Acta Mech. Sin. (2011) 27(5):796–802
DOI 10.1007/s10409-011-0462-8

RESEARCH PAPER

Influence of specimen-reconstituting method on the undrained response of loose granular soil under static loading

Noureddine Della · Ahmed Arab · Mostefa Belkhatir

Received: 29 March 2010 / Revised: 27 October 2010 / Accepted: 22 February 2011

Abstract This paper describes the results of an experimental study on the undrained shear behaviour of loose sand collected from the location close to the epicenter of the recent Chlef (Algeria) Earthquake (October 10, 1980). The study focuses on the effects of the mode of the soil deposition on the liquefaction resistance of the Chlef sand. For this purpose, the results of undrained monotonic triaxial compression tests performed on samples with initial density of 0.29 under initial confining pressures ranged from 50 kPa to 200 kPa are presented. The specimens were prepared by two depositional methods namely dry funnel pluviation and wet deposition. It was found that there was a marked difference in the undrained behaviour of sand in terms of maximal deviatoric stress, peak strength, residual strength and excess pore water pressure, even though the density and stress conditions were identical. The conclusion was that the soil fabric was responsible for this result. The results indicated also that at low confining pressures, the specimens reconstituted by the wet deposition method exhibited complete static liquefaction (zero effective confining pressure and zero stress difference).

Keywords Liquefaction · Undrained · Dry funnel pluviation · Wet deposition · Residual strength

1 Introduction

During earthquakes, the shaking of the ground may cause saturated cohesionless soils to lose their strength and behave like a liquid. This phenomenon is called soil liquefaction and will cause settlement or tipping of buildings, failures of earth dams, earth structures and slopes. The modern study of soil liquefaction has been triggered by numerous liquefaction-induced failures during the 1964 Niigata, Japan earthquake.

Numerous studies have reported that the behaviour of sands can be greatly influenced by the initial state of the soil. Polito and Martin [1] asserted that the relative density and skeleton void ratio were factors that seemed to explain the variation in different experimental results. Yamamuro and Lade [2,3] and Yamamuro and Covert [4] concluded that complete static liquefaction (zero effective confining pressure and zero effective stress difference) in laboratory testing is most easily achieved in silty sands at very low pressures.

Several specimen reconstitution techniques, tamping and pluviation being the most common, are in use in current practice. All of these objective is to replicate a uniform sand specimen at the desired void ratio and effective stresses to simulate the sand mass in-situ. However, the effect of the preparation method of the samples has been subjected to controversial researches. Many studies have reported that the resistance to the liquefaction is more elevated for samples prepared by the method of sedimentation than for samples prepared by the dry funnel pluviation and the wet deposition [5]. Other studies have found that the specimens prepared by dry funnel pluviation method tend to be less resistant than those reconstituted by wet deposition method [6,7]. Other researchers indicated that the tests prepared by dry funnel pluviation are more stable and dilatant than those prepared by wet deposition [8–10]. Vaid et al. [11] confirmed this result while showing that the wet deposition encouraged the initiation of liquefaction in relation to a setting up by pluviation under water. Yamamuro et al. [12] concluded after their laboratory investigation, that the method of dry pluviation supported the instability of the samples contrary to the method of sedimentation. Wood et al. [13] found that the effect of the method of deposition on the undrained behaviour

N. Della (✉) · A. Arab · M. Belkhatir
Laboratory of Material Sciences and Environment,
Civil Engineering Department,
University of Chlef,
Sendjas Street PO Box 151 Chlef 02000, Algeria
e-mail: nour_della@yahoo.fr

decreased when the density increased. They also found that this influence decreased with the increase of the fines content, particularly with the lower densities. The focus of this study was to identify the differences in undrained triaxial compression behaviour that can result from using different reconstitution techniques to create silty sand specimens.

2 Material tested

Silty sand samples were collected from a liquefied layer of the deposit areas close to the Chlef Earthquake epicentre (October 10, 1980). Figure 1 Shows craters of liquefied ground on banks of Chlef River [14]. Figure 2 illustrated a typical subsidence location of the liquefied soil and sample collection. All tests in the present study were performed on sand from Chlef (Algeria). The sand contains 0.5% of silt of the river of Chlef. The grain size distribution curve of this sand is given in Fig. 3. It is medium sand with rounded grains of medium diameter D_{50} = 0.45 mm and predominant minerals are feldspar and quartz. The silt component is non plastic with a plasticity index of 5.81%. The index properties of the sand used in this laboratory research work are presented in Table 1. The specimens were reconstituted at density (I_D = 0.29) representing the loose state.

