Analysis of the Swelling Behavior of the Tirs of Gharb (Morocco) Compared with Factors Related to the Change of Soil-Moisture

Tarik El Bahlouli [#1], Lahcen Bahi [#2]

[#] 3GIE Laboratory, Mohammadia Engineering School, Mohammed V- Agdal University
Rabat, Morocco

[1] tarik.elbahlouli@gmail.com

[2] bahi@emi.ac.ma

***Abstract*—The stability of the structures built on expansive soils or crossed expansive layers may be compromised as a result of a change of soil-moisture conditions. Knowledge of the behavior of the soil is considered a valuable data for engineers and practitioners of geotechnical and civil engineering, especially, in the phases of design and structural calculation. This paper is motivated by the extent of damage that should be avoided and can occur in the case of a pressure causing heave foundations, upward movement of flatwork or roadway cracking in spider or x-type pattern. First of all, the assessment of swelling characteristics depends on the conditions of starting wetting and saturation. For this reason, we suggested to establish an experimental study on the tirs or vertisol of Gharb region based on the swell oedometer test methods. A comparative analysis of swelling kinetics, swelling ratio and swelling pressure compared with test conditions is proposed. Our attention was focused, thereafter, on the influence of the wetting duration that interferes with a rise of degree of saturation and regression of suction. It was also valuable to study the influence of the initial condition of the soil in terms of water content combined with dry density. All of these factors follow some real sequences in the field.**

Keyword-Tirs, Oedometer, Swelling pressure, Swelling ratio, Soil-moisture.

I. Introduction

Geotechnical engineering for unsaturated soils begins to take great value since it is more representative of the real sate of the soil. In this context, we will focus, specifically, on expansive soils that appeared by an important volume change as a result of changes in soil-moisture conditions. It translates into upward and differential movements or excessive anisotropic pressures for civil engineering structures. In this sense, whether it is the swelling pressure, the swelling ratio, the rate of swelling under level load or kinetics curve are very important data for sector specialists for the structures design. Our paper is integrated in this perspective of soil-structure interaction and illustrated the influence of some factors related to the change of soil-moisture. These predisposition or trigger factors are studied for the case of a Moroccan soil, widespread in Morocco, as it happens, the tirs or vertisol of the Gharb region, as shown in Fig.1, in the northwest of the country. This expansive soil, are causing much damage suffered by buildings, railways and especially by roadways. It is very concerned about Moroccan engineers in the road sector, even in the phase of maintenance [1].

Fig. 1. Specimen soil of the tirs of Gharb Region

So, it is appropriate to enrol in the study of the tirs to better understand its characteristics and expansive behavior. For this, Oedometer apparatus are chosen and three swell oedometer tests methods (the free swell oedometer test method, the loaded swell oedometer test method and the chinese method) are performed to analyze the influence of :

- The conditions of starting wetting and saturation on the kinetics of swelling, the swelling ratio and the swelling pressure. This section aims to show the great influence of the combination "time to start wetting-time to start loading or unloading", in addition to the influence of the level of loading and unloading during saturation.
- The duration of wetting on the values of volume changes and swelling pressure. An analysis based on the degree of saturation and the change of the matric suction was developed for this purpose.
- The choice of initial conditions on the values of swelling pressure and the variation of swelling ratio. This section focuses on the influence of the initial water content and initial dry density on the swelling behaviour and characteristics.

II. Presentation Of The Studied Soil

Early researches (geographers, geologists, agronomists...) who visited Morocco in the late 19th Century and early 20th century, used the vernacular names of Moroccan farmers ('fellahs) to indicate several soils in the country. These are the names of the tirs (heavy clayey soil with dark color), hamri (red soil usually clayey), harch or harroucha (stony soil), dess or dehs (alluvium), faid (silty alluvium from Doukkala region), merzag (sandy soil with ferruginous concretions), etc...[2]. the tirs are first described in the Gharb plain which be interested in our paper. Then, the definition was extended to vertisols (agricultural nomenclature) rich in organic materials from moroccan atlantic depressions. The tirs are considered pedological plateau with regional extension.

The tirs of the Gharb region was sampled from the section of the provincial road RP4248 between the village of Karia and Mograne as shown in Fig.2. Sampling aeras are 20 to 27Km from the Kenitra City.

