Study On The Swelling Behavior Of The Green Clay Of Gzenaya (Morocco) Compared With Test Conditions

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ABSTRACT

Several studies were conducted to specify the characteristics of the swelling behavior. The swelling ratio and the swelling pressure are valuable to civil engineers and practioners especially in the phases of design and calculation. Really, the evaluation of these parameters, until now, is not unified.

It is proposed, in this paper, to review some qualitative and quantitative methods of expansive green clay of Gzenaya in Tangier (Morocco). Test procedures, evoked and based on the oedometer apparatus, are analyzed to show their direct influence on soil behavior during swelling. Particular attention is bore to the influence of the conditions of loading and saturation on the values of the swelling parameters and its kinetics of swelling.
The opportunity is offered to highlight other parametric conditions which interfere, seriously, in test conditions, in particular, the combination "initial water content-dry density" of the soil and its amount of fine size particles (smaller than 80 µm).

Keywords – Green clay, Oedometer, Swelling pressure, Swelling ratio, Test conditions.

1. Introduction

The swelling phenomenon causes much interest for geotechnical and civil engineers who aim to ensure their structures to the various disasters that can occur. A stability of engineering work immediately passes by a good appreciation of the "support" soil and soil-structure interaction.

In Morocco, the phenomenon of swelling soils is present: expansive soils known by several nomenclatures (hamri, gheiss, tirs, etc. ...) are spread over a large area of territory. This work is part of a contribution to the experimental analysis of a moroccan expansive soil, as it happens, the green clay of Gzenaya (Fig.1). This region is gaining momentum in the construction sector and civil engineering. The city plan, by its extension on peripheries, provides for the region of Gzenaya industrial zones (such as Tangier Free Zone “TFZ”) and residential aeras (a new city covering 1070 named “Gzenaya Al Jadida” is to build). Gzenaya represents the acess to Tangier (a city in northwest of Morocco between the Atlantic Ocean and the Mediterranean Sea) from the highway number A_1 between Rabat and Tangier (Fig.2).


Figure 1: Green clay of Gzenaya (Tangier) after sieving to 80µm in laboratory and drying.

The context is conducive to reflection on the swelling behavior of this expansive clay like its kinetics. The evaluation of the swelling ratio and swelling pressure appears also very important.
In truth, several methods of qualitative and quantitative predictions exist in the literature and vary sometimes in a contradictory way. Therefore, a definition of test conditions is necessary to better understand the characteristics of swelling. For this, we propose to be based on oedometer tests and to analyze the influences caused by:

- the choice of the test procedure (the Free swell oedometer test method, the Loaded swell oedometer test method and the Chinese method) on kinetics of swelling.
- the choice of the test procedure (the Free swell oedometer test method, the Loaded swell oedometer test method and the Chinese method) on the swelling ratio and pressure. This part aims to show and comment the influence of load level and timing of start the wetting on the parameters characterizing the phenomenon of swelling.
- the difference of the amounts of fine size particles smaller than 80 µm on the swelling pressure.
- the choice of initial conditions of the specimens soil through a factor “dry density-water content” on the swelling pressure.

2. Soil specimens

We were interested in green clays of Gzenaya through two principal sites (Fig.2) : the site 1 is

Figure 2: Localization maps of the region of Gzenaya in Tangier (Morocco) and sites location.

located at Tangier Free Zone "TFZ" and the site 2 on the other side of the trunk road number N_1. specimens tested in laboratory come from six trial pits. They are dug by using mechanical digger and after by hand in the aim to have intact cubes of soil. Three trial pits are conducted in the site 1 (Tp.1, Tp.2 and Tp.3) in depths of up to 3.80m and the others three in the site 2 (Tp.4, Tp.5 and Tp.6) in depths reaching 2 to 2,3m. Cubes of soil were crated. They were protected by a film of paraffin oil to provide a good hygrometric insulation and to avoid the exchange of moisture between them and the ambient conditions. It is noted that the soil specimens having the same depth (presumedly identical specimens) are taken from the same cube. This operation brings undisturbed soil specimens.

