# A Study of Effective Factors on the Behavioural Characteristics of Clayey Sands

Omid Naeemifar
*Tarbiat Modares University, Iran*

S. Shahaboddin Yasrobi
*Tarbiat Modares University, Iran*

Fifth International Conference on
Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics
*and Symposium in Honor of Professor I.M. Idriss*
May 24-29, 2010 • San Diego, California

# A STUDY OF EFFECTIVE FACTORS ON THE BEHAVIOURAL CHARACTERISTICS OF CLAYEY SANDS

**Omid Naeemifar**
PHD student of geotechnical engineering
Tarbiat Modares University, Tehran, Iran

**S.Shahaboddin Yasrobi**
Associate Professor, Tarbiat Modares University
Jalal-ale-Ahmad Ave., Tehran, Iran

## ABSTRACT

As in recent years liquefaction phenomena have occurred in sandy soils containing different amounts of clay contents, it was concluded that in addition to silty sands, clayey sands are also vulnerable to liquefaction phenomenon. So, the urge for comprehensive study aroused to cover the issue.

In this paper, the effect of clay content and its plasticity properties on behavioural characteristics of clayey sands under various density and confining pressure values have been investigated. To achieve the goal, about a hundred monotonic triaxial tests were performed on remoulded specimens of sandy soils containing different clay contents with different plasticity values. Based on the results, the latter factors affect peak strength, steady state strength, undrain brittleness and residual shear strength, considerably. Furthermore, great results obtained on the issue of whether clay content or plasticity properties variations is much effective.

## INTRODUCTION

Many studies have been focused on soil-related problems so far. These may include consolidation, soil settlement, or swelling for clayey soils. However, before some incidents like liquefaction phenomena had been recognized, sands were not defined as a sort of problematic soil. After some liquefaction and flow failure took place during Nigatta and Alaska earthquakes in 1964, comprehensive studies were carried out to explain sands behaviour under various situations.

Three general trends were observed for sands during undrained loading (situations such as earthquake or rapid static loading) based on various density and confining pressure values including hardening, softening, and limited strain softening [1, 7, 15, 17, 27, and 36]. In strain softening behaviour of sand, there is a significant strength loss after peak value and it continues to decrease until it reaches to a steady state. In this case, depending on topographical conditions and the induced residual shear strength, large deformations may occur, leading to landslides and slope failures afterwards. In limited strain softening, after an initial drop in strength, because of dilation and the following increase in soil volume (decrease in pore pressure), the strength rises again representing a temporarily steady state thus. Although deformations are more limited in respect to the previous case, extensive significant failures may happen. Hence, Kramer and Seed (1988) proposed this case to be considered as a sort of liquefaction phenomena.

Based on other studies, it was revealed that in addition to density and depth, other parameters are pivotal. They may include layer orders [2and 18], specimen preparation method [10, 20, and 22], fines content [3, 19, 24, 26, 29, 33 and 34], fines type [8, 11, 16, 28 and 35], and stress path [12]. They affect stress-strain behaviour of sands and the procedure of generation of excessive pore pressure.

As it was said previously, one of the most crucial factors that can affect soil behaviour is fines content and their types. Many investigations have been conducted on behavioural characteristics of clean and silty sands since liquefaction first observed in these kinds of soils. Most of studies suggest that sand liquefaction potential boosts with an increase in silt content until a threshold value and after that it starts to decline as silt content increases [16, 21, 24, 29, 30, and 33].
Unlike non-plastic fines, effects of plastic ones have been investigated rarely. It seems it was the outcome of this delusion that clay cohesion prevents the occurrence of liquefaction. Despite this idea, research following the Northridge (1994), Kokaeli (1999), and Chi-Chi (1999) earthquakes has identified a significant number of cases where

ground failure in silty and clayey soils containing more than 15% clay size particles caused considerable damage to buildings[5][9]. Moreover, as research continued it was showed that in addition to clay content, its plasticity [6][4][14], over-consolidation ratio [25] and pore pressure properties [13][31][32] are of the main concerns and can affect clayey sand behaviour substantially.

In any case, it seems that providing a fully proper judgment about the effect of clay content and its plasticity is not available, since most of recent studies have been carried out under different situations and applying a unique kind of clay. In the current paper, in order to satisfy appropriate conditions, similar conditions are defined for all the tests and then the effect of clay content's increase with various plasticity values has been investigated.

# EXPERIMENTAL PROCEDURE

## Test Materials

All basic geotechnical tests were performed in accordance with American Standard Test Method (ASTM). In this study, Firooz-kooh crashed silica sand (sand 161) was used since it demonstrates desirable properties (Table 1).

Clayey material properties (passed by #200 sieve) are demonstrated in Table 2. These natural clays selected in such a way that one possesses high and the other possesses low plastic properties. High plastic clay is obtained from a site near Gazvin city (latitude 35°46´19´´, longitude 50°3´46´´) and low plastic clay is obtained from a site near Mashhad city (latitude 37°22´24´´, longitude 58°45´40´´). By mixing these two different clayey materials with sand 161, the feasibility of a proper investigation on the effects of plasticity on specimens' behaviors was provided. The grain size distribution curves for snad161 and clays are presented in figure 1.

Table 1. Firooz-Kooh sand (sand 161) properties

| Sand 161 | Properties |
|---|---|
| 2.66 | Specific gravity (Gs) |
| 0.928 | Maximum void ratio $(e_{max})$ |
| 0.583 | Minimum void ratio $(e_{min})$ |
| 0.26 | D50 (mm) |
| 0.15 | D10 (mm) |
| 1.80 | Uniformity coefficient $(C_U)$ |
| 1.14 | Curvature coefficient $(C_C)$ |

Table 2. Low (L) and high (H) plastic clay material properties (passed by #200 sieve)

| Gs | Plastic Index (PI%) | Plastic Limit (PL%) | Liquid Limit (LL%) | Material |
|---|---|---|---|---|
| 2.64 | 11 | 17 | 28 | Mashhad Clay (Low plastic) |
| 2.64 | 30 | 25 | 55 | Qazvin Clay (High plastic) |

