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Shear strength of compacted Chlef sand: effect of water content, fines content and others parameters

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Abstract: This paper presents a laboratory study of the combined effect of the water content and fines content on the mechanical behaviour of Chlef sand in a medium dense state (RD = 65%) and dense state (RD = 80%). Several mechanical parameters were evaluated such as shear strength, cohesion and friction angle at different water content w = 0, 1, 2 and 3% and different fines content F_c = 0, 10, 20, 30 and 40%. The test results showed that the shear strength of Chlef sand decrease with the increase fines content F_c = 0 to 40%, our tests result also showed that the water content has a significant influence on the shear strength which decreases with the increase in the water content w = 0 to 3%. The fines content and the water content have a significant influence on the mechanical parameters c and φ. Cohesion increases with the percentage of fines and decreases with the increase of the water content while the friction angle decreases with the increase the fines content and the water content.

Keywords: fines content, water content, direct shear test, friction angle, cohesion.

List of Symbols

G_s	Specific gravity of solids
D_{10}	Effective grain diameter
D_{50}	Average grain diameter
C_u	Uniformity coefficient ($C_u = D_{60}/D_{10}$)
C_c	Coefficient of gradation ($C_c = (D_{30})^2/(D_{10})x(D_{60})$)
c	Cohesion
e_{max}	Maximum void ratio
e_{min}	Minimum void ratio
RD	Relative density
s_n	Normal stress
t	Shear strength
t_{max}	Maximum shear strength
j	Friction angle
DH	Displacement horizontal
DV	Displacement vertical
I_P	Plasticity index
F_c	Fines content
w	Water content
AP	Air pluviation
MT	Moist tamping
R^2	Coefficient of determination

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1 Introduction

The city of Chlef located in the north of Algeria 200 km from the capital Algiers and these areas have experienced a great seismic activity and an unstable region. This city has known several destructive earthquakes (1922, 1934, 1954 and 1980) [16]. Among these earthquakes is that of Friday, October 10, 1980 afternoon at 1:30 pm, it is the most disastrous earthquake experienced by the Chlef city with a magnitude of 7.2 on the Richter scale. Belkhatir et al. [11] reported that this event caused significant damage to civil and hydraulic structures near the epicenter of the earthquake. Part of the disorder was due to the liquefaction of the saturated alluvium of the foundation. Soil deformations associated with liquefaction such as lateral spreading, flow failure, ground fissures and subsidence, sand boils, and slope failures were observed. The epicenter of the earthquake was located 12 km away the east region of Chlef city (120 km west of Algiers) at latitude 36.143 ∘ N and longitude 1.413 ∘ E with a focal depth of about 10 km. The shear resistance of a soil is the principal parameter for evaluating the stability of building sites, so it is important to study the shear behaviour of sand subject to a risk of liquefaction (that is to say a loss of shear strength) like the city of Chlef. This resistance is a function of more parameters such us the relative density, the confining pressure, the overconsolidation ratio and the degree of saturation. However, the influence of the fines content and the method of preparation of the samples requires a thorough study. Various studies in the literature have largely evaluated the influence of the reconstitution method or the fines content but in an isolated manner on undrained behavior using the triaxial apparatus. Zlatovic and Ishihara [43] studied the stress-strain behaviour of loose Toyoura sand with several percent fines (0-100%) and three sample preparation methods, dry deposition (DD), moist placement (MP) and by water sedimentation (WS), it was demonstrated that peak resistance and residual strength are sensitive to variation in the fines content and the sample reconstitution method. For the samples prepared by dry deposition (DD) the void ratio increases with the increase of the fines content and consequently the resistance decreases. On the other hand for the samples prepared by moist tamping the void ratio decreases with the increase of fines content and the void ratio decreases and by therefore the resistance increases. While other authors, Benhamed et al. [12], Krim et al. [25], showed that the samples prepared by moist tamping (MT) have an unstable or metastable structure favoring the initiation and development of liquefaction, by against the method of dry deposition (DD) has a stable structure. Amini and Qi [2], Chang et al. [18] showed that sand resistance increases with the increase of fines content. While other researchers [4], [5], [10], [31], [32], [35] showed that the shear strength decreases with the addition of fines content. While others, Benghalia et al. [14], Bouferra and Shahrour [15] concluded that resistance decreases to a certain value of fines content and then tends to increase again. Recent research into the nature of soil structure and its mechanical stress-strain response indicates that the soil behaves as a collection of scale-level-dependent skeletons arranged in a particular manner ([39], [40]). However, many researchers have mentioned that the physical nature of silty sand is entirely different from clean sand ([2], [26], [33], [34], [38], [41], [42], [43]). They have recognized that the undrained shear strength (*Sus*) response depends effectively on the void ratio as a state parameter. It is also anticipated that the global void ratio (e) cannot represent the amount of particle contacts in the sand-silt soil sample mixture. As the void ratio and the proportion of coarse-grained and fine-grained soil change, the nature of their microstructures also changes. Due to a large grain-size distribution range and availability of voids larger than some grains, at low fines contents, some of the finer grains may remain inactive and swim in the void spaces without affecting or contributing to the force chain. Therefore, it is quite important to use new index parameters such as the inter-granular ([20], [29], [41]) and inter-fine ([20]) void ratios to assess the undrained residual shear strength response of sand-silt mixtures. Further investigations of the microstructure of soils including two sub-matrices (i.e. coarse-grain and fine-grain matrices) are therefore needed in order to gain insight into their influence on stress-strain and compression behaviour. It may be expected that soils or reconstituted mixtures with some amount of fines content would exhibit the behaviour of the dominant grain matrix. For fines content greater than 5%, the mechanical behaviour is dominated by fines contacts. The fines become activated and contribute to increase the resistance of the soil. Abhishek Rathnam et al. [1], Cfa et al. [17], Mohammad et al. [28], Monkul and Ozden [30], Najjar et al. [35], Rozalina and Ernest [36], Shanyoug et al. [37] concluded that the addition of fines in granular materials increases the cohesion and decreases the friction angle. The majority of this work investigated the influence of the sample preparation method, moist tamping (MT) w = 3% and dry deposition (DD) w = 0% on clean or natural sand or the impact of additional fines to the sand. First we will to study the influence of fines content on the shear strength of clean Chlef sand on dense state and medium dense state then the influence of water content (w = 0, 1, 2, 3%) on the shear strength and on the mechanical characteristics c and φ of clean sand and finally the influence of the preparation method on the shear strength of the sand-silt mixtures with a fines content 0, 10, 20, 30 and 40% and water content in the dry and the wet case.

2 Laboratory Test Program

2.1 Tested Materials

The tests were carried out on the sand of Oued Chlef (Chlef, Algeria), containing 0.5% of non-plastic silt with I_p = 5.02%. The sand was sieved to 0.08mm to obtain the fines, and then cleaned to obtain clean sand. The various parameters such as the maximum void ratio (e_{max}) (ASTM D4253 [7]) and the minimum void ratio (e_{min}) (ASTM D4254 [8]). The principal properties and the chemical analysis of the sand, the silt, and the sand-silt mixtures used in this laboratory research work are presented in Tables 1 and 2.

Table 1: Index properties of sand-silt mixtures.

Materials	F_c (%)	G_s	D_{10} (mm)	D_{50} (mm)	C_u	C_c	e_{min}	e_{max}
Clean sand	0	2.650	0.17	0.41	2.82	1.10	0.623	0.848
	10	2.653	0.08	0.38	5.28	1.70	0.487	0.811
Sand-silt mixtures	20	2.656	0.04	0.33	9.80	1.92	0.455	0.776
	30	2.659	0.03	0.32	13.31	0.84	0.421	0.749
	40	2.662	0.02	0.25	15.17	0.01	0.489	0.803
Chlef silt	100	2.667	-	0.03	-	-	0.593	0.783

The grain size distribution curve of clean sand, silt and sand-silt mixtures was obtained on the basis of ASTM D422-63 [6] standard are presented in Fig. 1. Various studies were carried out on the sand of Chlef, we cite some work of Arab et al. [4], Belkhatir et al. [10], Belkhatir et al. [11], Benssaleh et al. [13], Della et al. [21], Djafar Henni et al. [22], Hazout et al. [24], Mahmoudi et al. [27]. Clean sand was mixed with 10, 20, 30 and 40% fines to obtain a sand-silt mixtures. Figure 2 shows the photography of the sand, silt and sand-silt mixtures. Figure 3 shows the photography of clean sand and sand-silt mixtures prepared by the wet deposition method.

Table 2: Chemical analysis of tested materials [3].