Fig. 2. Localization maps of the region of Mograne (Morocco) and area of trial pits location

In the site, the tirs layer is in reaching 1m to 1.4m. This type of soil, very beneficial for local agriculture, is known by its hardness and density in the dry state and its sticky aspect when it is wet. The soil specimens tested in laboratory come from the soil intact cubes (trial pits in depth of 1.2m maximum) carefully protected by a film of paraffin oil to avoid the exchange of moisture with ambient conditions. They were crated thereafter. This helped to bring undisturbed soil specimens.

III. Preliminary Geotechnical Analysis

The tirs studied is highly plastic clay classified CH according to the Unified Soil Classification System (USCS) and it is classified as A-7-6 clay type according to the AASHTO classification system. The results of geotechnical identification and characteristics are summarizing in table 1.

TABLE I
Summary of Geotechnical Characteristics for the tirs Specimens

Specific density	ρ_s (g/ cm^3)	2.56
Dry density	ρ_d (g/ cm^3)	1,57-1.58
Initial water content	ω_i (%)	20.2
Amount of fine size particles less than 80µm	< 80µm (%)	92-94
Amount of clay size particles less than 2 µm	C_2 (< 2µm)(%)	58-61
Liquid limit	ω_L (%)	54-56
Plastic limit	ω_P (%)	20-21
Plasticity index	PI (%)	34-35
Initial void index	e_i	0.625
Optimum Proctor of dry density	$\rho_{d.OPM}$ (g/ cm^3)	1,53
Optimum Proctor of water content	ω_{OPM} (%)	22.1
Methylene blue value	MBV (g blue/100g dry soil)	5,02-5,13
Classification system	Unified Soil (USCS)	CH
	AASHTO	A-7-6

On the one hand, the methylene blue adsorption test, shown in Fig.3, confirms this content of clay size materials because the methylene blue value is between 4.5 and 6. We may also mention the French standard XP P94-011 (1999), which suggests the classification of the activity blue of the clay fraction of the soil (A_{CB}=MBV/C_2) [3]. A_{CB} value is greater than 8 which already qualify the tirs of Gharb as a moderately active soil.

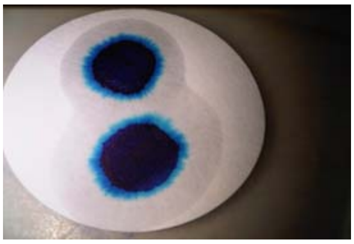

Fig. 3. Methylene blue adsorption test

On the other hand, the activity of the soil (A_C=PI/C_2) is greater than 0.55. In terms of qualitative assessment, the soil has a high swelling (swelling potential between 5% and 25%) [4] or very high swelling [5]. In conclusion of this paragraph, much research has been doted to the study of the swelling properties of the soil during the change of soil-moisture and using the geotechnical characteristics of the soil. They are based on simple laboratory tests and empirical relationships. Therefore, the similarity or contradiction of results with the real soil behavior depends on realistic ways of how these factors have been taken into account. The work of Rama Rao and Smart [6] and Snethen [7], all conclude that the use of these relationships to predict the evolution of the rate of swelling was, generally, devoid of success [8].

IV. Experimental Methodology

A. Testing Procedures Using Oedometer Apparatus

Three testing procedures were performed for predicting heave in swelling soils, kinetics of the phenomenon, the swelling pressure, the rate of swelling and the swelling velocity of the tirs of Gharb. These commonly used oedometer apparatus, as shown in Fig.4, involve tests where a constant applied load is maintained during inundation.

Fig. 4. Oedometer apparatus and equipments used in the test

1) Free Swell Oedometer Test Method: The test is described in the ASTM Standard D4556-95. In this method, the soil specimen is brought in contact with water and allowed to swell freely with a token load applied (7kPa). Then the soil is gradually consolidated back to its original volume in the conventional manner. The swelling pressure is defined as the stress necessary to consolidate the specimen back to its original volume [9].

2) Loaded Swell Oedometer Test Method: The test is described in the French Standard XP P 94-091. Five specimens of the same sample are subjected to different initial applied loads: 15kPa, 38kPa, 51kPa, 82kPa and 102kPa. Each of these specimens is allowed to swell freely. The resulting final volume changes are plotted against the corresponding applied load and stress. The stress corresponding to zero volume change is termed the swelling pressure [10].