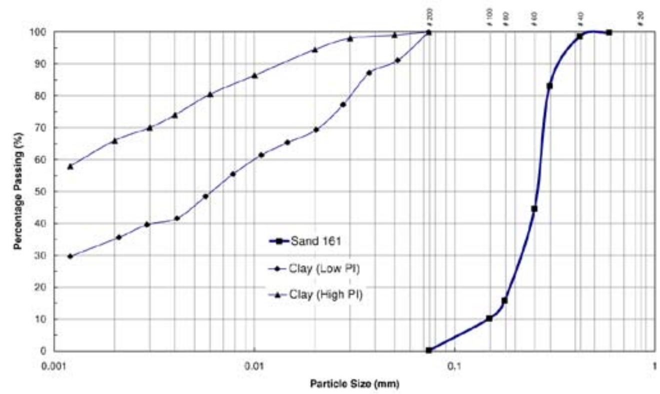



*Figure 1. Grain size analysis (sand 161, Mashhad clay (Low PI), Gazvin clay (High PI))*

## Apparatus and Methodology

The device used for conducting tests was a Japanese triaxial static apparatus. The device features high sensitive sensors, thus providing computer data logging. To conduct tests, strain controlled loading approach was applied by a $0.5mm/\min$ loading rate. Specimens were prepared using wet tamping method in which first dried clayey material passed by sieve #200 were mixed by sand to obtain a homogeneous mixture. After that, water was added to the mixture to provide 5 percent of humidity. Having obtained the appropriate blend, it was poured into a special mold and compacted in 6 layers. Prepared specimens were 50 mm and 100 mm in diameter and height, respectively. Although this approach might not present the field characteristics of the soil, Ishihara (1993) and Yasrobi (1997) showed that specimen preparation by this approach is beneficial. All tests were conducted under consolidated undrained conditions (CU).

In all tests a "B" value greater or equal to 0.97 was considered to represent fully saturated conditions. After reaching to a fully saturated condition, specimens were consolidated to desirable consolidation pressure and then were subjected to shear.

## Tests Program

In this study, in order to investigate fines content, plasticity, density, and confining pressure effects, initial tests conditions were adjusted in special manner, so it would be possible to investigate any factor influence while other desirable factors are held constant during the tests.

Two different density values used: a)$\gamma_d$=1.45gr/cm$^3$(Dr=27%) for loose state and b) $\gamma_d$=1.5gr/cm$^3$(Dr=45%) representing medium dense specimens. During this study, these densities represented two different liquefaction associated behaviors in clean sand specimens: complete strain softening leading to steady state and limited strain softening leading to a temporarily steady state (quasi-steady state).

For both density values, tests were conducted on specimens made of clean sand and its mixtures with 5, 10, and 15 percent of clay content for high and low plastic clays. Also in order to investigate the influence of confining pressure on tests results, all tests were conducted under two different confining pressures (100 and 400 Kpa).

Another important factor considered in specimens preparation was to use materials which had virtually the same specific gravity ($G_s$) values. Hence, not only they were prepared in constant dry unit weights ($\gamma_d$) but also they had constant void ratios. This would be very useful in comparing results. Void ratio values for $\gamma_d$=1.45gr/cm$^3$ and $\gamma_d$=1.5gr/cm$^3$ are 0.828 and 0.767, respectively.

In this paper every group of specimens has been named in a sequence of A-B-C letters, where "A" represents for specimen density, "B" for effective confining pressure applied in test, and "C" for clay type. For a high plastic clay (PI=30%), "H" and for a low plastic clay (PI=11%) "L", were used to be abbreviations. About clay content of specimens, wherever it was necessary, it was directly mentioned (For example, 1.45-400-H represents specimens which are made by mixing and compacting sand with desirable percent of high plastic clay in density equall to 1.45 gr/cm3. Its obvious that consolidation pressure of test is 400 Kpa).

Tables 3 and 4 demonstrate an overview of tests classifications for combinations of sand with low and high plastic clays. As it is obvious, for 8 different groups of density, confining pressure and clay type, tests were conducted on specimens made of clean sand and its mixtures with 5, 10 and 15 percent of clay content. Such a classification of parameters provides an appropriate and independent evaluation of each parameter's effect.

Table 3: General classification of tests for combinations of sand with low plastic clay

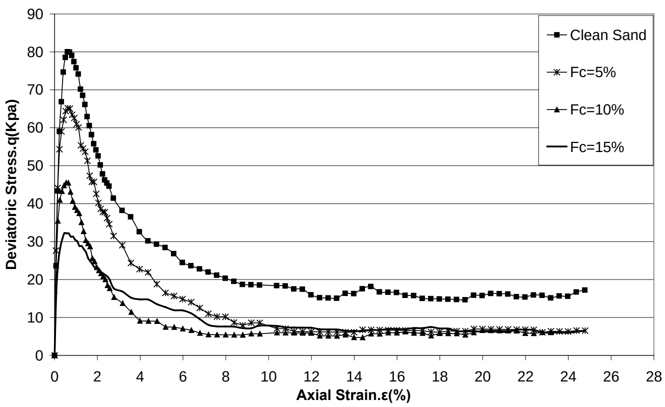
| Group | Test No. | Combinations | | Group | Test No. | Combinations |
|---|---|---|---|---|---|---|
| Group 1: 1.45-100-L | 1 | Clean sand | | Group 3: 1.45-400-L | 9 | Clean sand |
| | 2 | Sand+5%clay | | | 10 | Sand+5%clay |
| | 3 | Sand+10%clay | | | 11 | Sand+10%clay |
| | 4 | Sand+15%clay | | | 12 | Sand+15%clay |
| Group 2: 1.5-100-L | 5 | Clean sand | | Group 4: 1.5-400-L | 13 | Clean sand |
| | 6 | Sand+5%clay | | | 14 | Sand+5%clay |
| | 7 | Sand+10%clay | | | 15 | Sand+10%clay |
| | 8 | Sand+15%clay | | | 16 | Sand+15%clay |

Table 4: General classification of tests for combinations of sand with high plastic clay