3. Geotechnical characteristics

The results of identification tests are summarized in the table 1 and the table 2. They indicate that the soil is generally a plastic clay which represents high plasticity index and important amounts of clay size particles.

The methylene blue adsorption test (Fig.3) gives, also, an idea about this characteristic of plasticity and expansiveness (Methylene Blue Value: 4.5 < MBV < 6).

The thickness of layers are continuous and exceeds 3.7m in site 1. These findings confirm that the swelling of the green clay has to be considered in the new areas to build.

4. Qualitative evaluation of swelling

4.1. Swelling ratio

The evaluation of swelling can be performed according to several qualitative methods that are based on soil characteristics. Seed developed a classification chart based solely on the amount and type (activity A_c) of clay size particles (% < 2µm) [1]. Van der Merwe presented another classification chart of swelling soils [2]. It is based on three values : the plasticity index, the fraction of clay particles and the activity of clay particles. Using these two charts, it appears that the criterion evaluated is the swelling potential which represents the swelling ratio [3]. The results of this comparison are presented in the table 3. Despite some nuances of term and differences, it seems that the green clay of Gzenaya has a high swelling characterised by a swelling ratio ranging from 5 to 25%.

Table 1: Summary of geotechnical characteristics for soil specimens of site 1

	Site 1											
	Depth	Trial Pit	Specimen	(**) ω_i	(**) < 80µm	(**) < 2µm	(**) ω_L	(**) ω_P	(**) I_P	(**) ρ_{hi}	(**) MBV	Clasification
Units	m			%	%	%	%	%		g/cm^3	g blue/ 100g dry soil	(**) USCS symbol
	2,0	Tp.1	Sp.1	27	91	34	52	16	36	1,70	4,72	CH
	2,4	Tp.1	(*)Sp.7							1,83		
	2,6	Tp..2	Sp.2	26	88	36	51	14	37	1,71	4,64	CH
	2,8	Tp.2	Sp.8	26	80	33	50	17	33	1,70		CH
	3,0	Tp.3	Sp.9	27	81	32	51	17	34	1,69		CH
	3,2	Tp.3	Sp.10	27	85	33	50	16	34	1,69		CH
	3,4	Tp.3	Sp.3	27	80	37	53	17	36	1,72	4,85	CH
	3,7	Tp.3	Sp.11	27	78	37	51	14	37	1,73		CH

(*) this soil specimen contains 36% of the materials larger than 2mm

(**) ω_i : Initial water content

< 80µm : Amount of fine size particles less than 80µm

< 2µm : Amount of clay size particles less than 2 µm

ω_L : Liquid limit

ω_P : Plastic limit

I_P : Plasticity index

ρ_{hi} : Initial wet density

MBV : Methylene Blue Value

USCS : The Unified Soil Classification system

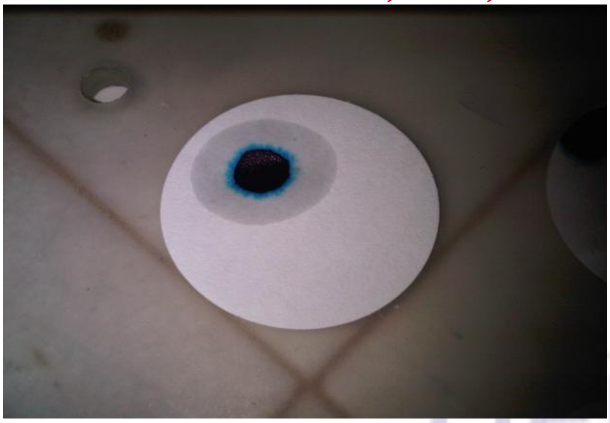

Figure 3: Methylene blue adsorption test.

4.2. Comment

It should be noted that these evaluations can not constitute, under any circumstances, the desired accuracy for a practionner and the required economy to study the projects. They have, however, a preliminary idea on the swelling soil. They must be considered with great precaution. Indeed, all these predictions relate to a free swelling of soil. They are, totally, unable to predict the rate of swelling soil under pressures [4].

