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Identification of the behavior of the Chlef sand to static liquefaction

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Abstract

An experimental study, realized in laboratory with the triaxial apparatus, proposes to evaluate the influence of the mode of soil deposition, initial density and confinement on the undrained behavior of the Chlef sand. The tests were conducted on specimens collected in situ of initial relative density of 29 and 80% (corresponding to depths of 10 m and 20 m, respectively), with initial confining pressure of 50, 100 and 200 kPa using two depositional methods that include dry funnel pluviation (DFP) and wet deposition (WD) with water content of 3%. All the samples were subjected to a monotonic loading after the consolidation phase. The test results show that the initial confining pressure and the relative density affect considerably the resistance to liquefaction. However, it increases with the confinement and the density. The results also show that the samples prepared with the dry funnel pluviation method have a greater resistance to liquefaction than those prepared with the wet deposition method, by mobilizing higher residual strength. ***To cite this article: N. Della et al., C. R. Mecanique 337 (2009).***

Résumé

Sur le comportement du sable de Chlef et sa résistance à la liquéfaction. Une étude expérimentale, réalisée en laboratoire à l'appareil triaxial, se propose d'évaluer l'influence du mode de déposition des sols, aussi celle de la densité initiale et du confinement, sur le comportement non drainé du sable de Chlef. Les essais ont été effectués sur des échantillons collectés in situ de densité relative initiale de 29 et 80 % (correspondant à des profondeurs de 10 m et 20 m respectivement), à des pressions de confinement initiales de 50, 100 et 200 kPa selon deux méthodes de reconstitution : la pluviation à sec et le placement humide avec une teneur en eau de 3 %. Tous les échantillons ont été soumis à un chargement monotone après consolidation. Les résultats expérimentaux montrent que le confinement et la densité relative affectent d'une manière très significative la résistance à la liquéfaction du sol. En effet cette dernière augmente avec la pression de confinement et la densité. Les résultats montrent aussi que les échantillons préparés avec la méthode de pluviation à sec présentent une résistance à la liquéfaction plus élevée que ceux préparés avec la méthode du placement humide, en mobilisant un effort résiduel plus grand. ***Pour citer cet article : N. Della et al., C. R. Mecanique 337 (2009).***

Keywords: Soils; Liquefaction; Undrained sand; Dry funnel pluviation; Wet deposition; Confinement; Density; Residual strength

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Mots-clés : Sols ; Liquéfaction ; Sable non drainé ; Pluviation à sec ; Placement humide ; Confinement ; Densité ; Résistance résiduelle

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1. Introduction

The risk of liquefaction occupies an important place in the design of urban planning construction. Liquefaction occurs due to an increase in the excess pore water pressure and a corresponding decrease in the effective overburden stress in a soil deposit. The soil loses its strength and behaves like a liquid. This natural phenomenon was responsible for many damage throughout the world: earthquakes in Alaska and Niigata 1964, El Asnam (Algeria) 1980, Loma Prieta 1989, Northridge 1994, Kobe 1995 and recently Izmir 1999.

The experimental study of the behavior of the soils requires a good control of the parameters that influence on the liquefaction resistance. Among these parameters, we can enumerate the sample preparation methods in the laboratory which was the topic of several earlier research projects.

It is extensively recognized that the mechanical behavior of sand depends significantly on its initial state in terms of void ratio (or relative density) and of the effective stressed state. We, however, rarely make reference to the initial structure of the material, in the sense of the geometric arrangement of the grains in the granular stacking, resulting of such or such method of reconstitution or formation of the material.

The effect of the method of preparation of the samples on the resistance to the liquefaction has been subject to much controversial research, because we do not find a consensus in the literature; some authors find that the resistance to liquefaction is more elevated for samples prepared by the method of sedimentation than for samples prepared by other methods, such as the dry funnel pluviation and the wet deposition (Zlatovic and Ishihara [1]); others find that the resistance to the liquefaction of the samples prepared by wet deposition more elevated than by dry funnel pluviation (Mulilis et al. [2], Yamamuro and Wood [3]).