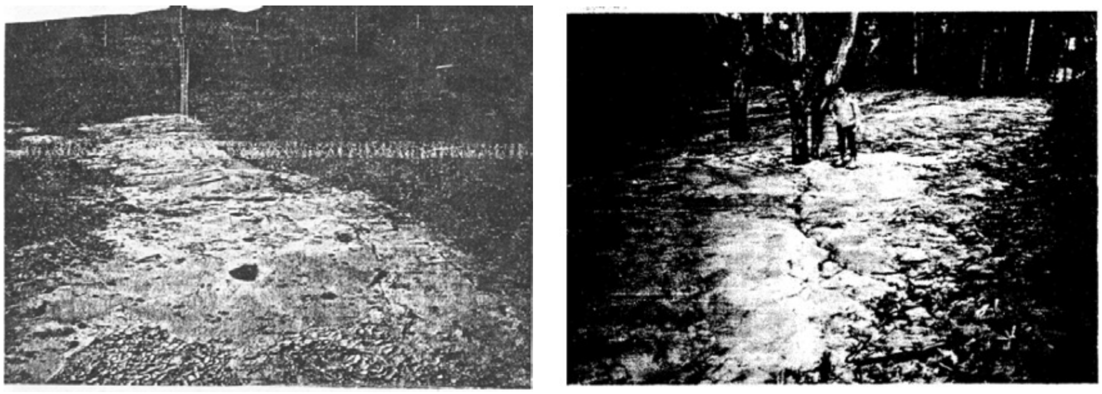

Fig. 1 Craters of liquefied soil on banks of the Chlef River

Fig. 2 Depressions in banks of the Chlef River

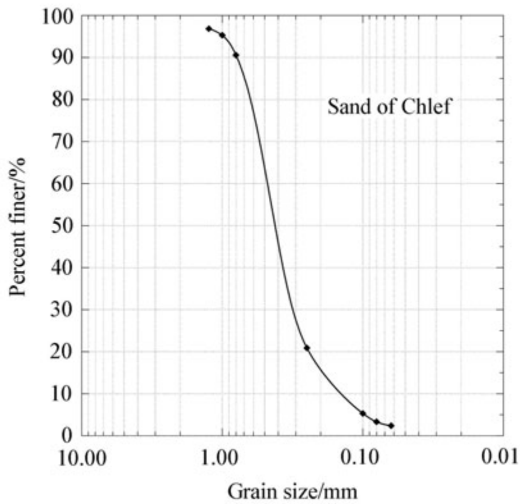

Fig. 3 Grain-size distribution curve of tested material

Table 1 Index properties of the used sand

Material	e_{min}	e_{max}	γ_{dmin}/ (g·cm^{-3})	γ_{dmax}/ (g·cm^{-3})	γ_s/ (g·cm^{-3})	Cu (D_{60}/D_{10})	D_{50}/ mm	D_{10}/ mm	Grains shape
O/Chlef	0.54	0.99	1.34	1.73	2.67	3.2	0.45	0.15	Rounded

3 Experimental procedures

Presented below is an experimental study of the behaviour of loose sand under static loading conditions. Undrained tests were performed.

3.1 Testing equipment

An advanced automated triaxial testing apparatus type Bishop and Wesley was used to conduct the monotonic undrained tests (Fig. 4).

Fig. 4 The triaxial system set up

3.2 Specimen preparation

In this study, two methods of sample preparation, namely dry funnel pluviation and wet deposition, were utilized. The methods are briefly described below.

In the first method, the dry soil is deposited in the mould with the help of a funnel by controlling the height; this method consists of filling the mould by tipping in rain of dry sand. To have loose samples, it is necessary that the height of fall is almost nil.

The second method consists of mixing the previously dried sand with a small quantity of water (3%) and then depositing the humid soil in the mould in as homogeneous a manner as possible. The soil was placed in successive layers. A constant number of strokes were applied to get a homogeneous and isotropic structure.