Table 2: Summary of geotechnical characteristics for soil specimens of site 2

	Site 2											
	Depth	Trial Pit	Specimen	(**) ω_i	(**) < 80µm	(**) < 2µm	(**) ω_L	(**) ω_P	(**) I_P	(**) ρ_{hi}	(**) MBV	Clasification
Units	m			%	%	%	%	%		g/cm^3	g blue/ 100g dry soil	(**) USCS symbol
	0,8	Tp.4	Sp.12	39	72	27	45	23	22			CL
	1,0	Tp.4	Sp.13	35	81	26	43	22	21	1,78		CL
	1,2	Tp.4	Sp.14	33	85	29	47	21	26	1,82		CL
	1,5	Tp.5	Sp.4	30	82	40	53	17	36	1,73	4,53	CH
	2,0	Tp.6	Sp.5	24	90	33	58	24	34	1,66	4,64	CH
	2,2	Tp.6	Sp.6	24	88	33	56	24	32	1,67	4,58	CH

(**) ω_i : Initial water content
< 80µm : Amount of fine size particles less than 80µm
< 2µm : Amount of clay size particles less than 2
I_P : Plasticity index
ρ_{hi} : Initial wet density
MBV : Methylene Blue Value
USCS : The Unified Soil Classification system

Table 3: Qualitative evaluation of potential swelling of specimens

Specimen	Activity	Classification of smelling according to	
	A_c	Seed	Van der Merwe
Sp.1	1.06	High	Very high
Sp.2	1.03	High	Very high
Sp.8	1.00	High	Very high
Sp.9	1.06	High	Very high
Sp.10	1.03	High	Very high
Sp.3	0,97	High	Very high
Sp.11	1,00	High	Very high
Sp.12	0.81	Medium	High
Sp.13	0.81	Medium	Medium
Sp.14	0.90	Medium	High
Sp.4	0.90	High	Very high
Sp.5	1.03	High	Very high
Sp.6	0,97	High	Very high

4.3. Swelling pressure

With an eye to have an order of magnitude of the pressure which the soil of Gzenaya could develop, we performed the filter paper method for measuring soil suction according to the ASTM Standard D5298 (Fig.4).

Figure 4: Filter paper method for measuring soil suction.

The water content of the filter paper corresponds to a suction value, as based of the filter paper calibration curve. Theoretically, the equilibrium water content of the filter paper corresponds to the matric suction of the soil when the paper is placed in contact with the water in the soil. For two disturbed samples, the same conditions site were reproduced. We obtain, 2.4pF for site 1 and 2.6pF for site 2.
The swelling pressure is proportional to soil suction with a coefficient greater than 1 for unsaturated soil [5]. It can be expected a swelling pressure greater than 25 kPa.

5. Testing procedures for the quantitative evaluation of swelling

Three testing procedures using oedometer apparatus (Fig.5) were performed in order to discuss the behavior and the characteristics of swelling of the green clay: The free swell oedometer test method, the loaded swell oedometer test method and the chinese method. Testing procedures belong to this category, keep a constant applied load during the test. Each method tries to simulate, as faithfully as possible, the boundary conditions on the ground depending on the behavior of the structure.

5.1. Free swell oedometer test method

The soil specimen is brought in contact with water and allowed to swell freely with a low pressure corresponding to the weight of the piston and the porous disk. Then the soil is gradually consolidated back to its original volume in the conventionnal manner. The maximum deformation relative to the initial height of specimen is the swelling potential. The swelling pressure is defined as the stress necessary to consolidate the specimen back to its original volume [6]. The test is described in the ASTM Standard D4546-95.

Figure 5: Equipment used in the oedometer methods.

5.2. Loaded swell oedometer test method

Four rings of "identical" specimens are subjected to different initial applied loads and allowed to swell freely. We follow the evolution of vertical deformation (swelling or collapse) as a function of axial stress. We plot the curve "swelling ratio-axial stress" or "void ratio-axial stress". The swelling pressure corresponds to zero volume change [7]. It is found from a extrapolation. This method is proposed by the French Standard XP P 94-091 (named method in parallel at different pressures).

