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State of the Art in Unsaturated Soil Testing

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Abstract In most soil mechanics laboratories, studies on soil behaviour are systematically carried out under saturated conditions in accordance with the TERZAGHI postulate. However, due to climatic conditions (arid, semi-arid, extreme continental), soils are often in a state of unsaturation and no longer meet Terzaghi's laws. These soils undergo alternating dry and wet seasons and are subject to drainage and humidification cycles. Depending on their nature, and especially in the case of fine soils, these variations in water status can lead to disorders due to phenomena such as swelling, shrinkage, or collapse. It is then necessary to have a good knowledge of these soils. To study unsaturated soils, it is then important to understand the phenomena which take place there and their mechanical behavior.

The present article therefore proposes to present an overview of the different phenomena that characterize unsaturated soils and particularly the tests proposed to explain their mechanical behavior.

Taking into account and controlling the unsaturated state of soils will allow to solve in a more efficient way the problems related to structures such as: embankment dams, dikes, road embankments, slopes, tunnels.

Keywords Unsaturated soils - suction - water retention - hydromechanical behavior

Introduction

Since the 1960s, soil mechanics has been mainly interested in totally saturated or totally dry soils [1]. According to "Terzaghi", in saturated soils, deformations are entirely driven by the "effective stress". However, in unsaturated porous media, the presence of air modifies the interactions between solid particles and water, which leads to the coexistence of three types of interface: solid-liquid, solid-gas and liquid-gas, which have very different specific energies. This state of non-saturation is characterized by the negative interstitial pressure (suction) due to the interaction between the three phases constituting the soil. This suction gives unsaturated soils physical and mechanical characteristics that differ from those of saturated soils and thus render insufficient the theory of classical soil mechanics, which had as its main assumption the saturation of the medium.

These types of soils, such as clay soils, which do not meet the Terzaghi principle, are a real concern because they are the cause of many problems related to the stability of structures such as dams, dykes, road embankments, slopes, tunnels, etc. .... Thus it is imperative to have a better understanding of the phenomena occurring in unsaturated soils. The behavior of unsaturated soils has been the subject of much research since the 1980s and continues to this day. The phenomenon of unsaturation concerns particularly clayey soils, however, it is necessary to note that the knowledge of the relative notions are not yet well known.

Thus, this article proposes to make an inventory of the current knowledge on unsaturated soils in three points through, the presentation of unsaturated soils and the various phenomena which characterize them, the methods of measurements and control of the suction and the influence of the suction on the mechanical behavior of unsaturated soils.

Presentation of unsaturated soils and their phenomena

Presentation of unsaturated soils

Unsaturated soils are solid-liquid-gas three-phase systems. For an unsaturated soil the interaction between the three phases, skeleton, water, air depends on the degree of saturation.

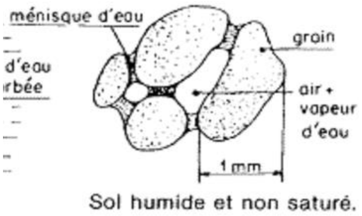


Figure 1: Presentation of the unsaturated porous medium

Phenomena observed in unsaturated soils

Suction

The presence of the gas phase results in a negative pore pressure or suction by considering atmospheric pressure as the origin of pressures. According to Mitchell [2], cited by ARAIRO 2013, suction is "a potential energy comparable to the hydraulic head in saturated soils corresponding to the energy required to bring free water from infinity to an unsaturated soil." For Leclercq and Verbrugge, [3], cited by Derfouf-Mounir, suction is the depression that must be applied to free water in an isothermal system to bring its potential to the same value as that of water contained in a soil sample free of any external constraint. Due to the interaction between the three phases constituting the soil, it conditions the properties of unsaturated soils and helps explain their mechanical behavior [4]. It is expressed in kPa or in centimeters of water column or by the potential of free energy (pF) corresponds to the decimal logarithm of the suction potential expressed in centimeters of water column.

Suction is essentially the result of two major components: matrix suction and osmotic suction [5].

Matrix suction, expressing the water retention capacity of soil components, is the sum of the capillary component (preponderant in granular soils) and a component associated with the adsorption forces developed by the soil particles (fine soil).

Osmotic soil suction is related to the salts present in the soil.

The different components of suction in a soil are at the origin of different physico-chemical phenomena, namely

Surface tension

The surface tension is at the origin of the cohesion by capillarity between two grains thanks, on the one hand, to the liquid-gas interface which behaves like a tense membrane and, on the other hand, thanks to the action of the pressure difference which tends to bring the grains closer together [6]. Capillarity is illustrated by the phenomenon of capillary rise of water in a tube of radius r immersed in a container containing water. The relationship between the radius of curvature of the spherical meniscus water-air in the tube and the pressure difference between air and water is given, in the hypothesis of cylindrical pores by Jurin's law:

$$u_a - u_w = \frac{2\sigma_s cos\theta}{r}$$

with ua and uw , the air and water pressures, σs the water-air surface tension, and θ the connection angle between the meniscus and the solid.

During soil desaturation, capillary menisci are formed; as the soil desaturates, the menisci become smaller and have smaller radii of curvature.