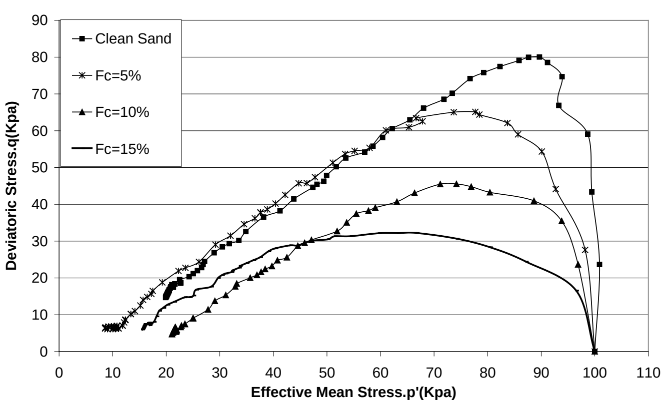
| Group | Test No. | Combinations | | Group | Test No. | Combinations |
|---|---|---|---|---|---|---|
| Group 5: 1.45-100-H | 17 | Clean sand | | Group 7: 1.45-400-H | 25 | Clean sand |
| | 18 | Sand+5%clay | | | 26 | Sand+5%clay |
| | 19 | Sand+10%clay | | | 27 | Sand+10%clay |
| | 20 | Sand+15%clay | | | 28 | Sand+15%clay |
| Group 6: 1.5-100-H | 21 | Clean sand | | Group 8: 1.5-400-H | 29 | Clean sand |
| | 22 | Sand+5%clay | | | 30 | Sand+5%clay |
| | 23 | Sand+10%clay | | | 31 | Sand+10%clay |
| | 24 | Sand+15%clay | | | 32 | Sand+15%clay |

## RESULTS

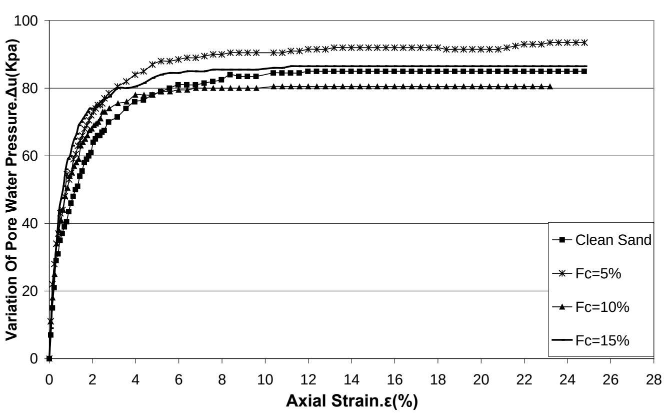
In figures 2a to 2c, results for different combinations of group 1.45-100-L (containing different clay contents) are presented. Obviously these results include stress paths and variations of deviatoric stress and pore pressure versus axial strain. Also, in Figures 3a to 3c results for different combinations of group 1.5-100-L are presented.




*(a).Deviatoric stress against axial strain*

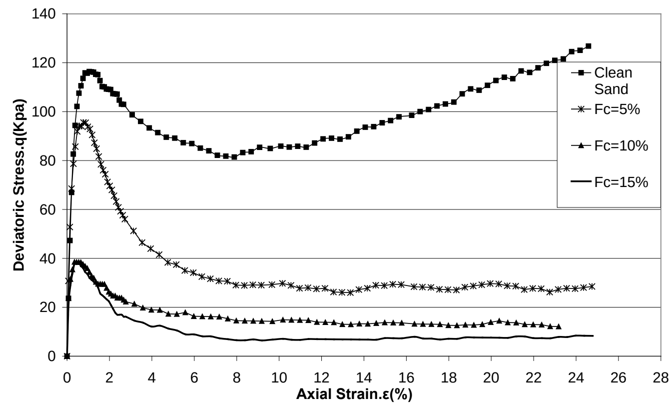



*(b).Plot of stress paths*

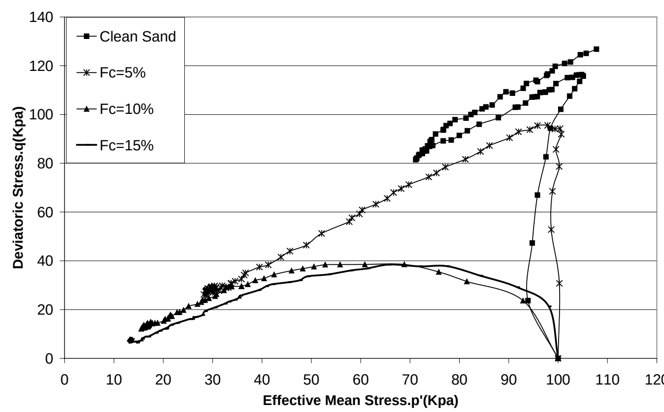



*(c).Excess pore water against axial strain*

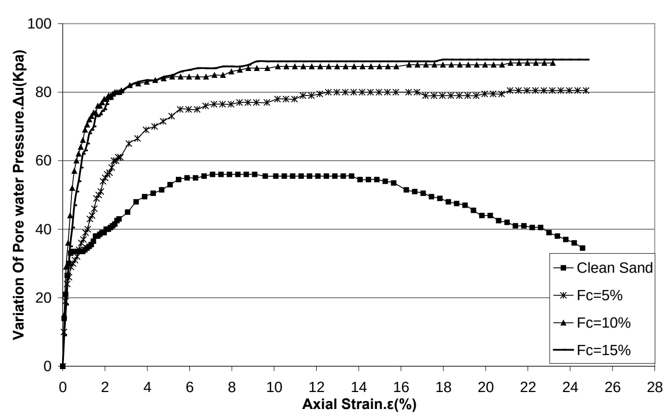
*Figure 2: Results for different combinations of group 1.45-100-L containing various clay contents*




*a).Deviatoric stress against axial strain*




*(b).Plot of stress path*




*(c).Excess pore water against axial strain*

*Figure 3: Results for different combinations of group 1.5-100-L containing various clay contents*