5.3. Chinese method

The test is described in the chinese technical code for construction in soil regions, GBJ 112-87. The chinese procedure is performed on a single soil specimen which is subjected to a pre-determined pressure, slightly larger than the anticipated swelling pressure, and then saturated. After the soil has swelled to an equilibrium condition, the soil specimen is then unloaded following the conventional oedometer test procedure. The swelling pressure is defined as the pressure on the rebound curve corresponding to the initial void ratio.

6. Results and analysis

6.1. Influence of the test procedure on the behavior of expansive soil

6.1.1. Kinetics

The first reflex is that the influence of the test procedure does not relate to only swelling ratio or swelling pressure, but also the kinetics of swelling that represents the evolution of the change of volume in time. So, for each experimental procedure, the behavior of soil was recorded during the humidification specimens.

The curves according to kinetics of swelling of the soil specimen Sp.4 are shown in the figure 6. They show the existence of two phases of swelling : primary swell and secondary swell. The primary swell occurs from time equals zero (start of wetting) to about 100 min. We note that during primary swell, there was a rapid decrease in the hydraulic conductivity (also known as permeability) of the clay. The swelling ratio curve has a waiting time before rising. Moreover, it rises when the load applied increases. The secondary swell occurs from a time of about 100 to 10000 min after wetting. The curves of kinetics becomes smoothed by increasing the load applied during the saturation of the ground. The surcharge pressure influences directly the behavior of swelling for an expansive soil.

6.1.2. Swelling ratio

The swelling ratio is important because it governs how fast water will enter the soil and cause foundation heave. Table 4 shows the values of the variation in the swelling ratio of the expansive green clay (in the steady state of swelling). The table 4 and the figure 6 confirm that the swelling ratio increases rapidly when the load applied at saturation is reduced. We specify that the swelling ratio is the highest of the free swell oedometer test method.