Composition (%)	Chlef sand	Chlef silt
Fire loss	14.34	10.85
Total Silica (SiO_2)	55.89	48.95
Alumina (Al_2O_3)	5.58	34.08
Oxide of iron (Fe_2O_3)	7.58	1.43
Oxide of titane (TiO_2)	0.00	0.00
Lime (CaO)	15.42	0.20
Magnesia (MgO).	0.00	0.42
Potash (K_2O)	Traces	2.26
Oxide of sodium (Na_2O)	Traces	0.06
Sulfates SO_4	0.28	0.00
Chlorides CL-Solubles in water	0.14	0.00
Carbonates $CaCO_3$	24.60	0.00
Insolubles	0.53	0.00
Organic materials	0.00	0.00

2.2 Experimental Procedures

In order to study the influence of the fines content and the sample preparation method on shear strength, a total of 120 direct shear tests were carried out at three normal stresses 100, 200 and 400 kPa. Sixty (60) tests are performed in a medium dense state (RD = 65%) and sixty (60) in a dense state (RD = 80%). The tests were performed using a square direct shear box 60 x 60 mm^2. The initial sample height was 25 mm. The test consisted to placing a sample in the shear box and subjected it to a vertical load N that represented the normal stress applied (100, 200 and 400 kPa) and a horizontal load T which was gradually increased. The direct shear test allowed measuring the peak and residual shear strength corresponding to every normal stress. All samples were prepared in three layers by compaction a known mass of the materials studied in the direct shear box to reach target void ratio (already calculated). The samples were prepared at four water contents w = 0, 1, 2 and 3% and at two relative densities (RD = 65% and 80%) under three normal stresses 100, 200 and 400 kPa. Two methods were used to reconstitute the sample, the dry deposition and the wet deposition methods. In the wet deposition method, the dry sand was mixed thoroughly with a water content of w = 1, 2 and 3% until a homogeneous soil sample was obtained. In the dry deposition method, the sand was deposited in the dry state (w = 0%). To achieve the two relative densities, the sample was divided into three layers. Each layer was compacted to achieve the dense state (RD = 80%), however, no compaction was necessary to achieve the medium dense state (RD = 65%), so only the sample surface was levelled off. All the tests were conducted at constant displacement rate of 1.00 mm/min according to ASTM D3080 [9]. The shear stress was recorded as a function of horizontal displacement up to an average shear strain of 7.5 mm.

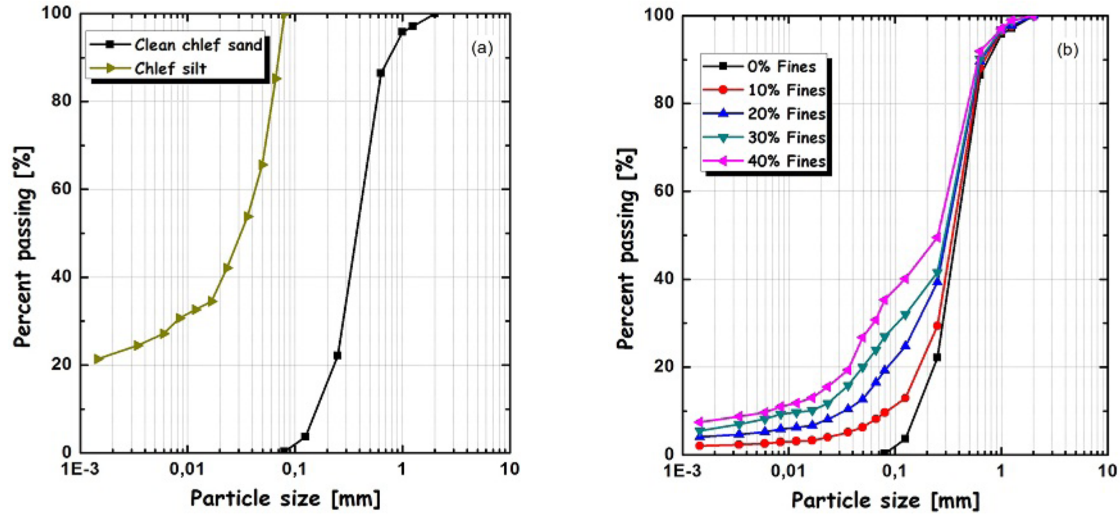

Figure 1: Grain size distribution curves of tested materials: (a) Sand and silt, (b) Sand-silt mixtures.

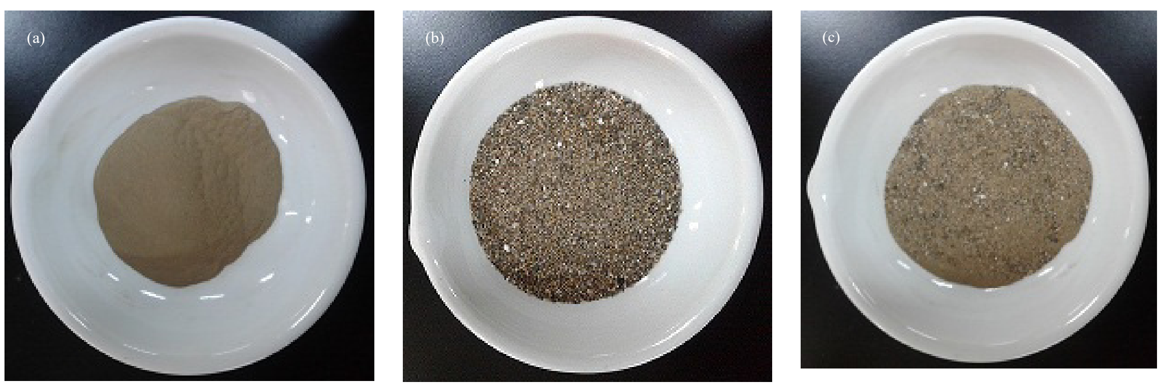

Figure 2: Materials used in this study: (a) fines content, (b) clean sand, (c) samples prepared by dry deposition sand-silt mixtures.

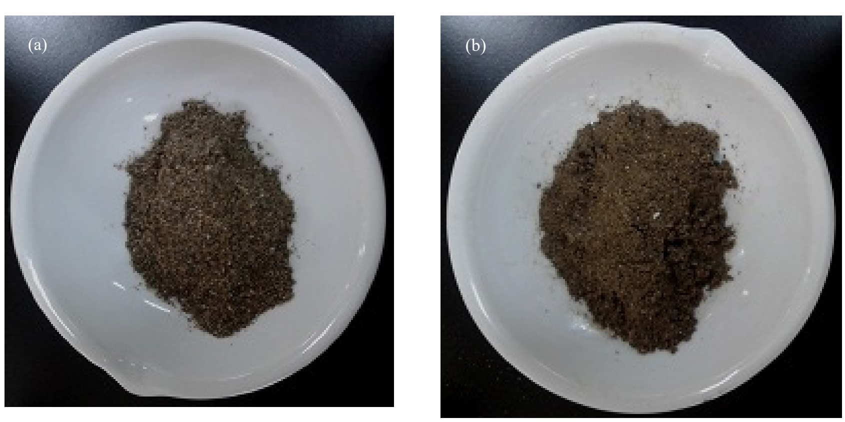

Figure 3: Samples prepared by wet deposition: (a) clean sand, (b) sand-silt mixtures.

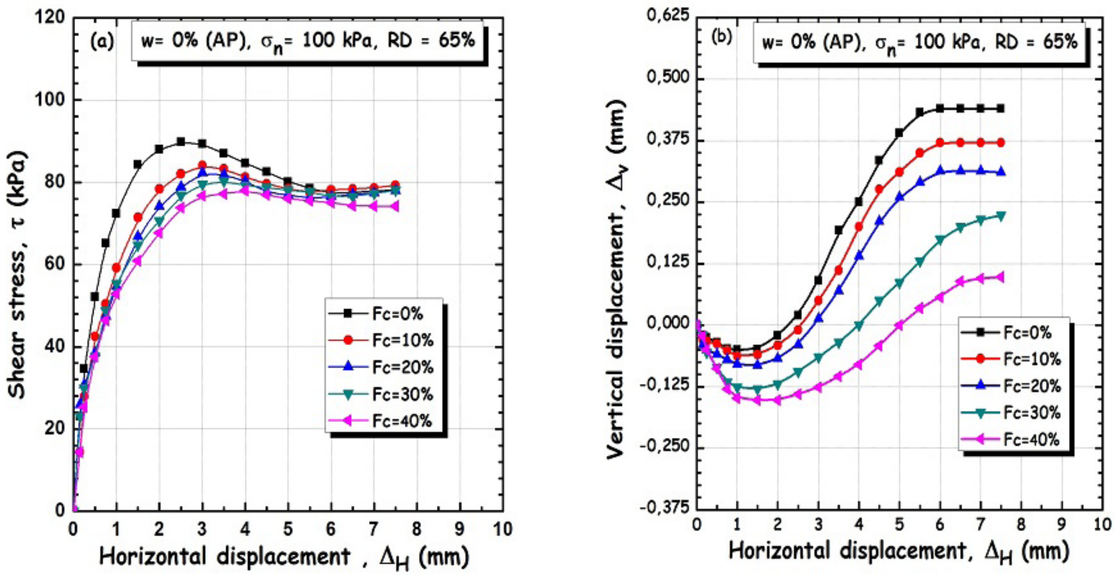

Figure 4: Effect of fines content on the mechanical behaviour of sand-silt mixtures (RD = 65%, σ_n = 100 kPa): (a) variation of the shear strength versus horizontal displacement, (b) variation of vertical displacement versus horizontal displacement.

