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INFLUENCE OF DRYING-WETTING CYCLES ON THE COMPRESSIBILITY OF CLAY SOILS IN THE COMMUNE OF HOUEYOGBE

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ABSTRACT

This article presents the results of an experimental laboratory study carried out with the odometer and the Richards press on a class A3 clay soil sample that had undergone drying-wetting cycles. These tests allowed us to analyze in fine the influence of the drying-wetting cycles on the compressibility and suction behavior of the soil object of our study.
This study reveals that the drying-wetting cycles have a certain influence on clay soils. Indeed, the compressibility index of the soil increases while the swelling index decreases according to the cycles; the pre-consolidation pressure and the oedometric modulus show a more or less constant variation; the permeability of the soil increases clearly when the number of cycles increases. Soil suction decreases as the number of drying-wetting cycles increases under extreme conditions.

KEYWORDS: clay soils, drying, humidification, suction, odometer.

1. INTRODUCTION

In the field of civil engineering in general and soil mechanics in particular, the major concern of designers and builders is to guarantee stability and durability of structures. But it is not rare to notice that several phenomena of instability affect the works erected on clayey soils. These soils with high plasticity present obvious characteristics of swelling and shrinkage due to humidification and drying. In Benin, according to J. AGBELELE Koffi (2016), these soils are found in the Lama region and more particularly in Houéyogbé. Examples of disorders related to the existence of swelling clays are numerous and varied (Y. KIKI (2004), V. GBAGUIDI et al. 2010). The problem of clayey soils comes from their contact with water. In the vicinity of saturation, these soils lose their mechanical resistance (Benchouk, Assia, 2015). Many researchers have studied the influence of wet-dry cycles on the engineering properties of natural clay (F. Yazdandoust,2010; Bao-tian Wang, 2014). The work of Popescu, 1980 Wahib Arairo (2013) reveals that the swelling capacity of the samples increases with the number of wetting and drying cycles. These repetitive soil swelling and shrinkage stresses cause significant damage to structures. Thus, this study focused on the Influence of hydric drying-wetting cycles on the compressibility behavior of clayey soils in the commune of Houéyogbé will allow for a better understanding of the phenomenon.

2. MATERIALS AND METHODS

Materials

The materials were collected at Tohounou in the commune of Houéyogbé located in the south of Benin and more exactly in the western depression of the Lama.

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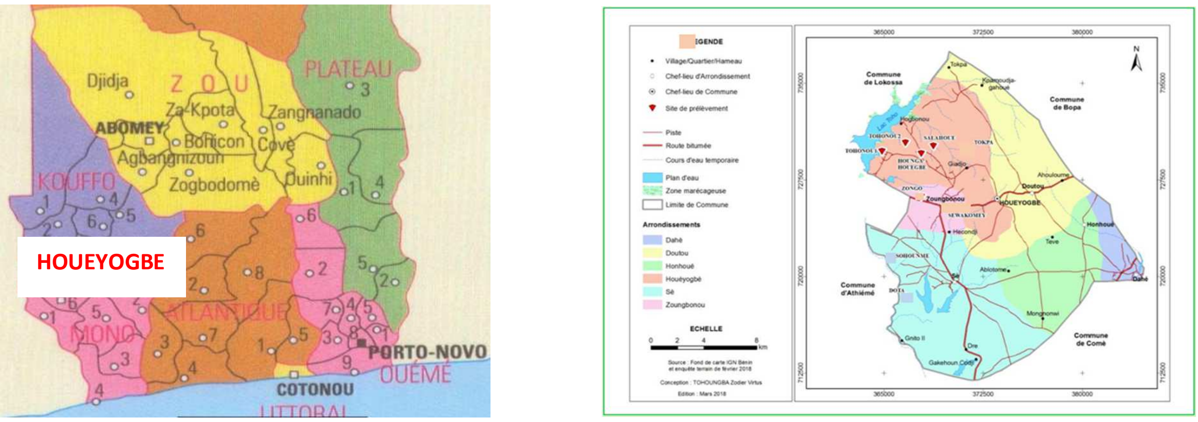


