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Study and Comparison of Swelling and Compressibility Characteristics of Crumb Marl, Flaky Marl with Attapulgite and Sandy Clay from the Diamniadio Urban Pole at the Oedometer

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Abstract

In Senegal, the Diamniadio, Sebikhotane and Bargny sector contains clay soils that are problematic for construction. In order to have more information on the behavior of the clay soils of Diamniadio, free swelling tests followed by load-discharge cycles were carried out according to standard NF P 94-090-1. These tests were carried out using an Oedometric device on the three samples from the study site (sandy clays with calcareous concretion, marls with crumbs and laminated marls with attapulgite) to apprehend their swelling aspects in saturated conditions. For the free swelling test, a determination of the different swelling phases will be carried out followed by a comparison of the rate of evolution of the phases for the three samples from the site. In the same vein, the compressibility characteristics of the samples will also be provided from load-unload Oedometric tests. Thereafter, we proceed to a comparison of the void index at the initial state of the samples after two charge-discharge cycles and the influence of the cycles on the reorganization of the internal structure of the samples. These studies will provide more information on the swelling behavior of Diamniadio soils in the presence of water.

Keywords

Clay Swelling, Expansive Soil, Evolution of The Swelling, Compressibility Coefficient, Charge-Discharge Cycle

1. Introduction

Swelling occurs gradually as the saturation of the clay structure changes along the depth of the clay layer. Water penetrates the clay structure by creating a network of interstices, which increases the void index. Knowledge of the potential characteristics of volume change in soils at the start of any engineering construction project is mandatory due to their relationship to uplift and lateral thrust due to expansion as well as settlement due to compression Rao *et al.* 2006 [1]. In the same vein, we are interested in other authors such as Josa, A., Alonso, E., and Lloret, A., 1988 [2], H. Asselman 2012 [3], David Mathon 2015 [4] etc. This part presents a detailed study of the different stages of swelling of three samples from the study site (crumb marl, laminated marl and sandy clay with calcareous concretion) but also their characteristics and their evolution during the charge-discharge cycles.

2. Measurement of Swelling Kinetics

2.1. The Measuring Instruments

The odometer is used as a measuring instrument in this study. It allows to measure the thickness variations of a cylindrical material specimen placed in a rigid ring under the action of an axial loading or a water immersion. It allows to describe both the amplitude and the swelling speed of expansive soils. The measuring device can be described in three parts (**Figure 1**).

a) The odometer cell is a cylindrical enclosure inside which the specimen is placed surrounded by a smooth, non-deformable wall called a mold. The mold prevents horizontal expansion, so the deformations that occur are only vertical. The soil test piece is enclosed between two porous stones that allow water to circulate.

b) The loading system depends on the loading method. For a weight-loaded odometer, it is a loading frame consisting essentially of a stable rigid lever. The latter allows forces to be applied in the axis of the piston by attaching flat melted disc weights to the lever.

c) The device for measuring the c. The displacement measuring device consists of a comparator which allows the displacements to be recorded manually or electronically to 1/1000 mm.

The comparator is brought into contact with the sample by a relay system that connects the measuring device to the piston.

For this study, three samples were taken from this site **Figure 2**. Intact and disturbed samples were collected with a truck equipped with a shovel. Intact samples in block form are mostly used for the various tests performed (water content, Oedometric test, specific weight, etc.).

2.2. Experimental Program

The tests are carried out on samples made to the size of the Oedometric rings from intact blocks. We made cylindrical specimens with two flat and parallel

Figure 1. The odometer, cell and its accessories.

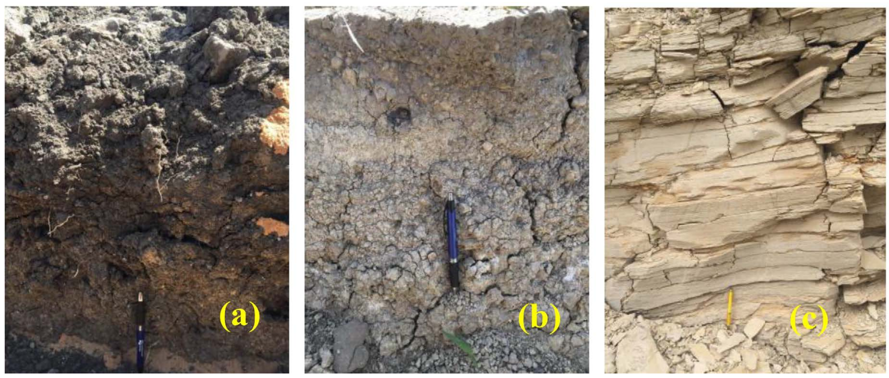

Figure 2. Soils of the study area: a) sandy clay with calcareous concretion; b) crumb marl c) attapulgite laminated marl.

faces while avoiding reworking them. The free swelling tests are carried out on the three samples from our study site. For each sample, we performed three free-swell tests until the sample stabilized. The stability of laminated marls is obtained around a fortnight, that of crumb marl around eleven days and that of sandy clays for a period of seven days. Once the sample has stabilized, we proceed to two charge-discharge cycles. Subsequently, we retained the most satisfactory results.