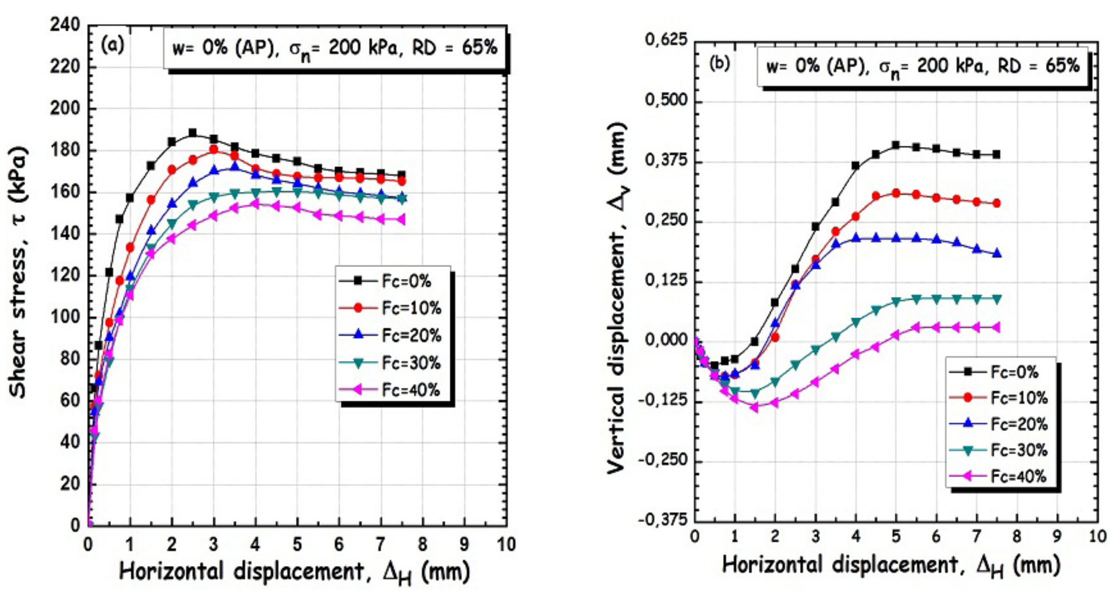

Figure 5: Effect of fines content on the mechanical behaviour of sand-silt mixtures (RD = 65%, σ_n = 200 kPa): (a) variation of the shear strength versus horizontal displacement, (b) variation of vertical displacement versus horizontal displacement.

3 Test Results And Discussion

3.1 Effect Of Fines Content, Density And Normal Sytress In The Dry State

The effect of fines content on the shear strength of Chlef sand in dense state (RD = 80%) and medium state (RD = 65%) sand was investigated as constituting five sand-silt mixtures F_c = 0, 10, 20, 30 and 40% under three normal stresses 100, 200 and 400 kPa. Figures 4a, 5a, 6a, 7a, 8a and 9a, illustrates the influence of the fines content on the shear strength of sand for w = 0%, it is noted that the maximum resistance decreases with the increase of the fines content these results are in good agreement with the results published in the literature on Chlef sand ([4], [5], [10], [11], [19]). The three samples with 0, 10 and 20% of the fines shows an increase of the shear resistance up to 2 mm and 2.5 mm of deformation then the resistance tends to decrease and stabilizes at 5 mm deformation. While the samples with 30% and 40% of the fines content

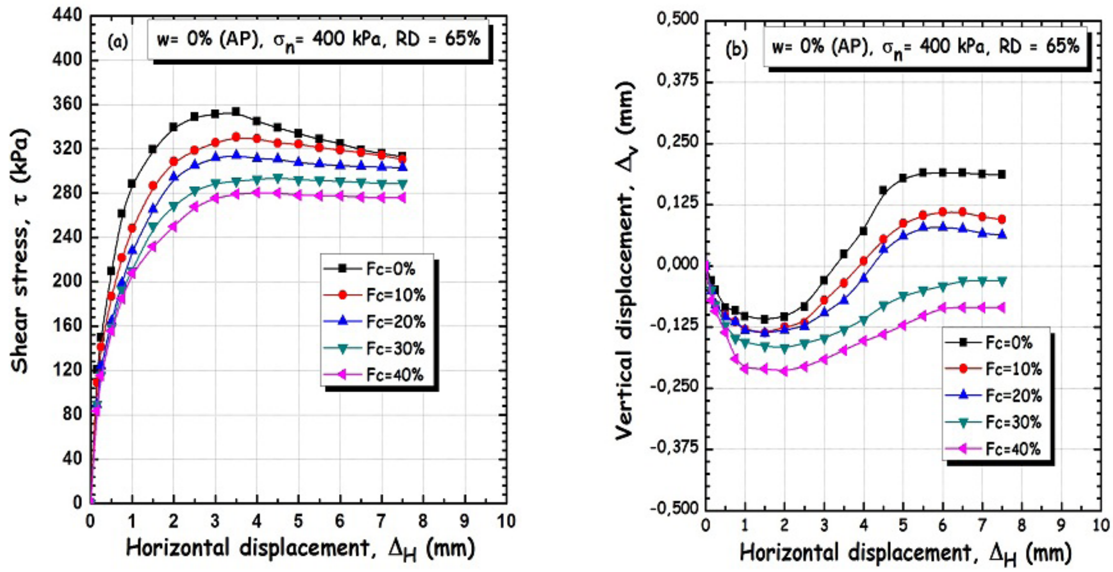

Figure 6: Effect of fines content on the mechanical behaviour of sand-silt mixtures (RD = 65%, σ_n = 400 kPa): (a) variation of the shear strength versus horizontal displacement, (b) variation of vertical displacement versus horizontal displacement.

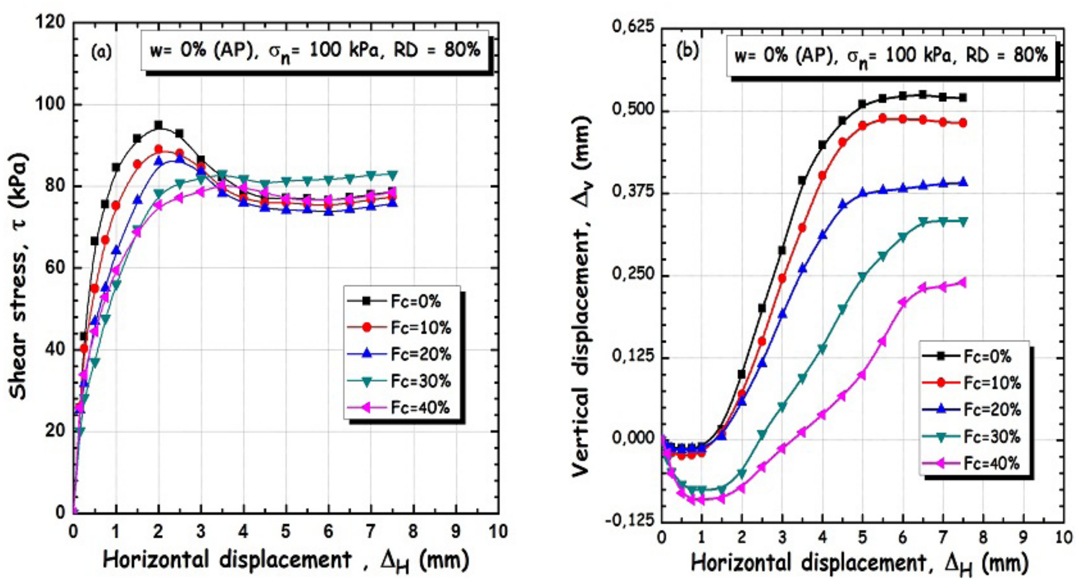

Figure 7: Effect of fines content on the mechanical behaviour of sand-silt mixtures (RD = 80%, σ_n = 100 kPa): (a) variation of the shear strength versus horizontal displacement, (b) variation of vertical displacement versus horizontal displacement.

have a small peak of resistance for deformations greater than 3 mm due to the increase in the amount of fines in the sand. Figures 4b, 5b, 6b, 7b, 8b and 9b show the vertical displacement versus the horizontal displacement. It is very clear that the increase of the relative density decreases the contractancy phase and increases the dilatancy phase whereas the increase of the normal stress increases the contractancy phase and reduces the dilatancy phase. Theses figures show that the increase in the fines content increases the contractancy phase and reduces the dilatancy phase due to the role of the fines content in amplification the contractancy phase and the five samples show a contractancy phase during small deformations (0 to 2 mm) followed by a dilatancy phase for large deformation (2 mm to 7.5 mm).