Figure N°1 : Sampling site (commune of Houéyogbé)

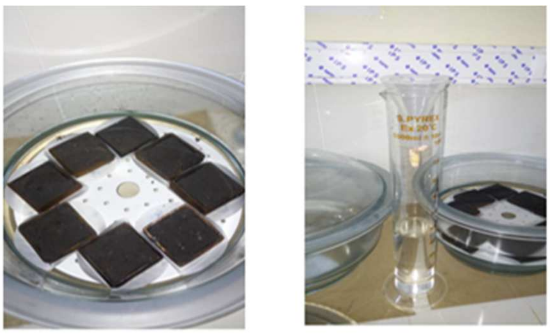
The characterization of the soils was carried out by means of geotechnical tests of physical and mechanical identification. The particle size analysis test by sieving and sedimentation (NF P 94-056), the particle size analysis by sedimentation (NF P 94-057), the test to determine the Atterberg limits (NF P 94-051) and the test to determine the specific weight (NF P 94-054) allowed us to identify and characterize the nature of the soils in place.

My hardware

The equipment used includes the Richards press, the odometer cell, and the oven and glass jar for humidification.

Etuve

Séchage à 105°C pendant 24h



Bocal en verre à double compartiments séparée par une plaque poreuse

Figure N°2 : Drying equipment Figure N°3 : Humidifying equipment

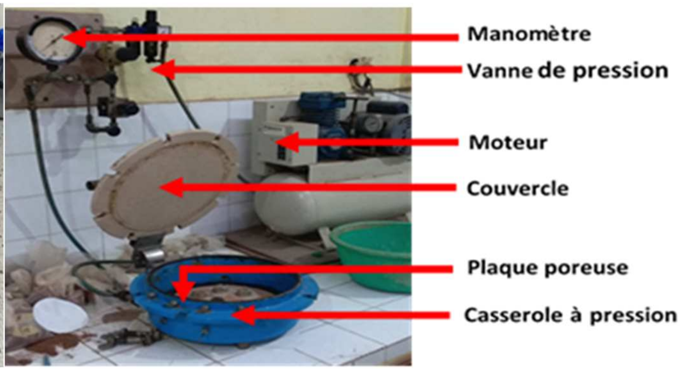


Figure 4: Odometer

Figure 5: Richards press

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Methods

Cycle test protocols

The application of the cycles on the samples in the laboratory was done in several phases. Thus, a cycle includes a drying and a humidification.

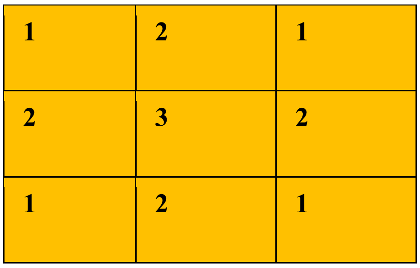
Drying (NF EN 1097-5)

Drying is carried out at 105°C in the oven until the sample mass is stabilized.

- Sample segmentation

To ensure that the drying is uniform in the sample, it was subdivided into 9 parts grouped into three zones: corner zone, side zone and central zone. The water content of each zone is determined and compared.

The segmentation in several parts allowed to appreciate the degree of drying of the different sections of the sample in order to confirm the uniformity of the drying and the validation of the methodology of dehydration of the material.



Dewatering and sectioning of a sample

Corner parts (1)

Side parts (2)

Central part (3)

Figure N°6 : Segmentation of the samples

- Drying kinetics

The steaming carried out at 105°C allowed to dehydrate the materials. After dehydration the material is considered as dry and having followed a phase of the cycle which is the drying corresponding to the dry period of the year. This methodology allows us to touch the extreme which is the minimum water content of the material and to approach the historical records of dryness. The sample is removed at the stabilization of the mass after 24H.