3) *Chinese Method:* The test is decribed in the Chinese Technical Code for Construction in Expansive Soil Regions, GBJ112-87. The chinese method testing procedure is conducted to obtain reference information for analysing foundation deformations in expansive soils. The procedure is performed on a single soil specimen which is subjected to a pre-determined pressure and then saturated. The pre-determined is determined in accordance with the site construction requirements and should be slightly larger than the anticipated swelling pressure. After equilibrium condition is reached, the soil specimen is then unloaded following the conventional oedometer test procedure. The pressure at the intersection of the rebound curve with the initial void ratio line is referred to as the swelling pressure. The chinese method is widely used in engineering practice in China due to the advantage that only one specimen is required to define both the swelling pressure and the swelling index.

B. Testing Procedure for Measuring the Matric Suction with the Contact Filter Paper Technique

The test is described in the ASTM Standard D5298. The contact filter paper technique is used to calculate the matric soil suction indirectly. Basically, the filter paper comes to equilibrium with the soil either liquid flow after a good protection, as shown in Fig.5, of the system “filter paper-soil” to avoid moisture loss. At equilibrium, the filter paper and the soil will have the same suction value. The gravimetric water content of the filter paper disc is measured. It is converted thereafter, to suction using a calibration curve of the Whatman filter paper n°42 (55mm diameter) used in our test. Thereby, at different initial water contents of the tirs, we can determine the Soil-Water Characteristic Curve (“SWCC”) in the wetting direction.

Fig. 5. The system “filter paper-soil” carefully protected will be in bag to avoid the influence of rays

V. FACTORS RELATED TO THE CHANGE OF SOIL-MOISTURE

A. Conditions of Starting Wetting and Saturation

The results of this part of study will allow to compare between swelling kinetics under different loads and swelling kinetics for unloading saturated specimens. We will also determine the swelling characteristics of the expansive soil after a cycle of loading and unloading. Fig.6 summarizes the difference between the three testing procedures using oedometer apparatus. It highlights the time to start wetting and applied loads, in addition to the overall mechanical behavior of the soil for each stage of the test.

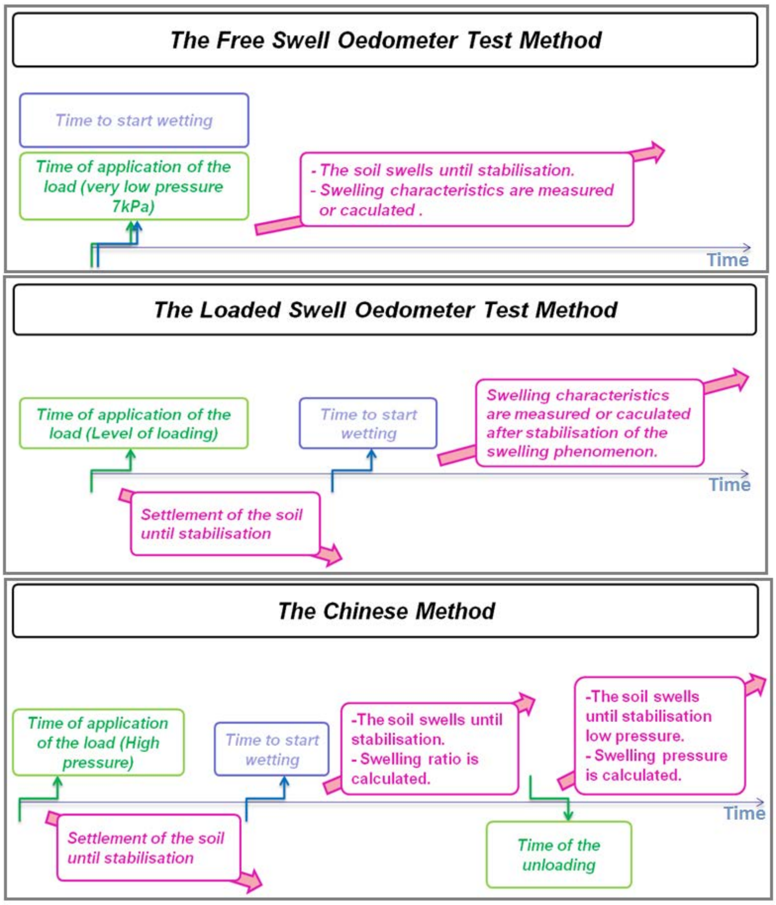

Fig. 6. Summary of the conditions of starting wetting and saturation of the three swell test oedometer methods

