EFFECT OF FINES ON THE STRESS-STRAIN BEHAVIOUR OF CHLEF SAND

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ABSTRACT

Silty sand soils are largely found in nature in varying proportions with sand and silt. The characteristics of clean sands concerning the shear strength have been studied extensively; however in the field sands are mixed with appreciable amount of silt or clay. Individual shear strength behaviour of silt as macro constituent has always remained embedded under the availability of two different soils, i.e. sandy and clayey soils. A major understanding in the last decade with respect to the behaviour of silty soils has led to important research activities in this field. One of the most specific features of silty soils is their low saturation strength, which has resulted in settlement of many structures constructed on them after years of construction. This paper presents the characterization of the engineering behaviour of sand containing different amounts of silt. A laboratory investigation has been conducted to study the effect of varying low plastic silt (IP = 5) on the shear strength characteristics of Chlef sand (Algeria). For this purpose, a series of drained and undrained monotonic triaxial compression tests were performed on reconstituted saturated silty sand samples with several different silt contents ranging from 0 to 50% within three separate density ranges (Dr = 12, 50, 90%). The results show that the stress-strain response and shear strength behaviour is controlled by the percentage of fines and the sample becomes contractive for all densities studied.

Keywords: Fines content, Shear strength, Friction angle, Drained test, Undrained tests.

1. Introduction

The shear strength behaviour of natural soils depends on the size shape, grains arrangement, interparticle contact and interactions at the particulate level. The stress-strain behaviour and the shear strength that silty sand soils can offer under different loading condition are dictated by the different types and sizes of grains within the soil matrix in the transfer of interparticle contact stresses. Traditionally, Soil Mechanics has broadly classified this soil in two classes, fine grained and coarse grained soils. Nevertheless this classification has lost the thrust and identity with growing soil mechanics challenges and with different types of soils encountered in the nature. The characteristics of clean sands have been extensively studied under different experimental conditions. These are Ottawa, Ticino, Monterey and Yamuna sands (Hardin 1978; Chung et al. 1984; Bolton 1986; Lo Presti 1987; Mishra 1981; Dalwadi 1990). However natural soils most of the time contain important quantity of fines. The results obtained from several years of research on clean sands could not be used directly for these soils. If realistic analyses are to be done of soil mechanics problems involving these these materials, information is needed about shear strength characteristics of such natural mixes of soils. The behaviour of such granular mixes has received recent more detailed study (Kuerbis et al. 1988; Pitman et al. 1994; Thevanayagam 1998; Thevanayagam and Mohan 2000; Yamamuro and Covert 2001; Naeini and Baziar 2004).

Silty soils are termed as transitional soils due to their inherent characteristics pertinent to sand as well as to clay, which is the underlying reason because of which it is seen that its individual behaviour as macro-constituent has not been a subject of much detailed study. Over 50 years ago, Terzaghi (1956) hypothesized that silt particles could create a "metastable" particle structure that could explain many complex geotechnical phenomena. On of the key properties of silty soils is their inherent instability, particularly when water content is increased with a tendency to become quick when saturated. It therefore requires a greater understanding of the soil microstructure and contribution of soil particles of different size to its shear strength response. This study presents the analysis of drained and undrained stress-strain behaviour and shear strength on saturated sand-silt mixture that is representative of silty sand found around Chlef region.