2.3. Swelling Kinetics

In the initial state, the clays are in equilibrium, but subjected to mechanical and/or water stresses, their structures undergo a change which can be visible on the surface. The kinetics of swelling, that is to say the existing relationship between deformation and time, is generally very slow and depends on the nature and condition of the soil and the level of loading. **Figures 3-5** illustrate the relationship between one-dimensional swelling and the logarithm of time.

The graph obtained by a free swelling test shows that the deformation can be broken down into an initiation phase, a primary swelling phase and a secondary swelling phase.

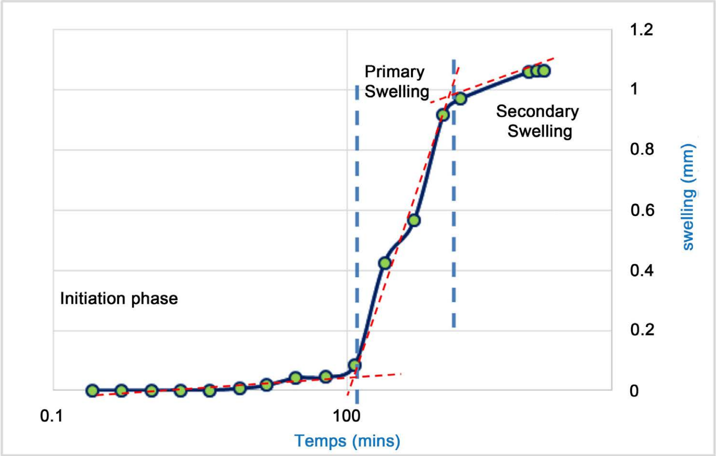

Figure 3. Free swelling of the crumb marl.

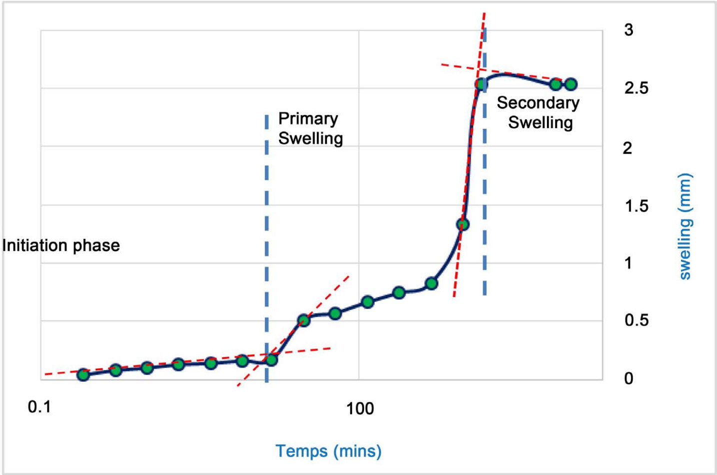

Figure 4. Free swelling of the laminated marl with attapulgite.

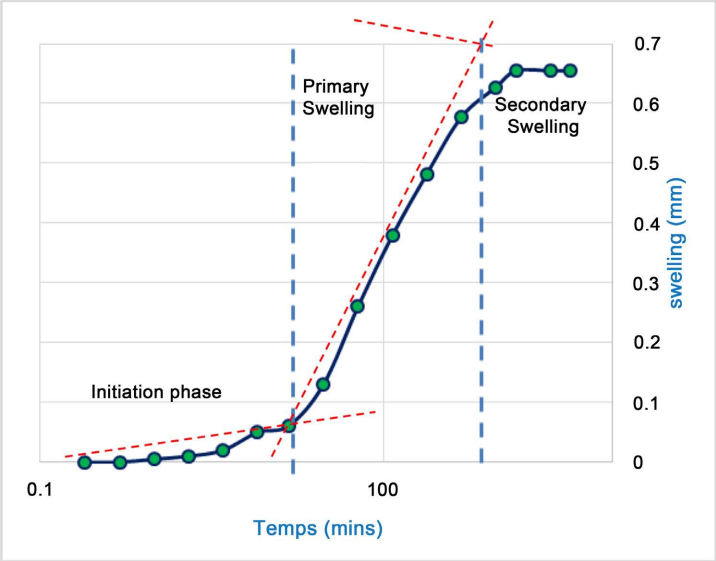

Figure 5. Free swelling of sandy clay with calcareous concretion.