Benahmed et al. [4] as well as Canou [5] and Ishihara [6] presented results showing that the tests prepared by dry funnel pluviation are more resistant than those prepared by wet deposition. Vaid et al. [7] confirmed this result, while showing that wet deposition encourages the initiation of the liquefaction in relation to a setting up by pluviation under water. Yamamuro et al. [8] showed that the method of dry pluviation supports the instability of the samples contrary to the method of sedimentation. Wood et al. [9] found on their side that the effect of the method of deposition on the undrained behavior decreases, when the density increases. They also found that this influence decreases with the increase of the fines content, particularly with the lower densities. Indeed, we carried out two sets of undrained triaxial tests using two methods of deposition such as the dry funnel pluviation and the wet deposition in order to define the effect of the method of preparation of the samples on the resistance to the liquefaction. Since there ware different possible modes of formation of the natural sandy solid masses, the use of the two modes of deposition of the Chlef sand, allows one to approach to the reality of the area, the final purpose being the characterization of the behavior of this sand to liquefaction, especially since the region is known for its high seismicity and soil liquefaction.

2. Material tested

All tests in the present study were performed on the sand of Chlef (Algeria) containing 0.5% of silt of the river of Chlef that crosses the city of Chlef to the west of Algiers. The granulometric curve of this sand is given in Fig. 2. The sand of Chlef is a medium sand, rounded with a medium diameter $D_{50} = 0.45$ mm. The contained silt is non-plastic with a plasticity index of 5.81%. Table 1 gives the physical properties of the used sand. The tests have been carried out on specimen collected from the region where the phenomenon of liquefaction was observed during the last earthquake (October 10th, 1980) near the Chlef river (see Fig. 1) for two relative densities RD = 29% and 80% respectively representing the loose and dense state, corresponding to the depths of 10 m and 20 m, respectively.

3. Experimental procedures

The experimental device used includes:

- An autonomous triaxial cell type Bishop and Wesley (Bishop and Wesley, 1975);
- Three controllers of pressure/volume type GDS (200cc);

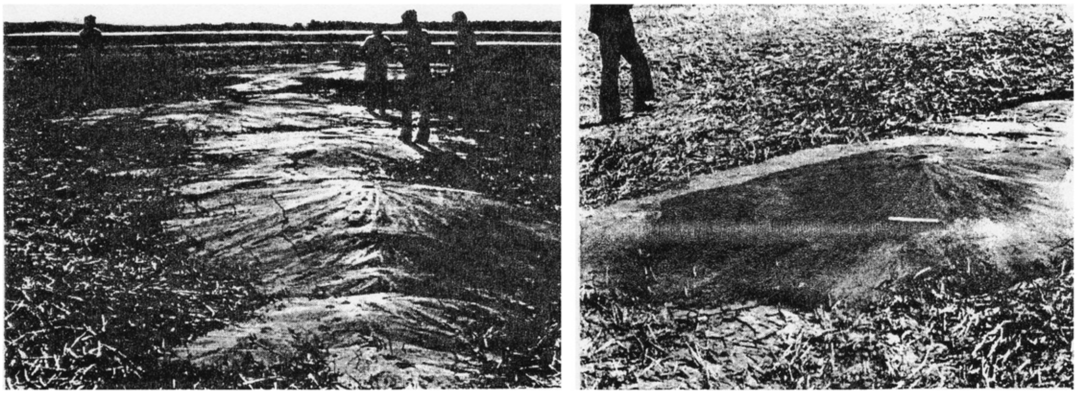


Fig. 1. Sand boils due to the liquefaction phenomenon at Chlef region.

Fig. 1. Cratères de sable dus au phénomène de liquéfaction dans la région de Chlef.

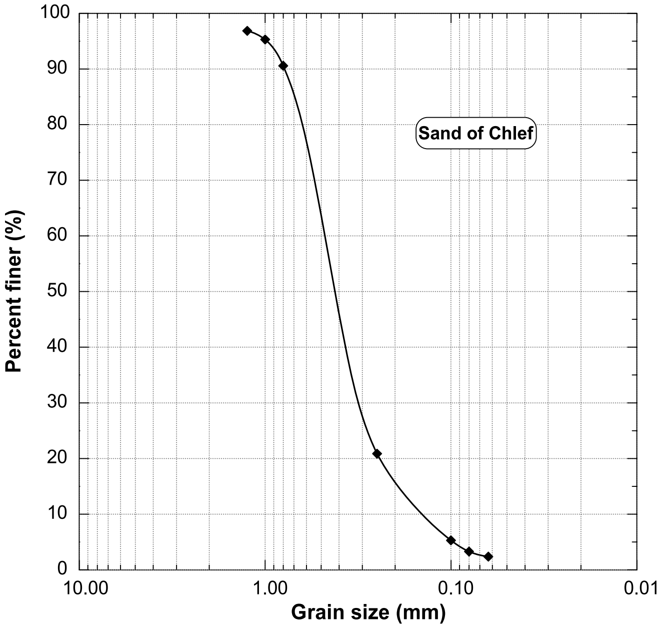


Fig. 2. Grain size of the sand used.