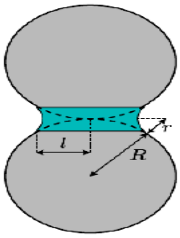


Figure 2: Capillary hazards in granular soil [7]

In a granular soil, the suction is only of capillary nature, defined by the menisci at the water-air interfaces. This water-air interface located at the intergranular contact is at the origin of an intergranular tensile force which tends to stiffen the soil and to hinder the rearrangements between the grains.

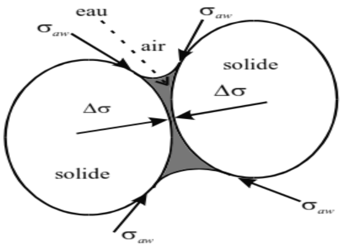


Figure 3: Effects of suction on soil grains

Adsorption phenomenon

In the soil, the surfaces of the solid phase are made of atoms that do not have all their chemical bonds satisfied. These surfaces tend to fill this lack by capturing atoms and in particular water molecules. It is the phenomenon of adsorption: a water molecule coming from the gaseous phase strikes the surface of the solid skeleton and is captured by its attractive field. This molecule can then leave the surface of the solid and return to the gas phase under the effect of thermal agitation. The exchange is permanent between adsorbed molecules and molecules of the gas phase.

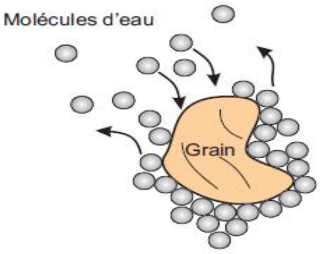


Figure 4: Agitation of adsorbed water molecules

Adsorption suction

For fine soils, it manifests itself, in addition to capillarity, by physico-chemical interactions between the clay layers due to clay minerals. The part of the physico-chemical suction is in general very important compared to the capillarity.

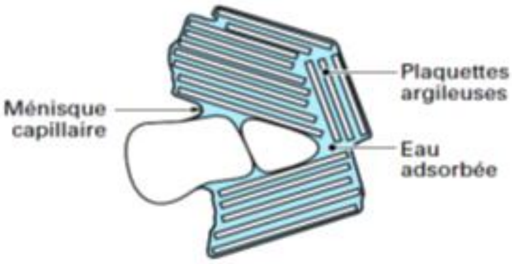


Figure 5: Suction in fine soils [7]

The tendency of ions to hydrate and the existence of concentration differences at several points in the soil are at the origin of osmotic suction, which can be defined as the pressure to be exerted to prevent equilibrium between two solutions of different concentrations brought into contact by a semi-permeable membrane. The osmotic suction evolves in the opposite direction of the saturation state of the soil [8].

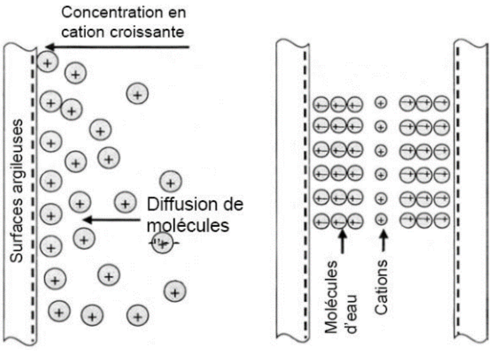


Figure 6: Mechanism of water adsorption on clay surfaces [2]

Materials and Methods

Several materials and techniques are proposed in the literature to impose or measure suction in unsaturated soils.

Suction measurement and control techniques

Suction measurement techniques

Several methods can be used to measure the suction in a soil. Total suction can be determined by measuring vapor pressure or relative humidity using the psychrometric method as well as the filter paper method. Matrix suction can be obtained directly or indirectly. For direct measurement, the tensiometer (in situ test) and the suction plate (laboratory test) are available. For indirect measurement, the filter paper method is available.

Measurement by the Tensiometer and Suction Plate Method

By definition, the matrix suction is given by: $S = u_a - u_w$

When the air pressure u_a is equal to the atmospheric pressure taken as reference, we have:

$S = -u_w$ with $u_w < 0$

The tensiometer and suction plate are designed to measure the negative pressure of water directly in the soil. It consists of a small deaerated water tank with one end covered by a layer of porous ceramic that is impermeable to air, but permeable to water, in order to prevent the passage of air.

To measure the negative soil pressure, the tensiometer is inserted into a pre-drilled hole in the soil or sample (Figure 11). When the water in the tank is in equilibrium with the water in the soil, the negative pressure of the tensiometer, measured by the manometer, directly provides the negative pressure of the soil water. This method is limited to a maximum suction of about 500 kPa due to cavitation. The principle of the suction plate is the same as that of the tensiometer.