1) Kinetics: It has been that for all the oedometer method, increase in swelling with log time is slow initially, increases steeply, and then reaches an asymptotic value. The curves swelling kinetics, represented on a semi-logarithmic diagram in Fig.7, are the same shape (“S”). This proves the existence of three phases of swelling along the time axis. In the first stage (primary swell) of hydration of tirs particles, water is absorbed in successive mono-layers on the surface of clay particles apart which referred to as interlayer or inter-crystalline swelling. The second phase (secondary swell) of swelling is due to double-layer repulsion. Large volume changes accompany this stage of swelling. The third phase (the steady phase) started when the tirs stopped swelling.

It should be noted that the initial swelling is generally less than 5% of the total swelling. This is essentially due to swelling of tirs clay particles within the voids of the coarser non-swelling fraction. Primary swelling develops when the void can no longer accommodate further clay particle swelling. It occurs at faster rate. After the primary swelling was completed, slow continued swelling occurs. It is observed that the end of primary swelling are varies within 200-1000 minutes. In general, the time needed for completion the primary swelling increase associated with increase of the saturation loading.

After water uptake, the expansive tirs can swell at a constant vertical pressure in the direction of loading as in the free swell oedometer test method and in the loaded swell oedometer test method, or in the direction of unloading variable as in the chinese method. In this context, the time required to reach an asymptotic value varies considerably comparing the three methods (between 5760min and 9000min). Indeed, the curves of kinetics become smoothed by increasing a level of loading (during the saturation) that coincides with the start of wetting.

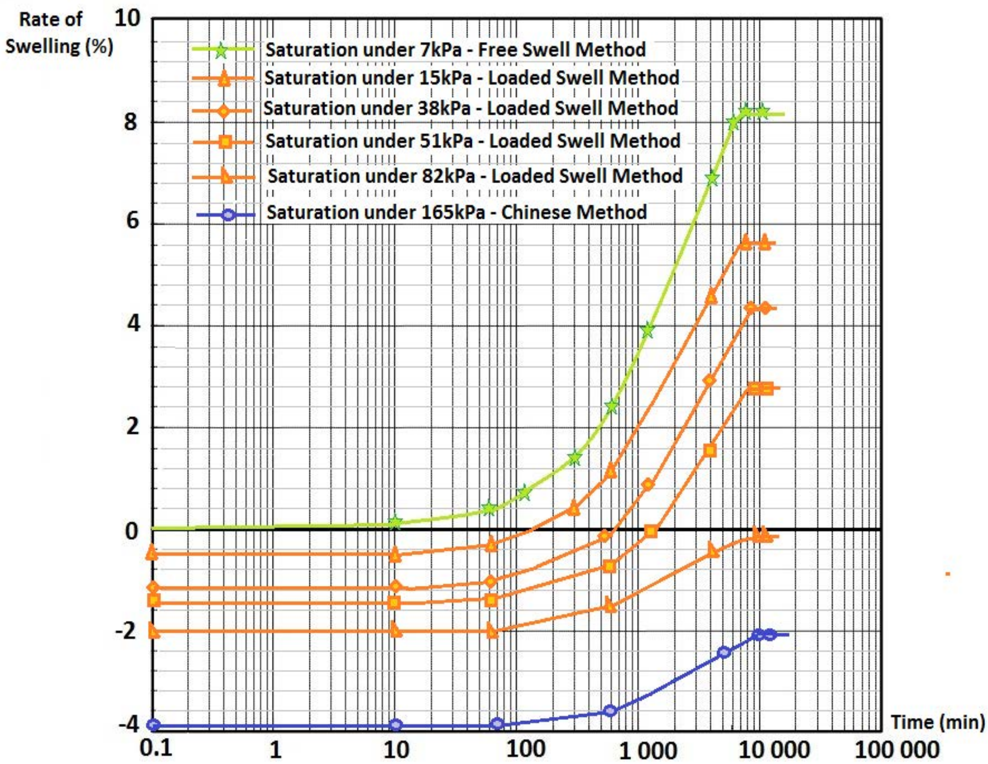

Fig. 7. Kinetics of swelling of the tirs during saturation

2) Swelling Ratio: According to the same curves of kinetics in Fig.7, the slopes rise during each test. The swelling velocity decreases after the first waiting time (after 10 minutes) and reaches its maximum in the first hour under the minimum load applied at saturation (the free swell method). During this time, the rate of swelling develops quickly before reaching the swelling ratio (in the steady phase). The swelling ratio is an important parameter characterizing the swelling behavior. It shows, in concrete terms, the amount of expansion that will occur in the field and cause roadway uplifting or foundation heave.