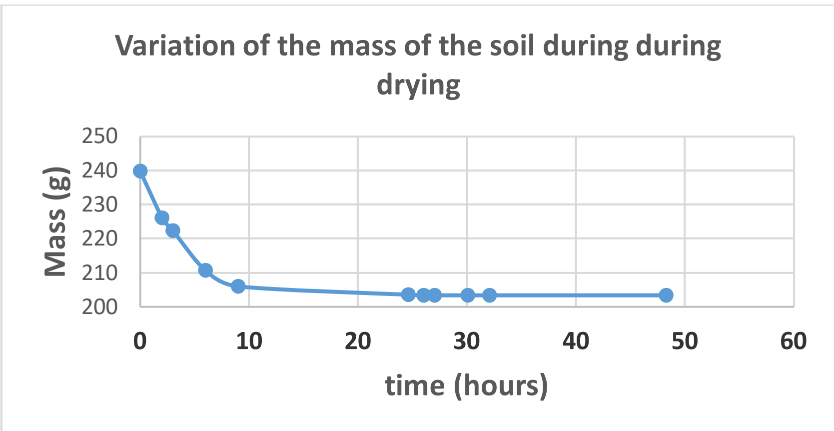


Figure 7: Curve of the drying kinetics

- Validation of the drying method

The results of the weighing and determination of the water content after 24 hours of drying reveal that a difference of only 0.027% is noted between the water contents of the different areas of the sample.

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The international standard ISO 11465:1993(en) states that generally, 16 to 24 hours are sufficient to dry most soils to a constant mass.

The small deviation observed and the standard allow the method to be validated.

Table N°1 : Water content of the different parts of the dried sample

Designation	**Corner parts**	**Side parts**	**Central part**
Sample parts	1	2	3
Wet mass (g)	62,59	66,62	15,40
Dry mass (g)	62,45	66,46	15,37
w (%)	**0,22%**	**0,24%**	**0,20%**
Average deviation	**0.027% Low**		

After this first phase of the cycle, which is drying, the second phase, which is humidification, follows in order to complete the cycle.

Humidification
Humidification is carried out in an immersion tank with two compartments separated by a porous stone. The material is soaked until its mass is stabilized.

- Sample segmentation

To ensure that the humidification was uniform, the sample was subdivided into 9 parts grouped into three zones: corner zone, lateral zone and central zone. The water content of each zone was determined and compared.

Part segmentation was used to assess the degree of wetting of the different sections of the sample to confirm the uniformity of wetting and validation of the sample saturation methodology.

. 1	**2**	**1**
2	**3**	**2**
1	**2**	**1**

Dewatering and sectioning of a sample

Corner parts (1)

Side parts (2)

Central part (3)

Figure N°8 : Segmentation of the samples

- Kinetics of humidification

Humidification was performed at room temperature in a glass jar with two compartments separated by a porous plate. The operation allowed to rehydrate the materials. It consisted in saturating the sample from below. The sample in the ring, is placed with filter paper on the porous stone. The water is sent in the jar until the ring's level. The water penetrates the sample and saturates it after 24 hours. This time is consistent with that obtained in the studies of **Sayem Hossain et al, (2016).**

This technique is used by **(Omran Alshihabi 2002)** to moisten samples during his research.
After rehydration, the material is considered as saturated wet and having undergone the second phase of the cycle that is humidification, corresponding to the rainy period of the year. This methodology allows us to reach the extreme that will be the maximum water content of the material and to approach the historical records of humidity caused by extreme rainfall. The sample is removed after the stabilization of its mass and another cycle starts again.