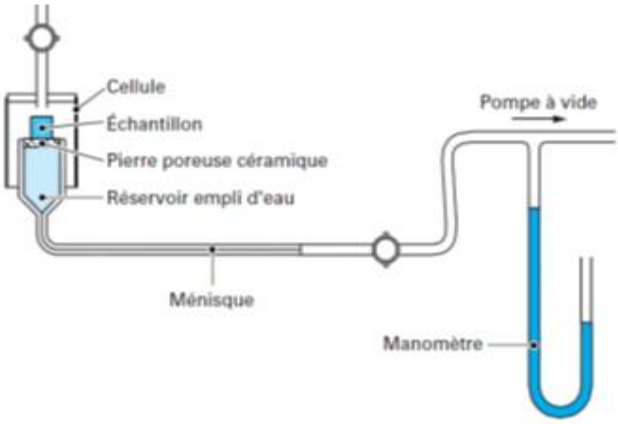
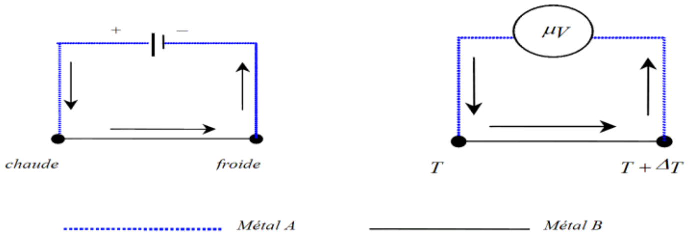


Figure 7: Tensiometer principle and tensiometer plate [9]

Measurement by the psychrometric method

The psychrometric method is based on the Kelvin equation which describes the relationship between the relative humidity of the gas phase in the vicinity of a gas-water interface and the total suction. It is a measurement of relative humidity by means of a thermocouple [10] which relies on the Peltier effect and the Seebeck effect [6].

The Peltier effect is illustrated in (Figure 8-a). When an electric current passes through a circuit made of two different metals, one of the junctions will be heated, and the other cooled. An electromotive force is generated in a circuit made of two different metals when the temperatures in the two junctions are different (Seebeck effect). It is proportional to the temperature difference between the two junctions. A microvoltmeter can be installed in the circuit to measure this electromotive force. (Figure 12-b)



a) Effet Peltier b) Effet Seebeck

Figure 8: Principle diagram Peltier effect and Seebeck effect

Measurement by the filter paper method

The filter paper technique is the simplest. It consists in splitting a soil sample in two parts to place a stack of filter papers composed of three measuring papers, previously humidified, and two protective papers. The whole is then waxed to prevent exchange with the atmosphere. At the moisture exchange equilibrium between the sample and the filter papers, the suction becomes identical in both media. The water content of the paper is then determined by weighing. Using the previously established calibration curve of the filter paper (Figure 9-b), the corresponding suction is determined, which is by definition the suction of the soil.

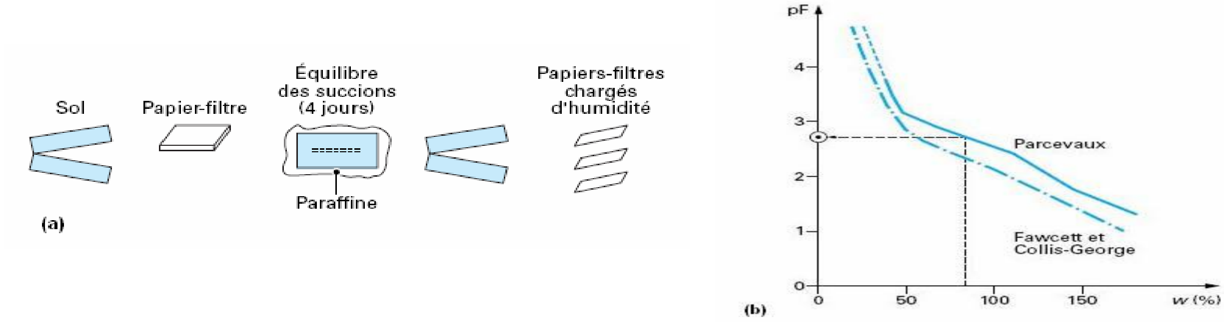


Figure 9: Filter paper method: (a) schematic diagram (b) filter paper calibration curves [11]

Suction control techniques

The monitoring techniques are designed in such a way that a suction can be imposed on the soil and the water content corresponding to the water balance can be measured. There are basically three techniques: the air pressure method, the osmotic method and the vapor pressure method. This last method allows to impose very high suctions. The principle is the same as that of the vacuum desiccator.

Control by the overpressure method

The air overpressure method is based on the principle of axis translation. The objective of the axis translation is to avoid the occurrence of cavitation in the measuring system. It consists in applying an air pressure higher than the atmospheric pressure to the ground (an overpressure), while the water pressure remains constant. Thus, the water pressure remains positive and avoids experimental difficulties.

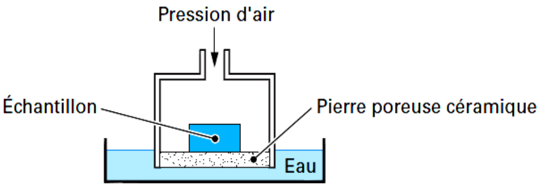


Figure 10: Richards cell for axis translation suction control

The air overpressure method is frequently used in the study of the hydromechanical behavior of unsaturated soil: determination of the water retention curve, determination of the hydraulic permeability coefficient at a given suction, controlled suction odometer tests, controlled suction triaxial tests, etc. This method is limited to a suction of less than 1500 kPa because of the resistance of the test equipment.