2. Experimental program and test procedure

In this paper, we present a laboratory study on the behaviour of a mixture sand-silt. For this purpose, series of undrained and drained triaxial compression tests under monotonic loading condition were carried out on reconstituted saturated samples of Chlef sand with variation in non-plastic silt content ranging from 0 to 50% to assess the variation in shear strength characteristics and stress-strain behaviour. The sand and silt used in this laboratory investigation were obtained by the dry sieve analysis and wet sieve analysis. The physical properties of the soils used during this study are summarized in table 1. The grain size distribution curves for the tested soils are shown in Figure 1. The variation of emax and emin versus the fines content is illustrated in Figure 2. Monotonic drained and undrained compression tests were carried out on isotropically consolidated sand samples with 0, 10%, 20%, 30%, 40% and 50% non-plastic silt. The different soil ratio samples are designated as S100M0, S90M10, S80M20, S70M30, S60M40 and S50M50, where S represents sand and M silt and numbers represent their respective percentage were tested at an initial confining pressure of 100 kPa. All specimens were prepared by first estimating the dry weights of sand and silt needed for a desired proportion into the loosest, medium and densest state (Dr = 12, 50, and 90%) using undercompaction method of sample preparation which simulates a relatively homogeneous soil condition and is performed by compacted dry soil in layers to a selected percentage of the required dry unit weight of the specimen (Ladd 1978). Dry pluviation method was used to prepare samples. The specimens were 70 mm in diameter and 70 mm in height in order to ovoid the appearance of instability lines (sliding surfaces) and buckling of samples. After the specimen has been formed, the specimen cap is placed and sealed with O-rings, and a partial vacuum of 25 kPa is applied to the specimen to reduce the disturbances. Saturation was performed by percolating carbon dioxide and then de-aired water from the base of the specimen and a minimum Skempton coefficient-value greater than 0.96 was obtained at back pressure of 100 kPa. All test specimens were isotropically consolidated at mean effective pressure of 100 kPa, and then subjected to undrained and drained monotonic triaxial loading with a constant strain rate of 0.167% per minute.

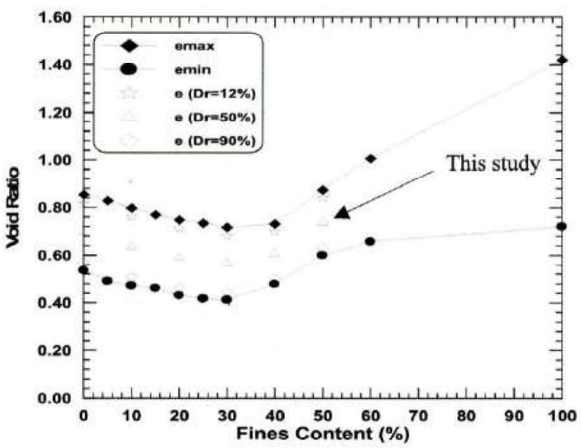

Figure 2: Maximal and Minimal void ratios of the sand-silt mixtur

Material	Silt Content (%)	G_s	D_{50} (mm)	C_u	e_{min}	e_{max}	I_p(%)
Clean Sand	0	2.680	0.36	2.35	0.535	0.854	-
Silty Sand	10	2.682	-	-	0.472	0.798	-
	20	2.684	-	-	0.431	0.748	-
	30	2.686	-	-	0.412	0.718	-
	40	2.688	-	-	0.478	0.732	-
	50	2.69	-	-	0.600	0.874	-
Silt	100	2.70	0.06	-	0.72	1.420	5.0