Fig. 2. Courbe granulométrique du sable utilisé.

Table 1
Principal properties of the used sand.

Tableau 1
Caractéristiques principales du sable utilisé.

Material	$e_{\min}$	$e_{\max}$	$\gamma_{d\min}$ (g/cm^3)	$\gamma_{d\max}$ (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

- A void pump joined to a reservoir in order to deaire the demineralized water;
- A microcomputer equipped with software permitting the piloting of the test and the data acquisition.

3.1. The mold used in sample preparation

The samples are prepared with the help of a mold constituted of two semi cylindrical shells. The two shells can easily be joined or embossed one with the other with the help of a hose clamp. In order to maintain the cuff made of latex along the partitions of the mold, four aspiration ducts are pierced in the conducted shells. These ducts communicate with the inside of the mold by rows of small holes (1 mm of diameter). They are joined to flexible hoses that are assembled in a single tube. This last can be connected to a void pump.

3.2. Methods of sample deposition

The two methods used to reconstitute the samples of sand are dry funnel pluviation (tipping) and wet deposition. In the method of dry funnel pluviation (DFP), the dry soil is deposited in the mold with the help of a funnel with control of the height; this method consists in filling the mold by tipping in rain of the dry sand. To have loose samples, it is necessary that the height of fall is quasi-nil. The method of wet deposition (WD) consists in mixing with the most possible homogeneous manner, the sand, previously dried, with a small quantity of water (3%) and the deposition of the humid soil in the mold with control of the content in water. The soil is placed finely by successive layers. We apply a constant number of strokes to get a homogeneous and isotropic structure. This method is more convenient for the sand, because it can provide some samples with a large range of indications of void ratio.

3.3. Preparation of the sample

The samples used are cylindrical in shape of 70 mm of diameter and 140 mm height ($l/d = 2$). The mass of sand to put in place is evaluated according to the wished density (the initial volume of the sample is known), the state of density of the sample being defined by the relative density:

$$I_{\mathrm{D}} = (e_{\max} - e)/(e_{\max} - e_{\min}) \tag{1}$$

3.4. Saturation and consolidation of the sample

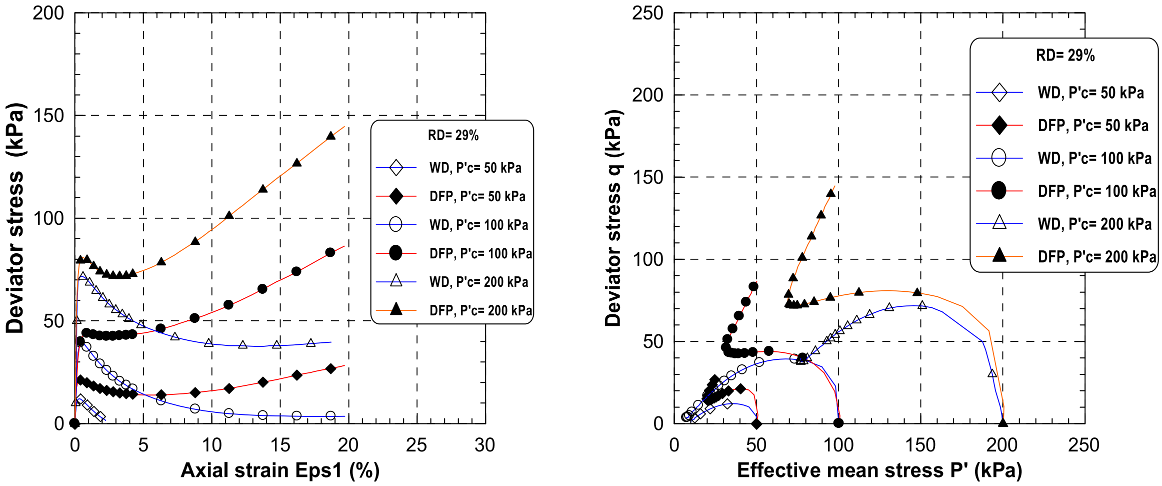
The saturation is an important stage in the experimental procedure because the response of the sample under undrained loading depends on its quality. To get a good degree of saturation, we use the technique of the carbon dioxide elaborated by Lade and Duncan [10]. This technique consists in making the carbon dioxide circulate through the circuits of drainage and the sample to weak debit during a certain time, in order to occupy all voids and to chase the air contained in the sample. Then, we make the de-aired and demineralized water circulates to chase the interstitial gas and to occupy its place dioxide and water. In order to consolidate the sample, we apply in the same way a rise in pressure in the cell (GDS n1) and inside the sample (GDS n2). The application of a back pressure, with the help of the GDS n2, improves the quality of the saturation while compressing the micro-bubbles of the interstitial gas that can still be present after the phase of saturation. We maintain these two pressures (in the cell and inside the sample) during a whole night to assure a good consolidation.