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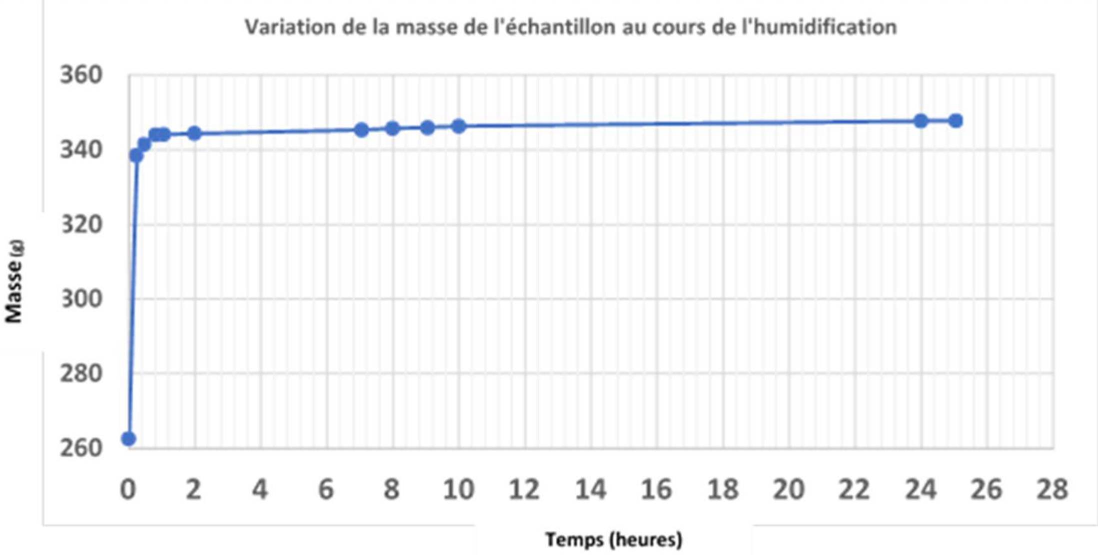

Figure N°9 : Curve of the kinetics of humidification

- Validation of the humidification method

The results of weighing and determination of water content reveal that a deviation of only 0.026% is noted on the water contents of the different areas of the sample: Verification method used by **(Omran Alshihabi 2002).**

Table N°2 : Water content of the different parts of the humidified sample

Designation	**Corner parts**	**Side parts**	**Center part**
Sample parts	**1**	**2**	**3**
Wet mass	**84,30**	**91,81**	**56,21**
Dry mass	**56,3**	**61,33**	**17,51**
w (%)	**49,73**	**49,70**	**49,69**
Average deviation	**0,026%**		

After this second phase, the sample is considered to have undergone a complete drying-wetting cycle noted (C1).

Overall testing process

To evaluate the influence of the different drying-wetting cycles on the soil studied, we proceeded to determine the odometric characteristics and the suction of the samples. Each sample underwent cycles :
C0 : sample in an intact state that has not been cycled
C1 : intact sample having undergone one (01) drying-wetting cycle
C2: intact sample having undergone two (02) consecutive drying-wetting cycles
C3: intact sample having undergone three (03) consecutive drying-wetting cycles
C4: intact sample having undergone four (04) consecutive drying-wetting cycles
C5: intact sample having undergone five (05) consecutive drying-wetting cycles

Samples from each of the cycles C1, C2, C3, C4, C5 were subjected to odometer tests (standard NF PP94-090-1) and suction tests using the Richards press. The results of the tests are analyzed to assess the effect of the cycles on the soil samples studied. The parameters that were used as a basis to appreciate the influence of cycles on the Tohonou soil are the following: The compressibility index, the swelling index, the pre-consolidation stress, the odometric modulus, the permeability coefficient and the soil suction.