Table 1: Physical properties of sand-silt mixture

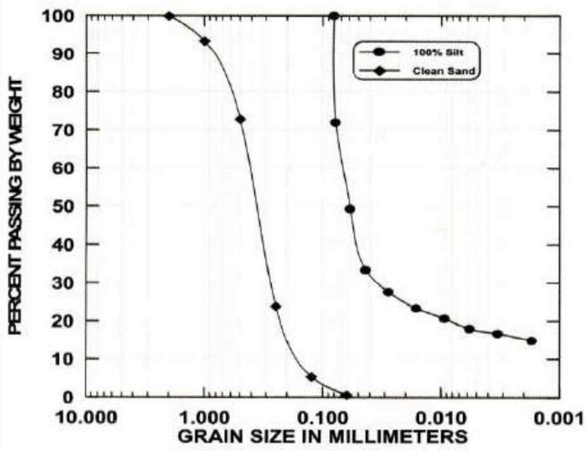

Figure 1: Grain size distribution curves

The testing apparatus used to carry out the tests is GDS automatic stress-path dynamic triaxial system (GDS Instruments 2 Hz, UK). The instrument has a GDS type stress-path cell which is connected to four digital pressure controllers for the control and monitoring of cell, back, lower chamber pressure and volume respectively and one for pore pressure. All the controllers are connected to a computer controlled data acquisition system for recording and calculation of various data sets through the use of GDS software. The GDS apparatus uses hydraulic pressure loading system and the axial load is applied through the lower chamber of the GDS stress path cell. All undrained triaxial tests for this study were carried out at strain rates, which were slow enough to allow pore pressure change to equalize throughout the sample with the pore pressure measured at the base of sample. The drained compression tests were sheared at strain rates slow enough to allow full dissipation of pore water pressure during loading. All the tests were continued up to 24% axial strain.

3. Test results and discussions

3.1. Drained compression tests

Figures 3a, 3b and 3c show the results of drained compression tests carried out on silty sand samples with silt contents ranging from 0 to 50% for three initial densities (Dr = 12, 50 and 90%). We note in general for the three cases that the fraction of fines affects in a significant manner the variations of the deviator stress. Indeed, the increase in the fraction of fines between 0 and 50% leads to a reduction in the initial stiffness of the soil consequently in its resistance peak (maximum deviatoric stress).

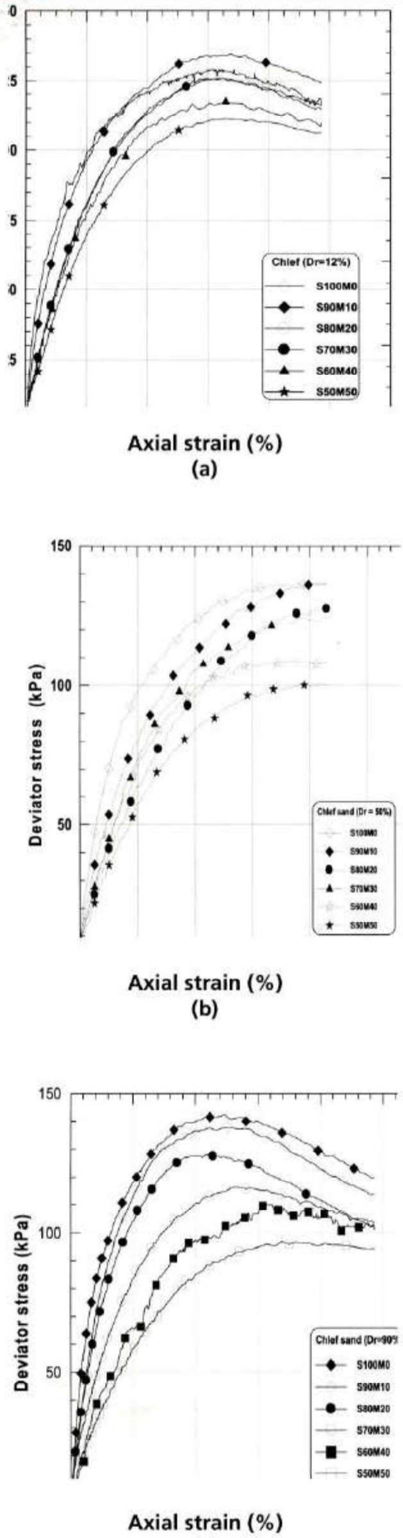

Figure 3: Stress-strain variation during drained tests

(σ_3'=100 kPa)

Concerning the volume change (Figure 4), we note that the clean sand and samples with lower fines content (F_c⟨30%) present a phase of contractancy followed by a dilatancy phase. In the loose state, clean sand and samples with 10%, 20% and 30% the dilatancy appears from an axial strain of 12.5%, while for those with fines content of 40% and 50%, we observe solely a phase of contractancy (Figure 4a). For medium dense samples, particularly for the clean sand, the dilatancy phase appears from 8% in the axial strain, while for samples with 10% to 30% fines content, the dilatancy is delayed and appears from an axial strain of 13%. For samples with 40% and 50%, we observe only a phase of contractancy (figure 4b).