Triaxial tests were performed on cylindrical specimens measuring 70 mm in diameter and 140 mm in height (H/D = 2.0). The mass of sand to put in place is determined according to the desired density (the initial volume of the sample is known). The state of density of the sample was defined by the density index

$$I_D = (e_{max} - e)/(e_{max} - e_{min}), \quad (1)$$

where e_{min} and e_{max} indicate the minimum void ratio and the maximum void ratio, respectively; e is the target void ratio and I_D is density index.

After the specimen has been formed, the specimen cap is placed and sealed with O-rings, and a partial vacuum of 15 kPa to 25 kPa is applied to the specimen to reduce disturbances.

3.3 Saturation and consolidation

Saturation of the specimens was accomplished by flushing the specimen with carbon dioxide for approximately 20 min [15], after which de-aired water was slowly added from the bottom of the specimen. Application of a back pressure improves the degree of saturation, which was estimated by calculating Skempton's B-parameter as the ratio of measured pore water pressure increase induced by an increase in cell pressure in undrained conditions, and the corresponding increase in cell pressure. The B value was measured to test specimen saturation, and a minimum value greater than 0.96 was obtained for all tests. The triaxial test samples were isotropically consolidated under confining pressures ranging from 50 kPa to 200 kPa prior to static loading.

3.4 Shear loading

All undrained triaxial tests for this study were carried out with strain controlled conditions at a constant strain of 0.167% per minute, which was slow enough to allow pore pressure change to equalize throughout the sample with the pore pressure measured at the base of sample. All the tests were continued up to 20% axial strain.

4 Results of the tests conducted

4.1 Effect of confining pressure

Figure 5 shows the results of the undrained triaxial compression tests performed in this study. All tests were performed on specimens composed of Chlef sand and each specimen was monotonically loaded in compression under undrained conditions. Figure 5a presents the undrained stress-strain curves, while Fig. 5b shows the effective stress paths on the Cambridge p'–q diagram in which $p' = (\sigma'_1 + 2\sigma'_3)/3$ and $q = \sigma'_1 - \sigma'_3$. It was noticed that as the confining pressures increased, the liquefaction resistance (deviatoric stress) increased for both dry funnel pluviation and wet deposition methods. As can be seen, for the samples reconstituted by the wet deposition method, complete static liquefaction occurred at the lowest confining pressure (50 kPa). Static liquefaction was coincidental with the formation of large wrinkles in the membranes surrounding the specimens. At a confining pressure of 100 kPa the specimens undergo temporary liquefaction characterized by the condition where the undrained stress difference first achieves an initial peak, after which it declines to a minimum value. Finally at confining pressure of 200 kPa the resistance to liquefaction increases.

It is clear from Fig. 5, that when the initial confining pressure increased from 50 kPa to 200 kPa, the specimens reconstituted by the dry funnel pluviation method exhibit behaviour that is characterised by increasing stability or increasing resistance to liquefaction. The effect of increasing confining pressure is to increase dilatant tendencies in the soil.

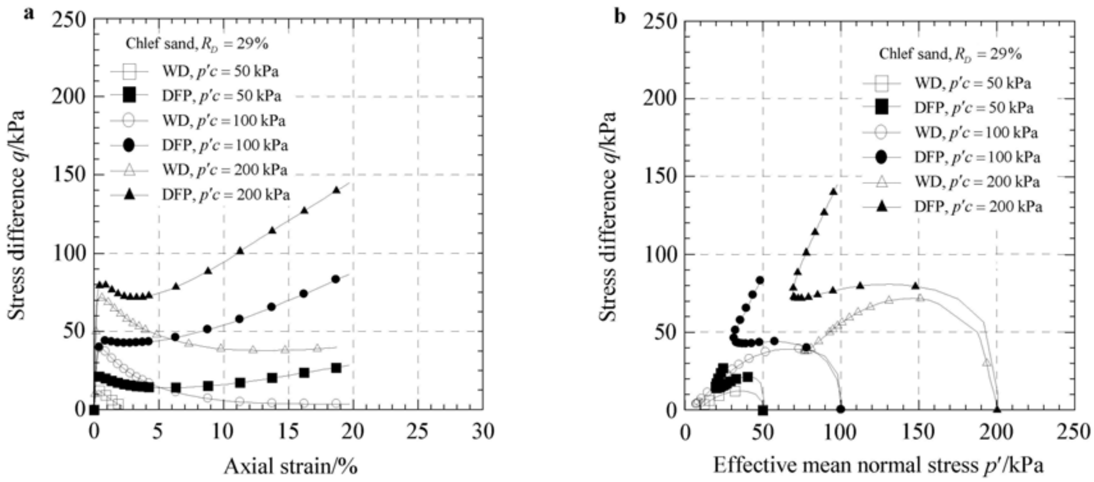

Fig. 5 Undrained tests on loose sand. **a** Deviator stress-strain curve; **b** Stress path