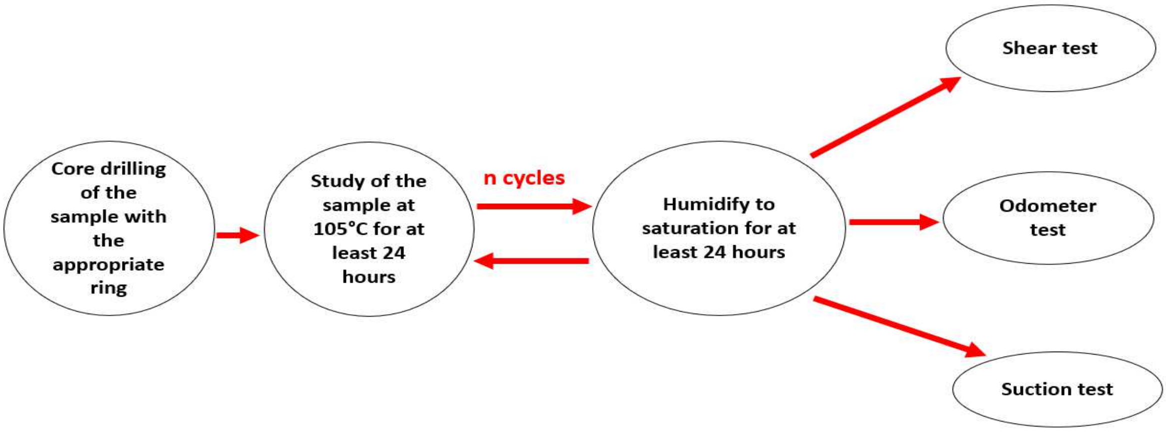

Figure N°10 : Summary diagram of the global testing process

3. RESULTS AND DISCUSSION

The results of the identification tests allowed us to characterize the soil under study, in order to specify its geotechnical nature.

Table N°3 : Results of the identification tests

TOHONOU							
Inf 0.315 mm (%)	**Less than 0.08 mm (%)**	**Density of solid grains (ɣs) (t/m3)**	**Organic matter content (M O)**	**VBS**	**WL (%)**	**IP**	**GTR Class**
82	**70**	**2,28**	**0,4**	**11,00**	**81**	**35**	**A3**

The results of the granulometric analysis tests by sieving and by sedimentation according to the standards (NF P 94-056) (NF P 94-057) are presented in the graph below.

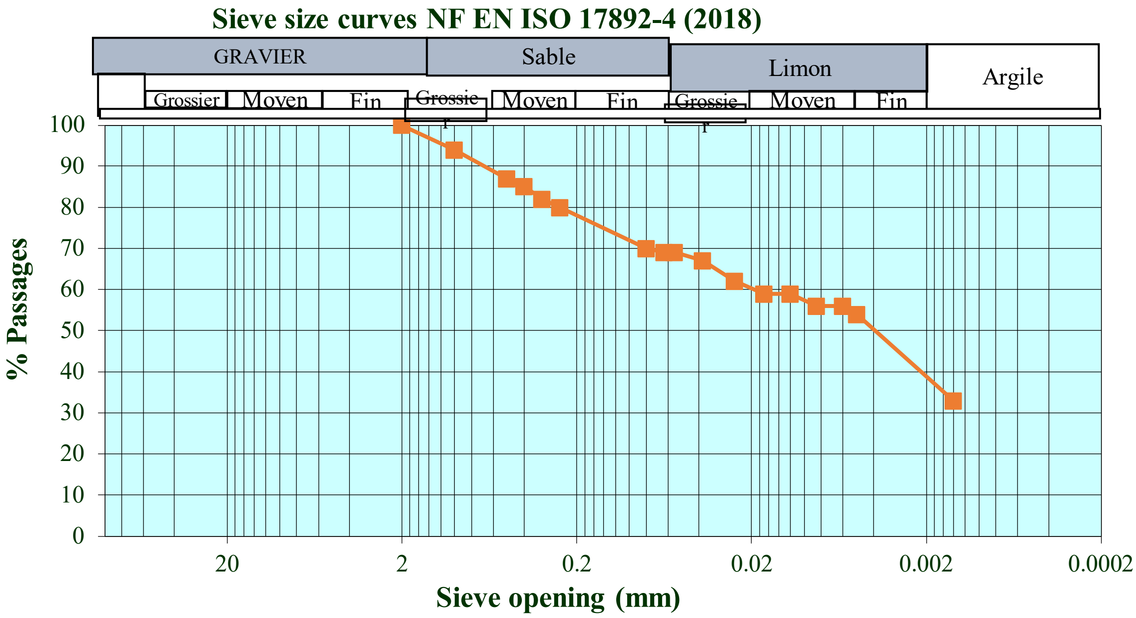

Figure N°11 : Particle size curve

The results of particle size analysis show us that more than 60% of the elements are lower than the 80µm sieve and more than 40% of the 40µm sieve. According to Taylor's classification this soil is clayey.