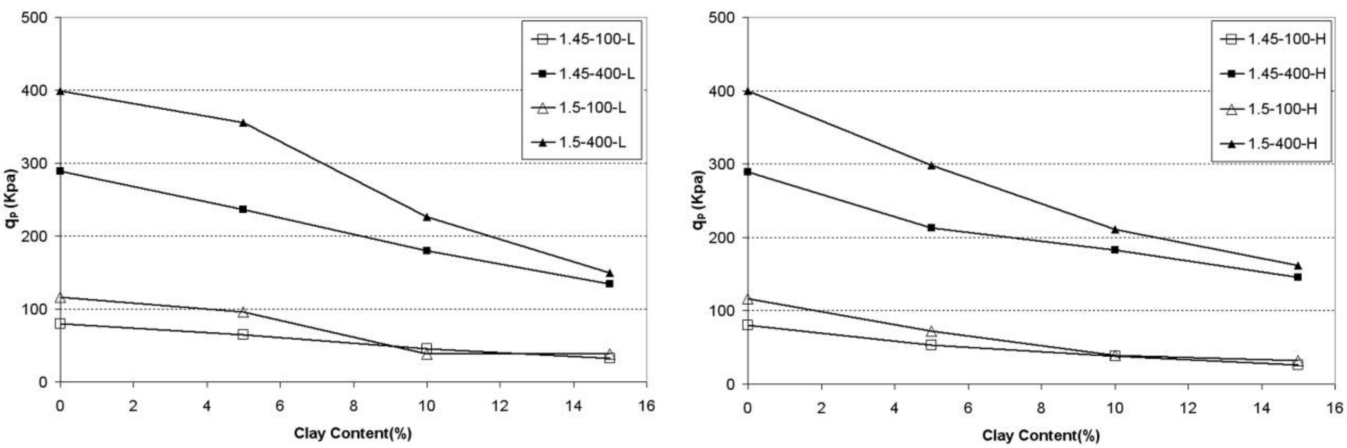
Then instead of a direct representation of stress-strain curves, stress paths, and pore pressure-strain graphs, values of peak and steady state strength or other pertinent values were extracted (from graphs mentioned above) and revealed in the form of various desirable graphs. Thus, there would be better conditions to compare their variations more accurately and properly. Full results and detailed information are presented in the thesis (Naeemifar 2007), submitted for the degree of master of science at Tarbiat Modares university.

## VARIATIONS AND DISCUSSION

### Peak Strength Value

### Clay content, density, and confining pressure influence

Figure 4 shows the peak value variations versus clay content for different mixtures of sand and clay, both for high plastic and low plastic clays. Apparently in all the graphs as clay content rises up, peak values drop. Taken microscopic photos (image1) reveal that as clay content enhances, specifically after about 5 percent admixture content, chain-like structures are brought about within its texture while clay particles represent unstable bridges between sand grains. Such kind of structures are not stable, since clay content is not as high as enough and as the strength touches its peak value, these structures collapse and fall between the available hollow spaces within themselves. Hence, a considerable decrease in peak value happens.

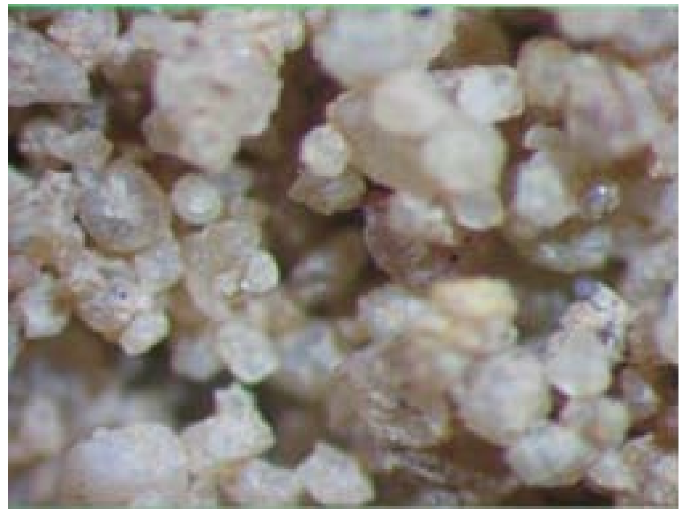



*a) Low plastic clay* *b) High plastic clay*

*Figure 4- variations of peak shear strength versus clay content increase under different condition*

In figures 4a (4b), by comparing results of 1.45-100-L(H) with 1.45-400-L(H), or 1.5-100-L(H) with 1.5-400-L(H), it is found that for a same density an increase in confining pressure raises peak value for clean sand as well as for its mixtures with clay. This happens when grains and particles subside through the structure and become more involved, escalating grains surficial forces thus.

Also considering 1.45-100-L(H) against 1.5-100-L(H), or 1.45-400-L(H) versus 1.5-400-L(H), one reaches to these conclusions: first, in a same confining pressure as density rises up, peak value does the same. Second, the more clay contents the more coherence in graphs happens. The latter means as clay content escalates, density's influence on peak value declines.

*a) clean sand (MF:40X-6X,1.45)* *b)sand+15 %high PI clay (MF:40X-6X,1.45)*

*Image 1-Microscopic texture comparison between clean sand and clayey sand*

It should be noticed that as density increases, peak value is expected to increase, too. Nevertheless, it causes empty spaces among soil particles to decrease. This eventually will lead to more contact between clay and sand particles and probably more decrease in their inter-particle friction, reducing strength finally. In other words, increase in density is caught up to some extent and the effect of density becomes pale in high clay contents.

Plasticity effects

In figures 4a and 4b, comparing strengths for two different clay types with different plasticity properties yet same clay content, same density, and same confining pressure, lead us to find that peak strengths for various levels of clay admixtures are higher for lower plasticity. Regarding to microscopic images (image1), it can be concluded that it is because of an increase in unstable structures in high plastic clays.

Steady State's Strength Value

In strain softening and limited strain softening behaviors which usually happen in loose and medium dense deposits of sands, specimen's strength drops after a peak value and it continues to decrease till a steady state or temporary steady state. Fundamentally, steady state of a soil mass represents a situation of constant volume, constant normal stress, constant shear stress, and constant deformation velocity in which soil deforms permanently and continuously [27]. In this section effects of different parameters on strength value of steady state have been investigated.