The quality of the saturation is evaluated with the measure of the coefficient of Skempton (B) according to a classic process: we give an increment $\Delta\sigma$ of the confining pressure of 100 kPa in an undrained condition, we measure the response of the interstitial pressure Δu and we evaluate the degree of saturation by the formula $B = \Delta u/\Delta\sigma$.

4. Results of the tests conducted

4.1. Effect of confining pressure

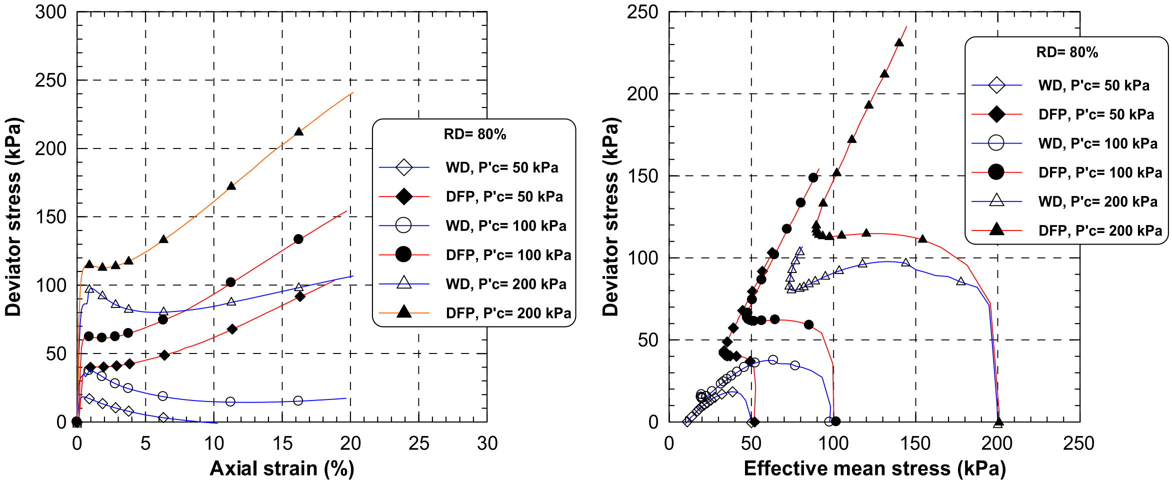
For the purpose of studying the effect of variation of effective confining pressure on liquefaction resistance, we conducted a series of tests. Figs. 3 and 4 show the results of the undrained triaxial compression tests performed in this study. All tests were performed on specimens composed of Chlef sand and each specimen was monotonically loaded in compression under undrained conditions. Figs. 3a and 4a present the undrained stress–strain curves, while Figs. 3b and 4b show the effective stress paths on the Cambridge p'–q diagram in which $p' = (\sigma_1' + 2\sigma_3')/3$ and



(a) (b)

Fig. 3. Undrained tests on loose sand: (a) deviator stress–strain curve, (b) stress path.

Fig. 3. Essais non drainés sur sable lâche : (a) courbe de cisaillement, (b) chemin de contrainte.



(a) (b)

Fig. 4. Undrained tests on dense sand: (a) deviator stress–strain curve, (b) stress path.

Fig. 4. Essais non drainés sur sable dense : (a) courbe de cisaillement, (b) chemin de contrainte.