Control by the osmotic method.

$$\psi_0 = -\frac{\rho_w RT}{\omega_v}\, ln(X)$$

The osmotic suction is given by:
Where:
X is the molar fraction of water in the solution which represents the concentration of the solution,
R is the constant of perfect gases,
T is the absolute temperature,
ρw is the density of water and
ωv is the molar mass of water vapor.
The greater the mole fraction of water or the greater the concentration of the solute, the greater the suction.

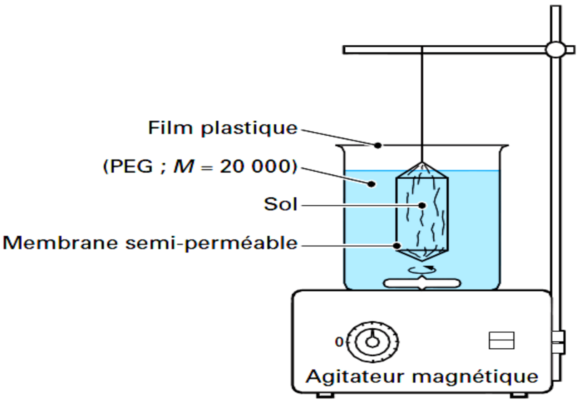


Figure 11: Implementation of the osmotic technique

The osmotic method is based on the mechanism of osmotic pressure created in the soil using a semi-permeable membrane and a solution. The solute used is polyethylene glycol 20000 (PEG 20000). The size of the PEG 20000 molecules is larger than the pore size of the semi-permeable membrane used. As a result, the membrane is permeable to water but not to large PEG 20000 molecules.

When the soil is brought into contact through a semi-permeable membrane with the PEG solution prepared beforehand at a certain concentration, because of the difference in chemical potential between the pore water of the soil and the PEG solution, an exchange of water between the solution and the soil will occur (tendency to equilibrium). If the solution is contained in a relatively large vial, this exchange of water can be considered to have little effect on the concentration of the solution. Therefore, when equilibrium is established between the water in the soil and the solution, the chemical potential of the solution can be considered to represent the suction in the soil.

Williams and Shaykewish [12] calibrated the relationship between concentration and suction for PEG 20000 solution at 25 °C was calibrated experimentally (Figure 12).

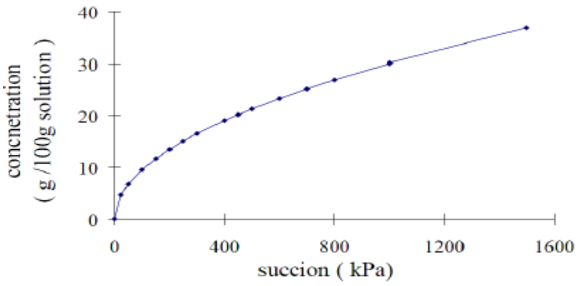


Figure 12: Calibration curve of PEG solution concentration versus suction (at 25°C)

Vapor pressure control

This technique is based on the Kelvin equation. A soil sample is placed in a vacuum chamber containing a solution of known chemical composition. Each type of saturated salt solution has a known relative humidity according to its physico-chemical properties. When the equilibrium between the soil and the solution is reached by water vapor transfer, the suction of the soil is equivalent to the relative humidity of the solution.

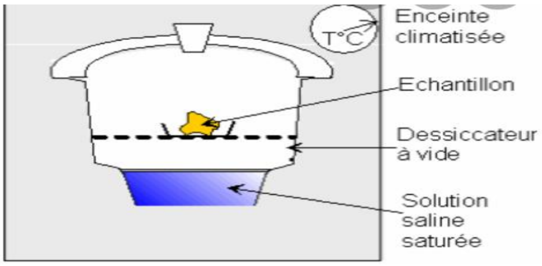


Figure 13: Vapor phase suction control

Table 1 provides the measured relative humidity values and equivalent suctions corresponding to different saturated salt solutions [7]. This technique allows to impose a very high suction (a few hundred MPa).

Table 1: Relative humidity RH and total suction of different saturated salt solutions

Saturated solutions	**Temperatures = 20°C**		**Temperature = 30°C**	
	HR (%)	**Suction (MPa)**	**HR (%)**	**Suction (MPa)**
K_2SO_4	97	4.113	96	5.512
KNO_3	93	9.8	91	12.734
KCl	86	20.364	85	21.943
NaCl	76	37.055	75	38.843
$NaNO_2$	66	56.104	63	62.385
$Mg(NO_3)_2,6H_2O$	55	80.721	52	88.294
$K_2CO_3,2H_2O$	44	110.85	43	113.954
KCH_3CO_2	20	217.31	22	204.44
KOH	9	325.125	7	359.059

Table 2 gives an order of magnitude of the applicable suction for various methods and also the order of magnitude of the time required [6]. The psychrometer and the tensiometer allow for the actual measurement of suction in the test tube. On the other hand, the other techniques (overpressure of air, osmotic method, vacuum desiccator) impose a variation of suction or its equilibrium at a given value.