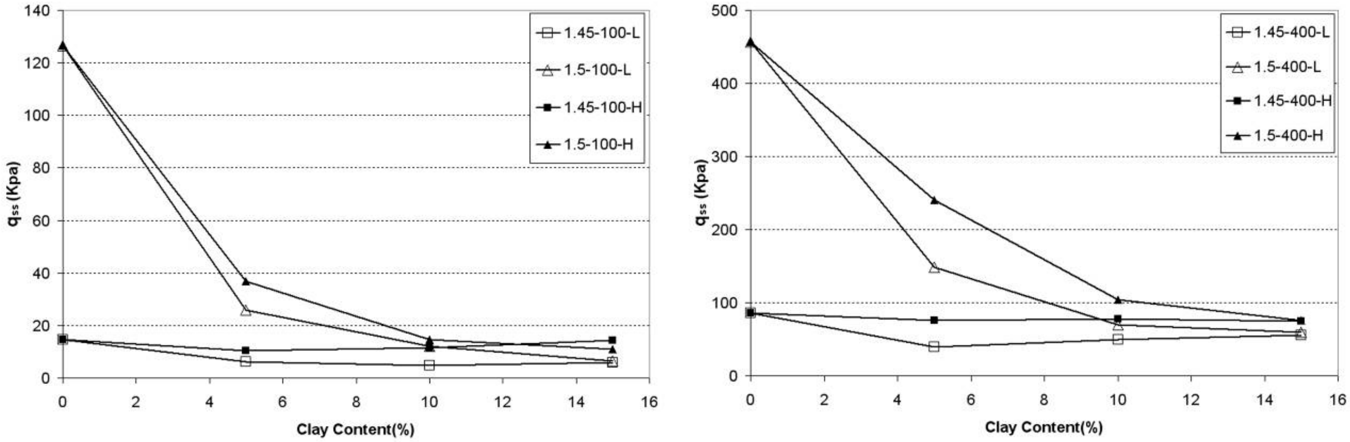
Clay content, confining pressure, and density effects

In figure 5, strength variations of steady sate versus clay content for sand mixtures with low and high plastic clay contents have been demonstrated (both for 100 and 400 KPa confining pressures).

In figures 5, comparison between 1.45-100(400)-L with 1.5-100(400)-L, or 1.45-100(400)-H with 1.5-100(400)-H mixtures gives us the following conclusions: first, for $\gamma_d = 1.5\, gr/cm^3$ strength is higher and as clay content increases up to about 5 percent, the strength drops substantially and it remains constant after 10 percent. The considerable loss up to about 5 percent clay admixture is due to clay particle invading spaces among sand particles thus making a significant decrease in interlocking forces. In this way, much less energy will be used to relieve this interlocking.

Since interlocking forces are higher in more dense specimens, generally the effect of clay content increase in strength loss is much evident for denser specimens.

However after 5 percent clay content, there will be little strength loss since interlocking forces for dense specimens have decreased and the lines representing different density values reach a same trend. Also while comparing values of figures 5a and 5b together under same conditions, it is crystal clear that a rise in confining pressure leads to a rise in steady state strength.




*a) 100 KPa confining pressure* *b) 400 KPa confining pressure*

*Figure 5- variations of steady state strength versus clay content increase under different conditions*

<u>Plasticity effects</u>

The analogous fact which is apparent in both figures above is that as clay plasticity builds up, the respecting lines move upward (e.g. consider 1.45-100-L and 1.45-100-H, or 1.45-400-L and 1.45-400-H). This means that assuming other parameters to be constant (density and effective confining pressure), for a same clay content, the more clay plasticity the more strength specimens gain. It seems that high PI clay brings about much more difficulty for sand particles to slide on each other in large deformations. Furthermore, the clogs made of sand and high PI clay particles are bigger and stronger, thus giving more friction and strength during sliding (with respect to low plastic clay).

<u>The effects of confining pressure and density on steady state strength variations of a sand deposit</u>

In this section, we will discuss about different parameters roles on steady state strength loss in respect to clean sand strength. In figure6, the vertical axis represents steady state strength loss in respect to clean sand strength under same conditions using the following equation:

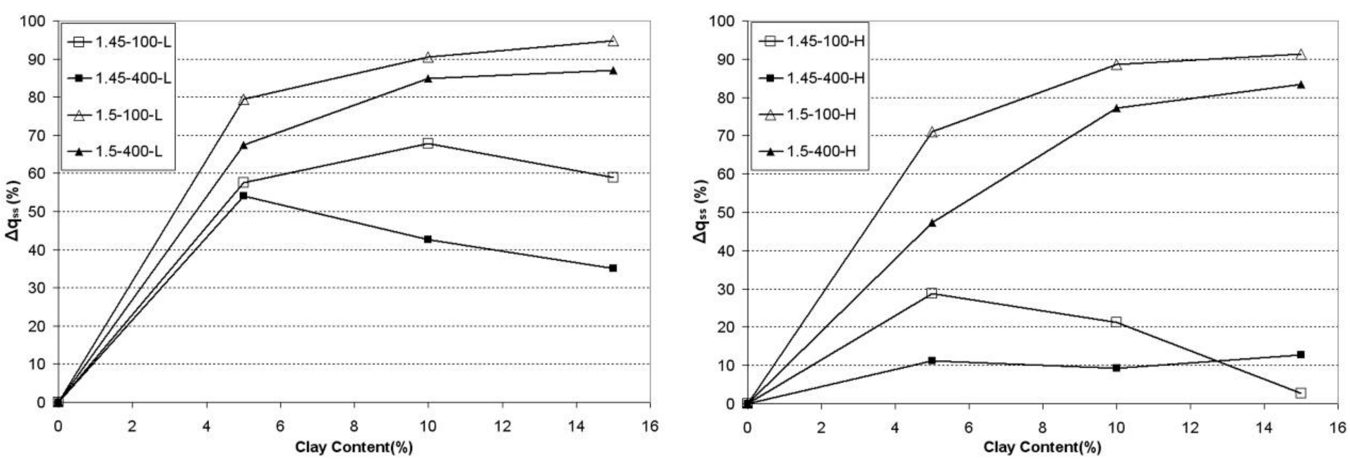
$$\Delta q_{ss}(\%) = -\left(\frac{q_{ss} - q_{ss_{cs}}}{q_{ss_{cs}}}\right) \times 100 \qquad (1)$$

