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RESEARCH ARTICLE

Experimental Characterization of the Hydromechanical Properties of the Gypsum Soil of Sebkha of Oran

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Abstract
This paper deals with hydro-mechanical investigation of saline gypsum soil properties from Sebkha of Oran in respect with their impact on the feasibility of the project of the second runway of the Es-Sénia airport in Oran (Algeria). The geological and in-situ geotechnical studies prior to the construction phase of the airport runway revealed underground cavities supposed to be created from salts and gypsum dissolution in the Sebkha soil. Standard laboratory experiments are used to determine permeability coefficient, isotherm curve, shear resistance and elastic parameters of two soils. These ones are affected by the variation of water table level that varies according to the dry period (summer) or the rainy period (winter), creating cyclic hydric conditions. The paper presents a comparison of parameters of these two soils in saturated and partially saturated conditions. The results of tests performed in laboratory are compared with those performed in situ in order to check their representativeness before a detailed comparison of the effect of water conditions. The two soils have similar behavior highly sensible to water with some particularities.

Keywords
saline soils, runways, cavities, permeability, saturated, partially saturated hydromechanical, capillary

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1 Introduction

The presence of soluble salts or exchangeable sodium or both in soils is one of the most severe environmental problems that could seriously impacts the stability of geotechnical constructions. This problem is faced in many countries in the world under different climatic conditions and more significantly in the arid and semi-arid regions. Generally, the soil salinity-sodicity in these regions is caused by several factors: geological effects, climatic conditions and groundwater movement with considerable potential evaporation and limited rainfall. Saline and sodic soils are constituted by excessive levels of soluble salts and sodium adsorbed at the cation exchange sites [1], [2]. This saline and sodic character affect negatively plant growth and causes the degradation of the soil structure and consequently procures them unfavorable physical properties. Then, it is important to evaluate the properties of these soils and the nature of the resulting problems for civil engineering structures projects where the stability, durability and safety concerns are omnipresent. It is also essential to understand the soil behavior, identify the interaction of different conditions in order to diagnose these complex mechanisms and anticipate engineering techniques in design step to avoid structure problems.

Several recent works are published on the mechanisms responsible for the salinity of soils including various experimental programs for identification of kinetics exchange of substances and the gypsum solubility in aqueous systems (Morse and Arvidson 2002, Loos et al. 2004, Gledhill and Morse 2006a, 2006b and Finneran and Morse 2009), or evaluation of soil salinity [7] for Chaco-Canyon soil and [8] for a soil salinity problem in Brazil.

Lu and co-authors [9] investigates the hysteresis phenomenon in the hydrologic and mechanical properties of partially saturated soils. They show that the soil-water retention curve, hydraulic conductivity function, and suction stress characteristic curves are intrinsically related. The permeability coefficient is the most variable soil property and represent an important parameter to examine the sodic effect on the water infiltration of the soil. (Nagy et al. 2013) proposed different testing method of permeability coefficient and show its variability also in the case of homogeneous layers. Other authors are interested to the study of the suction like an important parameter to making the difference between the behaviour of saturated and unsaturated soils [10].

The present investigation aims to the characterization of the geotechnical properties of the two soils layers from ground of Oran airport runway in order to establish on the one hand a set of parameters for a thermohydromechanical model used to numerical prediction of the bahaviour of the ground with the presence of the cavity and on the other hand examine the effect of saline-sodic character on the soil properties. For this purpose, a number of laboratory tests are carried out on reconstituted (at optimum modified Proctor water content and density) soil samples to measure key hydromechanical parameters.

The triaxial compression test at various confining pressure is used to identify the shear behavior of the Sebkha soils.

In saturated conditions, the water permeability is identified using tests at constant hydraulic head. In addition, the isotherm sorption curve is identified in unsaturated conditions by using the gravimetric and salt solutions method in both wetting path (during the saturation of samples) and drying path (during the sample drying). Measuring the sample mass evolution during water uptaking or drying the relative permeability is also identified by a procedure based on the inverse method proposed in [11].

2 Materials and testing methods

2.1 Soil and Site Description

This work is devoted to an experimental study of the ground soils of the second runway of the Es-Senia airport in Oran (Algeria), built on a very complex hydro geotechnical site with soils characterized by high content of soluble salts, gypsum and sodium [12] [13]. The level of the salt water table varies seasonally from 1m under the surface (in the case of heavy rainfall) to 4 meters in depth during the dried season impacting by this variability the properties of the ground soils and consequently the stability of the runway [12] and [13].

In this hydrogeological context of the site, several parameters may be at the origin of the appearance of underground cavities in different sizes and depths (Fig. 1). Among possible origin the dissolution of anhydrite or gypsum layers, washing of salts, or the dissolution of carbonates and limestone by the table water are evoked. This dissolution can procreate numerous human and material damages, especially toward the risk for the collapse of the constructions built on the surface such as the landing strips for planes.

Fig. 1 Various cavities detected in Es-Senia airport site.

It is found from geological studies that basically, two layers are affected by the variation of the water table being susceptible to lead to creation of cavities. Therefore, the characterization of the soil properties in saturated and unsaturated conditions must be taken into consideration in the analysis of the stability of the runway and to understand the impact of the cyclic hydric conditions caused by the variability of the water table on the creation of the cavities.

Soils used in this study were obtained from the sampling carried out on the two layers gypsum soils with a fine grained from Es-Senia airport area located near the great Sebkha of Oran, western of Algeria (Fig. 2). The subsoil of the site is characterized by a quaternary age alluvium consisting essentially by gypsum whitish beige clay, brownish beige to greenish brown plastic concreted and alternately of gypsiferous – sandstone crusts in some locations and by strongly gypsum sandy silts in other locations. The description of the lithology of the site is given in the Table 1. Because of the importance of the water table on the behavior of soils, in this study we distinguish two soils as being situated on two sides of the water table (0 to 4m and 4 to 8m). Samples obtained from the first layer (soil-1) are designated respectively: layer 1-sample-1 from (0.6 to 2m) and layer1-sample -2 from (2 to 4m) and the second layer-2 (soil 2) from (4 to 8m).

This geological formation results from the deposition of fine products generally resulting from disintegration and fragmentation of the nearby mountains. The Sebkha of Oran is one of the vast depressions endoreic of the north of Africa, constituting the main reservoir supplying the highly saline groundwater in the region. The development of these saline and humid area is due to winter precipitation, river water and basin flows, and a higher evaporation in summer [13].