For dense samples, we remark that the presence of fines delays in a significant manner the appearance of the phase of dilatancy. Indeed, it appears after 4,5%, 5%, 6% and 10% respectively for the fines content F_c = 0, 10, 20 and 30%; beyond those fines contents, we observe solely a phase of contractancy (Figure 4c).

3.2. Undrained compression tests

Figures 5, 6,and 7 show the results of undrained compression tests carried out for different fines content ranging from 0 to 50% at 100 kPa mean confining pressure within three separate density ranges (Dr = 12, 50, 90%). We notice in general that the increase in the amount of fines leads to an increase of the water pressure (Figure 6). This increase results from the role of fines in the increase in the contractancy of the mixture observed during the drained compression tests. Indeed, the increase in the pore water pressure leads to a reduction of the confining effective pressure and consequently to a decrease of the peak resistance of the mixture as it is illustrated by figure 5. The stress path diagram (p', q) shows clearly the role of the fines in the decrease of the average effective pressure and the maximum deviatoric stress (Figure 7). In this case, the effect of fines on the undrained behaviour of the mixture is observed for the lower fines content (F_c = 10%), and becomes very marked beyond 20%. These results are in good agreement with the observations of Shen et al. (1977) and Troncosco and Verdugo (1985).

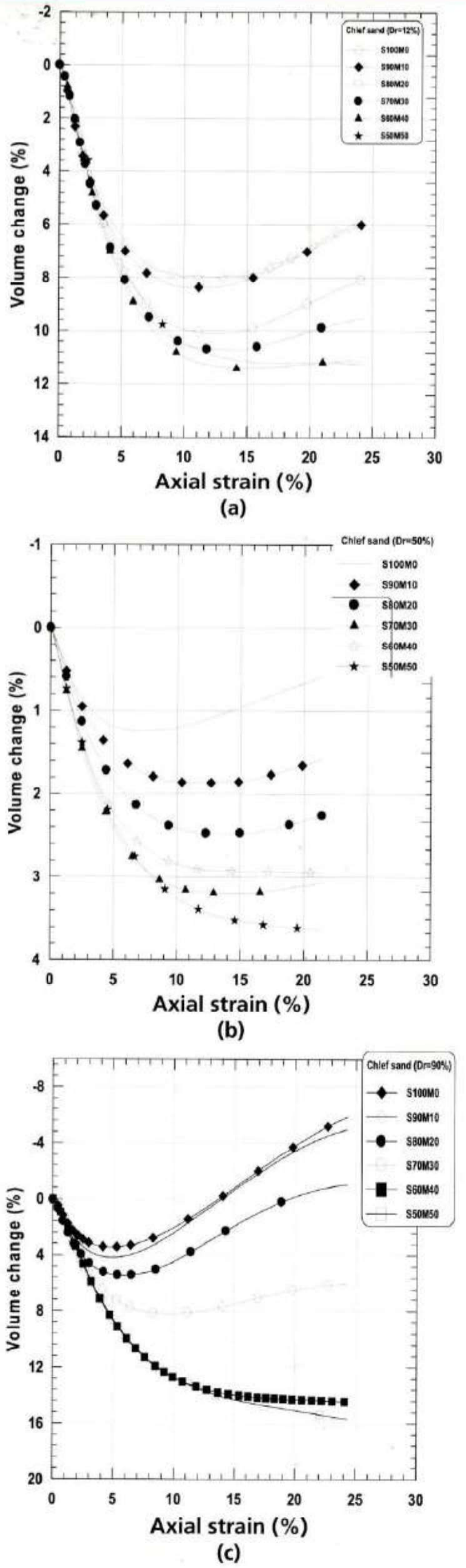

Figure 4: Volumetric response during shearing (σ_3'=100 kPa)