$q = \sigma'_1 - \sigma'_3$. It is noticed that as the confining pressures increased, the liquefaction resistance of sands 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 in the two tests at loose and dense densities with the lowest initial confining pressure (50 kPa). Static liquefaction was coincidental with the formation of large wrinkles in the membranes surrounding the specimens. At confining pressure of 100 kPa the specimens undergo to 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 for both loose and dense densities.

In Figs. 3 and 4 for the dry funnel pluviation method it is clear that, when the initial confining pressure is increased from 50 kPa to 200 kPa the specimens with relative densities of 29% (loose) and 80% (dense) exhibit behavior that is characterized by increasing stability or increasing resistance against liquefaction. The effect of increasing confining pressure is to increase the dilatant tendencies in the soil.

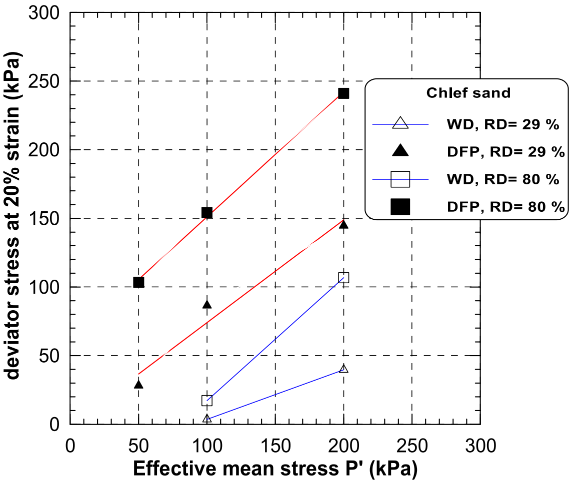


Fig. 5. Effect of the relative density on the undrained response of sand.

Fig. 5. Influence de la densité relative sur la réponse non drainée du sable.

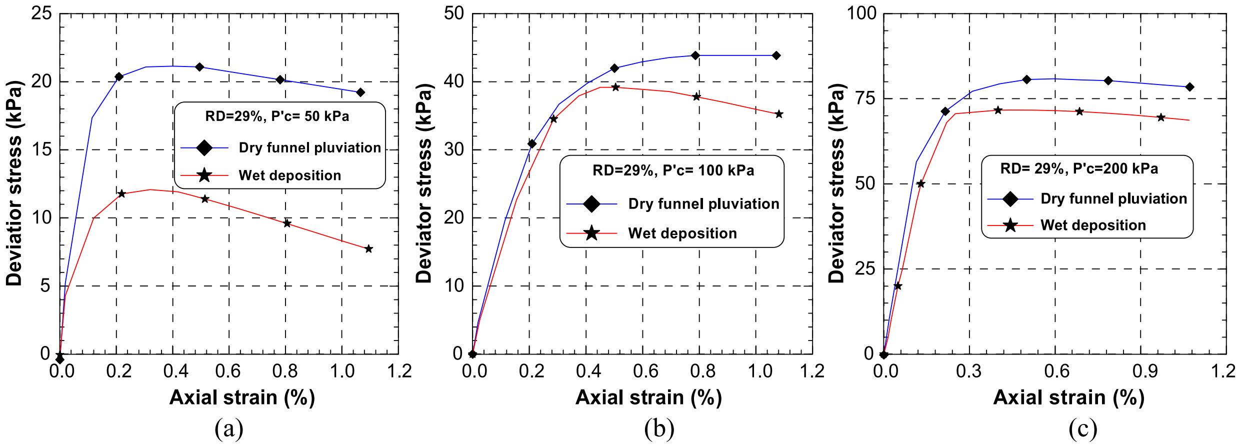


Fig. 6. Influence of the preparation method on the deviator at the beginning of the loading (loose state).

Fig. 6. Influence de la méthode de préparation sur le déviateur au début du chargement (état lâche).