The odometer tests allowed us to evaluate the evolution of the mechanical characteristics of the TOHONOU soil after 5 drying and moistening cycles. The graphs below show the compressibility curves as well as the evolution of the compressibility index, the swelling index, the pre-consolidation stress, the permeability and the odometer modulus.

- Odometer test curves

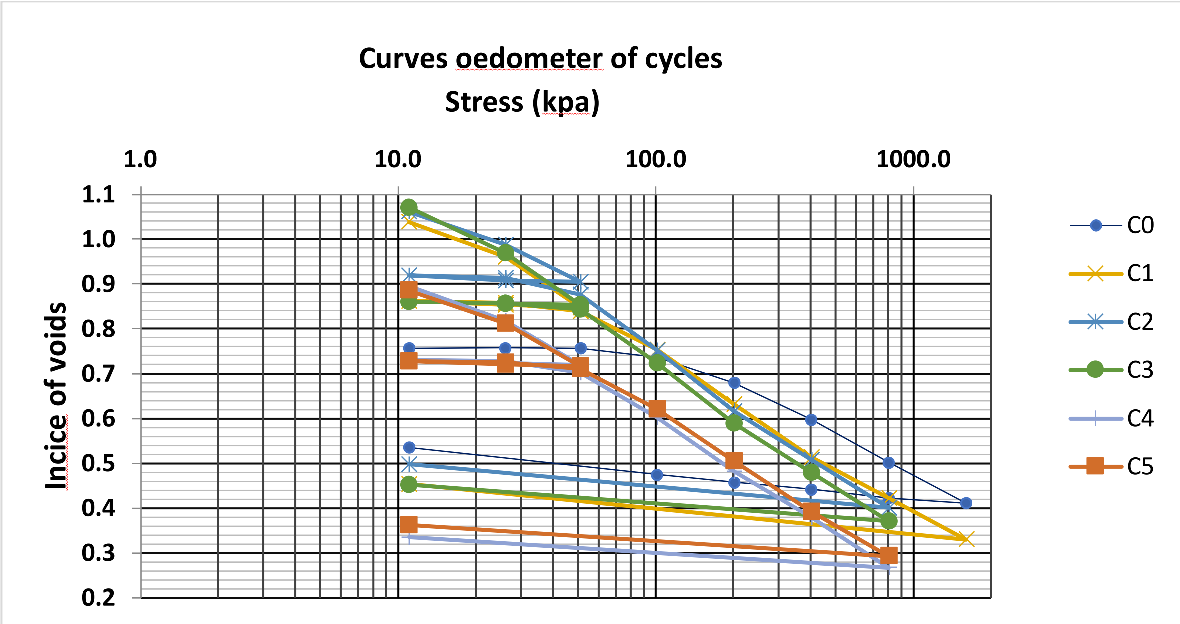

Figure 12: Odometer curves

- Compressibility index

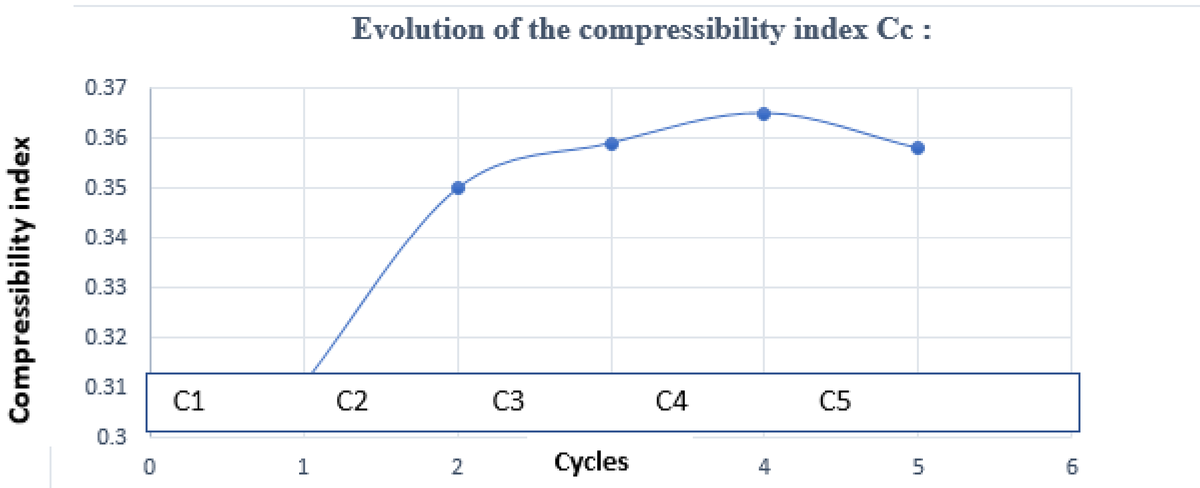

Figure 13: Curves of compressibility indices

The graph above shows a growth in soil compressibility as it cycles through the soil, in other words, the soil is more compressible each time it goes through a drying-wetting cycle.

Cui et al (2002) conducted a series of odometer tests on FoCa7 swelling clay under different suction values and found that the compressibility index of swelling soils decreases with increasing suction. In other words, the decrease in suction will cause the compressibility of the material to increase. This result is in agreement with our