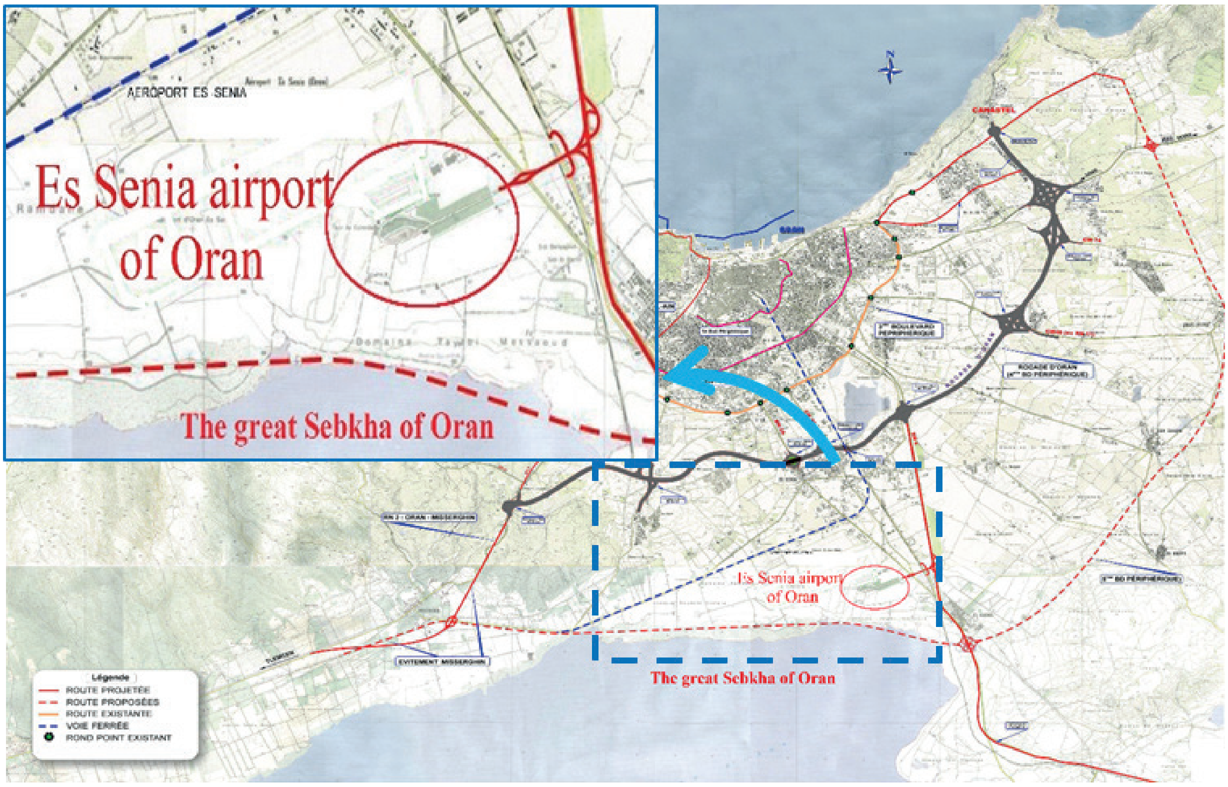

Fig. 2 Situation map of the studied site of the Es-Senia airport near the great Sebkha of Oran [14].

Table 1 The soil description under the landing strip of the airport of the Sebkha of Oran.

Depth (m)	Soil description
0.0 – 0.6	Topsoil
0.6 – 4.0	Beige clay strongly gypseous, alternating from gypsiferous – sandstone crusts
4.0– 8.0	Silty soil, sandy and strongly gypsum,
8.0 – 24.0	Greenish marl gypseous, slightly concreted, becoming more or less gypseous, alternating from gypsiferous – sandstone crusts in depth and in some places.

The ion chromatography analysis of water table at 4m depth, reveal that the most dominant substances are: Cl^-, NO^{-2}, NO^{-3}, SO_4^{-2}, PO_4^{-3}, Na^+, Mg^{+2}, K^+ et le Ca^{+2}. Tables 2 and 3 showing respectively anions and cations analysis of the site water.

Table 2 The anions analysis [mg/l]

Cl^-	NO^{-2}	NO^{-3}	SO_4^{-2}	PO_4^{-3}
664,150	5,500	101,100	1929,550	33,200

Table 3 The cations analysis [mg/l]

Na^+	NH^{+4}	Mg^{+2}	K^+	Ca^{+2}
436,150	0,277	164,300	13,912	634,700

The existence of saline water table of varying depth, depending on seasonal periods. In periods of drought, this water table is located from 3 to 4 meters in depth; it can reach 1m depths in the case of heavy rainfall in winter period. The chemical composition of the water of the Sebkha depends essentially on mineral dissolution, precipitation of other minerals and concentration by important evaporation which means that the water salinity is closely linked to rain water.

An analysis of X-ray diffractometry were carried out on the soil in order to identify the soil mineralogy and complete the understanding of the dissolution phenomenon. Observations are performed on fractions <20mm recovered after drying over samples of 100g.

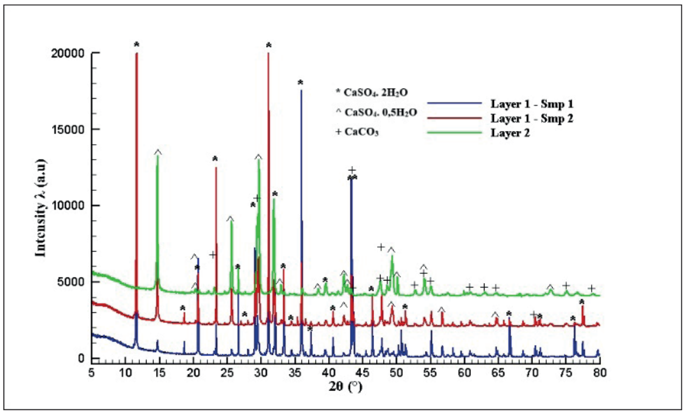

Fig. 3 Diffractometry x-ray analysis of the samples from the both gypsum soils.

From the X-ray diffractogram on Fig. 3, we can notice that both soils contain mainly gypsum in the hydrated form (calcium sulfate-hydrate $CaSO_4.2H_2O$) and dried (calcium sulfate-hemihydrate $CaSO_4.0.5H_2O$) and limestone (calcium carbonate $CaCO_3$). This presence or predominance of carbonate and calcite minerals is a factor that strongly influences the nature of the chemical reactions and the alteration processes.

Indeed, these minerals are among the softer and more soluble components of the soils because of weak ionic bonds between the cations and the anionic complexes. They have a high solubility in H_2O that allows them to alter easily and re-precipitate to other places and possibly on other forms. In addition, traces of other minerals were found as: Al, Mg, Ti, Fe_3, $SrSO_4$, Fe_3O_4 and the Quartz on the layer 1 and only Fe_3O_4 on the layer 2 but in small quantities. This can be explained by the presence of the clay on the first layer and the transport of charged ions by groundwater and their deposit during the dry period. Cerqueira et al. 2015, explains this action by the migration of the coexistence of amorphous Fe oxides as well as others anions and theirs fixation in gypsum soils by the sorption and desorption action.

The classification tests were carried out using the European standards procedures. For summarize, the distribution results of grain sizes show that the predominant fine fraction of particle size smaller than 80 µm is about 53 to 82%. Generally, the liquid limit is after 22.58 to 47.75% and the plasticity index from 3.64 to 28.36% in some different zones. After the CASAGRANDE diagram, the material tested has relatively a high plasticity at very high levels in some places in particular in profoundly [16,17].

It should be also noted that for other samples taken from other survey points, the determination of the ATTERBERG limits was not possible in others places due to the silty clay gypsum formation containing large proportions of gypsum [16,17].