The three free swelling curves of our samples each consist of an initiation phase, a primary swelling phase and a secondary swelling phase MEDJNOUN. 2014 [5]. A detailed study of the phases shows that:

The initialization phase: under the effect of chemical forces, the dry part of the sample attracts the water particles, which then generates a flow in the interstices. This phase serves to prepare the pores of the surface part of the soil to begin the interparticle swelling. Once these forces are damped, interparticle swelling begins to occur and the sample enters the primary swelling phase.

The phase of primary swelling: it is characterized by the swelling of the surfaces of the clay particles surrounding the saturated pores as well as the swelling of the clayey sheets which are in the clay particles. In this phase, the interfoliar swelling occurs massively and progressively. The clay sheets attract the water particles, hence the important volume deformation of the sample. The primary swelling time depends on the particle size, the nature of the clay minerals and the height of the sample.

The secondary swelling phase: in this phase a swelling damping is recorded, the sample is completely saturated and the small deformations are linked to the rearrangements of the particles and the stabilization of the chemical bonds. It marks the onset of the physicochemical properties of expansive soils. This phase can last several days. Other authors subdivide them into two main phases, the first of which consists of the initiation phase and the second the primary swelling phase, and according to the work of Al-Mukhtar *et al.* 1999 [6], the first phase represents 77% of the final deformation and the second is slower.

Figure 6 shows a comparison between the three swelling kinetic curves of our three samples.

For all three samples, the swelling rates reach 0.00075 $mm \cdot min^{-1}$ for the crumb marl, 0.0041 $mm \cdot min^{-1}$ for the sandy clay, and 0.0115 $mm \cdot min^{-1}$ for the laminated marl at the end of the initiation phase. We note at the level of crumb marl and sandy clay with calcareous concretion that the initiation phase is very slow compared to laminated marl with attapulgite. This shows that the latter is more reactive in the presence of water, this strong reaction in the presence of water is due to its large specific surface or **Table 1** which also explains its greater value during its initiation phase. Expansive minerals increase in volume when flooded with water. Due to their negatively charged surfaces and large specific surface area, these clay minerals adsorb water along the interlayer spacing (Van Olphen, 1977) [7]. Surface hydration causes the individual clay platelets to move apart from each other. The initiation phase is essentially governed by the swelling and non-swelling fraction of the material.

The end of the second phase (primary swelling), translates the end of the aspiration. This stage begins with an abrupt onset and gradually decreases to a maximum asymptotic time. It represents almost all of the bulge, the slope of the curve is much steeper in laminated marls, followed by friable marls then clayey-sandy with calcareous concretion; this shows the fact that the first two

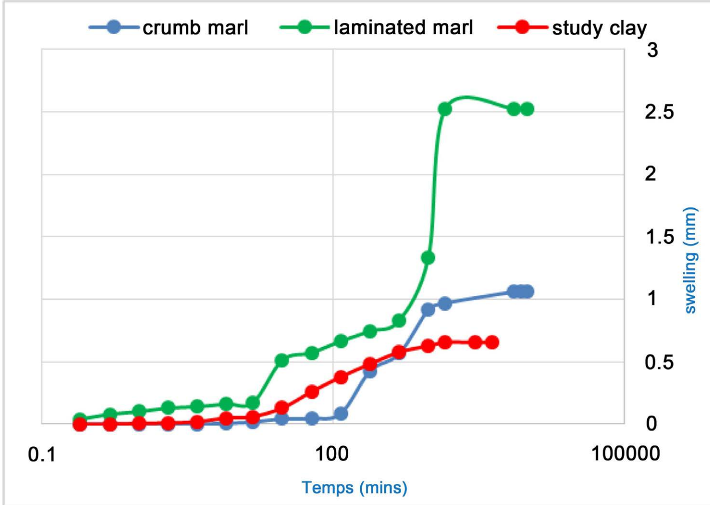

Figure 6. Comparison of the free swelling curves of the three samples.

Table 1. Some parameters obtained from the methylene blue test.

Parameters	V_b	V_{BS}	SST	$V_{b_{c2}}$	SSA
Blackish sandy clay	200	3.10	64.88	0.13	2.72
crumb marl	370	6.39	133.74	0.16	3.35
Flaky marl	400	7.17	150.07	0.23	4.81

The methylene blue tests are carried out according to the French standard [NF P18 - 592].

have a higher swelling. The results of the characterization tests of these soils in Table 2 are in perfect harmony with the swelling amplitudes found.