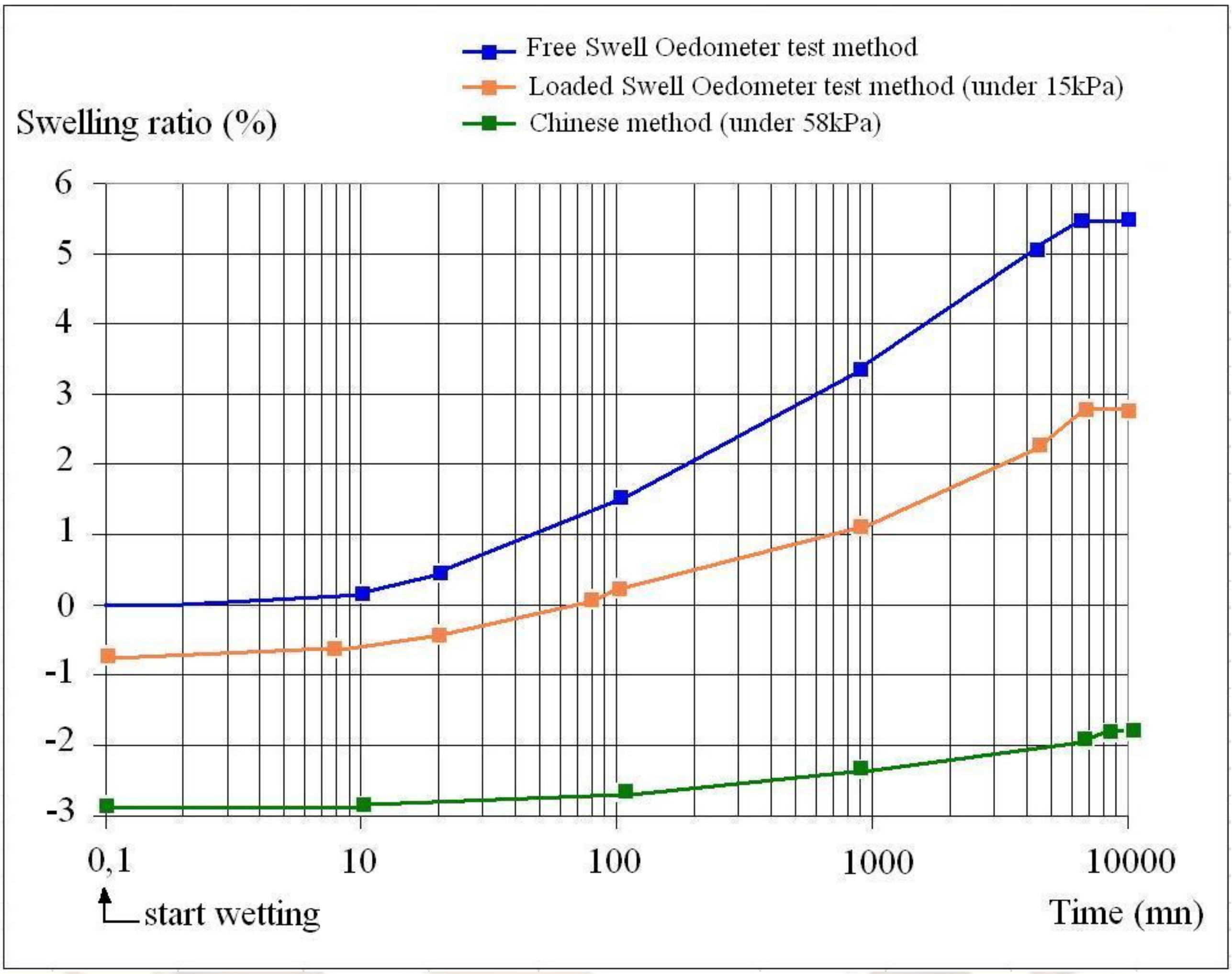

Figure 6: Kinetics of swelling for the soil specimen Sp.4 in the saturation phase.

For the specimen Sp.4, the curve of kinetics (Fig.6) shows that the swelling potential (the swelling ratio under 7kPa in the free swell method) is about 5.5%. The maximum swelling potential is observed in the soil specimen Sp.5 (7.4%).

Table 4: Values of the swelling ratio of the green clay specimens.

Specimen	Free Swell method	Loaded Swell method		Chinese method (after unloading the predetermined pressure)
		Ratio	under	
Sp.1	7.2%	4.10 %	15kPa	2.30% (67kPa)
		0.37 %	45kPa	
Sp.2	5.1%	2.51 %	15kPa	1.50% (57kPa)
		0.30 %	37kPa	
Sp.3	6.1%	3.32 %	15kPa	1.80% (63kPa)
		0.88 %	37kPa	
Sp.4	5.5%	2.83 %	15kPa	1.65% (58kPa)
		0.52 %	37kPa	
Sp.5	7.4%	4.58 %	15kPa	2.25% (77kPa)
		1.14 %	45kPa	
Sp.6	7.0%	3.87 %	15kPa	2.20% (67kPa)
		0.12 %	45kPa	

The effect of surcharge is important because it is usually the lightly loaded structures such as concrete flatwork, pavements, slab-on-grade foundations, or concrete canal liners that often impacted by expansive soil.

The influence of the timing of start the wetting on the swelling ratio is clear. Indeed, the swelling ratio of the soil specimens in the chinese method after unloading is much lower than that in the free swell method. In addition, according to the loaded method, the void ratio before loading and the void ratio after unloading are not the same (fig.7). It is as if the soil remembers its history of stresses in the loaded swell oedometer test method (during the unloading phase) and the chinese method (after unloading the pre-determined pressure).

6.1.3. Swelling pressure

Table 5 lists the various values of the swelling pressure using the three methods. The free swell method has a swelling pressure higher than the loaded swell method (difference between 25% and 30%) and the chinese method (difference between 62% and 68%). The figure 7 shows that the swelling pressure for the specimen Sp.5 is 55kPa in a logarithmic representation (axial stress-void ratio) according to the Loaded swell method. Figure 8 and figure 9 show, respectively, the graphs interpreting the free swell oedometer test method (soil specimen Sp.4) and the chinese method the specimens (soil specimen Sp.2.). The maximum swelling pressure is observed in the soil specimen Sp.5 (74kPa).

Table 5: Values of the swelling pressure of the green clay specimens.