According to the USCS/LPC classification, this soil is designated as clay and limestone-gypseous and fine soils very sensitive to water.

2.2 Sample preparation

All specimens are prepared according the optimum water content and their dry density obtained by the Optimum modified Proctor (OPM) test using the French norm [18]. The variation of the dry density depending on the optimum water content for the two studied soils ($\gamma_{d\_OPM} = f\,[W_{OPM}\,(\%)]$) is represented on Fig. 4.

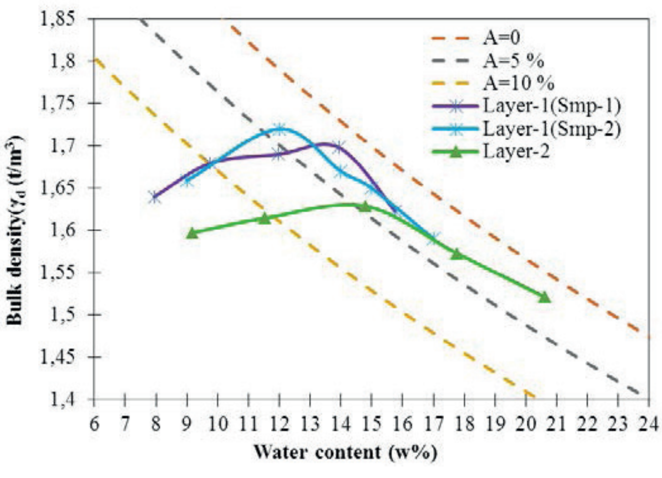

Fig. 4 Compaction curve of natural soil at the optimum modified Proctor energy for the two soils.

The maximum dry masses found for different levels optimal water content are summarized in table 4 below.

Table 4 The optimal water content values WOPM (%) and corresponding maximum dry densities γd-Max (kN/m3).

Layers		Depth	$\gamma_{d\text{-}Max}$ (kN/m³)	W_{OPM} (%)	$I_{CBR\_Immediate}$
Layer-1	Sample-1	(0.6-02m)	17.1	13.52	39.8
	Sample-2	(02-04m)	17.2	12.00	40.9
Layer-2		(04-08m)	16.3	14.50	46.1

All cylindrical samples used for the hydro-mechanical tests have been compacted according standards [19] using the compaction velocity of 0.95 mm/min to obtain finally a size of (50 mm x 100 mm).

3 Experimental program and methods

3.1 Mechanical characterization

In order to compare the mechanical properties of the two soils on sides the water table, the mechanical tests are carried out by standard triaxial test at various confining pressure. These confined compression tests are coupled with the water permeability in saturated case.

3.1.1 Triaxial test

Consolidated undrained triaxial test is carried out according the standards. Prior the shear test, samples are saturated at 540KPa, and consolidated after 24 hours. The rate of 0.05mm/min is used in the shear stage of the compression triaxial test. This test is performed for three confining pressures (600 KPa, 800 KPa and 1000 KPa) in order to determine the failure Morh envelope. Figure 5 shows the responses of the two soils during shearing phase. The strain-stress curves during the sharing phase manifest no particular behaviors: a peak is observed for weak confining pressures while there is perfect plastic behavior for higher confinements. Samples form Soil-1 seems to be more sensitive to the confining pressure manifesting a higher friction resistance. As an illustration, while at 800 KPa of confinement the soils have almost the same response, for a confining pressure of 1000 KPa.the sample-2 of the soil 1 (2 to 4 m) shows a higher resistance.

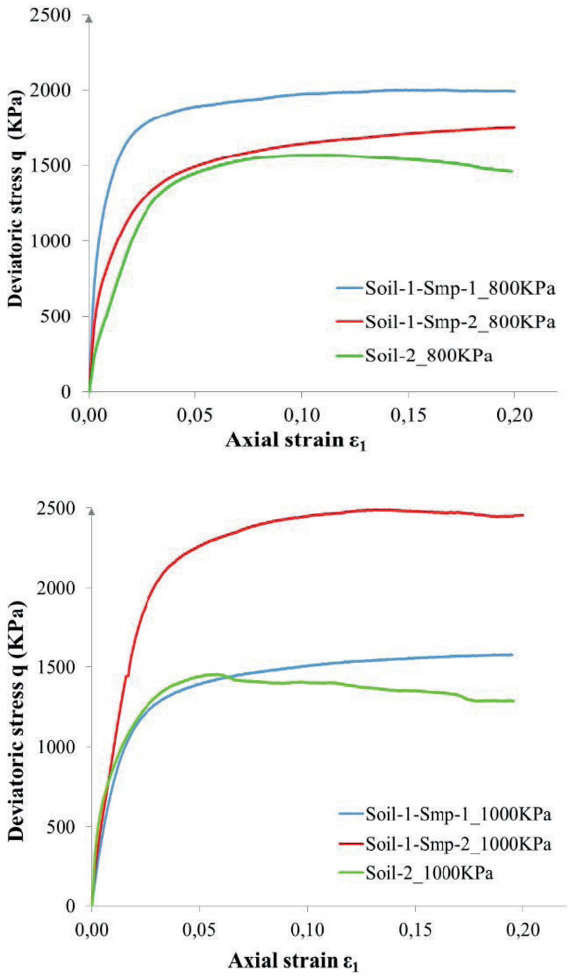

Fig. 5 Deviatoric stress - axial strain response for the two soils at various confining pressure.

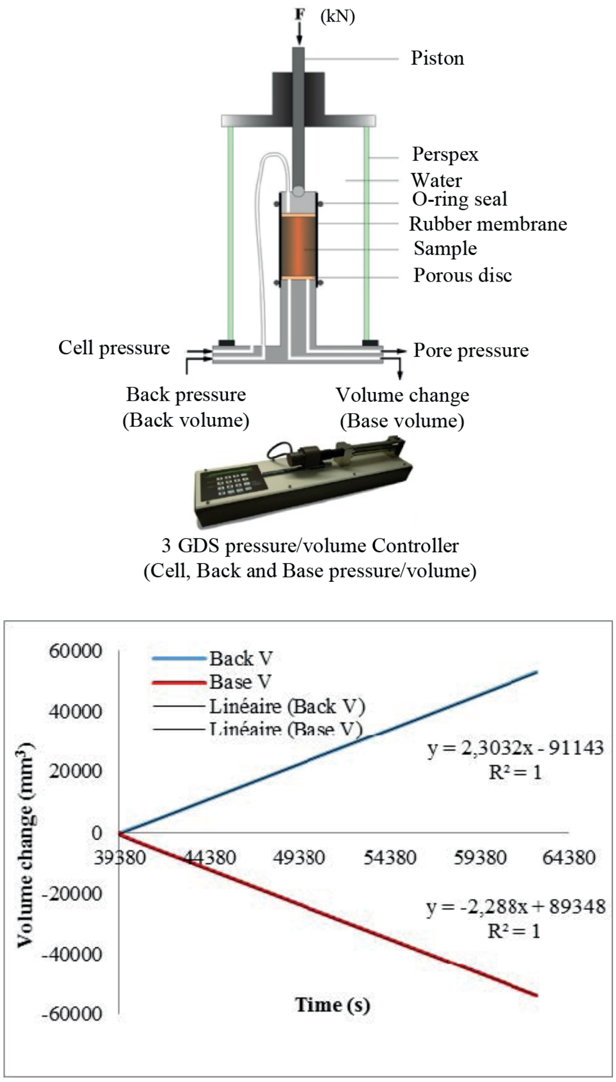

Fig. 6 Schematic principle of water permeability test and typical in/out flow curve example obtained during the test.