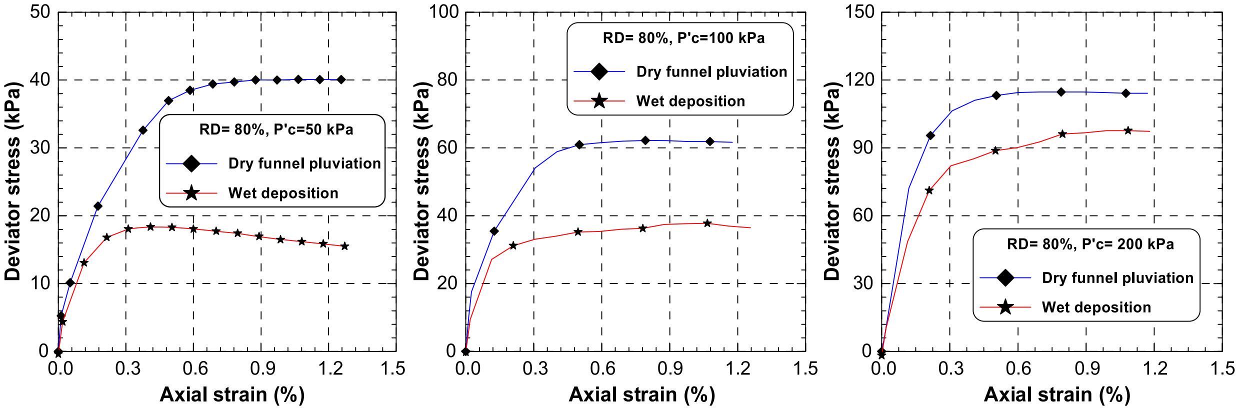
4.2. Effect of the initial density

Fig. 5 shows the evolution of the resistance to the monotonic shearing according to the initial relative density of the sand. We note that the resistance to the liquefaction represented by the deviator at 20% of strain, increases appreciably with the density of soil for the two methods of deposition of the samples used, with a more pronounced increase for the method of dry funnel pluviation, where the values of the maximal deviator pass from 28.23 kPa for a loose soil and a confinement of 50 kPa to 240.97 kPa for a dense soil and to a confinement of 200 kPa, contrary to the method of wet deposition where the evolution of the resistance is less pronounced.

4.3. Effect of the method of deposition

4.3.1. Effect of preparation method at the beginning of loading

Figs. 6 and 7 show the results of the loose and dense samples tests at the beginning of the loading (before the deviator peak). For the whole set of those tests, we notice that the samples prepared by the method of dry pluviation (DFP) have a resistance to liquefaction higher than those prepared by the method of wet deposition (WD) at the beginning of the loading. The samples sheared under an effective pressure $P'c = 50$ kPa present a very important



(a) (b) (c)

Fig. 7. Influence of the preparation method on the deviator at the beginning of the loading (dense state).

Fig. 7. Influence de la méthode de préparation sur le déviateur au début du chargement (état dense).

variation (peak deviator) (Figs. 6a and 7a), then this variation tends to decrease with the increase in the confining pressure (Figs. 6b, 6c, 7b and 7c).

4.3.2. Variation of the deviator stress

Fig. 8 shows the results of the set of undrained triaxial tests led on samples of different densities with the two used methods of deposition. We note in these results that the method of deposition by dry funnel pluviation (DFP) gives more significant values of the deviator at peak of strain, therefore a much higher resistance to liquefaction, contrary to the wet deposition method (WD) where we note some weaker values of the deviator at peak for weak densities (loose state for RD = 29%) with progressive stabilization around a very weak or nil ultimate stationary value meaning the liquefaction of the sample.

4.3.3. Variation of the residual strength

When loose sand is subjected to undrained shearing beyond the point of peak strength, the undrained shear strength drops to a near constant value over large deformation. Conventionally, this shear strength is called the undrained steady-state shear strength or residual shear strength. However, if the strength increases after passing through a minimum value, the phenomenon is called limited or quasi-liquefaction. Even limited liquefaction may result in a significant strains and associated drop in resistance. The residual shear strength is defined by Ishihara [6] as:

$$S_{us} = (q_s/2)\cos\phi_s \tag{2}$$

where q_s and ϕ_s indicate the deviator stress and the mobilized angle of interparticle friction at the quasi-steady state. We rightly note that the preparation method of the samples somehow considerably affects the evolution of the residual strength (S_{us}). Indeed the results of the Fig. 9 that give the evolution of the residual strength, show that this resistance is nil for the samples prepared by the wet deposition method (WD) to a confinement of 50 kPa since there have been collapse of the samples, on the contrary and for confinement of 100 and 200 kPa, the samples prepared by the method of dry funnel pluviation (DFP) mobilize a more significant residual strength in relation to those prepared by the wet deposition method (WD).