Specimens	Free Swell method	Loaded Swell method	Chinese method	
			Pressure value	under
Sp.1	66 kPa	48 kPa	24 kPa	67 kPa
Sp.2	55 kPa	40 kPa	18 kPa	57 kPa
Sp.3	62 kPa	45 kPa	22 kPa	63 kPa
Sp.4	58 kPa	42 kPa	20 kPa	58 kPa
Sp.5	74 kPa	55 kPa	28 kPa	77 kPa
Sp.6	66 kPa	46 kPa	24 kPa	67 kPa

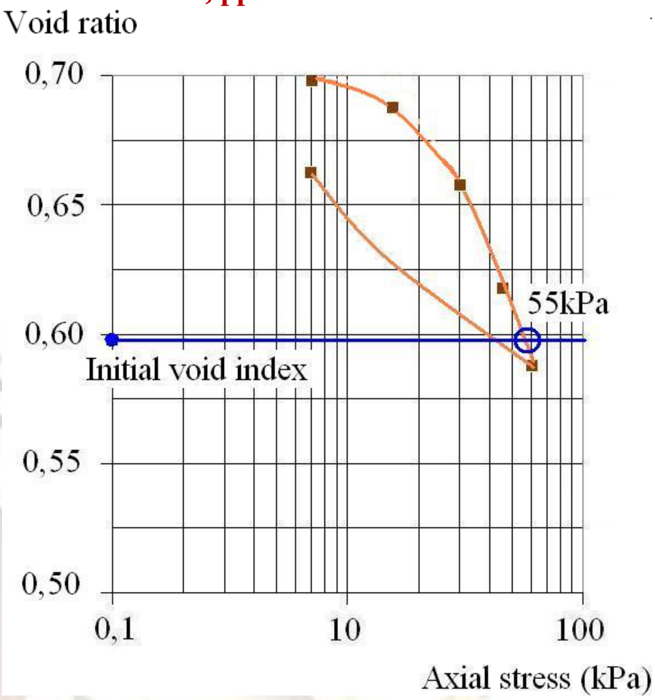

Figure 7: Swelling pressure for the soil specimen Sp.5 according to the loaded swell oedometer test method.

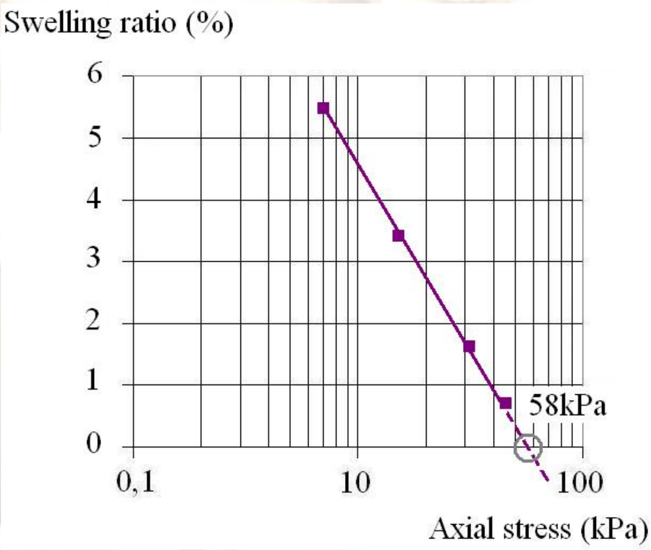

Figure 8: Swelling pressure for the soil specimen Sp.4 according to the free swell oedometer test method.