3.1.2 Water permeability

The low water permeability can slow the infiltration of rain water an impact the dissolution process of the carbonate rocks In order to confirm the nature of the two soils on both sides of the groundwater table, the water permeability is determined. The constant head test is carried out according to AFNOR standards [20]. Permeability test is performed using the triaxial cell after the saturation stage of CU triaxial tests. The records of the water volume (in and out) are performed in continue as shown in Fig. 6.

3.2 Isotherm curve and vapor permeability

The water absorption and its kinetics are of a first order importance for understanding and explain the role of water table evolution on the stability of soils concerned by the transit dry-wet zone. In our experimental program, these the identification of water retention curve and relative permeability were performed using similar techniques.

3.2.1 Water retention test

The identification of water retention curve (known also as sorption-desorption isotherm) for studied soils is performed using gravimetric salt solution method. The test consists to put samples of soils in a cell whose relative humidity is kept constant by a salt solution, and measure the mass variation up to its stabilization. It is possible to follow the kinetic of the water gain or water loss versus time for each relative humidity at a fixed temperature. The different salts used in our tests allow to obtain atmosphere with constant relative humidity at various level covering a range of relative humidity from 12 to 100 %. The mass variation is followed using a balance with a resolution of 10^{-4}g. The saturation is calculated from the mass change after equilibrium and mass stabilization of the samples. It is an already known result that most of materials exhibit hysteresis of water retention curve, so this curve is identified for each soil in both dried (during drying) and wet (during saturation) branches.

3.2.2 Relative permeability test

If the kinetics of water up taking or lost is recorded (by recording the mass evolution of samples when it is put in a new relative humidity for example) it is possible to identify a relative permeability using the method developed in Homand et al. (2004). In order to assure an unidirectional transfer that make easer the inverse procedure of relative permeability identification, the cylindrical samples were waterproofed on the lateral faces (Fig. 7). These cylindrical samples of dimensions 2.0 cm in height and 5.0 cm in diameter are cut from the reconstituted compacted samples prepared for triaxial test and dried at 60°C for 48 hours. The samples are covered laterally with a plastic film, hardened in the paraffin and weighted.

From the Soil-1 (layer 1 in the depth 0 to 4m) concerned by the unsaturated characterization, two samples are tested, one for drying path and the other for wetting path. After preparation, both samples are attached to a balance at 10^{-4}g of a precision via a wire and placed in beakers containing salt solutions. The sets of samples and beakers are placed in a thermal chamber at (20 ± 1°C) and far from the light. Both balances are connected to a computer recording mass samples in continue up to the mass stabilization (Fig. 8).

Fig. 7 Cylindrical samples used for relative permeability test with paraffin protection.

Finally the relative permeability identification is deduced using the process proposed in [11].

4 Results and discussion

4.1 Identification of hydromechanic parameters

The laboratory tests presented in this paper are parts of a research work including THM-C characterization and modeling in order to understand and predict the behavior of the saline soil of the Sebkha of Oran. Limited to experimental characterization this paper aims to identify the hydromechanical properties of two layers situated on two sides of the water table. The undrained elastic parameters (Young modulus and Poisson's ratio) are identified on the bases of strain stress curves of triaxial CU tests. The shear parameters (Cohesion C and friction angle) are also identified from these results using effective stress values at peak (table 5)

The stress path followed by tested samples during CU tests (Fig. 9) clearly show the similitude of their behaviors in such conditions. As compared to normally consolidated soil path on

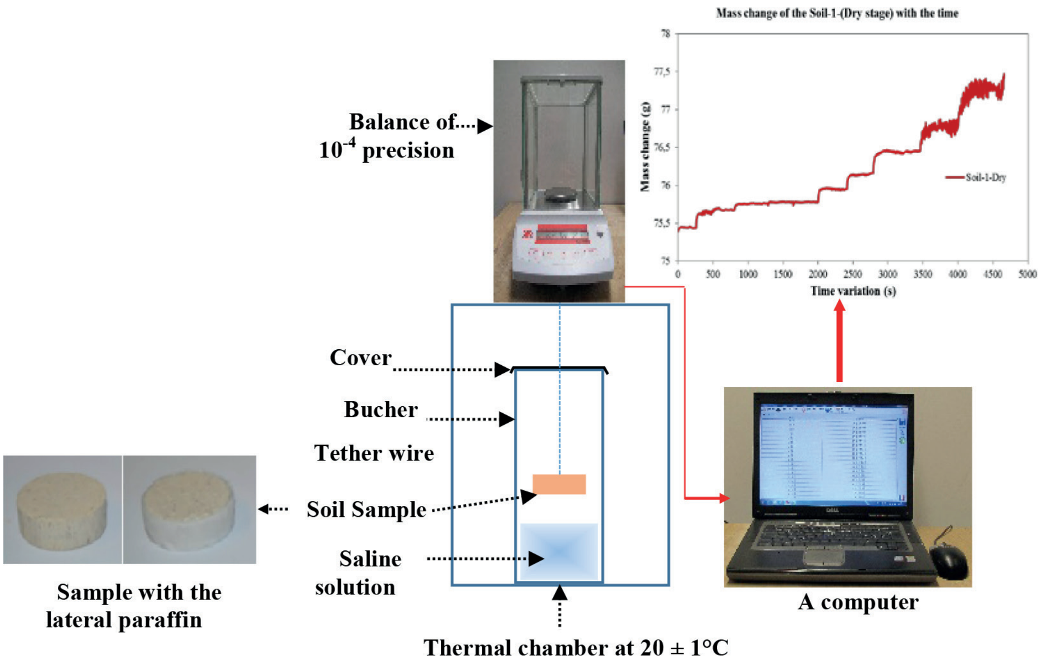

Fig. 8 Patterns of experimental device of conduct of trial of relative permeability.

such tests (a straight line in the plane p'-q) the path stress of all samples exhibit a curvature falling in the over consolidated domain. Since all samples are reconstituted one, this curvature should be interpreted as an indication that stress applied on samples during the compaction/reconstitution is superior to the maximal consolidation stress used on our tests (1000kPa). In turn, this calls for a verification of results obtained during our tests and in situ tests to be sure that reconstituted samples are representative to the undisturbed state of soils in situ.