In equation 1:

$q_{ss}$ is steady state strength for any optional mixture

$q_{ss_{cs}}$ is steady state strength for the clean sand of that optional mixture

In figure 6, the graphs of steady state strength losses versus clay contents have been demonstrated for high and low plastic clays. In figure 6a (6b), comparing 1.45-100-L(H) with 1.45-400-L(H), or 1.5-100-L(H) with 1.5-400-L(H), it is revealed that the lines of higher confining pressures lay beneath the others. This means that for a same increase in clay content the more confining pressure, the less loss in steady state strength happens. In other words, the steady state strength of deeper deposits is less sensitive to clay content increase.




*a) Low plastic clay* *b) High plastic clay*

*Figure 6-Steady state strength loss (in percentage) versus clay contents increase under different conditions*

Now, if we consider 1.45-100-L(H) and 1.5-100-L(H), or 1.45-400-L(H) and 1.5-400-L(H) mixtures' trends in figure 6a(6b) we may see that those lines representing higher densities lay above the others, which means steady state strengths of denser sands are more sensitive to clay content increase.

A general study of figures 6a and 6b reveals that most of changes in steady state strength is up to about 5 per cent clay content, thereupon its gradient lessens and in some cases becomes negative.

This points to less strength loss as clay content increases. Hence it seems that in low clay contents, clay has the crucial role and the occupation of rooms between sand grains by clay particles leads to significant decrease in inter-particle friction and effects so great drop in strength. On the other hand by clay content increase after about 5 percent, the mixture's plasticity boosts and plays much crucial role rather than the clay particles themselves. It means that in high clay contents, the rise in mixture plasticity prevents the significant loss in strength and even in some cases it leads to regaining strength.

Variations Of Undrain Brittleness

In this section, the variations of undrain brittleness versus clay content increase has been investigated. Undrain brittleness is defined as the slope of stress- strain graph after peak point until reaching steady state (fig 7).

The post peak behavior characteristics can be investigated properly using this parameter.

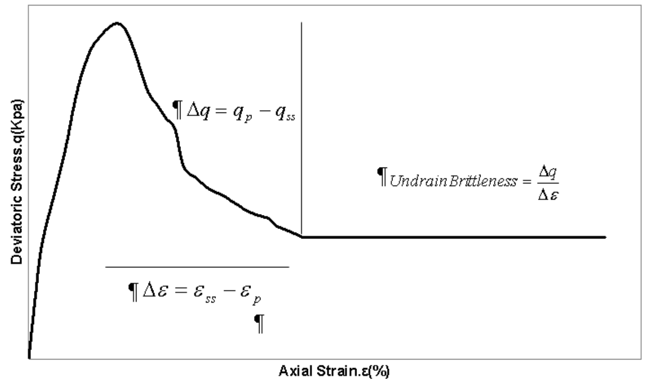



*figure 7:The definition of undrain brittleness*

The effect of clay content, density and confining pressure on the undrain brittleness variations

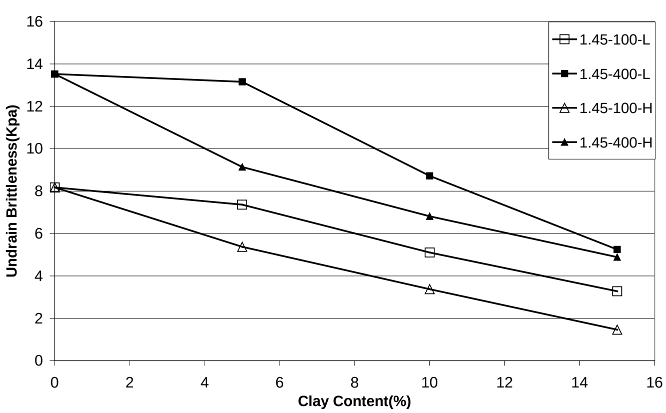
In fig 8 (a & b), the variations of undrain brittleness versus clay content increase has been demonstrated both for low and high plasticity clays. Apparently, it can be seen that as the clay content increases, the undrain brittleness drops significantly. It means that any increase in clay content leads to increase in ductility of the mixture.

Also by comparing the results of 1.45-100-L(H) with 1.45-400-L(H) in figure 8a or 1.5-100-L(H) with 1.5-400-L(H) in figure 8b, it can be seen that increasing the confining pressure will increase the brittleness of the mixtures.

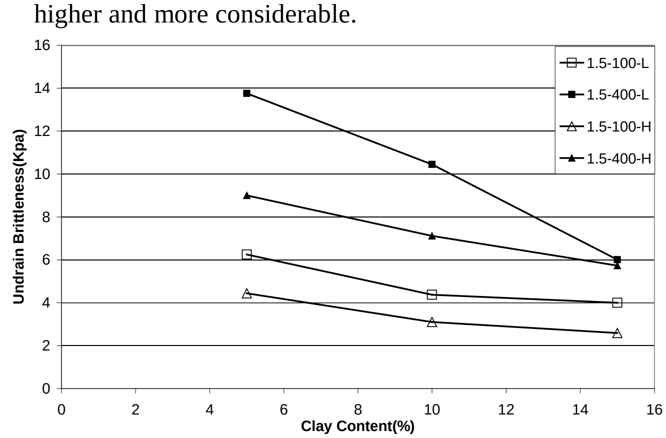
Investigating about density effects shows that density hasn't any significant effect on the undrain brittleness.

The effect of plasticity on the undrain brittleness variations

In fig 8, by comparing the results of 1.45(1.5)-100-L with 1.45(1.5)-100-H or the 1.45(1.5)-400-L with 1.45(1.5)-400-H, it can be concluded that the undrain brittleness decrease when the plasticity increases. It means that for the same clay content, the ductility of mixtures with higher plasticity clays is higher and more considerable.