Figures 10a and 10b illustrate the Mohr-Coulomb failure line that represents the relationship between the maximum shear stress (t_{max}) and the normal stress (s_n) according to the following expression:

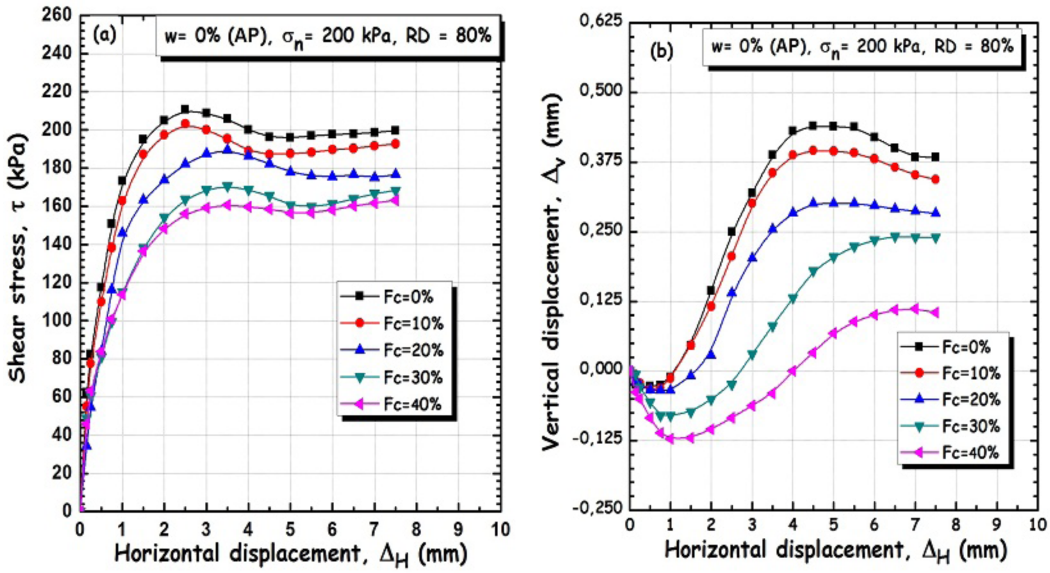

Figure 8: Effect of fines content on the mechanical behaviour of sand-silt mixtures (RD = 80%, σ_n = 200 kPa): (a) variation of the shear strength versus horizontal displacement, (b) variation of vertical displacement versus horizontal displacemen.

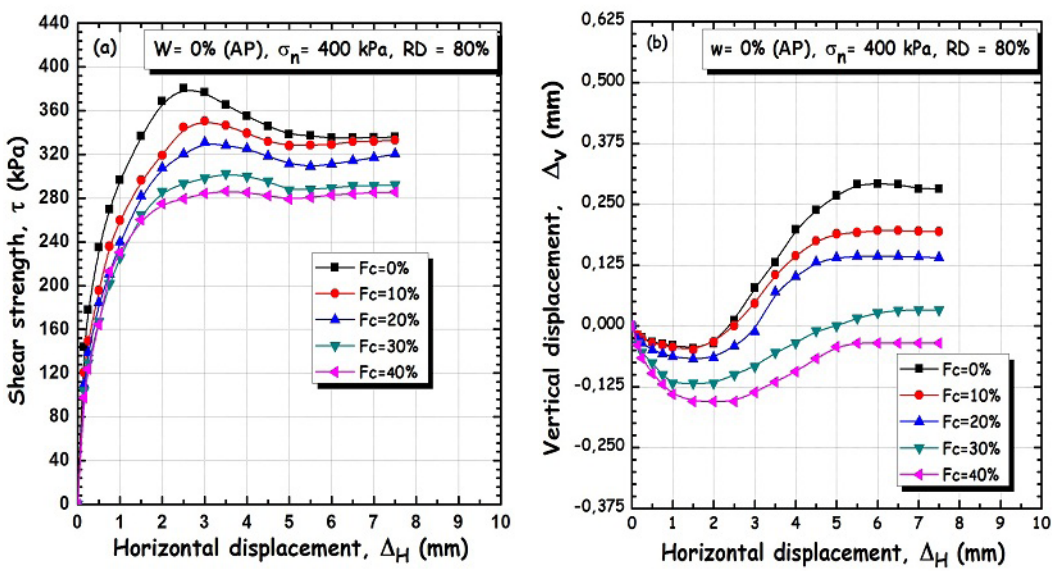

Figure 9: Effect of fines content on the mechanical behaviour of sand-silt mixtures (RD = 80%, σ_n = 400 kPa): (a) variation of the shear strength versus horizontal displacement, (b) variation of vertical displacement versus horizontal displacement.

$$t_{max} = s_n \, tgj + c \qquad (1)$$

Where c and j are the cohesion and the internal friction angle, respectively.

From these figures, it is possible to evaluate the mechanical characteristics c and φ. It is observed for the sand with medium dense state (RD = 65%) and the dense state (RD = 80%) that the slope of the failure line has a greater value 0.89 and 0.97 and this slope decrease with the increase of the fines content. Another observation was observed in this study, the difference between the resistances increases with the increase of the normal stress, that is to say the influence of the fines fraction becomes more pronounced at a great normal stress. Figures 11a and 11b present the mechanical parameters of sand versus the fines content. It is observed from these figures that the increasing of fines content from 10% to

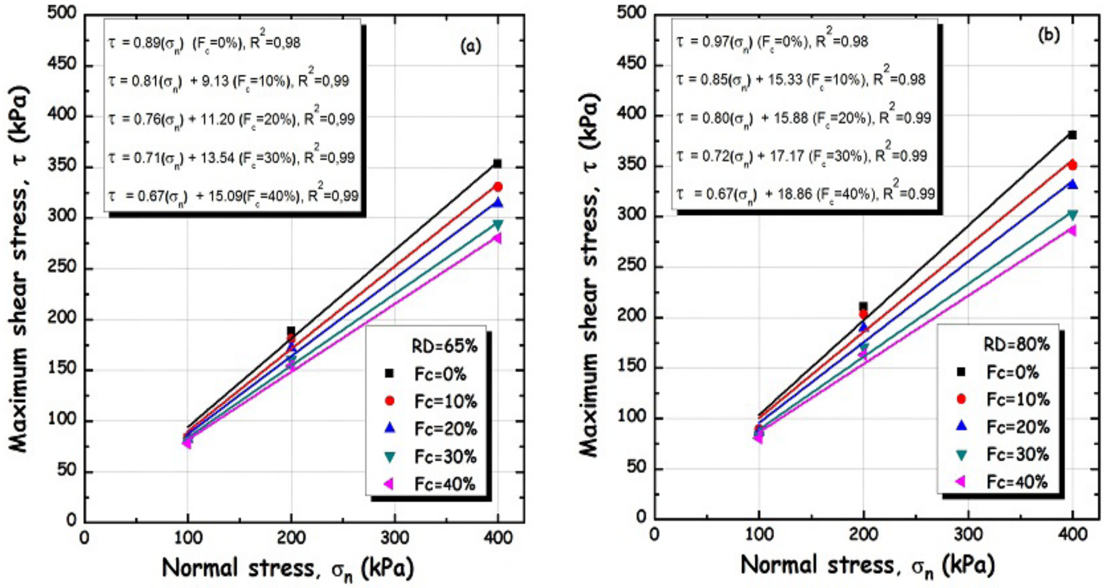

Figure 10: Effect of fines content on the mechanical behaviour of sand: Maximum shear stress versus normal stress.

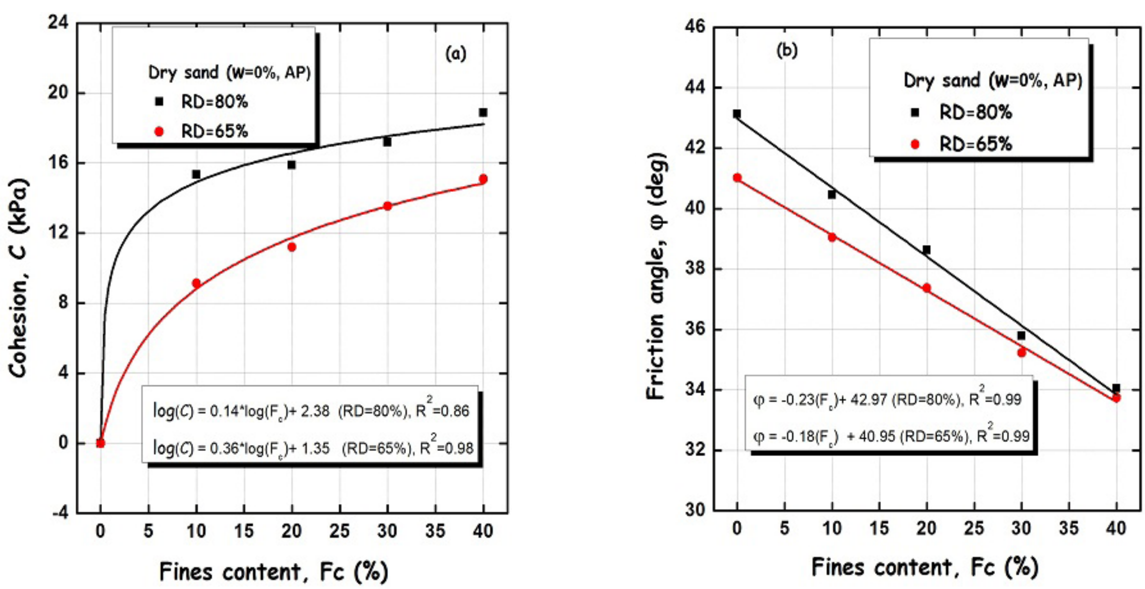

Figure 11: Effect the fines content on the mechanical characteristics of (clean) sand, (a) cohesion versus fines content, (b) friction angle versus fines content.