Temporary liquefaction is described as the condition where the undrained stress difference first achieves an initial peak, after which it declines to a minimum value. This is caused by rapidly rising pore pressure which decreases the effective stresses.

Increasing dilatancy or resistance to liquefaction can also be observed by examining the ratio of the minimum stress difference to the initial peak stress difference ($q_{\min}/q_{\text{peak}}$) shown in Fig. 6 for the wet deposition method. A ratio ($q_{\min}/q_{\text{peak}}$) of zero indicates complete liquefaction, and a ratio ($q_{\min}/q_{\text{peak}}$) of unity represents completely stable behaviour. The inset diagram in Fig. 6 shows that this ratio is zero at initial confining pressure of 50 kPa, indicating complete static liquefaction. The ratio then increases at initial confining pressures from 100 kPa to 200 kPa, indicating that the specimen exhibits more dilatancy and, thereby, more resistant to liquefaction.

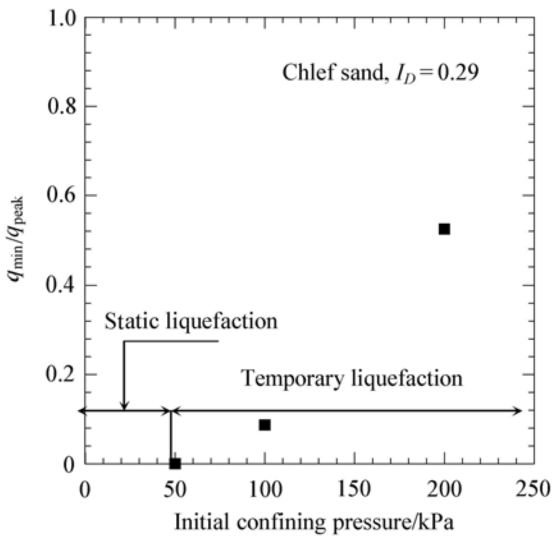

Fig. 6 Resistance to liquefaction for the wet deposition method

4.2 Effect of the deposition method

4.2.1 *Deviatoric stress*

The effect of the specimen's reconstitution method on maximal deviatoric stress is shown in Fig. 7a. It can be noticed that the dry funnel pluviation method (DFP) gives more significant values of the maximal deviator, therefore a much higher resistance to liquefaction, contrary to the wet deposition method (WD) where some weaker values of the maximal deviator were noted, with progressive stabilization around a very weak or nil ultimate stationary value meaning the liquefaction of the sample.

The same tendencies are noted for the variations of the values in the peak deviatoric stress given in Fig. 7b. As it can be seen, the samples conceived by the dry funnel pluviation method (DFP) exhibit a resistance to monotonic shearing, slightly higher to those made by the wet deposition method (WD).

4.2.2 *Excess pore pressure*

The influence of the sample preparation methods on excess pore pressure is illustrated in Fig. 8. As shown by Fig. 8a for the dry funnel pluviation method, the variation of the pore pressure curves presents two phases: the first shows a very high initial rate of generation, giving account of the strongly contracting character of the Chlef sand. In the second phase, rate is going to decrease progressively with the axial strain, meaning the dilating character of the material. The developed excess pore pressure in the samples prepared by the wet deposition method is presented in Fig. 8b. It can be seen that the samples exhibit a very high contracting character, with an expansion rate highly elevated from the beginning of the shearing and progressive stabilization toward an ultimate value, to associate to the stabilization of the deviatoric stress.