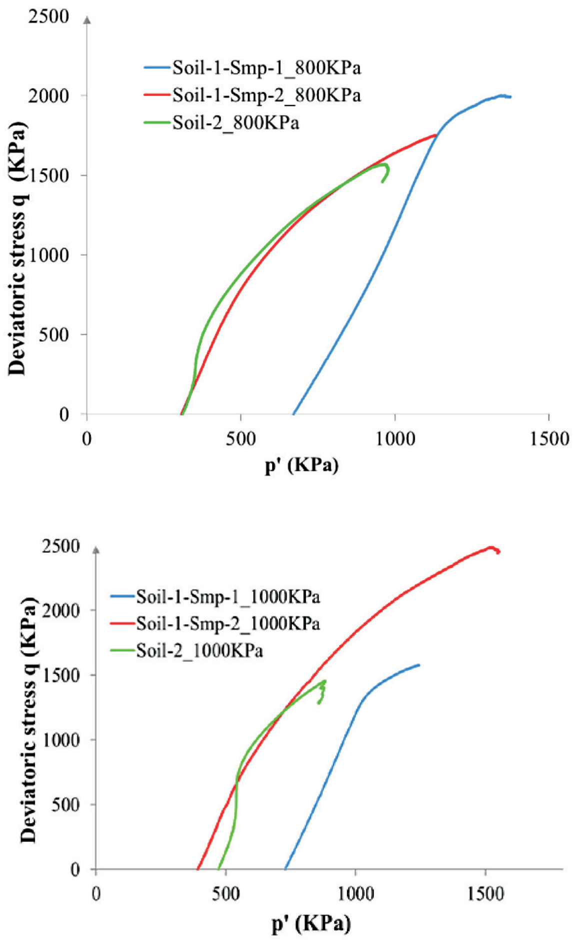

Fig. 9 Stresses path in p'-q plan of tested samples from two studied soils during triaxial CU tests at various confining pressure.

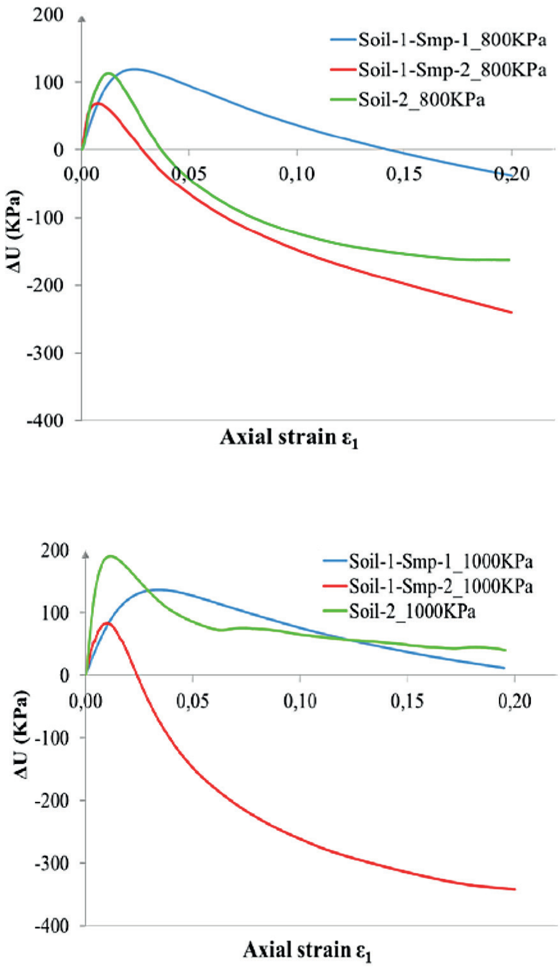

Fig. 10 Pore pressure variation - axial strain response for the two soils at two confinement 800 and 1000KPa.

This over consolidated behavior is confirmed by the variation of pore pressure and volumetric strain during the CU triaxial tests (Fig. 10): an overall shrining phase with increase of pore pressure is followed by a dilatation and a relative decrease of pore pressure. This kind of behavior is typical for heavy over consolidated soils [21] et [22].

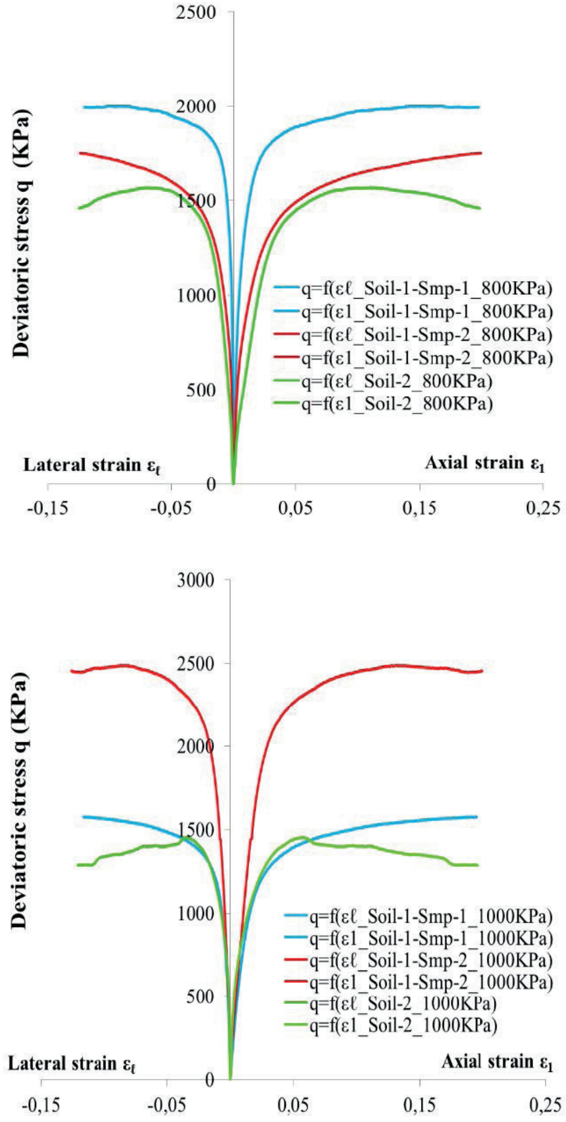

Fig. 11 Stress –strain response for the tow soils at two confinements of 800KPa on the left and 1000KPa on the right.

To illustrate the soil behavior under deviatoric stress, the stress – strain curves at confining pressure of (800 and 1000KPa) relative to the two soils are presented on Fig. 11.

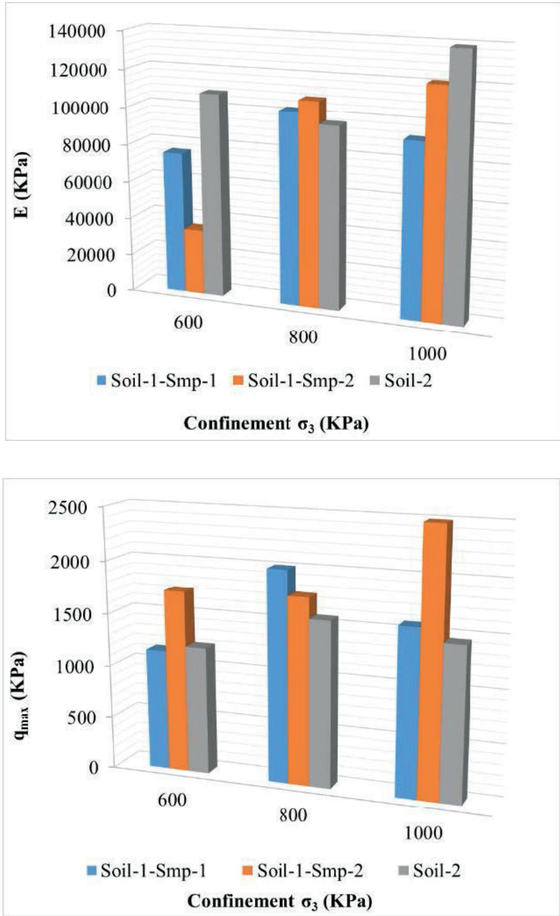

Fig. 12 Young Modulus E (KPa) on the left and the deviatoric max stress qmax (KPa) variation on the right for the three confinement 600, 800 and 1000KPa.

