Influence of fines content on the response of sand –clay mixtures ( $\gamma_d = 1.5 \frac{gr}{cm^3}$ )

#### IV. RESULTS' ANALYSIS

##### A. Peak Strength Value Variations

As it is clearly shown in Figs. 2 and 3, when 5% of clayey materials were added to specimens, the peak value of stress-

strain graph does not change significantly (rather than 10% and 15% of added clay materials). It seems that when the quantity of clay materials increases from 0% to 5%, no great change occurs in surface contacts of sandy particles. This indicates that such quantities of clay particles are swallowed up between sandy particles, and therefore does not affect surface contacts of them.

As the peak value of strength takes place at low strains, in which the structure of specimens has not been affected seriously, it changes slightly. with a comparison in Fig. 2 (c) and 3 (c), it's obvious that the generated pore pressures, both in clean sand and clean sand plus 5% of clayey materials, are approximately same as each other (for low strains of peak values). After the clayey material contents rise to 10% and 15%, they occupy some rooms among the sandy particles, in addition to hollow spaces between them. This leads to a looser structure which in return excesses pore pressure and eventually decreases effective stress. So, stress values and surface frictions between particles become low, and so the peak strength values are low, too. This is the reason that for 10% and 15% of clay added specimens drop is more significant rather than 5% added clay specimens.

For different density values, peak values of strengths corresponding to 10% and 15% of clay added specimens are almost as equal (Figs. 2 (a) and 3 (a)). These results are in contrary to the results for clean, and 5% added clay specimens, in which greater density means greater peak value of strength. It may be concluded that when clay contents rise, density plays a less important role. Note that in both density values when clay contents are equal to 5%, all the clay particles are placed in the hollow spaces among sandy particles. So, the total behavior is mainly controlled by properties of sandy particles contacts. When density raises, decrease the hollow spaces between sand particles. in this condition, for more contents of clay, in contrast to looser densities, fewer clay particles are needed to occupy empty spaces between the sandy particles and so more particles are placed between sand particles. This leads to a more decrease of peak strength value.

##### B. Value of Steady State Strength Variations

In contrast to a peak value, adding more clay for about 5% affects steady state values considerably. As it was said earlier, it is obvious in Figs. 2 (c) and 3 (c) (changes in pore water pressures) that the variations of excess pore water pressure in strains less than 1%, for clean sand and clean sand plus 5% added clay is about the same. But when strains exceed 1%, the values disperse considerably. This excess of pore water pressure is due to the increase in clay contents and their adhesive property, which finally leads to decrease in effective stress values beyond strains corresponding to the peak value. Furthermore, when clay particles occupy rooms between sandy particles the friction between sandy particles reduces, so their slippage on each other increases. All of these lead to significant decrease in steady state strength by addition of 5% clayey materials.

By a comparison between Figs. 2 and 3, one can clearly understand that for more dense specimens ( $\gamma_d = 1.5 \frac{gr}{cm^3}$ ) rather than looser ones, the effect of 5% added clayey materials is more significant. It seems that for looser specimens (Fig. 2) because of looser interlocking between sandy particles, the behavior of steady state is independent of dilation in sand or breaking of these locking. So, by the addition of 5% clayey materials, the kind of behavior doesn't change. But in more dense specimens (Fig. 3) by the addition of 5% clayey materials, after the structure collapses and strains develop, clayey particles occupy spaces between sandy particles. Thus, the friction and locking between sandy particles decrease dramatically and the energy to beat these resisting forces decrease, too. So, when the strains reach those corresponding to the semi-steady state, the sand containing 5% clayey materials does not dilate in contrary to clean sand, and its degradation of strength continues till the steady state. It can be concluded from all above that more dense specimens are more sensible to clay content. These changes are apparent in other graphs corresponding to these two density values. For example, in Fig. 3 (c), for clean sand, the excess pore water pressure decreases after the semi-steady state because of dilation. But when 5% of clayey materials is added, the structure tends to be more compressive and so when the strains develop, excess pore water pressure increases until it reaches the steady state, thus becomes stable. This changes semi-steady state behavior into strain-softening behavior.

The surprising is laid within Figs. 2 (a) and 3 (a) when 5% and 10% of clay is added, the strength of steady state drops significantly, but for 10% and 15% of added clay, these values are about the same. It may be due to exceed a specific threshold value, in which the sandy structure tends to become a clayey one. So, the strengths rise again. Also, clay content increasing results in more and larger clogs being made (which are greater than clayey and sandy particles) through the structure of specimens, which are the other factors preventing loss of strength by the friction.

#### V. CONCLUDING REMARKS

Based on Figs. 2 and 3, it's clear that by adding clayey materials up to 15% to specimens, specimens expose the tendency to behave in a strain-softening manner.

Different clay added percentages result differently. 5% of added clay leads to significant loss in values of steady-state strength, vice versa the peak value. By this amount reaches to 10% the strengths of steady state do not change considerably, vice versa the peak value. 15% of added clayey materials mean slight changes both in values of steady-state and peak value. The structure of specimens and their density affect the effect of clay contents. It seems as density or specific dry unit weight rises; clay content affects the behavior and strengths values more significantly.

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