40% leads to increase in the cohesion in logarithm manner from 0 to 15.09 kPa for the medium dense sample and from 0 to 18.86 kPa for the dense sample, and the angle of friction decrease in linear manner from 41.67° to 33.82° for the medium dense sample and from 44.13° to 34.05° for the dense sample, the values of the cohesion and the friction angle are illustrated in Table 3. Our tests result are in good agreement with those found by Flitti et al. [23] where the cohesion of Chlef sand-silt mixtures increases and the friction angle decreases with the increase of the fines content ([4]).

3.2 Effect Of Water Content On The Clean Sand

Figures 12a and 13a illustrate the variation of shear stress versus horizontal displacement under shear stress of 200 kPa and two relative densities 65% and 80%. It is very clear that shear strength decreases with the increase the water content from 0 to 3%. For the sample with a water content of 0, 1 and 2% the resistance increases to a value between 2.5 mm and 3.5 mm deformation, then this resistance tends to decrease to a minimum value. For

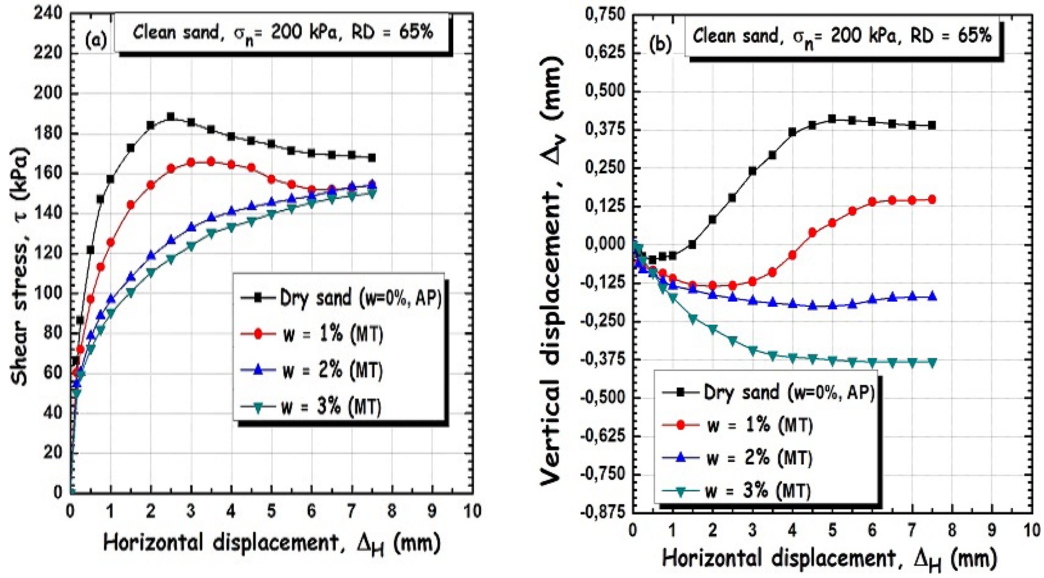

Figure 12: Effect of water content on the mechanical behaviour of clean sand (RD = 65%, σ_n = 200 kPa): (a) variation of the shear strength versus horizontal displacement, (b) variation of vertical displacement versus horizontal displacement.

Table 3: Cohesion and friction angle for tests result.

Material	Fc (%)	RD (%)	c (kPa)	j (°)
	0	65	0	41.67
Clean sand		85	0	44.13
	10	65	9.13	39.01
		80	15.33	40.36
	20	65	11.20	37.23
Sand-silt mixtures		80	15.88	38.66
	30	65	13.54	35.37
		80	17.17	35.75
	40	65	15.09	33.82
		80	18.86	34.05

the sample with 3% of water content the behaviour of the dense sand behaves in the same manner as dry loose sand which the mobilized shear stress increases continuously with the increase of horizontal displacement for the three normal stresses. Figures 12b and 13b illustrate the vertical displacement versus the horizontal displacement, these figures show that the increase in the water content has a very clear influence on the volume behaviour, the samples with 0 and 1% of water content show a contractancy phase followed by a dilatancy phase while samples with 2 and 3% water content present only the contractancy phase due to the increase in the water content in the soil.

Figures 14a and 14b illustrate the Mohr-Coulomb failure line that represents the maximum shear stress versus the normal stress. From these figures, it is possible to evaluate the mechanical characteristics c and φ. It is observed that the slope of the failure line is very important for the dry sand and decrease with the increase of the water content and the shear resistance increases with the increase of the normal stress. Figure 15 shows that friction angle decreases linearly from 41.67° to 36.13° for the dense sample with a relative density of 65%, for a relative density of 80% the friction angle decreases from 44.13° to 37.23°, the value of the cohesion and the friction angle are shown in Table 4. The decrease in the friction angle for the two relative densities is due to the presence of water between the grains of the sand and the amount of water creates instability between the grains of the sand.

Figures 16a and 16b show the influence of the water content on the maximum shear strength, the results show that the samples prepared by a relative density RD = 80% gives a greater resistance than of RD = 65% and the maximum shear stress decrease linearly with the increase of water content according to the following expression:

$$t_{max} = A(w) + B \quad (2)$$

The results show that the coefficient A decrease with the increase of the density and the normal stress, and against the coefficient B increase with the increasing of the density and the normal stress. The coefficient A and B are presented in Table 5.

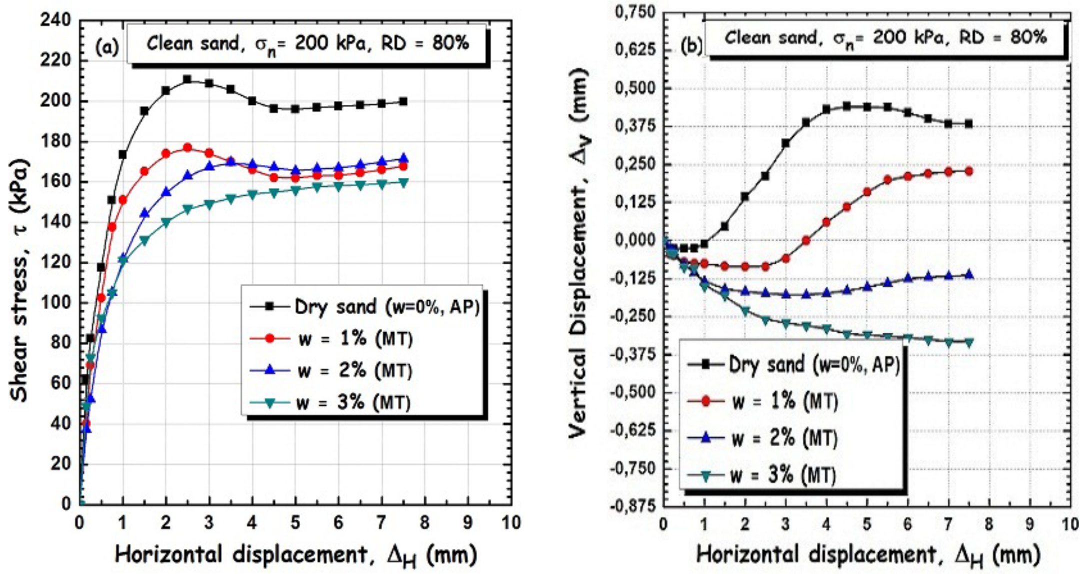

Figure 13: Effect of water content on the mechanical behaviour of clean sand (RD = 80%, σ_n = 200 kPa): (a) variation of the shear strength versus horizontal displacement, (b) variation of vertical displacement versus horizontal displacement.

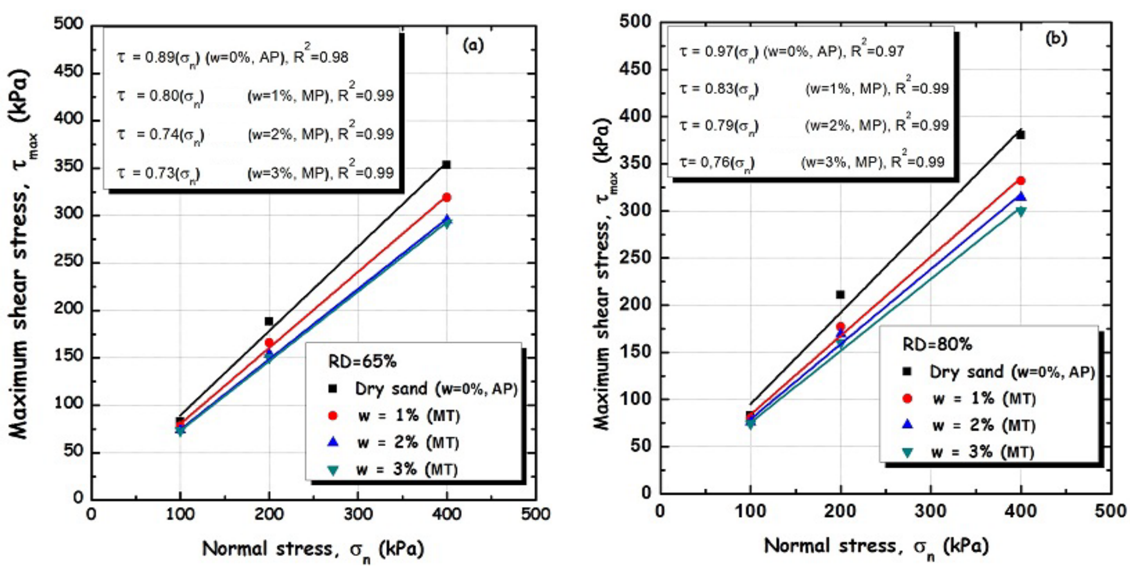

Figure 14: Effect of water content on the mechanical behaviour of clean sand: Maximum shear stress versus normal stress.