Furthermore, most techniques give a slow response (at best a few hours, but often weeks or months). In fact, whatever the method used, the measurement is only correct if the specimen reaches an equilibrium state corresponding to the test conditions.

Table 2: Different techniques for measuring and controlling suction

	Suction measurement technique			**Suction control technique**		
	tensiometer	**Psychrometer**	**Filter paper**	**By air pressure**	**Osmotic control**	**By saline solutions**
Measured suction	matrix	total	Total or matrix	matrix	matrix	total
Suction interval (KPa)	[0.5; 500)	[100;7000)	(50;10000]	s< 1500	s< 12000	[4200;325000)
Accuracy	Very precise	Specifies	Not very precise	Very precise	Specifies	Not very precise
Duration of the measurement	Hours	Hours	Weeks	Some days	Some days	Months
Note	Quality of contact between porous stone and soil	Sensitive to temperature variation	The simplest method	Quality of contact between porous stone and soil	Sensitive to temperature variation	

Results and Discussions

Water Retention Property

A key water characteristic of unsaturated soils is provided by water retention curves (WRC), which quantify the ability of soils to attract and retain water. These curves are determined by subjecting a sample to a cycle of drying and rewetting by applying increments of increasing and then decreasing suction, most often using the Richards cell for low suction, and osmotic desiccant for higher suction.

This curve represents the retention capacity of soil at different suctions [13]. It defines the relationship between volumetric water content θ, or mass w, or degree of saturation Sr, and matrix suction ψ [14].

Two parameters are of particular interest on the water retention curve of a soil, namely:

a) The Air Entry Value (AEV or ψa) representing the suction value at which the larger pores begin to drain and thus promote air entry into the soil.

- The suction equivalence corresponding to a degree of saturation (Sr) of 90% or 95% (ψa = ψ90 or ψ95, [15]), is the degree beyond which the material is considered saturated ;
- Determination of the air entry value (AEV) is easily accomplished by the method of tangents (ψa = ψBC, [6, 16]).

(b) The suction at residual saturation (ψr) representing the suction at which any change no longer results in a significant change in water content. The corresponding water content or residual water content θr corresponds to the point where the liquid phase becomes discontinuous in the porous medium. Under wetting conditions, this suction value is also known as the water entry value (WEV).

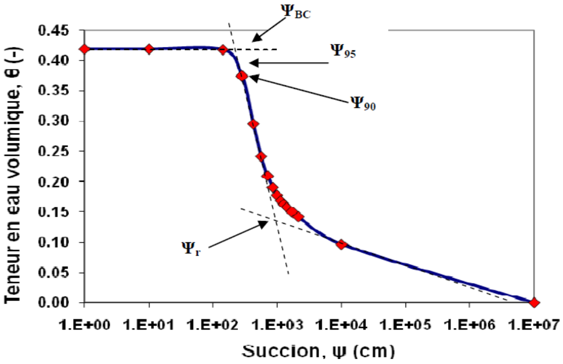


Figure 14: Determination of the parameters of the water retention curve of a non-compressible material

The retention curves for the same material in desorption and adsorption show a difference in the drainage and imbibition paths (figure 15). There is therefore no one-to-one relationship between suction and its conjugate variable (water content for example).

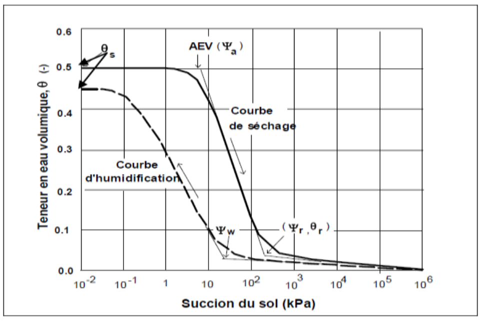


Figure 15: Retention curve with hysteresis loop [17]

The water retention curve is often used to estimate the hydraulic conductivity function. It is also related to the volume change properties and is used to derive other soil properties, such as shear strength under unsaturated conditions.

Reliability in the determination of CRE is of paramount importance in the practice of unsaturated soil mechanics. This is complex because changes in pressure can result in changes in volume and flow properties [18].

The retention curve is influenced by different factors such as the initial void index, the initial water content, the particle size.

Kawai et al [18] found that the AEV is inversely proportional to the logarithm of the void index. Vanapalli et al. [20] published the results of water retention curves of a clayey silt under different compaction states.

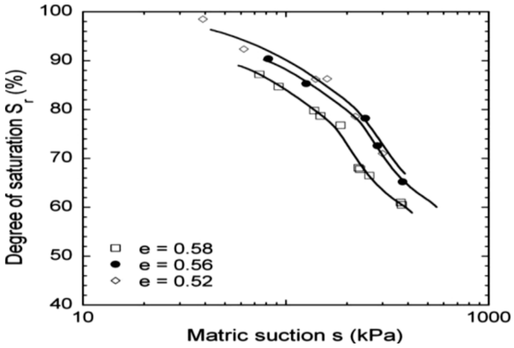


Figure 16: Water retention curves under different compaction conditions [20]

There is a wide range of AEV that corresponds to different void index values. The densest soils have a higher EVA [20].