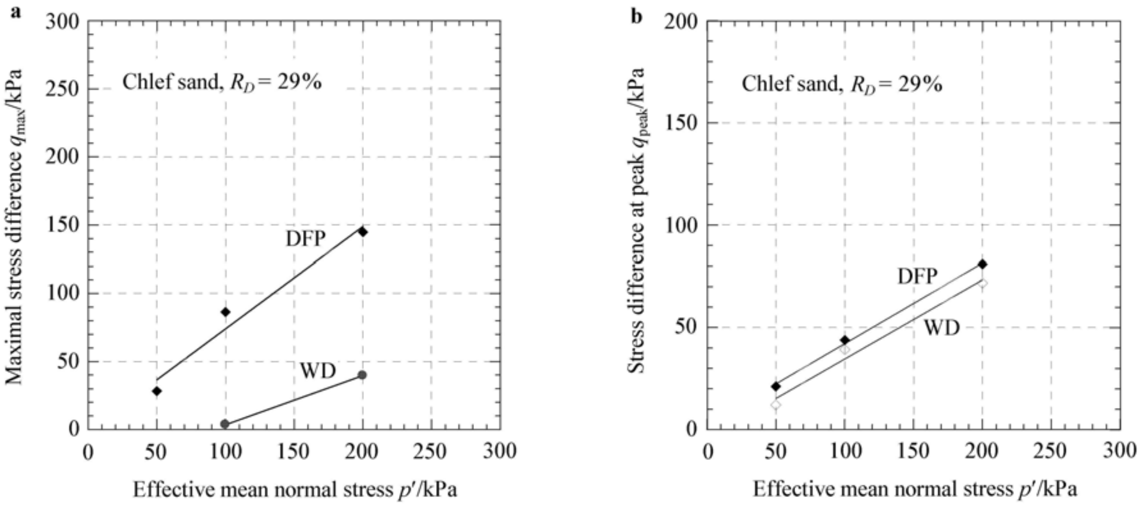

Fig. 7 Effect of the deposition method on **a** Maximal deviatoric stress; **b** Deviator stress at peak

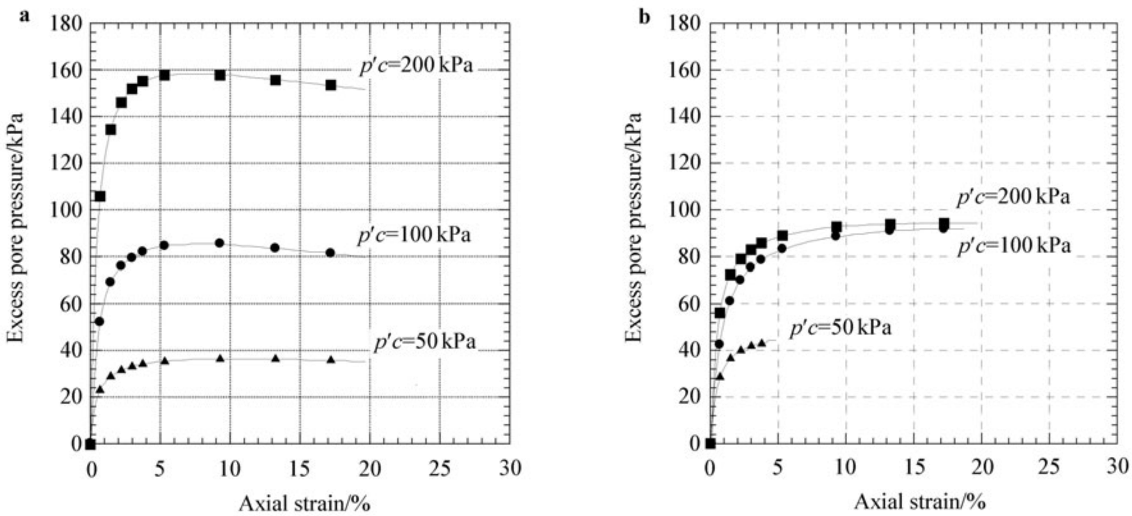

Fig. 8 Effect of sample reconstitution methods on the excess pore pressure (R_D = 29%). **a** Dry funnel pluviation method; **b** Wet deposition method