For each oedometer method, we present in the table 2, the values of the swelling ratio. The maximum value corresponds to the free swell oedometer test with a very low pressure during saturation followed by the value obtained in the loaded swell oedometer test. The minimum value corresponds to the chinese method of high pressure during saturation. Moreover, the value of swelling ratio decreases greatly by increasing the pre-determined pressure in the chinese method. So, the choice of this parameter is very influential.

TABLE II
Values of the swelling ratio of the tirs specimens

Oedometer Method	**Free swell test**	**Loaded swell test**		**Chinese method**	
		Value	**Saturation under**	**Value**	**Saturation under**
Swelling ratio (%)	8.20	6.15 5.48 4.12 1.91 0.12	15kPa 38kPa 51kPa 82kPa 102kPa	1.95 0.84	165kPa 200kPa

In other side, multiple unloading levels were made (using the chinese method) after an initial loading of 165kPa, and inundation with distilled water after the settlement of specimen soil. Levels chosen are similar to a part of the loading levels of the loaded swell method: 51kPa, 38kPa and 15kPa in descending order. The table 3 provides values of the swelling ratio. The large discrepancy between the swelling ratio under the same final pressure leads to say that it is as if the soil remembers its history. Therefore, there is a strong dependence between the stress history and the swelling behavior.

TABLE III
Values of the swelling ratio of the tirs specimens in Loading and unloading direction

Oedometer Method	**Loaded swell test**		**Chinese method**	
	Value	**Loading direction**	**Value**	**Unloading direction**
Swelling ratio (%)	6.15	15kPa	4.39	15kPa
	5.48	38kPa	3.11	38kPa
	4.12	51kPa	2.79	51kPa

3) Swelling Pressure: Table 4 shows the values of vertical swelling pressures in the three oedometer methods studied. The swelling pressure decreases by increasing load level during the process of saturation. This finding follows the results for the swelling ratio. In fact, the swelling pressure is affected by the process of contacting water.

TABLE IV
Values of the swelling pressure of the tirs specimens

Oedometer Method	**Free swell test**	**Loaded swell test**	**Chinese method**	
			Value	**under**
Swelling pressure (kPa)	164	104	20	165kPa
			13	200kPa

On one hand, it is wisdom to say that there have been a number of controversies regarding the results of the free swell test oedometer method. The most serious criticism of this method is that it does not represent the normal sequence of loadings experienced by the soil in the field. The soil in the field will not absorb water and swell with the structural loads applied later, but rather vice-versa [11]. This method has another limitation in that it involves both a volume increase and decrease, and therefore incorporates hysteresis into the estimation of the in-situ stress state. As a result, the measured swelling pressure is greater than the swelling pressure measured using other methods as illustrated in Fig.8. An overestimation is expected when based on oedometer curves with low saturation load. We note that the unloading oedometer curves for the chinese method, as shown in Fig.8, has a discontinuity in alignment. This contradicts the linear relationship between the swelling ratio and the logarithm of the applied load. However, linearity is checked when largely decreases the applied loads. Consequently, the use of this line will lead to an underestimation of the value of the swelling pressure.

4) Explanations: During the wetting of the soil, the evolution of the volume change with the combined time at loading applied (during the saturation) induced that the rate of swelling develops "in comfort" for the the free swell method because the expansiveness is not prevented by against vertical pressure. The inundation of the soil in the water, from the outset, causes a rapid infiltration of free or gravitational water and leads, therefore, to the formation of the diffuse double layer which implies a certain swelling. The fact to soak the soil after application of increasing loads (in the loaded swell method) or the application of a higher pressure value greater than the anticipated swelling pressure (in the Chinese method) and, subsequently, let the soil saturate under these loading levels, strengthens the resistance of the intermolecular and colloidal bonds and prevents high swelling energy dissipation in the saturation phase (case of the loaded swell method) even in the phase of unloading followed saturation (in the Chinese method) . The system “load-soil” has an additional potential energy of interaction of soil particles [8].