At low suction, soils with a low void index show negligible variation in the degree of saturation, the soil can be treated as completely saturated.

The (Figure 17) illustrates the effect of water content on the CRE [21] of a clayey sand with a low liquid limit, the clay fraction was calcium montmorillonite.

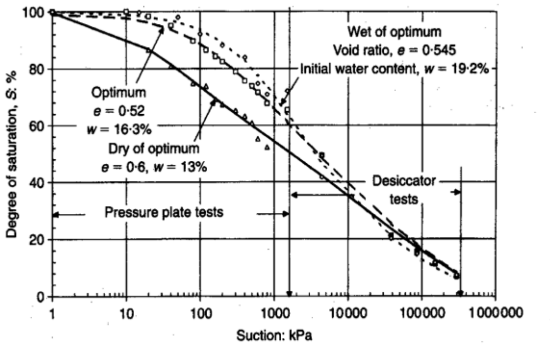


Figure 17: Water retention curve for compacted samples with different initial water contents [21]

The initial value of the water content has a considerable influence on the shape of the curve. The AEV increases with the initial water content.

The sample with the highest value of initial water content shows a steeper CRE. Vanapalli et al [21] show that for samples compacted to a higher than optimum initial water content, the mode of association of elementary particles in the soil (microstructure) controls the resistance to desaturation, the pore space is in an occluded state. Consequently, these soils have a greater retention capacity. However, a soil, compacted to an initial water content below the optimum, has an open structure with large interconnected pores and in this case the arrangement of the soil aggregates (macrostructure) controls the water behavior. Desaturation for this type of sample is faster.

The CREs of soils with different initial water contents tend to converge to the same degree of residual saturation for large suction values.

The particle size controls the size and distribution of the pores, and consequently the microstructure. For water retention curves, the air entry pressure and residual suction of a soil decreases when D10 (the diameter in mm corresponding to 10% by mass of the sieve) increases, i.e. when the percentage of fines decreases.

According to Hong Yang et al. [22], sand has a lower air entry pressure value than clay. The slope of the CRE is also consistent with the slope of the soil particle size curve. Thus, the hysteresis effect is more emphasized as D10 decreases.

A water retention curve for a soil is characterized by four parameters: the maximum water content, the residual water content, the air entry pressure and the slope beyond the air entry pressure.

From the different factors that affect the water retention curve we can conclude:

- ✓ The maximum and residual water content depends on the nature of the soil studied, for a clay soil the residual water content will be greater than that of a granular soil.
- ✓ The air inlet pressure depends on the grain size and the compactness of the material under study. Loose soils (high porosity) have a lower air entry pressure than dense soils. Dense soils are more resistant to desaturation than loose soils since the air entry pressure increases with decreasing porosity.
- ✓ The slope of the water retention curve is steeper for soil with a uniform particle size.
- ✓ The hysteresis effect depends on the storage capacity of the soils: the hysteresis will be more marked in the case of a clay soil, where the possibility of having saturated occluded pores is greater.

Effect of suction on the mechanical behavior of unsaturated soils

The influence of suction on mechanical behavior is the subject of extensive research. The most elaborate mechanical tests are performed by controlling or imposing suction on the soil sample. In particular, the mechanical behavior is explicitly a function of the suction. A change in soil moisture will lead to a change in suction, which will imply changes in the mechanical behavior of soils.

Shear strength

Data on the shear strength of unsaturated soils are mainly related to the fracture properties, obtained with shear boxes or triaxial cells with controlled suction by air overpressure.

Early results in the literature for unsaturated soils suggested a linear increase in shear strength with suction [6]. More recent studies have shown that a linear relationship is not appropriate for all soils and for the entire suction range [23].

The increase in cohesion has always been observed by all authors; it corresponds to the intergranular or interregnum cementing action of the suction.

On the other hand, the angle of friction does not always increase with suction, as shown in the diagram in Figure 18, which combines the results obtained by different authors on various soils: Guadalix clay (wL = 33%, IP = 13.6); Madrid clayey sand (wL = 32, IP = 15); Jossigny silt compacted to w = 15.5% (wL = 37, IP = 18); weakly compacted Trois-Rivières silt (IP = 7, ei ≈ 1) [7].

These results from controlled suction triaxial tests show that shear strength increases with suction: apparent cohesion increases with suction; the angle of friction varies with suction but in an unclear way, and with soil type.