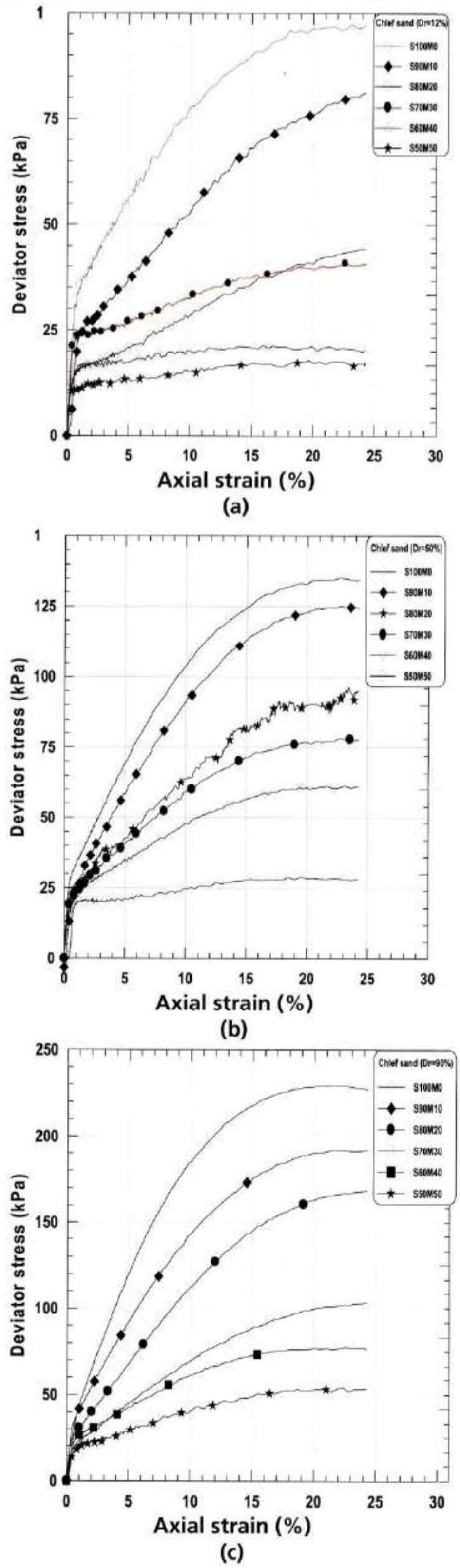

Figure 5: Stress-strain variation during undrained tests (σ_3'=100 kPa)