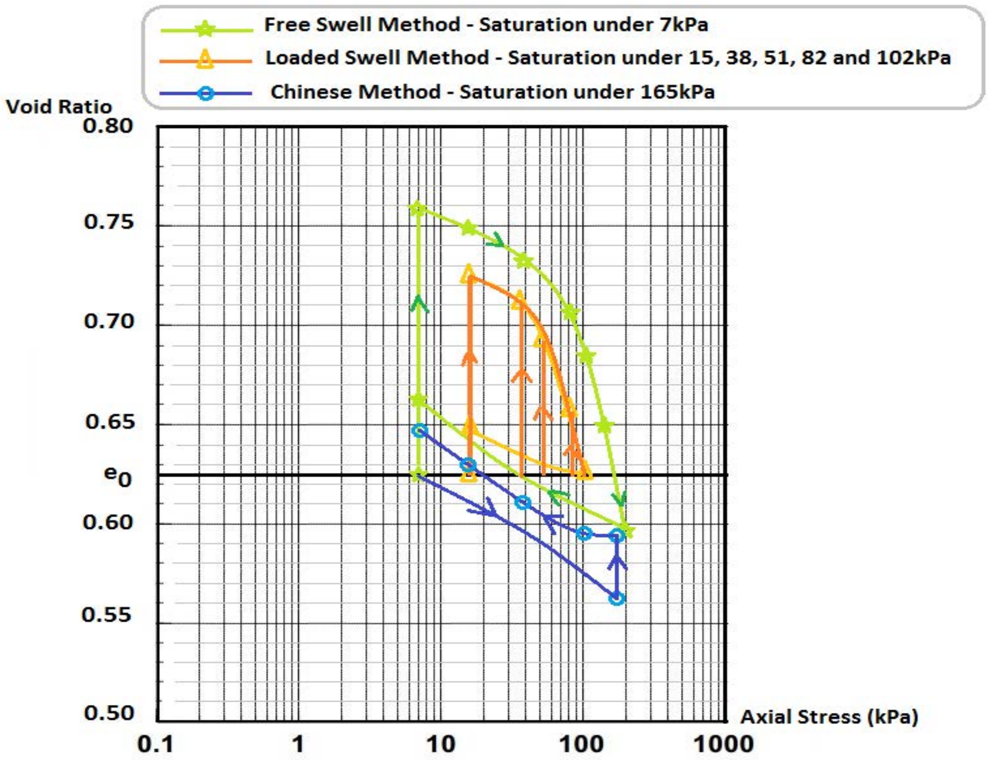

Fig. 8. Swelling curves of the three swell test oedometer methods

B. Influence of the Wetting Duration

The wetting duration has a serious impact on the extent of damages caused by the swelling phenomenon. These are more important that the duration of moistening is long. Compacted specimens at a constant dry density (1.57g/cm^3) and initial water content (18%).

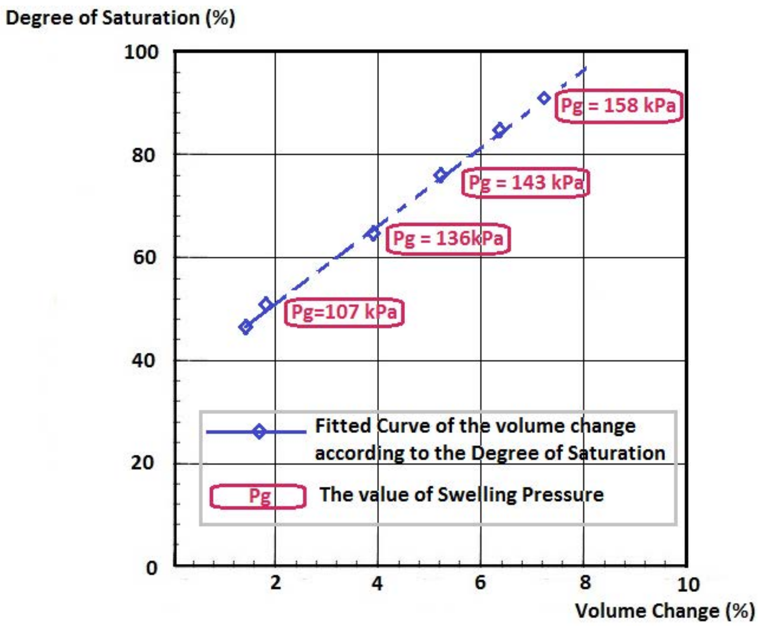

Fig. 9. Variation of the volume change and the swelling pressure according to the variation of the degree of saturation

In the oedometer apparatus, the tirs specimens are saturated at various final degrees of saturation. Then, their volume changes (under 7kPa) are measured directly and their swelling pressures are concluded following loading process.