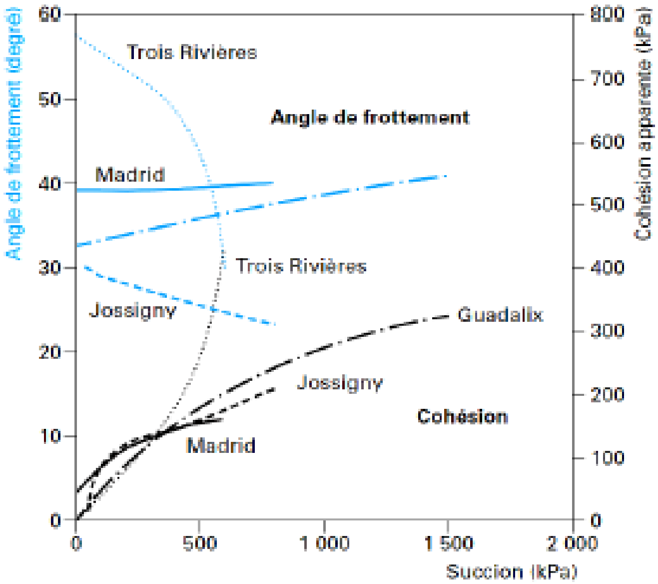


Figure 18: Evolution of the angle of friction and apparent cohesion as a function of suction for different soils [7]

These observations were confirmed by Tuffour [24] and Drumright and Nelson [25], who observed constant friction angles (respectively on two compacted Israeli clays - IP = 20% and 38% - and on a non-plastic soil at near-optimum dry density - 1.84). It was observed that a decrease in the friction angle for a very loose soil (ei = 0.97) and Juca et al. [24] observed an increase in the friction angle on swelling clays. Overall, the trend seems to be toward an increase in the angle of friction for rather plastic and dense soils and a decrease for less plastic and loose soils.

Figure 19 shows, in a plane showing the stress deviation as a function of the axial deformation, the results of triaxial tests at different levels of suction [26] carried out at constant suction on Jossigny silt. We can distinguish different points since with the increase of the suction we can see:

- An increase in the apparent modulus of rigidity
- An increase in shear strength

The increase in the initial modulus of the material shows a stiffening of the material.

The increase in shear strength is reminiscent of the effect of confining stress on the results of a triaxial test while the appearance of the deflector peak tends to show its embrittlement. The increase in inter-granular attraction can lead to stiffening since the meniscus bond between grains is similar to the effects of cementing for high suctions. This rigidification tends to bring an unsaturated soil to a meta-stable state with a higher porosity at equal mechanical stress, which explains its embrittlement.

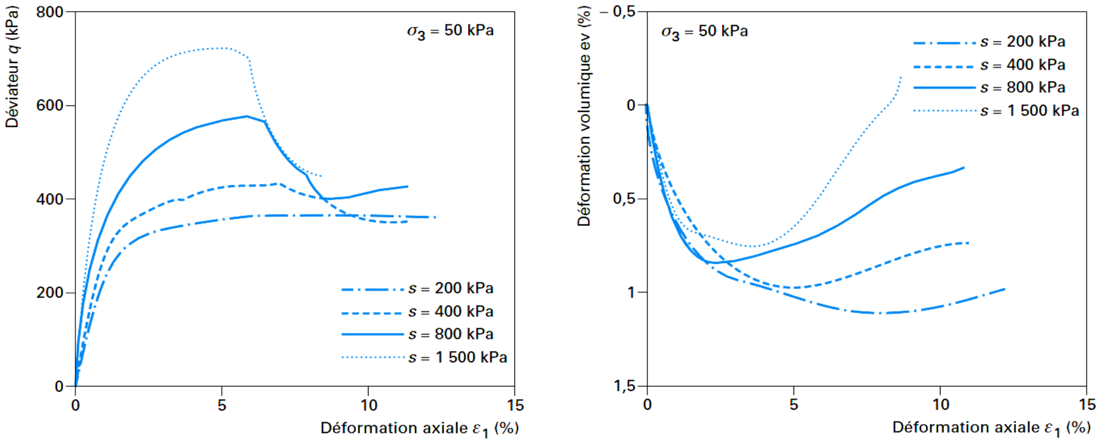


Figure 19: Triaxial tests at different suction levels [26]

Volumetric behavior

The analysis of the volume behavior of an unsaturated soil is very complex. This complexity can be illustrated by Figure 20-b which presents the plane of the volume deformations as a function of the axial deformations in the context of tests on the Jossigny silt [26]. These curves show that suction has no influence on the initial slope in contracting. However, the influence of suction is important in the case of dilatancy. It can be seen that the greater the suction to which the material is subjected, the greater the dilatancy.

On the other hand, Cui et al [26] conducted a series of oedometer tests on FoCa7 swelling clay under different values of suction and found that the compressibility index of swelling soils decreases with increasing suction, as shown in Figure 21-a: This is due to the change in the physico-chemical properties of interlamellar water in swelling soils that occupies the pores which makes evacuation more difficult even for fairly large values of suction hence the decrease in the compressibility of swelling soils

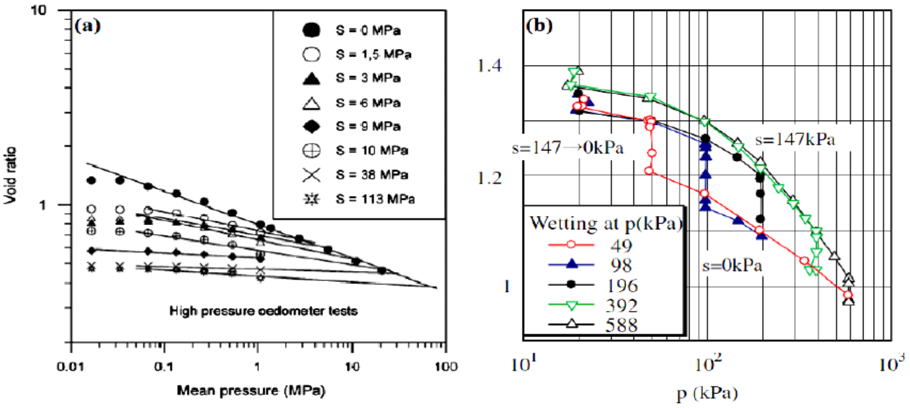


Figure 20: Results of compression tests on: (a) swelling soil [26] and (b) non-swelling soil

This finding is in contradiction with the results of non-swelling soil tests obtained shown in Figure 20-b.