Figure 12 shows the Young's modulus and the deviatoric stress at peak for the various soils at different confining pressure. While a more or less regular increase of the Young's modulus with confining pressure is observed for both soils, the results show a dispersion of values despite of the fact that samples were reconstituted using exactly the same procedure of compaction.

The values of water permeability (K) obtained from constant head test are converted to a reference temperature of 10°C using a corrective factor:

$$K_{10} = \alpha x K_T \tag{1}$$

with K_T: being the measured permeability at the room temperature (m/s), T: the current water temperature during triaxial conducted test (°C) and α the second order corrective factor

$$\alpha = \frac{1.359}{1 + 0.0337xT + 0.00022xT^2} \tag{2}$$

A very good reproducibility of water permeability is observed (table 5) knowing that in such kind of measurements the differences up to one order are often reported in the literature. Combined with differences/variabilities of mechanical parameters this might signifies that most probably this differences reflects more the natural spatial variability of soils, than the differences in their preparation.

Table 5 Some physical and index properties of the reconstituted soil in laboratory.

Layers / Property		Layer-1 Smp-1	Layer-1 Smp-2	Layer-2
Depth (m)		0 – 2 (1.65m)	2 – 4	4 – 8
γ_d (t/m³)		1,56	1,62	1.60
Porosity n (%)		32.73	34.62	32.14
E (Pa)		97459.78	114751.43	117930.28
ν		0,36	0,42	0.45
Triaxial test (CU+u)	C (KPa)	24.96	0	0
	φ (°)	33.63	43.74	44.11
Permeability coef K_{10} (m/s)		1,25E-07	1,46E-07	1.23E-07

The sorption-desorption isotherm curves are illustrated on Fig. 13. Each point in these curves coincide with the saturation of a sample at a constant relative humidity once the equilibrium of sample with atmosphere is achieved, manifested by the stabilization of sample mass. This stability takes several days to be established and more than 18 days for the relative humidities of 55%, 66%, 76% and 86%. As expected an important hysteresis is observed between wet and dry path for all soils for all humidity (soil 1 sample 1 and 2, and soil 2). While an hysteresis of water retention curve is a common feature of almost all soils, the amplitude of this hysteresis in our samples is something not so frequent. In many cases, this amplitude of hysteresis is in connection with the presence on the samples of some salts with characteristic relative humidity in a close range of RH.

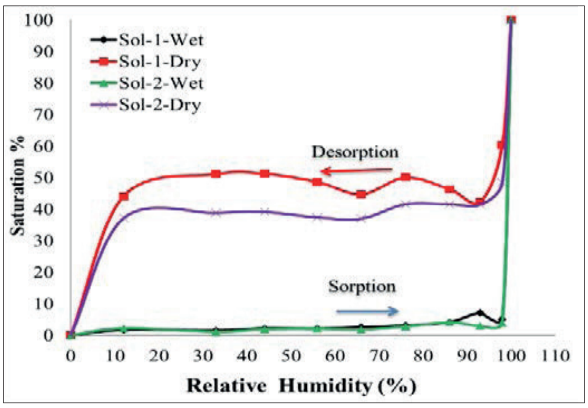

Fig. 13 Sorption-desorption isotherms curve of the three reconstituted soils.

The figure 13 shown that desorption is about 50% for the soil – 1, it's more than the soil – 2 at 40% of desorption. However, the sorption is very small and insignificant for the two soils. That may be explains by the compaction of the sample, wherever all the porous are minors and the samples finding it hard to absorbed saline solution. But for the desorption phase, the samples are saturated, so the water opens the pores to stay there, then it is easy to lose the weight as absorbed moisture.

In order to achieve the adjustment parameters of representative retention curve for both soils, the empirical expression of [23] is used:

$$S_{lq} = \left[1 + \left(\frac{P_c}{P_r}\right)^n\right]^{\left(\frac{1-n}{n}\right)} \tag{3}$$

with; S_{lq} beign water saturation (%), Pc capillary pressure (Pa), Hr the relative humidity (%), ρ_{lq} volumetric mass of liquid (kg/m³), m_{lq} volumetric mass content of liquid (kg/m³), R universal gas constant R = 8,314 m³·Pa·mol⁻¹·K⁻¹ and T absolute temperature (°K)

Recall that this expression supposes a one-to-one relationship between the capillary pressure and liquid saturation. One has to choose a single water retention curve, representing both wet and dried branches and "mean curve" was used in our cases (Fig. 13). Then the capillary pressure for a given relative humidity is calculated from the Kelvin relationship assuming valid the hypothesis of perfect gazes:

$$P_c = \frac{\rho_{lq}.R.T}{m_{lq}}.In\left(H_r\right) \tag{4}$$

Finally the Van Genuchten parameters for the "mean" isotherm curve are obtained by minimizing the error between predicted and measured curve. The parameters Pr (air inlet pressure) and power coefficient n of the van Genuchten law are given in Table 6.

Table 6 The fitting parameters of van Genuchten determined from the isotherms of different soils.

	Pr (MPa)	n
Soil_1	2,47E-01	1,76
Soil_2	2,43E-06	1,25

The piecewise-constant relative permeability for a given step of relative humidity change could be identified using in one hand the masse variation (water up-taking or water lossing) and on the other hand the inverse identification procedure described by [11] is used. For the sake of simplicity, the procedure is not described here in details (interested reader could check the theoretical bases on the above-cited reference) and only results are described. For a 1D water transfer in the axial direction of a cylindrical sample, the masse taking or loss of a sample as a function of time when the sample is placed from an initially capillary pressure p_{cp0}, to a constant relative humidity atmosphere p_{cp} is obtained on form of an infinite sum:

$$\Delta M_{lq}\left(t\right) = \rho_{lq}\Omega\left(p_{cp}^{imp} - p_{cp}^{0}\right).\eta_0.\left[1 - \sum_{n=0}^{\infty} E_n\left(t\right)\right] \tag{5}$$

where;

$$E_n\left(t\right) = \frac{8}{\left(2n+1\right)^2.\pi^2} \cdot e^{\left(-\frac{\lambda_{lq}}{\eta_0}\omega_n^2 t\right)} \tag{6}$$

with;

$$\omega_n = \frac{(2n+1).\pi}{L} \tag{7}$$

with; Ω being the volume of samples, λ_{lq} the liquid conductivity in unsaturated conditions ($m^2/Pa/s$), λ_{lq}^0he liquid conductivity of fully water saturated sample ($m^2/Pa/s$), p_{cp} Capillary pressure (Pa), ρ_{lq} volumetric mass of liquid (kg/m^3), M_{lq} water masse variation on the sample (equal to measured mass variation (kg) and η_0 hydromechanical parameter (Pa^{-1}) similar to a specific heat for a thermal problem or a specific storage coefficient in hydrogeology.