The analysis of Fig.9 has allowed us to conclude that even if the degree of the saturation is not very high, the swelling may be important. Likewise, we conclude that a wetting of short duration has the same swelling effects on the light structures during swelling as a wetting of long duration.

This is confirmed from the Soil-Water Characteristic Curve ("SWCC"), in Fig.10, which shows the matric suction increases as a lower initial water content (or initial degree of saturation). The water is drawn into the soil by the suction pressures. In reality, the combination of both shrinkage cracks and high suction pressures allows water to be quickly sucked into the expansive tirs, resulting in a higher swelling ratio and more gradual and differential movement of the foundation, pavements or flatwork. Therefore, we can say that the values of the swelling pressure rise by increasing final degrees of saturation (as shown in Fig.9). In truth, the swelling pressure is moderately affected by the change in water content rather than a wetting duration. We must fear the worst for both large surface deposits of tirs and the climate of Gharb area, sometimes, characterised by alternating periods of rainfall and drought.

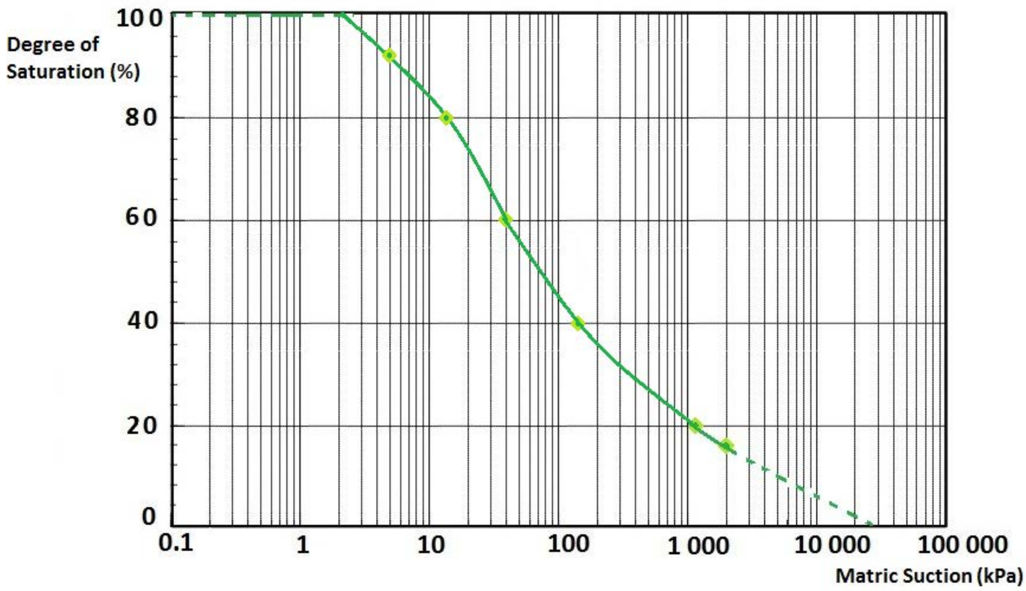

Fig. 10. Soil-Water Characteristic Curve of the tirs (in the wetting direction)

C. Influence of Density and Water Content

Compacted soil specimens were prepared by varying their initial water contents and dry density. Fig. 11 shows that the value of the swelling pressure, obtained by the free swell oedometer test method, decreases significantly by increasing initial water content and decreasing dry density. It is seen also that the value of swelling ratio decreases seriously around optimum proctor of dry density and water content (about 1.5%). However, at a low dry density and high water content may not have additional swelling soil, but they could still cause the structure to downward movement if they should dry out [12]. If the soil dries enough before construction and if the design is done in order to counteract the swelling pressure, we could probably attend subsidence during a rewetting of the soil even more than it is customary that the contact pressure provided by the foundations will be greater than the anticipated swelling pressure in the aim to feel its effect in depth. The instability of the soil should be feared in both directions [1].