These results were obtained using the triaxial suction controlled apparatus under an isotropic stress path. Thus, the effect of suction on the volume behavior of an unsaturated soil depends on the swelling or non-swelling nature of the soil. For non-swelling soils, with the increase of suction, the liquid phase passes from the funicular regime to the pendular regime. Water in this case acts as a lubricant that facilitates grain rearrangement. In this same context, Uchaipichat studied the effect of initial saturation state on the volume behavior of soils [27]. A series of isotropic compression tests with controlled suction were conducted, starting from a completely saturated state (s = 0) and increasing the suction in steps. Thus another series of tests was conducted, starting from a suction s = 300 kPa and rewetting the samples to decrease the suction to the desired value. The curves were plotted in the plane of the effective stress

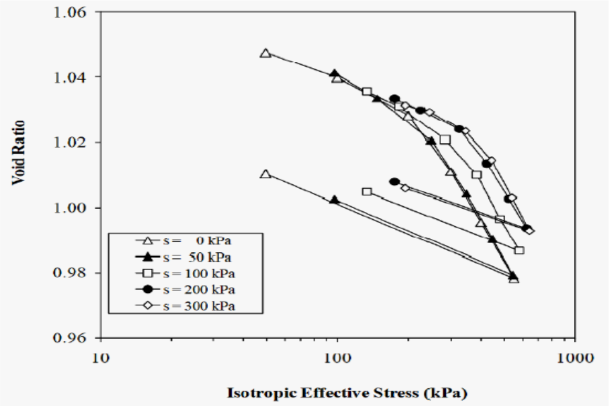


Figure 21: Controlled suction compression curves of compacted kaolinite [27]

If we trace these curves in the plane of the net pressure we obtain the following curves

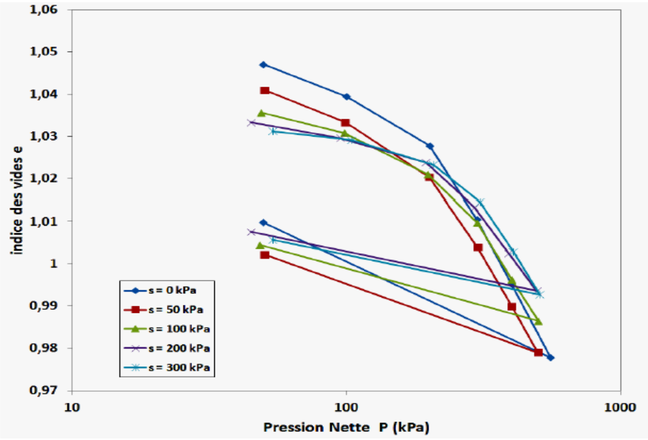


Figure 22: Void index variations during isotropic suction-controlled compression tests of a compacted kaolinite traced in the net pressure plane P [27]

According to this study, the effect of suction is almost negligible on the compression index Cc (almost all curves are parallel). However, the suction shows its influence on the swelling index which seems to decrease with increasing suction. The choice of the stress variables seems to have a great influence not only on the study of the effect of suction on compressibility.

To conclude on the effect of suction on the compressibility of unsaturated soils we can indicate that

- ✓ The preconsolidation pressure increases as the suction increases.
- ✓ The variation of the compression index as a function of suction depends on the nature of the soil studied and its compactness.
- ✓ The wetting of a dry soil, can generate a phenomenon of swelling if it is under a weak constraint but a phenomenon of collapse if it is under a strong constraint; the mechanical constraint influences the importance of swellings and collapses. Let us note that the phenomenon of shrinkage and swelling of a soil also depends on the stress which is applied to it.
- ✓ A change in suction can cause irreversible volume deformation for a soil under a given load [28].

Conclusion

The unsaturated state in which soils are mostly found in many regions, raises problems that are not usually dealt with in classical Soil Mechanics (which is rather focused on saturated soils). Understanding and predicting the behavior of unsaturated soils requires a fairly thorough knowledge of the interaction phenomena of the phases constituting the soil. Through the rereading of the different tests approached by several researchers, points of divergence persist: for example, the equivocation remains on the evolution of the cohesion according to the variations of the suction, the phenomenon of hysteresis which complicates the control of the behavior of the unsaturated soil according to its water content.

This bibliographic synthesis shows that there are many expectations regarding the study of unsaturated soils. The mechanics of unsaturated soils will have to see the light of day with clear, verifiable postulates, in order to remove all the equivocations that still persist.

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