Casagrande box shear tests were performed at a constant speed (1.5 mm/min) under three normal stresses (0.706 kN, 1.412 kN and 2.824 kN) and under total saturation of the sample.

The following table summarizes all the data collected with the methylene blue test on the three soils studied.

The remarks that we can draw from these curves of swelling kinetics are first of all a very varied latency time during the initiation phase. The difference in speed can be explained by the fact that the three samples studied do not have the same porosity. The latter is higher in the attapulgite laminated marls than in the crumb marls. On the other hand, the laminated structure of the attapulgite marls facilitates water penetration at the interfaces between laminae. The second sequence would correspond to the time required for water to penetrate the pores of the sample until it is saturated. This phase is governed by the clay content which is higher in both marls but also by the nature of the clay mineral. According to the classification of the Uniform Building Code (1997) [8] the clay mineral of the laminated marl is montmorillonite, the mineral most sensitive to swelling. In the last phase it will take several days to obtain stability. The laminated marl recorded more time to obtain this stability.

Table 2. Geotechnical characteristics of the three samples

Parameters	Crumb marl	laminated marl with attapulgite	Sandy Clay
$W_l\,(\%)$	178.15	266.20	73.30
$W_p\,(\%)$	50.15	120.32	32.16
$I_p\,(\%)$	128.00	145.88	41.14
e_0	0.682	1.01	0.27
n	0.405	0.51	0.21
% < 2 mm	99.72	100	95.20
% < 0.5 mm	99.11	100	89.94
% < 0.1 mm	97.36	100	60.15
$\% < 2\ \mu_m$	40.29	31.61	23.23
K (m/s)	$1.15 \cdot 10^{-9}$	$1.53 \cdot 10^{-9}$	$8.90 \cdot 10^{-10}$
C (kPa)	81.5	236.72	119.67
φ	3˚	4˚	3.6˚

In this table above, the laboratory tests carried out are as follows: 1) Particle size analysis by sieving [NF P 94 - 056]; 2) Particle size analysis by sedimentometry [NF P 94 - 057]; 3) Atterberg limits [NF P 94 - 052-1]; 4) Casagrande box shear tests [NF P 94 - 071-1]; 5) Swelling tests using an odometer [NF P 94 - 090-1]; 6) Permeability at variable heat ISO 17892-11.

3. Loading and Unloading Tests with an Oedometer Device

Load-unload tests were performed on all three samples. The test consists of three main phases.

The first phase: consists in obtaining the maximum free swelling in the saturated state of the sample;

The second phase: Once the stability is reached, series of loading will be carried out and for each loading, we wait until the sample is stable to put an additional load.

Third phase: In this phase, we will perform a step by step unloading and the swelling values will be taken once the sample is stable.

In this study, two loading-unloading cycles were performed. The loading-unloading curves are shown in the following Figures 7-9.

After several tests were performed, the most reliable results are selected and summarized in Table 3.

The study shows that all three specimens are over consolidated and that the preconsolidation stress σ_p is greater than the effective stress σ'. In all cases, the preconsolidation stress remains constant throughout the cycles. Comparing the consolidation curves obtained under cyclic loading, it can be seen that the cycles have the effect of reducing the consolidation amplitude and rate. During the second loading-unloading cycle, the void index decreases, which shows that a reorganization of the internal structure has occurred. This reorganization is much more pronounced on the laminated marls and sandy clays because the

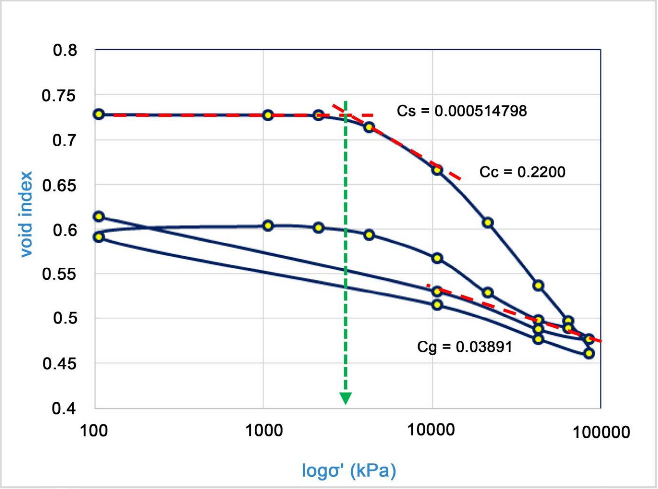

Figure 7. Loading-unloading cycle with the crumb marl oedometer.