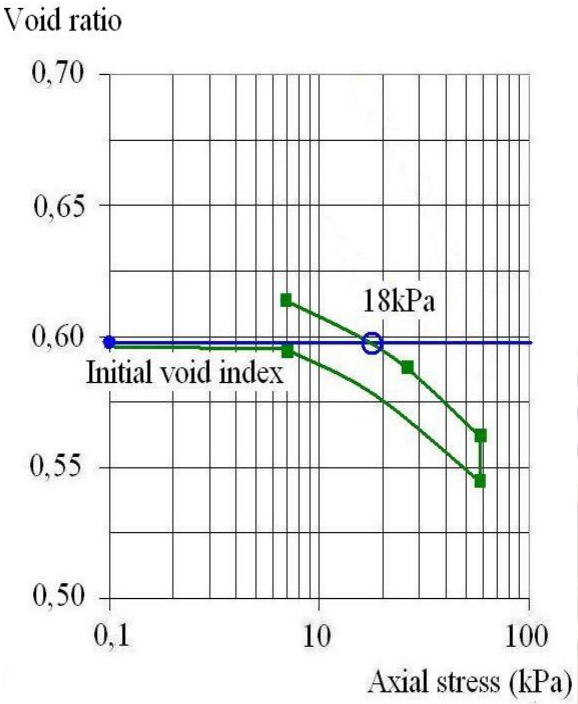

Figure 9: Swelling pressure for the soil specimen Sp.2 according to the chinese method.

6.1. 4. Interpretation

For chinese method, the low measured swelling pressure appears to be primarily due to the plastic deformation [8] (settlement and heave under compressive load) taking place during the test.

Moreover, it is paramount to say that expansive clays swell in response to changes in several forces [9] acted on clay particles :

- Surface tension in the menisci of water contained between the particles (tends to pull the particles together, compressing the soil).
- Osmotic pressures (tend to bring water in, thus pressing the particles further apart and expanding the soil).
- Pressures in entrapped air bubbles (tend to expand the soil).
- Effective stresses due to external loads (tend to compress the soil).
- Colloidal forces (tend to compress the soil).
- London-Van Der Waals intermolecular forces (tend to compress the soil).

In comparison with the loaded swell oedometer test method and the chinese method, the free swell oedometer test method is under a friction of "ring/soil". Despiste this consideration, it has the maximum swelling pressure. This may be due, mainly, to intermolecular resistance which develops especially in the loaded swell method. The resistant effect caused by the loading and the structural bonds on the development of swelling leads to different values of swelling pressures in the event of loading and unloading [10]. This is the case also of the chinese method because the swelling pressure is defined on the unloading curve after loading and saturation. In the case of the static loading and after saturation of the specimen, with stabilization of vertical deformation, the system "load-soil" has an additional potential energy of interaction of soil particles. This potential energy evolves the system to a new equilibrium state in which intermolecular and colloidal bonds are stronger [4].

This interpretation is valid for the chinese method and the loaded swell method, but, it is quite different for the free swell method. Indeed, the free water (gravitational water) seeps rapidly in the soil and causes the formation of the diffuse double layer which brings back the soil for certain swelling.

It follows that the frame of the swelling characteristics and the behavior of expansive soil depends directly on the selected method.

6.1. 5. Comments relating on the test conditions

It is necessary to be careful regarding the results of free swell oedometer tests. In truth, this method does not represent the normal sequence of loadings experienced by the soil in the field. A volume change is combined with hysteresis to estimate characheristics of swelling. Normally, the in situ soil swells under confining pressures. This is in opposition to the Loaded Swell method that it follows the same sequence as in the field. The loading-wetting procedure is frequently used as a result of its similarity of typical in situ stress paths [11]. The importance of the chinese method comes owing to the fact that it provides basic information for modeling and analyzing foundation deformations in expansive soils. The swelling is done under an important pressure which takes into account the site conditions and the strains for calculate the foundations. In some way or other, the two last methods, the loads are first applied to the soil and the soil undergoes compression, then the soil swells when the wetting starts.

Attention is to be given to choice of the pre-determined pressure in the Chinese method because when it increases, the swelling pressure decreases automatically [8].

All the testing are performed on a single soil specimen except the Loaded Swell method. It requires "identical" undisturbed specimens, what is not completely obvious scientifically.

6.2. Influence of the amount of fine size particles on the swelling pressure

According to the results obtained during the free swell oedometer test method (Table 5), the soil specimen Sp.4 has the greater value of the amount of clay size particles (%<2µm = 40%). Its swelling pressure has a lower value (58kPa) compared with the other majority of specimens tested. But, its amount of fine size particles smaller than 80µm is 82%. Soil Specimens Sp.5 and Sp.1, respectively, with 90% and 91% of the amount of fine size particles (smaller than 80µm), have the greatest values of swelling pressure exceeding 60kPa. It is clear that the clay size particles in the specimen Sp.4 are less active compared with the others. The Mineralogical type and its distribution is the main cause. The influence of particles on the swelling should not be made, only, by referring to its clay fraction, but rather to the whole of the content of clay particles in the soil [12] (amount of fine size particles smaller than 80µm).