4.2.3 Residual strength

When loose sandy soils are subjected to undrained loading beyond the point of peak strength, the undrained shear strength declines to a near constant value over large deformations. Conventionally, this shear strength is called the undrained steady-state shear strength or residual shear strength. However, if the shear strength increases after passing through a minimum value, the phenomenon is called limited or quasi-liquefaction. Even limited liquefaction may result in significant strains and the associated drop in resistance. Ishihara [10] defined the residual shear strength S_{us} as

$$S_{us} = (q_s/2)\cos\phi_s = (M/2)\cos\phi_s(p'_s), \tag{2}$$

$$M = 6\sin\phi_s/(3-\sin\phi_s), \tag{3}$$

where q_s, p'_s and ϕ_s indicate the deviator stress $(\sigma'_1 - \sigma'_3)$, the effective mean principal stress $(\sigma'_1 + 2\sigma'_3)/3$ and the mobilized angle of inter-particle friction at the quasi-steady state (QSS), respectively. For the undrained tests conducted at a constant confining pressure and various initial relative densities and fines content, the deviatoric stress q_s was estimated at the quasi-steady state point along with the mobilized internal friction angle (Fig. 9). Furthermore, the residual shear strength was calculated according to the relation (2).

Figure 10 shows the evaluated undrained residual shear strength S_{us} and its variation with confining pressures and reconstitution methods. It is clear from this figure that the samples preparation method considerably affects the evolution of the residual strength. Indeed this residual strength is nil for the samples prepared by wet deposition (WD) to a confining pressure of 50 kPa, 100 kPa and 200 kPa, because of collapse of samples, contrary to the samples prepared by the method of dry funnel pluviation (DFP) which mobilize a more significant residual strength.

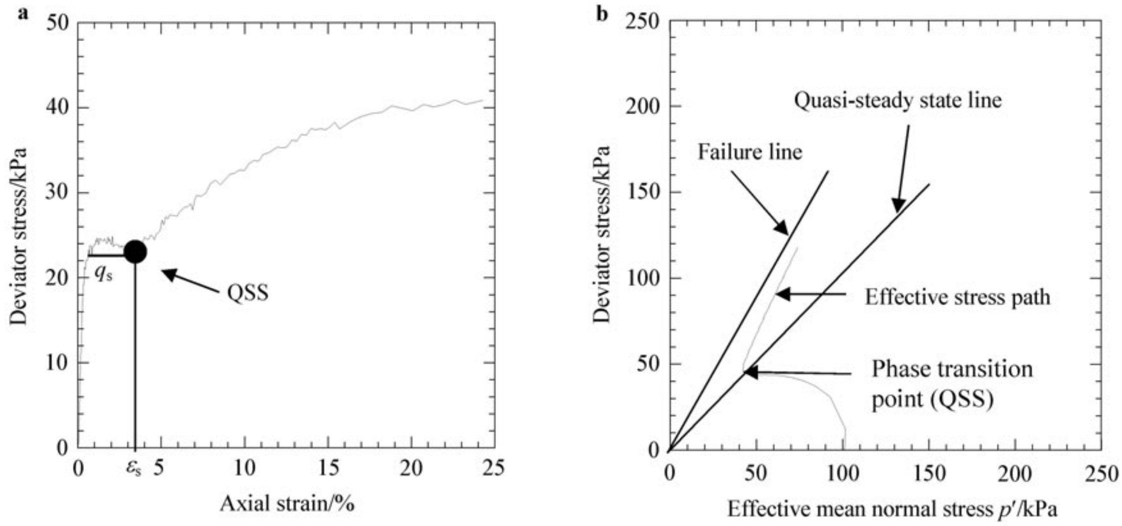

Fig. 9 Determination of the phase transition point

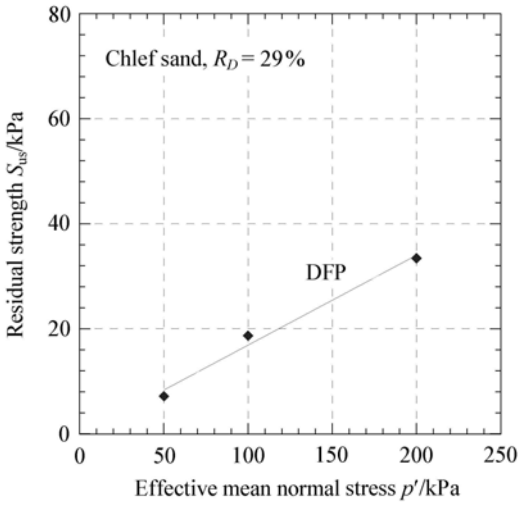

Fig. 10 Effect of the deposition method on the undrained residual shear strength

5 Conclusion

A testing program to investigate the behaviour of sandy soil and to study the effects of confining pressures and sample preparation methods was undertaken. Undrained triaxial compression tests were performed on Chlef silty sand at initial relative density of 29% representing a loose state, for confining pressures ranging from 50 kPa to 200 kPa. Two methods of sample preparation, namely, dry funnel pluviation and wet deposition were used. The following primary conclusions were obtained as a result of this study:

(1) Within the range of variables studies and the testing techniques used, the method of sample preparation has a detectable effect on the undrained behaviour. Dry funnel pluviation method appeared to indicate a more volumetrically dilatant or stable response, while wet deposition method appeared to exhibit a more contractive or unstable behaviour.