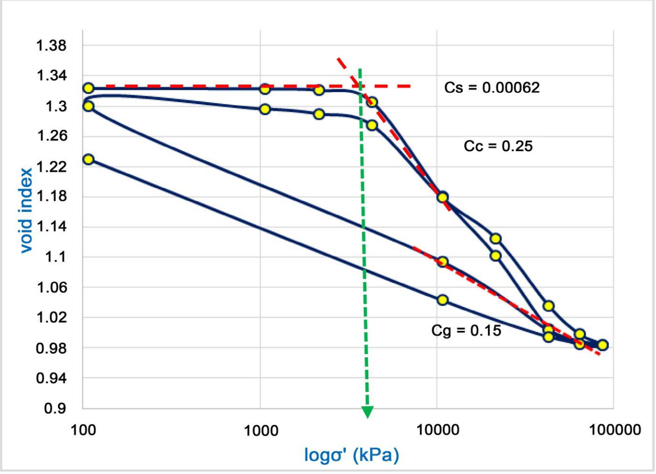

Figure 8. Loading-unloading cycle with the oedometer of the laminated marl.

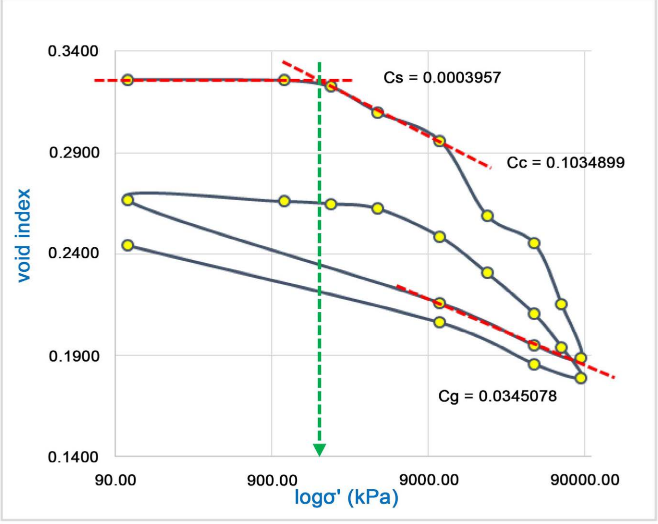

Figure 9. Oedometer loading-unloading cycle of sandy clay.

Table 3. Summary of compressibility characteristics.

Compressibility characteristics	Crumb marl	Laminated marl	Sandy Clay
e_0 (labo)	0.66	1.01	0.274
C_c	0.22	0.25	0.10
C_s	5.15E−04	6.34E−04	3.96E−04
C_g	0.04	0.15	0.03
E_{oed} (kPa)	867981.22	2123215.60	907954.04
γ_{sat}	2.26	2.24	2.54
σ_p (kPa)	5900	3900	2000
σ_{v0} (kPa)	819.72	819.72	819.72
e_i	0.77	0.63	0.32
e_f	0.62	0.52	0.24
ε_g	13.66	23.38	10.95

e_0: Initial void index; C_s: Decompression coefficient; C_v: Consolidation coefficient σp: Reconsolidation stress; C_c: Compression coefficient; E_{oed}: Oedemic modulus; S_r: Degree of saturation; σ_{v0}: vertical stress

latter have lower compressibility and decompression coefficients than the laminated marls. The results of the table also show that the amplitude of swelling of the laminated marl is largely higher than that of the crumb marl with 23.38% against 13.66% and twice higher than that of the sandy clay with 10.95%. We can thus deduce that the leafy marl is the most dangerous in the presence of water.

4. Conclusion

This experimental study allowed to highlight a certain number of phenomena involved in the free swelling of the three samples. It is noted that the initiation phase and primary swelling have a very slow rate compared to the secondary swelling. The free swelling recorded after immersion in the oedometer reveals that the site is made up of potentially swelling soils with a high risk of shrink-swell. The values found in the free swelling tests show that the attapulgite laminated marl is most susceptible to swelling, followed by the crumb marl and then the sandy clay. The secondary swelling phase is very slow and may take more days. Similarly, oedometer load-unload tests reveal that during the second load-unload cycle, the initial void index decreases significantly for crumb marl and sandy clay but moderately for laminated marl. These results show that particle rearrangement following water influx is slower in the laminated marl, therefore it stabilizes late compared to the other two samples. All three samples are moderately compressible to fairly highly compressible with a compressibility coefficient (Cc) between 0.10 and 0.30. Following the evolution of the void index in the initial state during the load-unload cycles, a complementary study to know the number of cycles necessary to obtain a steady state for each sample would be interesting.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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