We notice at the end that our results are in perfect agreement with those given by Benahmed et al. [4] and Ishihara [6] which found that the samples prepared by dry funnel pluviation (DFP) have a resistance to liquefaction higher than those prepared by the method of wet deposition (WD). Zlatovic and Ishihara [1] by changing the method of preparation, found that the resistance of the samples prepared by the method of dry funnel pluviation decreases with the increase in the fraction of fines while the samples prepared by sedimentation present a reduction in resistance until a fines content of Fc = 30% then reincrease. Mulilis et al. [2] found from their side that the samples prepared by wet damping present a resistance higher than those prepared by dry funnel pluviation.

These differences of behavior noted between the two methods of deposition, can be explained by the fact that the molecules of water contained in the structures prepared by wet deposition method constitute some macropores easily

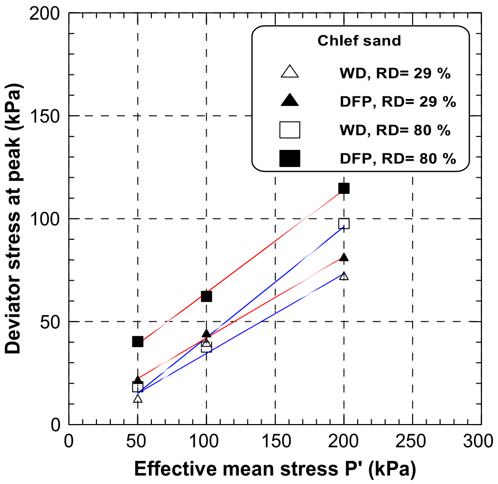


Fig. 8. Effect of the deposition method on the deviator stress at peak.

Fig. 8. Influence de la méthode de déposition sur le déviateur au pic.

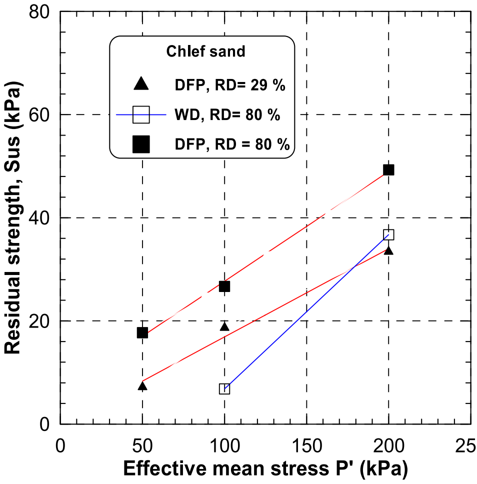


Fig. 9. Effect of the deposition method on the residual strength.

Fig. 9. Influence de la méthode de déposition des échantillons sur la résistance résiduelle.

Fig. 10. Failure of the sample prepared by the wet deposition method.

Fig. 10. Liquéfaction d'un échantillon préparé par la méthode de placement humide.

compressible at the time of the shearing of the sample and at the same time prevent the grain–grain adhesion from which the faculty of the sample is to contract. This trend accelerates the instability of the samples which show a very weak resistance and even provokes the phenomenon of liquefaction of the sand for the weak densities and weak confinements leading to the collapse of the sample as it is shown in Fig. 10. Contrary to the structures of the samples prepared by the method of dry funnel pluviation that show a more dilating behavior.

5. Conclusion

This article included a presentation of the results of a study in laboratory about the influence of the mode of sample deposition, the relative density and the confinement on the behavior of Chlef sand, collected at sites where the phenomenon of liquefaction has appeared in previous earthquakes. The study included the undrained triaxial tests that have been conducted to relative density of 29% and 80% for confinements of 50,100 and 200 kPa.

The realized tests permitted to identify two well differentiated sandy structures, feature of the modes of deposition, one stable and the other unstable. The first method named dry funnel pluviation (DFP) gives stable samples (dilating), the second method named wet deposition (WD) encourages contractance, therefore the instability of the samples. The difference of these behaviors can be explained by the fact that in the method (WD), the presence of the water confers to soil a higher porosity, what leads to easily compressible samples encouraging a volumetric response very contracting making the soils very vulnerable to the liquefaction. It has been shown also that the resistance to the liquefaction increase with the relative density and the confinement. One of the practical problems that may arise in these results, is the characterization of wet sandy materials used as hydraulic fill in embankments construction, without the possibility of in situ compaction effective and which can therefore, lead to massive structure unstable under liquefaction, not to mention the high seismicity of the Chlef region that could lead to instability in these wet sandy soils, at least in the sand layers at medium depth.

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