(2) As the confining pressures increased, the liquefaction resistance of Chlef sand increased for both dry funnel pluviation and wet deposition methods. The maximal deviatoric stress and peak strength increase with the increase of the initial confining pressure. Complete static liquefaction occurred at low confining pressure for the samples prepared by the wet deposition method and as confining pressures increased, the soil became more dilatant and more resistant to liquefaction.

(3) The excess pore water pressure increases for both the two depositional methods (dry funnel pluviation and wet deposition) with a decrease tendency for the first one and stabilization for the second one.

(4) The residual shear strength of sand is sensitive to the sample preparation methods. The dry funnel pluviation method gives higher values of the residual shear strengths than the wet deposition method.

References

1 Polito, C.P., Martin, II J.R.: A reconciliation of the effects of non-plastic fines on the liquefaction resistance of sands reported in the literature. Earthquake Spectra, **19**(3), 635–651 (2003)

2 Yamamuro, J.A., Lade, P.V.: Static liquefaction of very loose sands. Canadian Geotechnical J. **34**(6), 905–917 (1997)

3 Yamamuro, J.A., Lade, P.V.: Steady state concepts and static liquefaction of silty sands. J. Geotech. Geoenv. Eng. ASCE **124**(9), 868–877 (1998)

4 Yamamuro, J.A., Covert, K.M.: Monotonic and cyclic liquefaction of very loose sands with high silt content. J.

Geotech. Geoenvironmental Engineering ASCE, **127**(4), 314–324 (2001)
5 Zlatovic, S., Ishihara, K.: Normalized behavior of very loose non-plastic soils: effects of fabric. Soils and Foundations, **37**(4), 47–56 (1997)
6 Mulilis, J.P., Seed, H.B., Chan, C.K., et al.: Effects of sample preparation on sand liquefaction. Journal of Geotechnical Engineering Division, ASCE, **103**, 91–108 (1977)
7 Yamamuro, J.A., Wood, F.M.: Effect of depositional method on the undained behavior and microstructure of sand with silt. Soil Dynamics and Earthquake Engineering **24**, 751–760 (2004)
8 Benahmed, N., Canou, J., Dupla, J.C.: Initial structure and static liquefactionproperties of sand. Comptes Rendus Mécanique **332**(11), 887–894 (2004)
9 Canou, J.: Study contribution and assessment of sand liquefaction characteristics. [Ph.D. Thesis]. The Ecole Nationale des Ponts et Chaussées, Paris (1989)
10 Ishihara, K.: Liquefaction and flow failure during earthquakes. Geotechnique **43**(3), 351-415 (1993)
11 Vaid, Y.P., Sivathayalan, S., Stedman, D.: Influence of specimen reconstituting method on the undrained response of sand. Geotechnical Testing Journal **22**(3), 187–195 (1999)
12 Yamamuro, J.A., Wood, F.M., Lade, P.V.: Effect of depositional method on the microstructure of silty sand. Canadian Geotechnical Journal **45**(11), 1538–1555 (2008)
13 Wood, F.M., Yamamuro, J.A., Lade, P.V.: Effect of depositional method on the undrained response of silty sand. Canadian Geotechnical Journal **45**(11), 1525–1537 (2008)
14 Clough, W. G., Mass, S. S., Hamou, H.: Observation of liquefaction and landsliding as a result of the October 10, 1980 El-Asnam, Algeria Earthquake, Report O John A. Blume Earthquake Engineering Center, Department of Civil Engineering, Stanford University, Caliofornia, Februay, 43 (1981)
15 Lade, P.V., Duncan, J.M.: Cubical triaxial tests on cohesionless soil. Journal Soil Mechanics and Foundations Division ASCE **99**(10), 793–812 (1973)