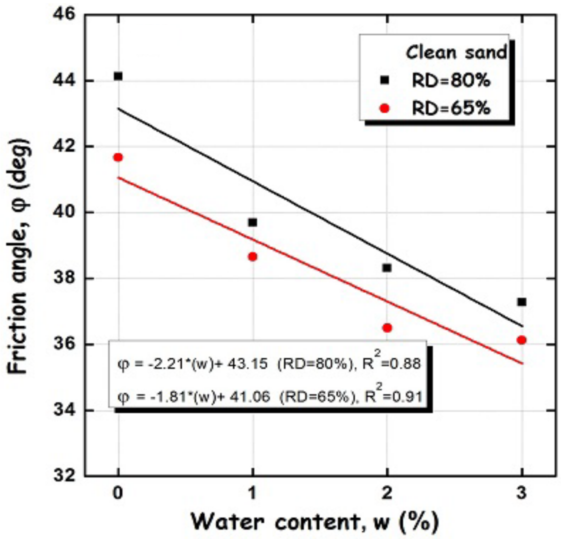

Figure 15: Effect of water content on the friction angle versus water content of clean sand.

3.3 Difference Between The Effect Of The Fines Content In The Wet State And The Dry State

Figures 17a, 17b, 19a and 19b show the difference between the effect of the fines content on shear strength in the wet and dry state. It is observed that the behaviour in the wet state is similar at the behaviour of loose dry sand, the shear strength of fines fraction from 0 to 40% in the dry state is greater than the samples prepared in the wet state with w = 3%, this difference in shear strength due to the increase of the amount of water content in the soil used in this study, in addition the effect of fines content in dry sand and 3% of water content decrease the strength of the sand-silt mixtures. It is observed that increasing the relative density from 65% to 80% increases the shear strength. The effect of adding 3% water content for sand-silt mixtures varies between F_c = 0 to 40% is presented in Figures 18a, 18b, 20a and 20b. It is noted that the mixture of sand and silt prepared in the dry state (w = 0%) has a small contractancy phase followed by a dilatancy phase, while the same samples prepare at w = 3% of water content and with F_c = 30 and 40% of fines content presented as the contractancy phase due to increase the amount of water in the mixtures.

Figures 21a and 21b show the Mohr-Coulomb failure line that represents the maximum shear stress versus the normal stress. It is noted that increasing the water content in sand-silt mixtures decreases the mechanical characteristics c and φ, however the addition of the water content in the clean sand decreases the mechanical

Table 4: Cohesion and friction angle for test result.

Material	w (%)	RD (%)	c (kPa)	j (°)
	0	65	0	41.67
		85	0	44.13
	1	65	0	38.66
Clean sand		80	0	39.69
	2	65	0	36.50
		80	0	38.31
	3	65	0	36.13
		80	0	37.23

Table 5: Coefficients A, B and R^2 for equation (2).

s_n (kPa)	RD (%)	A	B	R^2
100		-5.221	88.869	0.94
200	65	-12.52	183.33	0.90
400		-20.73	345.97	0.89
100		-6.83	94.153	0.98
200	80	-15.94	203.42	0.87
400		-25.48	370.26	0.90

characteristic c and φ, 3% of water content influences in a significant manner on the mechanical characteristics of the sand-silt mixtures for a range varies between 0 and 40% of silt.

Figures 22a and 22b illustrate the influence of fines on the maximum shear strength, the results show that the samples prepared by the air pluviation method (AP) gives greater resistance than the samples prepared by the moist tamping method (MT), it is very clear that the maximum resistance decreases in a linear manner with the increase of the fines content according to the following expression:

$$t_{max} = A(F_c) + B \qquad (3)$$

Tables 6 and 7 illustrate the coefficients A, B and the corresponding coefficient of determination (R^2) for the Chlef sand-silt mixtures for the moist tamping method and the air pluviation method.

3.4 Difference Between The Air Pluviation And Moist Tamping Method

The difference between the method of sample preparation, moist tamping and air pluviation is illustrated in Figures

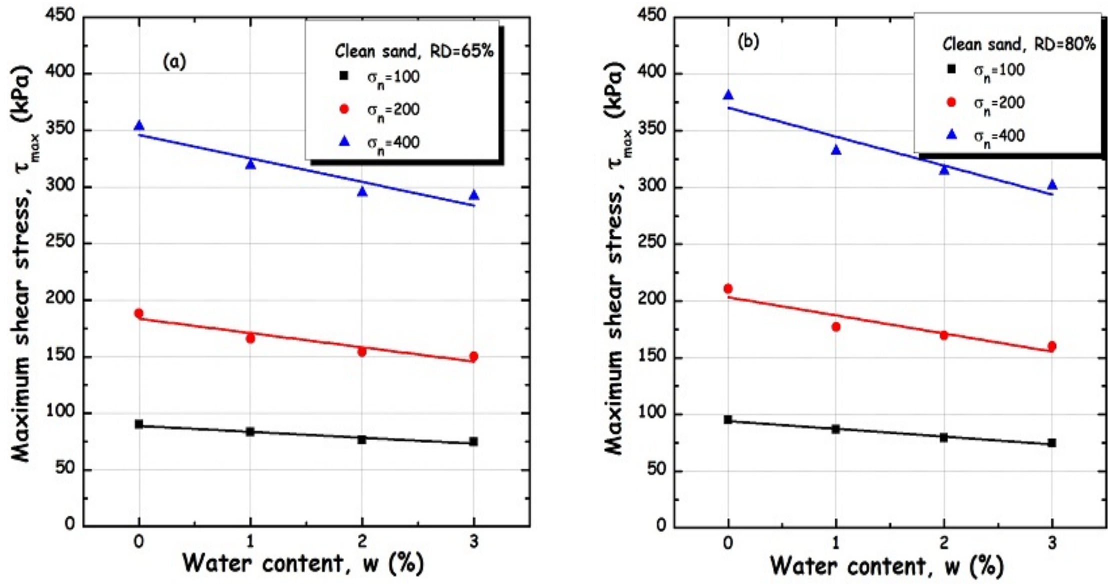

Figure 16: Effect of water content on the mechanical behaviour of clean sand: (a) RD = 65%, (b) RD = 80%.

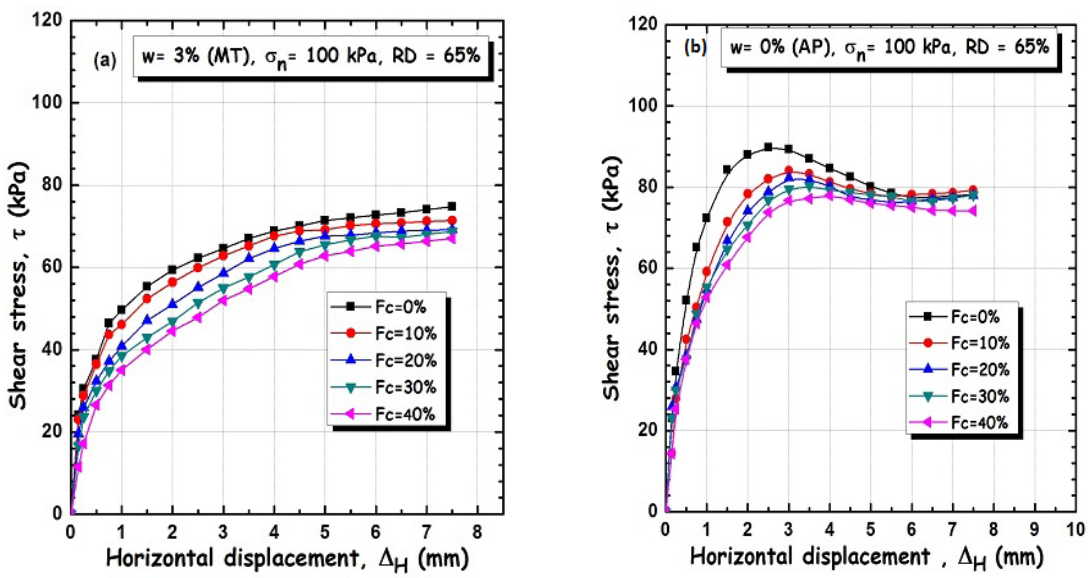

Figure 17: Effect of fines content on the mechanical behaviour of sand-silt mixtures (RD = 65%, σ_n = 100 kPa): (a) variation of the shear strength versus horizontal displacement (w = 3%), (b) variation of the shear strength versus horizontal displacement (w = 0%).