6.3. Influence of the dry density and water content on the swelling pressure

Three specimens of soil were prepared by variying two parameters influencing swelling directly : the dry density and initial water content. The test procedure used in this study is the free swell oedometer test method (Fig. 10). The swelling pressure increases significantly when the initial water content decreases and the dry density increases. the most expansive condition is when the soil has a high dry density and a low moisture condition. This often occurs when near-surface clays becomes desiccated, such as during a hot and dry summer season in Tangier.
We noted that a low dry density and high water content may not have additional swell for soil, but they could still cause the structure to experience downward movement if they should dry out [13]. Thus it is not unusual for near-surface clays to experience changes in dry density and water content throughout the season, depending on whether they have absorbed water and swelled-up during the rainy season, or shrunk and dried-out during the dry season.

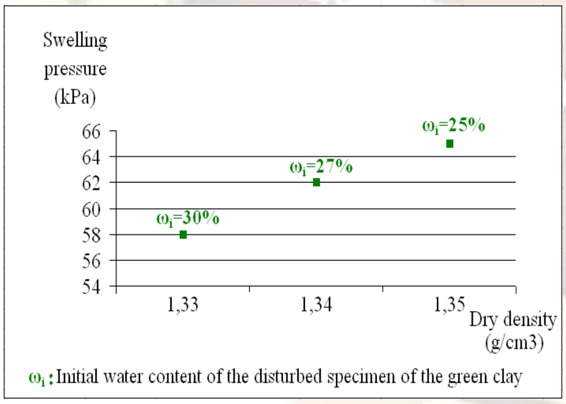

Figure 10: Variation of the swelling pressure according to the variation of initial states of soil (initial water content and dry density).

7. Conclusion

Knowledge of the volume change characteristics in soils at the outset of any engineering construction project is obligatory because of their relationships to heave with foundations. This study investigated the swelling behavior of undisturbed field samples of Gzenaya green clay using several oedometer methods. At the end, we realise the strong dependence between the test conditions and the behavior of swelling of expansive soil. If they affect the parameters characterising swelling, the result can not be useful only if we define, in a correct way, the testing method to choose, the loading modes to be used, the timing to start wetting and the initial conditions to advocate by following a reasoning which takes into account the physical soil characteristics, the history and the future projections of the state of in situ soil.
We noticed, trough this paper that kinetics of swelling is directly influenced by the surcharge pressure. This, give us an idea on the attitude of the swelling speed to rise or decrease during the phases of swelling. This parameter is often related to the capacity of the structural, intermolecular and intramolecular bonds of the soil to remain maintained and not deteriorate totally. The destruction of these bonds caused by the effects of the water and the loading, will surely be a decisive element for understanding the swelling behavior of the soil. In other words, the influence of the test conditions are dominating.

The swelling ratio and the swelling pressure do not depend only on axial pressure applied but also on the level of loading applied during saturation. For this reason, the timing to start wetting in interaction with the pressures used is a valuable factor to avoid possible over-estimates of the swelling parameters. The phenomenon of swelling is very complex. A small change of the initial conditions of the soil such as the water content and the dry density can bring to extreme values of the swelling pressure. Moreoever, we wifh to affirm that the analysis of the swelling on a site can present a significant difference in its swelling pressure compared with the mineralogical expansive activity of each soil specimen.

However, the found values of the swelling ratio and the swelling pressure conduce to say that the swelling of Gzenaya green clay must be considered seriously especially in this urban sprawl. Those values can exceed, respectively, 7% and 70kPa. So, the phenomenon must be more studied in order to have adequate conclusions by adapting the needs to the test conditions and also to the other conditions which influence swelling such as the site conditions and the climatic conditions.

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