*a)Dry unit weight = 1.45 gr/cm$^3$*




*b)Dry unit weight = 1.5 gr/cm$^3$*

*Figure 8:Variations of undrain brittleness versus clay content increase under different conditions*

Residual Strength Study

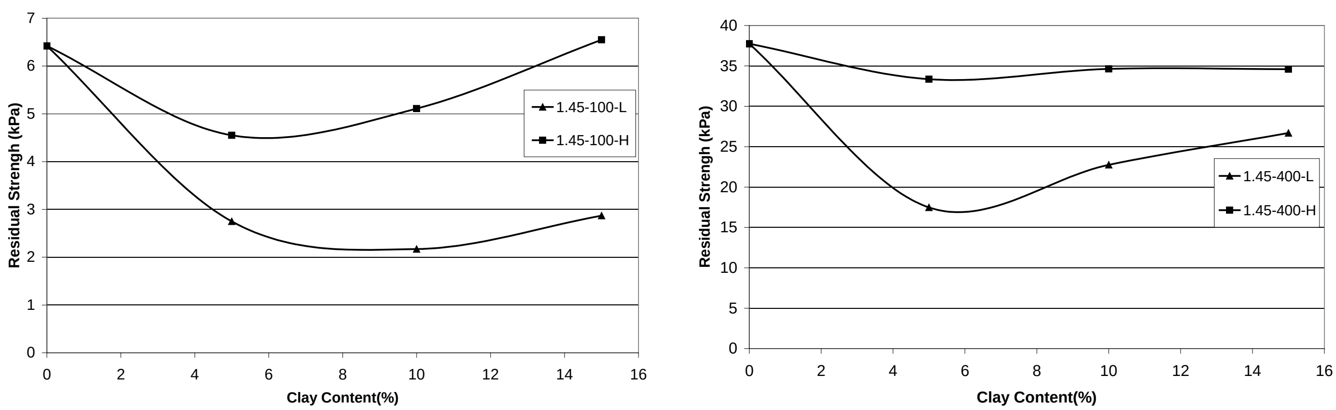
Generally when the soil behaviour is perfect strain softening, after the strength reaches a climax, it drops significantly until it levels out in large strains (steady state).
The shear strength of the soil under this condition is called residual strength and it is important in stability analysis and other relevant problems. This parameter is a function of angle of internal friction and it is calculated on a plane of Mohr's circle which has $(45+\frac{\varphi}{2})$ degrees angle with horizon. It can be calculated using equation 2:

$$S_U = \frac{COS\varphi}{2} q \qquad (2)$$

The $S_U$ value for any case is calculated by substituting appropriate values of $\varphi$ and q. In the following section a graph for residual strength variations against clay content increase will be presented.

Clay content and confining pressure effects on residual strength

In figure 9, residual strength variations for clay content increase have been demonstrated based on different mixtures. If we accept the shape of lines in graphs as a general trend, it is obvious that for both graphs as clay content rises up to 6 or 8 percent, the residual strength decreases. Yet, it begins to increase after about 8 percent clay content.
By a comparison between 1.45-100-L and 1.45-400-L, or 1.45-100-H and 1.45-400-H in figures 11a and 11b, it might be seen that as confining pressure increases the residual strength does so.




*a) Confining pressure of 100 KPa* *b) Confining pressure of 400 KPa*

*Figure 9: variations of residual strength versus clay content increase under different conditions*

The effect of plasticity on residual strength variations

Considering curves of 1.45-100-L and 1.45-100-H, or 1.45-400-L and 1.45-400-H, it is clear that for lower PI admixtures, not only the residual strength is lower, but also its variations are more significant. Furthermore, as strength values start to boost again, the mixtures containing high PI clays gain values near to clean sand ones, however this is not true for low PI clays.
So it seems that by increasing plasticity, soil's strength develops against flow failures.

CONCLUSIONS

In this study in order to investigate effects of fines content and their plasticity on behavioral characteristics of sands, about a hundred consolidated undrained triaxial tests were performed. Tests were conducted in a special manner to study other parameters such as density and confining pressure in addition to fines content and plasticity.

To achieve these goals, in addition to using appropriate graphs representing tests' results, some images taken by electronic microscope were provided in the text in order to better understanding of explanations. The most important achievements are as follow (these results are valid by increasing clay up to 15 %):

- ❖ As clay content increases (for constant void ratio or dry density), peak strength and steady state strength in stress-strain curves drop. However, as plasticity increases for same level of clay content, peak strength decreases slightly, while steady state strength rises.
- ❖ As confining pressure and density increase, peak and steady state strength values do the same. Despite this fact, as clay content increases, effect of density

tends to pale. Thus in high clay contents strength values for two different density values are almost the same.

- ❖ It seems that steady state strength decrease for shallow sand specimens is more sensitive to clay content increase. Also it was concluded that denser specimens are more sensitive to any increase in clay content and their behavior changes much significantly.
- ❖ As the clay content increases, the undrain brittleness drops significantly while the ductility of mixtures with higher plasticity clays is higher and more considerable
- ❖ The residual strength value decreases as clay content increases up to about 6 to 8 percent, yet it increases after that value as clay content does the so. For mixtures containing high PI clays, the residual strength is higher while its variation is less significant.
- ❖ Based on the results, it seems that for lower clay contents, fines content governs behaviors. However as clay content increases, gradually the role of plasticity becomes more pivotal

REFERENCES


Alarcon- Guzman,A.,Lwonards,G.,Chameau,J.I.(1988) "Undrain monotonic and cyclic strength of sands"Journal Of Geotechnical Eng .ASCE ,VOL.114. No10, pp.1089-1109

Amini,F .,Qi,G.,(2000)"Liquefaction testing of stratified silty sands" Journal Of Geotechnical and Geoenviromental Eng. ASCE ,pp208-217

Bouferra.R . Shahrour.I(2003)" Influence of fines on the resistance to liquefaction of a clayey sand" Laboratoire de Me´canique de Lille, University of Sciences and Technologies of Lille, Polytech Lille, France