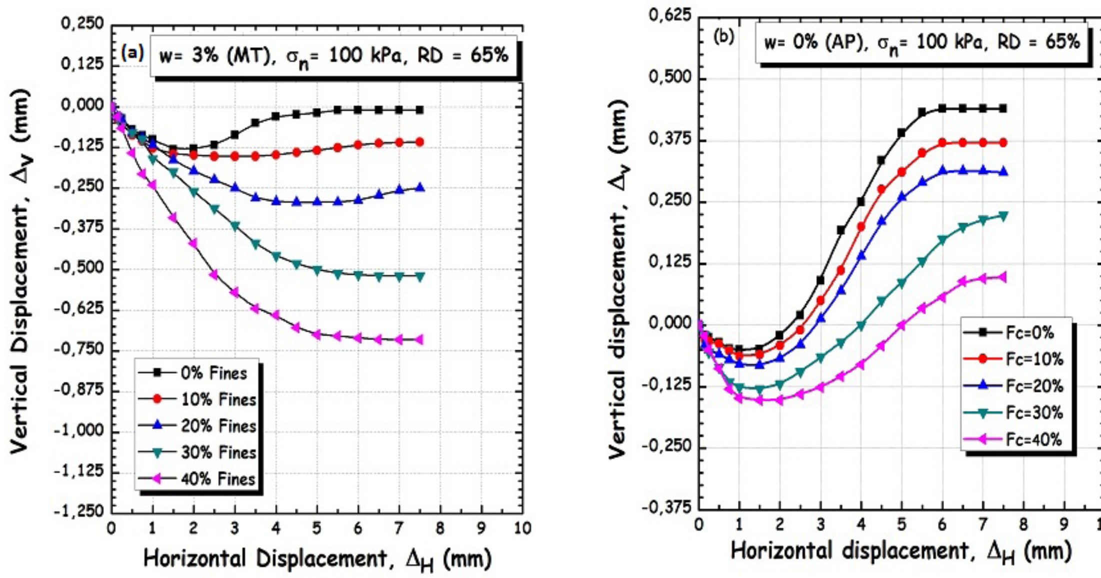

Figure 18: Effect of fines content on the mechanical behaviour of sand-silt mixtures (RD = 65%, σ_n = 400 kPa): (a) variation of vertical displacement versus horizontal displacement (w = 3%), (b) variation of vertical displacement versus horizontal displacement (w = 0%)

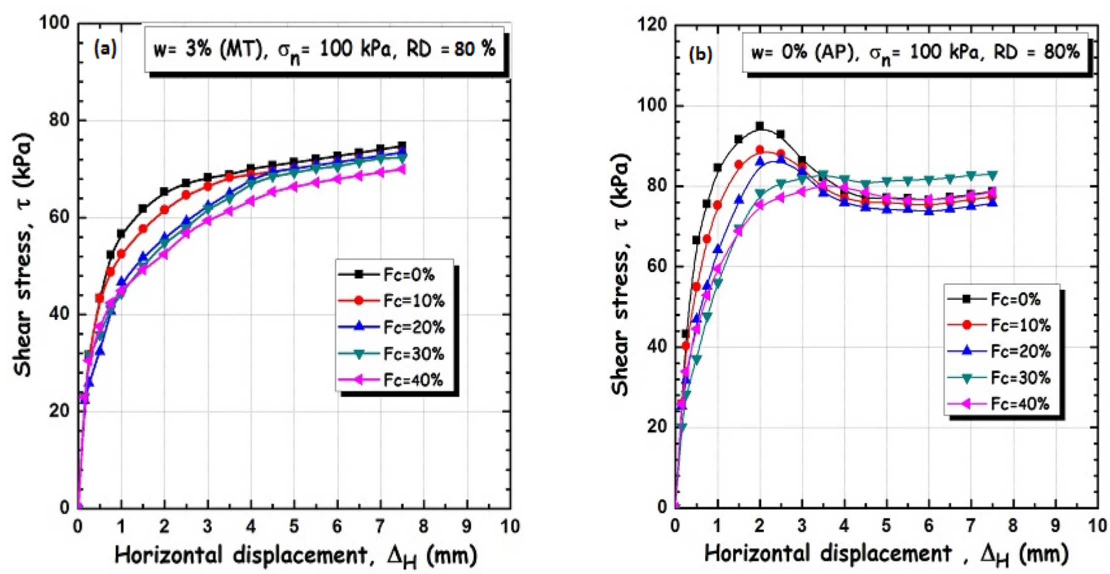

Figure 19: Effect of fines content on the mechanical behaviour of sand-silt mixtures (RD = 80%, σ_n = 100 kPa): (a) variation of the shear strength versus horizontal displacement (w = 3%), (b) variation of the shear strength versus horizontal displacement (w = 0%).

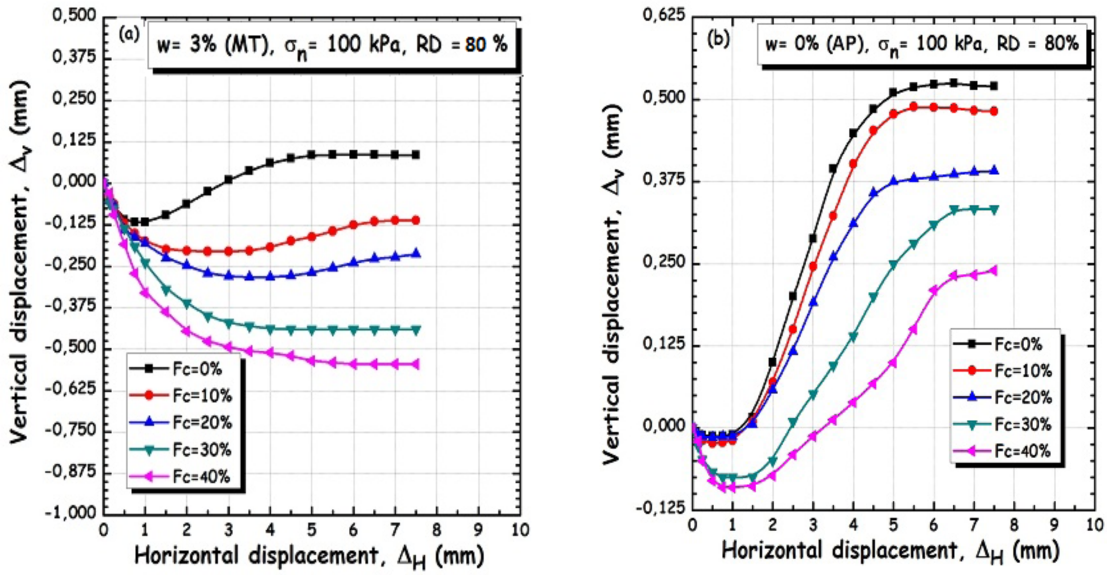

Figure 20: Effect of fines content on the mechanical behaviour of sand-silt mixtures (RD = 80%, σ_n = 400 kPa): (a) variation of vertical displacement versus horizontal displacement (w = 3%), (b) variation of vertical displacement versus horizontal displacement (w = 0%)

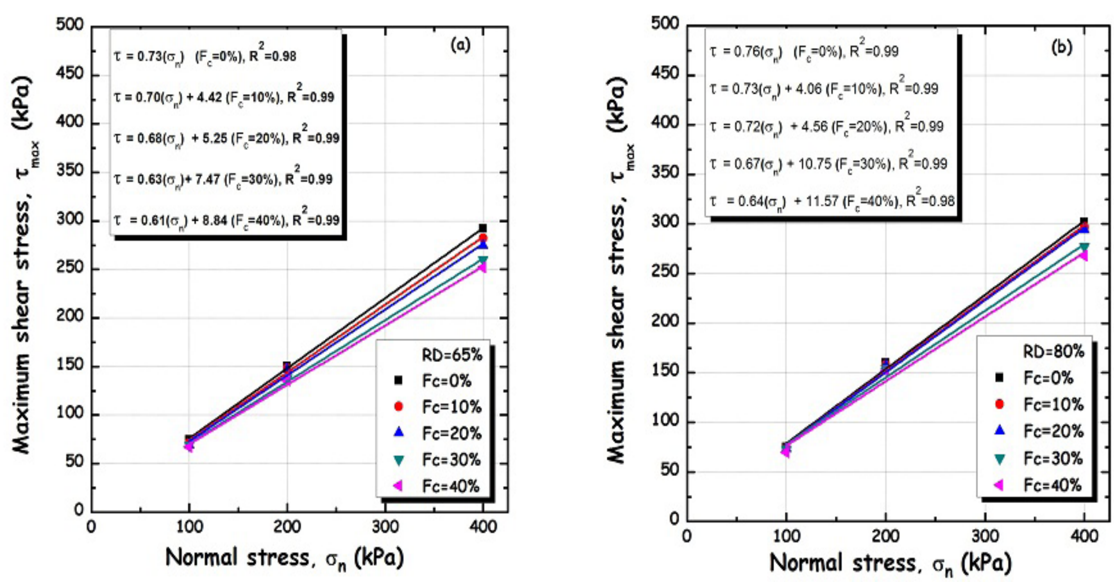

Figure 21: Effect of fines content on the mechanical behaviour of sand-silt mixtures: Maximum shear stress versus normal stress (w = 3%).