For a given curve of wetting (drying) between two relative humidity, one looks the liquid conductivity λ_{lq} and the hydromechanical parameters η_0 are identified through an optimization procedure in order to fit the best the masse variation as a function of time (Fig. 14).

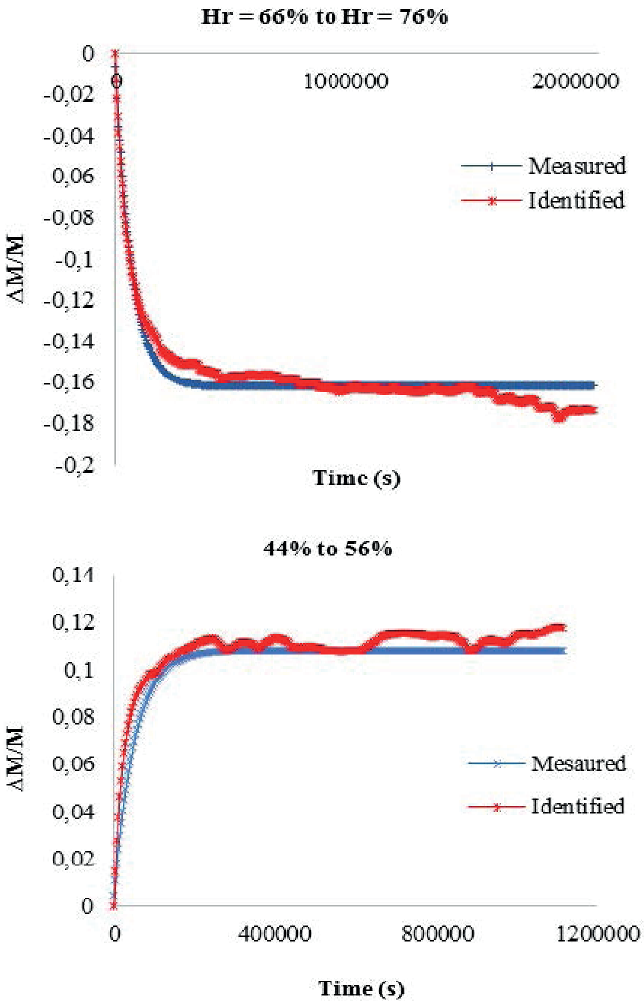

Fig. 14 Relative mass variation for imposed relative humidity 66% for the dry stage and 44% for the wet stage.

Once the λ_{lq} is identified, supposed to be constant for a step of relative humidity change, the relative permeability is calculated by:

$$K = \frac{\lambda_{lq}}{\lambda_{lq}^0} \tag{8}$$

Note that relative permeability identified by this procedure is more an effective parameter that count also for Fick's vapor diffusion. In fact, the mass up-taking (lossing) of a sample when the relative humidity is changed, is a combined effect of advection (described by the relative permeability) and vapor diffusion process (described by a Fick diffusion) that play simultaneously. Since the curve of masse variation, during our procedure is adjusted considering the advection phenomenon only, this means that identified "relative permeability" count for all transfer properties, including the Fick diffusion.

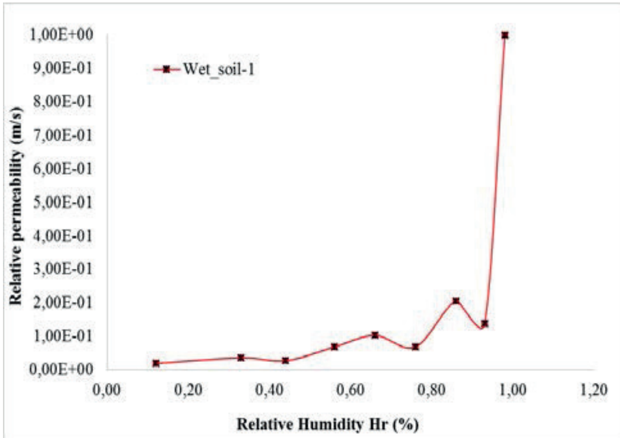

Fig. 15 Relative permeability as a function of relative humidity.

4.2 On the representativeness of laboratory tests

The results of laboratory tests on reconstituted samples from two soils, despite of common features, manifest some differences that could put in question their representativeness in respect with real behavior of these soils.

The variability of mechanical parameters has been firstly analyzed in order to verify whether the two soils (three layers) considered in this study could/should be considered as mechanically different. A one-factor ANOVA statistical test was performed, with results shown in table 7 using analysis toolbox from Excel software.

Table 7 Results of variance analyses of Young's modulus

Detailed report				
Groupes	# samples	Sum	Mean	Variance
Soil 1 Lay 1	3	264,00	88,00	100,00
Soli 1 Lay 2	3	250,00	83,33	1344,33
Soil 2	3	316,00	105,33	186,33

Variance analysis	SRE	# D.O.F	SRE_N	F
Inter Groups	806,22	2,00	403,11	0,74
Inner Groups	3261,33	6,00	543,56	

The analyse of the variance of Young modulus show that the differences of mechanical parameters are statistically significant which means that for the future studies these layers must be considered as mechanically distinct.

Likewise, the two parameters ANOVA analyse (taking as parameters the confining pressure and soil layers) of peak deviatoric stress (not presented here in details) confirm these differences.

The mechanical parameters from laboratory tests, on reconstituted samples, are compared with in situ measured parameters reported in geotechnical report [16,17]. The results of three ANOVA (for three layers) are indicated on the table 8 (only final results).

Table 8 Comparison of in situ and laboratory results of mechanical parameters

	Mean Young modulus (MPa)			
	In situ	**Laboratory**	**F**	**Probability**
Soil 1	81	84	0,028	0,87
Soil 2	58,4	51,7	0,13	0,73

As demonstrated by these results, there is a statistically significant difference between mechanical parameters on laboratory tests on reconstituted samples and those measured in situ. The origin of these differences should be explained principally by the conditions of reconstituting soils, but also by the differences on the metrology of measurements. For in situ parameters, various empiric relations have been used in order to obtain the Young's modulus from STP results which inevitably lead to unquantifiable differences with laboratory measured data even in case of no-disturbed samples. In respect with these conditions and the probabilities of H0 hypothesis (equality of mean values of in situ and laboratory samples), even if stricto sensus form statistically point of view this is not fully true, the tested in laboratory samples could be considered as representative of in situ soils.

5 Conclusions

The laboratory tests on reconstituted samples from two soils of the second runway of Es-Senia Aiport of Oran (Algeria) are presented. The objective of these tests is to identify hydro-mechanical parameters of these to soils in saturated and partially saturated conditions. The results show that the three layers from two soils considered in this study represents three distinct mechanical entities and should be considered as such. In respect with the representativeness of the laboratory test, the statistical tests of the equality of mean values, show that despite the differences the reconstituted tests could be considered as representative to soils in situ. Nevertheless more tests are to be performed to confirm this representability in respect with shear strength parameters.