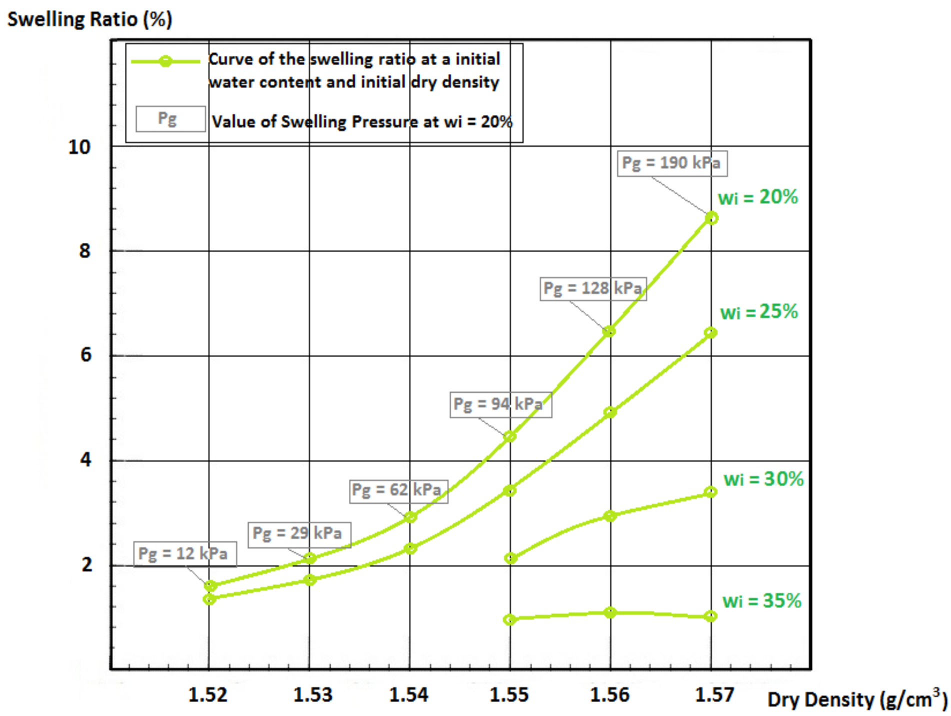

Fig. 11. Curve of the swelling ratio and the values of swelling pressures according to the variation of the initial dry density and water content

At the site, the swelling pressure can be maximized with a minimum initial water content followed by a wetting (rain for example). This case can occur on the surface but it is usually accompanied by a change of dry density due to the shrinkage cracks in dry climate [13]. Water penetration into the pores does not mean the beginning of a process of swelling. We need sufficient pressure able to increase the distance between soil particles and break the structural bonds. For this reason, the soil swells if it is dense because the distance between particles is less than the thickness of the hydrated envelopes [8]. Additionally, it is suggested that expansive soils should be compacted to a lower density than the optimum proctor density and to greater initial water content than the optimum proctor water content, in order to guard against the harmful effects of swelling phenomenon.

VI. Conclusion

This study investigated the swelling behavior of undisturbed and disturbed specimens of the tirs of the Gharb region in Morocco using three oedometer methods at constant applied load during saturation. Our tests show that it is possible to underestimate or overestimate the swelling pressure in the case of the choice of parameters and factors related to a change of soil-moisture. The wide range of values obtained for the swelling ratio, the rate of swelling under load and the difference between kinetics, lead us to say that the conditions of starting wetting and saturation with his famous combination “start wetting-level of loading during saturation”, the variation of the degree of saturation or initial suction and the variation of initial conditions through initial “water content-dry density” are important factors that carry weight to the knowledge of swelling characteristics data of expansive soil.

The phenomenon of swelling is very complex. A small change of the factors related to the change of soil-moisture can bring the expansive soil to extreme values of the swelling pressure, the velocity of the swelling, the volume change and the swelling ratio. Moreoever, the found values of the swelling ratio and the swelling pressure conduce to say that the swelling of the tirs of the Gharb region must be considered seriously, especially, in urban sprawl or during the construction of roadways or railways. Those values can exceed, respectively, 8% and 160kPa. Therefore, it is essential to define test conditions, the input data of the site in their entirety and the history of in-situ soil before searching correlations that may exist between different parameters of expansive soils because many other factors affect the swelling behavior and consequently the swelling characteristics.

Acknowledgment

The authors wish to acknowledge the technical staff of geotechnical engineering Laboratory in Mohammadia engineering school for providing Laboratory facilities.

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