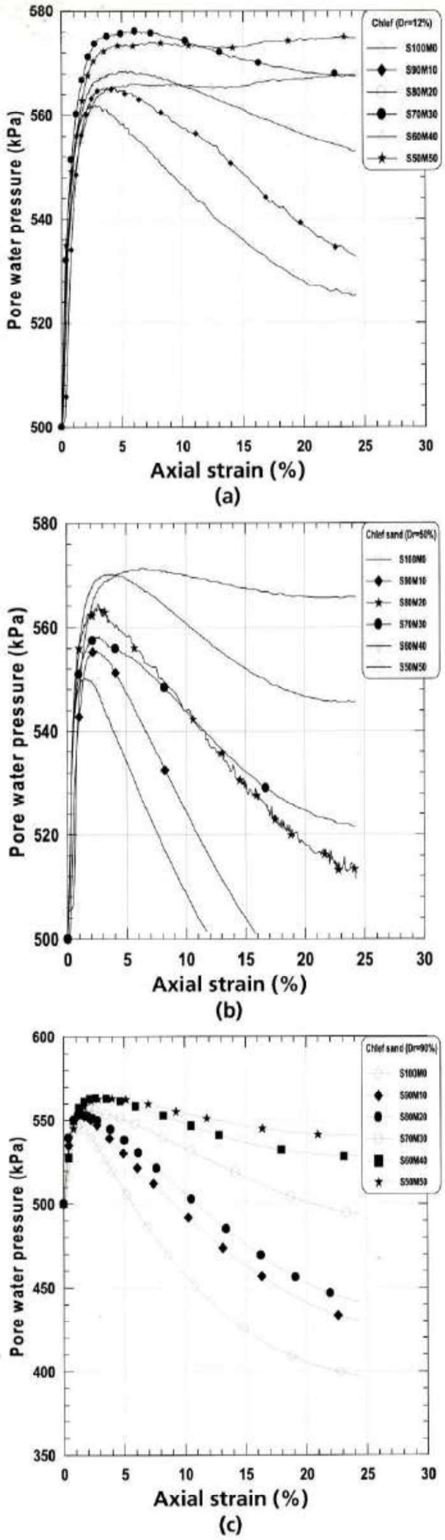

Figure 6: Pore pressure response during shearing
(σ_3'=100 kPa)

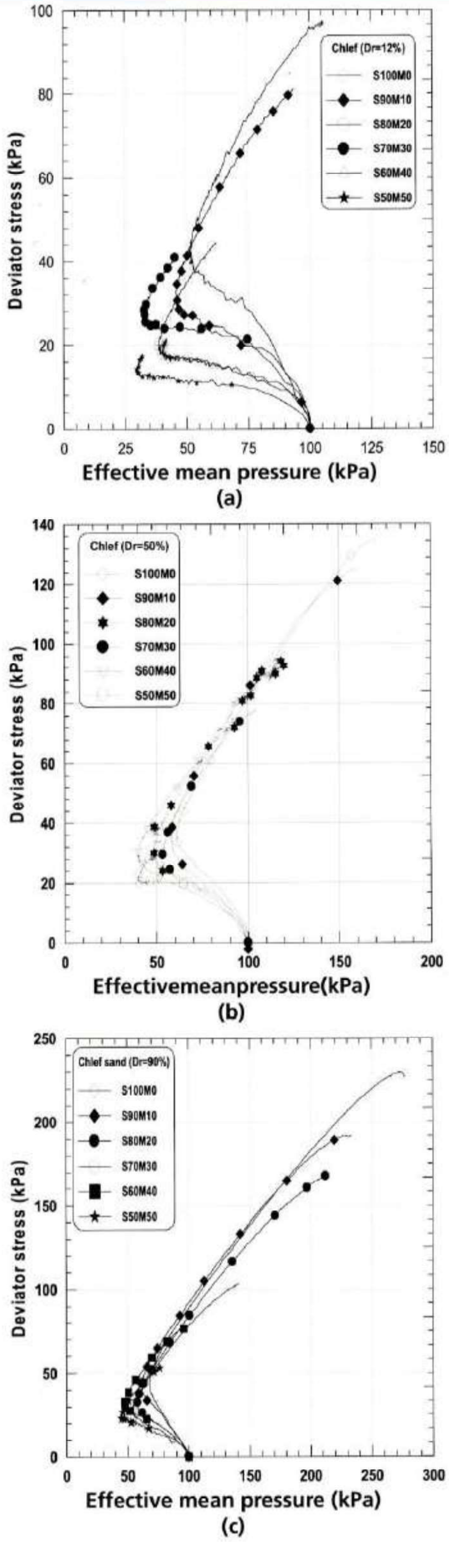

Figure 7: Stress path with different silt content
(σ_3'=100 kPa)

4. Conclusion

Results of the triaxial compression tests were analyzed to assess both the stress-strain behaviour and shear strength parameters of silty sand under both drained and undrained conditions. It was found that the percentage of non-plastic fines affects considerably the shear strength parameters of sand, especially its internal friction angle. It was also observed that the structural packing of the particles during shearing controls the volumetric response as well as the pore pressure variation, which is directly related to the amount of fines controlling the behaviour of sands. The soil response observed in this study is strictly applicable only to the silt and sand gradations used in this laboratory investigation. Further work is required to study the effects of different gradations on the behaviour of silty sands.

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