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References

[1] Aubert, G. "Les sols sodiques en Afrique du nord.". (Sodic soils in North Africa.) In: *Annales de l'Institut National Agronomique*, pp. 185–196. 1975. (In French) http://horizon.documentation.ird.fr/exl-doc/pleins_textes/pleins_textes_5/b_fdi_02-03/01402.pdf

[2] Bellanca, A., Neri, R. "Dissolution and precipitation of gypsum and carbonate minerals in soils on evaporite deposits, central Sicily: isotope geochemistry and microfabric analysis.". *Geoderma*, *59*(1–4), pp. 263–277. 1993. 10.1016/0016-7061(93)90073-T

[3] Morse, J. W., Arvidson, R. S. "The dissolution kinetics of major sedimentary carbonate minerals.". *Earth-Science Reviews*, *58*(1–2), pp. 51–84. 2002. 10.1016/S0012-8252(01)00083-6

[4] Loos, D., Pasel, C., Luckas, M., Schmidt, K. G., Herbell, J.-D. "Experimental investigation and modelling of the solubility of calcite and gypsum in aqueous systems at higher ionic strength.". *Fluid Phase Equilibria*, *219*(2), pp. 219–229. 2004. 10.1016/j.fluid.2004.02.011

[5] Gledhill, D. K., Morse, J. W. "Calcite dissolution kinetics in Na–Ca–Mg–Cl brines.". *Geochimica et Cosmochimica Acta*, *70*(23), pp. 5802–5813. 2006. 10.1016/j.gca.2006.03.024

[6] Finneran, D. W., Morse, J. W. "Calcite dissolution kinetics in saline waters.". *Chemical Geology*, *268*(1–2), pp. 137–146. 2009. 10.1016/j.chemgeo.2009.08.006

[7] Tankersley, K. B., Dunning, N. P., Thress, J., Owen, L. A., Huff, W. D., Fladd, S. G., Bishop, K. J., Plog, S., Watson, S. A., Carr, C., Scarborough, V. L. "Evaluating soil salinity and water management in Chaco Canyon, New Mexico.". *Journal of Archaeological Science: Reports*, *9*, pp. 94–104. 2016. 10.1016/j.jasrep.2016.07.014

[8] Bouaziz, M., Matschullat, J., Gloaguen, R. "Improved remote sensing detection of soil salinity from a semi-arid climate in Northeast Brazil.". *Comptes Rendus Geoscience*, *343*(11–12), pp. 795–803. 2011. 10.1016/j.crte.2011.09.003

[9] Lu, N., Kaya, M., Collins, B. D., Godt, J. W. "Hysteresis of Unsaturated Hydromechanical Properties of a Silty Soil. *Journal of Geotechnical and Geoenvironmental Engineering*, *139*(3), pp. 507–510. 2013. 10.1061/(ASCE)GT.1943-5606.0000786

[10] Fredlund, D. G., Rahardjo, H. "*Soil Mechanics for Unsaturated Soils.*" John Wiley & Sons, Inc., Hoboken, NJ, USA. 1993. DOI: 10.1002/9780470172759

[11] Homand, F., Giraud, A., Escoffier, S., Koriche, A., Hoxha, D. "Permeability determination of a deep argillite in saturated and partially saturated conditions.". *Internatonal Journal of Heat Mass Transfer*, *47*(14–16), pp. 3517–3531. 2004. 10.1016/j.ijheatmasstransfer.2004.02.012

[12] Moussa, K. "Etude d'une Sebkha ; la Sebkha d'Oran (Ouest algérien).". *Géologie*, Oran, Algérie. 2007. (In French) http://hydrologie.org/THE/MOUSSA_K.pdf

[13] Chikhaoui, M., Nechnech, A., Hoxha, D., Moussa, K. "Contribution to the Behavior Study and Collapse Risk of Underground Cavities in Highly Saline Geological Formations.". In: *Engineering Geology for Society and Territory - Vol. 6*., (Lollino, G., Giordan, D., Thuro, K., Carranza-Torres, C., Wu, F., Marinos, P., Delgado, C. (Eds.)), Springer International Publishing, Cham. pp. 393–397. 2015. 10.1007/978-3-319-09060-3_68

[14] ING. "Photogrammetric rise of the Oran city with the location of the great SEBKHA." 1988.

[15] Cerqueira, B., Arenas-Lago, D., Andrade, M. L., Vega, F. A. "Using time of flight secondary ion mass spectrometry and field emission scanning electron microscopy with energy dispersive X-ray spectroscopy to determine the role of soil components in competitive copper and cadmium migration and fixation in soils.". *Geoderma*, *251–252*, pp. 65–77. 2015. 10.1016/j.geoderma.2015.03.026

[16] LTPO. "Reconnaissance géotechnique préliminaire de la 2ème Piste (07/25) de l'Aerodrome d'Oran Es-Sénia". (Preliminary geotechnical 2nd track (07/25) from the airfield of Oran Es-Senia). 2005. (In French)

[17] LTPO. "Contrôle et suivi géotechnique des travaux de réalisation de la 2ème Piste (07/25) de l'Aerodromed'OranEs-Sénia.". (Control and geotechnical monitoring of the construction works of the second track (07/25) from the airfield of Oran Es-Senia). 2007. (In French)

[18] Association Française de Normalisation. "NF P94-093 Sols: reconnaissance et essais - Détermination des références de compactage d'un matériau - Essai Proctor normal. Essai Proctor modifié.". (Soils: investigation and testing - Determination of the compaction reference values of a soil type - Standard proctor test - Modified proctor test). Norme Française, 1999. (In French)

[19] Association Française de Normalisation. "NF-EN 13286-53 Méthode d'essai de fabrication, par compression axiale, d'éprouvettes cylindriques traitées aux liants hydrauliques de masse volumique apparente et de teneur en esau". (The manufacture methods for specimens test of hydraulically bound mixtures using axial compression.) Norme Française, 1999. (In French)

[20] Association Française de Normalisation. "P 94-512-11 ICS Détermination de perméabilité à charge constante et à charge variable décroissante. Reconnaissance et essais géotechniques. Essais de laboratoire sur les sols. Indice de classement : 13.080.20 ; 93.020.". (Determination of permeability at constant load and with decreasing variable load. Reconnaissance and geotechnical testing. Laboratory tests on soils.) Norme Française, 2005. (In French)

[21] Biarez, J., Hischer., P. Y. "Lois de comportement des sols remaniés et des matériaux granulaires, 3ème edition.". (Laws of behavior of reworked soils and granular materials, 3rd edition.) Ecole Centrale de Paris, 1990. (In French)

[22] Fleureau, J.-M., Verbrugge, J.-C., Huergo, P. J., Correia, A. G., Kheirbek-Saoud, S. "Aspects of the behaviour of compacted clayey soils on drying and wetting paths.". *Canadian Geotechnical Journal*, *39*(6), pp. 1341–1357. 2002. 10.1139/t02-100

[23] van Genuchten, M. T. "A Closed-form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils1.". *Soil Science Society of America Journal*, *44*(5), pp. 892–898. 1980. 10.2136/sssaj1980.03615995004400050002x