Boulanger,R.,Idriss,I.M.(2006)”Liquefaction susceptibility criteria for silts and clays” Journal Of Geotechnical and Geo environmental Eng., ASCE ,VOL.132 , No.11 ,pp.1413-1426

Bray,J.D.,et.al(2004a)”Sub surface characterization at ground failure sites in adapazari, turkey” "Journal Of Geotechnical and Geo environmental Eng., 130(7) ,pp.673-685

Bray,J.D.,Sancio,R.B(2006)”Assessment of the liquefaction susceptibility of fine-grained soils” Journal Of Geotechnical and Geo environmental Eng., ASCE ,VOL.132 , No.9 ,pp.1165-1176

Castro,G.(1969)"Liquefaction of sands "Harvard Soil Mechanics Series , No.81 ,Cambridge

Chung.K.Y.C.and Wong.I.H.,(1982)"Liquefaction potential of soils with plastic fines",Proceeding of soil dynamics and earthquake engineering. Conf.,Southampton, pp887-897

Chu,D.B.,et al.,(2004)”Documentation of soil conditions at liquefaction and non liquefaction sites from 1999 chi-chi (Taiwan)earth quake” Soil Dyn. Earth quake Eng.,24(9-10),pp.647-657

Degregorio,V.B.,(1990)"Loading systems, sample preparation, and liquefaction" Journal of GT.ASCE.VOL116,No5,pp805-821

Guo,T .,Prakash, S.,(1999)"Liquefaction of silt and silt-clay mixtures" Journal Of Geotechnical and Geoenviromental Eng.,pp706-710

Georgiannou, V. N., Burland, J. B. & Hight, D. W. (1990)." The undrained behaviour of clayey sands in triaxial compression and extension"Geotechnique 40, No. 3,431-449

Gratchew,I.B.,Sassa,K. and Fukuoka,H.(2006)”How reliable is the plasticity index for estimating the liquefaction potential of clayey sands” Journal Of Geotechnical and Geo environmental Eng., 132(1) ,pp.124-127

Gratchew,I.B,et al(2006)”The liquefaction of clayey soils under cyclic loading” Engineering Geology86(2006).pp.70-84

Ishihara,K.,(1993)"Liquefaction and flow failure during earthquakes " Geotechnique,VOL43,No.3,351-415

Koester,J.,(1993)"Effects of fines type and content on liquefaction potential of low to medium plasticity fine-grained soils" National earthquake conference

Kramer,S and Seed,H.B.,(1988)"Initiation of soil liquefaction under static loading condition " Journal Of Geotechnical Eng .ASCE,VOL.114.No4,pp.412-430

Kokusho.T,(1999)"Water film in liquefied sand and its effect on lateral spread" Journal Of Geotechnical and Geoenviromental Eng, 125(10),817-826

Lade ,P.V. and Yamamuro,J.A.,(1997)"Effects of nonplastic fines on static liquefaction of sands" Canadian Geotechnical Journal,VOL34,pp918-928

Ladd,R.S,(1978)"Preparing specimens using under compaction"ASTM, Geotechnical Testing journal ,GTGODJ ,VOL1,No.1,pp16-23

Law ,K.T. and Ling,Y.H.,(1992)"Liquefaction of granular soils with noncohesive and cohesive fines"Proceedings of the tenth world conference on earthquake engineering,Rotterdam,pp1491-1496

Mulilis,J.P.,and et al .(1977)"Effect of sample preparation on sand liquefaction" Journal Of Geotechnical Eng.ASCE,VOL103.No2,1977,pp. 91-108

Naeemifar, O, "Effects of Fine Content With Different Plasticity Values on Liquefaction Potential of Sands"; Thesis for MSc., Engineering Faculty -Tarbiat Modarres University-Tehran-Iran

Naeini,S,A.,Baziar.(2004)"Effect of fines content on steady state strength of mixed and layered samples of a sand".Soil Dynamics and Earthquake Engineering Journal,VOL.24,pp.181-187

Ovando-Shelley, E. , Perez G., B. E. (1997)." Undrained behaviour of clayey sands in load controlled triaxial tests" Geootechnique 47, No. 1, pp97-111

Pitman.T.D.,Robertson,P.K.and Sego,D.C.,(1994)"Influence of fines on the collapse of loose sands", Canadian Geotechnical Journal,VOL31 ,pp728-739

Polous S.J.,(1981)"The steady state of deformation" Journal Of Geotechnical Eng . ,ASCE,VOL107,No5,pp553-562

Polito.C.P,(1999)" The effects of non-plastic and plastic fines on theliquefaction of sandy soils" PHD Dissertation (Faculty of the Virginia Polytechnic Institute)

Polito ,C .,Martin ,J.,(2001)"Effects of nonplastic fines on the liquefaction of resistance of sands ",Journal Of Geotechnical and Geoenviromental Eng, 408-415

Singh,S. (1996)"Liquefaction of silts and silty sands"11th world conference on earthquake engineering,Elsevier.

Sridharan,A.,Rao,O.And Murthy,N.S.(1986)"Liquid limit of montmorillonite soils"Geotech.Test.J.9(3)pp.156-159

Sridharan,A.,Rao,O.And Murthy,N.S.(1988)"Liquid limit of kaolinitic soils" geotechnique,38(2),191-198

Xenaki,V.,Athanasopoulos,G.,(2003)"Discussion of Effects of nonplastic fines on the liquefaction resistance of sands" Journal Of Geotechnical and Geoenviromental Eng., ASCE, pp408-415

Yamamuro, J.,Lade,P.,(1998)"Steady state concepts and static liquefaction of silty sands" Journal Of Geotechnical and Geoenviromental Eng., ASCE ,VOL.124 , No.9 ,pp.868-877

Yasrobi, S.S., "Investigating the Effects of Content and Shapes of Fines on Steady State Behavioural Properties of Saturated Sands to Assess Liquefaction Potential in Such Soils"; Thesis for PhD, Civil Engineering School, Sharif University of Technology, 1997.

Yoshimi,M.,Robertson,P.K.,and Wride,C,E(1999)"Undrain shear strength of clean sand to trigger flow liquefaction " Canadian Geotechnical Journal , VOL36 , No5, pp891-906