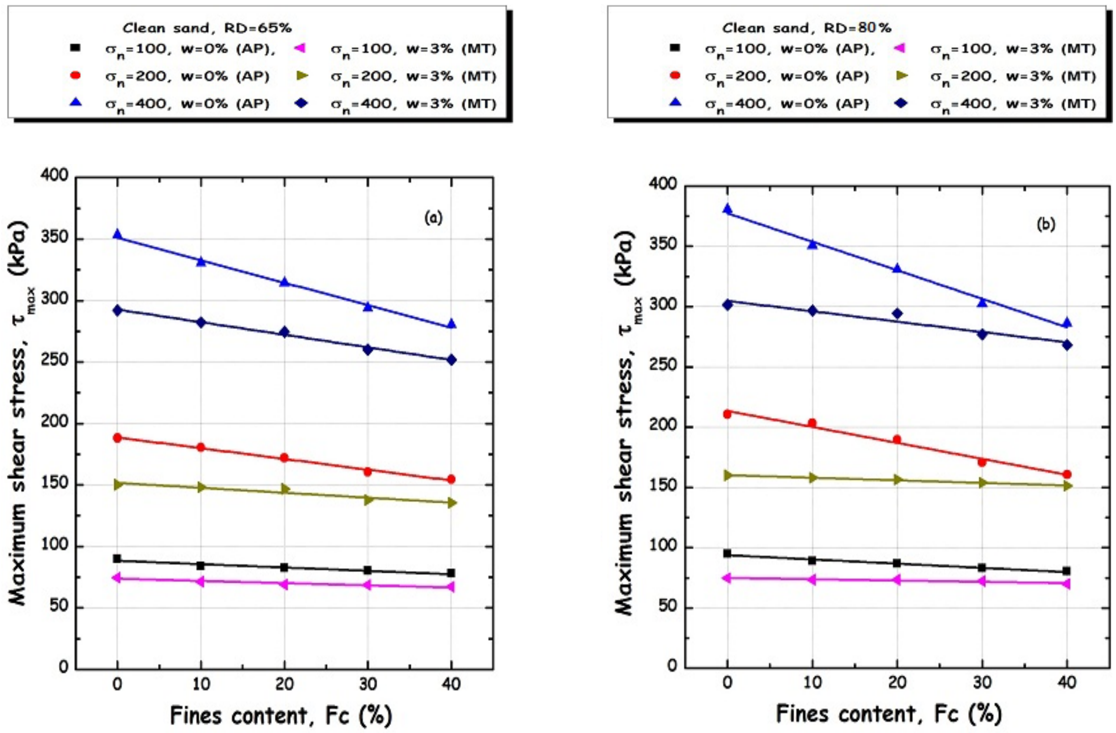

Figure 22: Effect of depositional method on the mechanical behaviour of clean sand: (a) RD = 65%, (b) RD = 80%.

Table 6: Coefficients A, B and R^2 for equation (3) (RD = 65%).

s_n (kPa)	Preparation method	A	B	R^2
100		-0.274	88.4	0.93
200	Air pluviation (AP)	-0.875	188.68	0.99
400		-1.823	350.92	0.99
100		-0.179	73.794	0.92
200	Moist tamping (MT)	-0.400	151.71	0.90
400		-1.024	292.67	0.99

Table 7: Coefficients A, B and R^2 for equation (3) (RD = 80%).

s_n (kPa)	Preparation method	A	B	R^2
100		-0.351	93.826	0.97
200	Air pluviation (AP)	-1.325	213.47	0.98
400		-2.366	377.46	0.99
100		-0.106	74.932	0.88
200	Moist tamping (MT)	-0.214	160.2	0.98
400		-0.860	304.74	0.91

23a and 23b, it is noted that the shear strength of clean sand increases with increasing density and confining pressure. The air pluviation method gives greater strengths compared to the samples prepared by the method of moist tamping. The samples prepared by the air pluviation method show a peak of resistance between 2 and 3.5 mm of horizontal displacement while the samples prepared by the moist tamping method do not show a peak of resistance and the clean sand behaves the same behaviour of dry loose sand.

4 Conclusions

This paper presents the effect of water content, fines content, density and normal stress on the shear strength, volume change and mechanical parameters c and φ of Chlef sand. Based on the results of the experimental data the following conclusions were obtained:

The increase of the fines content (F_c) from 0 to 40% induces a reduction in the maximum shear strength and the dilatancy of the Chlef sand and increases the contractancy phase. The friction angle decreases from 41.67° to 33.82° for the medium dense sample and from

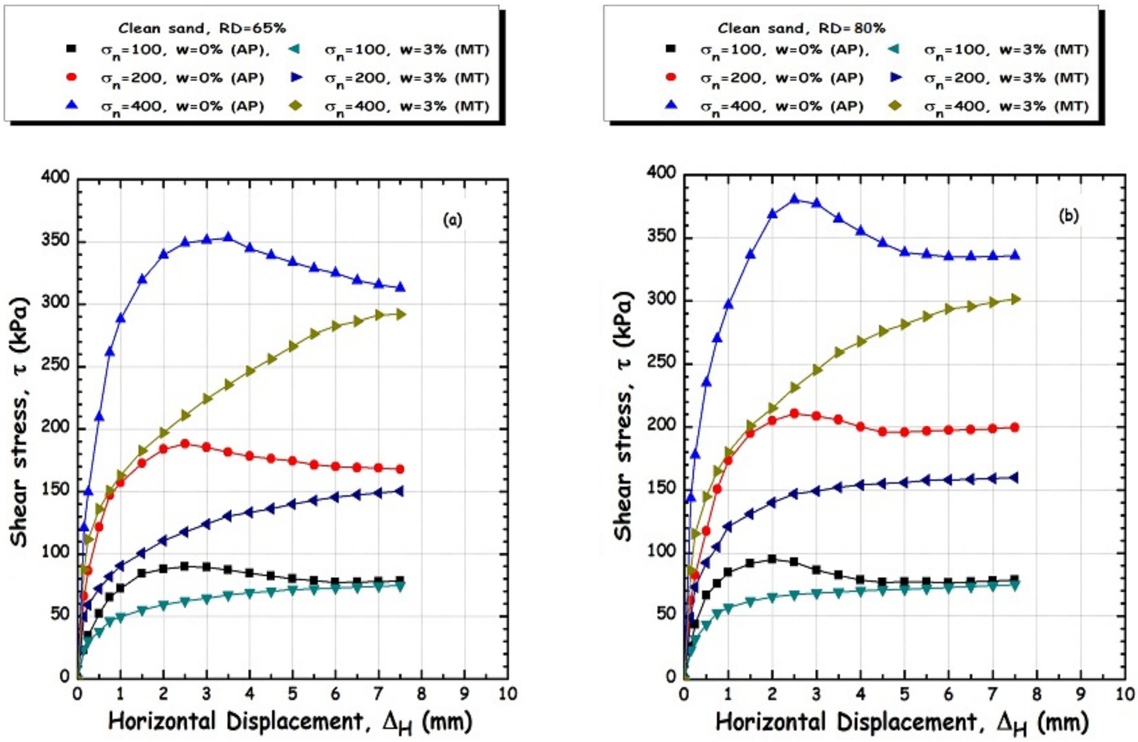

Figure 23: Effect of the depositional method on the mechanical behaviour of clean sand: (a) variation of the shear strength versus horizontal displacement (RD = 65%), (b) variation of the shear strength versus horizontal displacement (RD = 80%).

44.13° to 34.05° for the dense sample while the cohesion increases from 0 to 15.09 kPa for the sample medium dense and from 0 to 18.86 kPa for the dense sample.

The water content (w) has a very significant influence on the shear strength of Chlef sand, the increase of the water content very clearly reduces the resistance of Chlef sand and the friction angle (j) and decreases the cohesion (c) for the two relatives densities. For RD = 65%, the friction angle was decreases from 41.67° to 36.13°, whereas for RD = 80%, the friction angle decreases from 44.13° to 37.23°.

It is very clear that the effect of the combination of fines content-water content has a negative effect on the mechanical behaviour on the sand-silt mixtures used in this study and on the mechanical characteristics c and φ, according to the results found, the fines fraction becomes more pronounced at high normal stress and in the dry state w = 0%.

The maximum resistance decreases in a linear manner with the increase of the water content and the fines content.

The shear strength increases with the increase the relative density and the normal stress, and mechanical parameters c and φ are improved with an increase in density from 65% to 80%. The influence of the fraction of the fines and the water content becomes more pronounced at great normal stress.

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