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tests. This could be due to the degradation of the physico-chemical and or microstructural properties of the material when the cycles increase. Thus, the inter-lamellar water in the swelling soils no longer being able to occupy the pores to reinforce the cementing effect between the grains weakens the material, hence the increase in compressibility as a function of the cycles.

- Swelling index

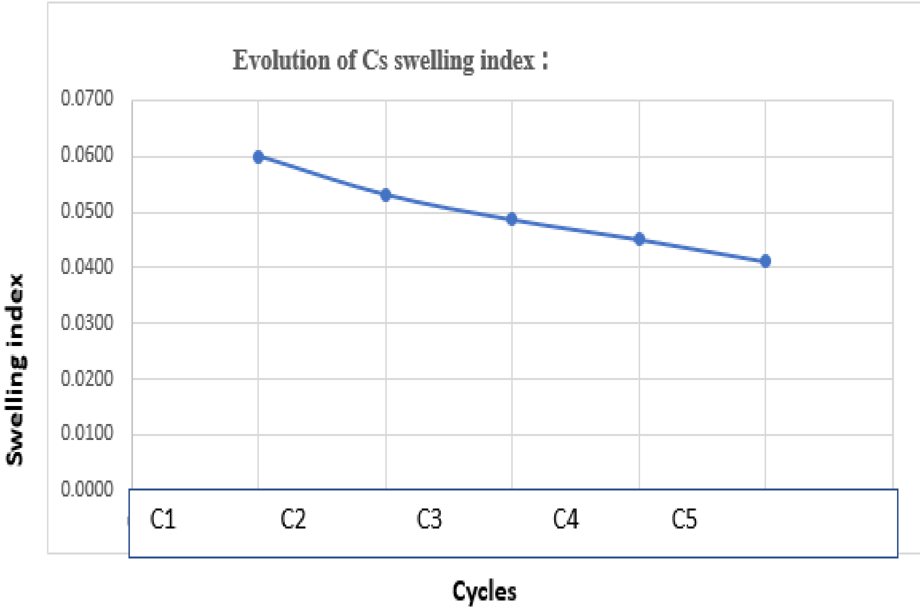

Figure 14: Curve of the evolution of the swelling indices

The graph shows that the swelling index decreases during the different hydric cycles that the soil sample experiences. Suction shows its influence on the swelling index which seems to decrease with increasing suction. **Uchaipichat (Uchaipichat (2010))**. This result is not in agreement with ours. This study by Uchaipichat was to investigate the effect of initial saturation state on the volume behavior of soils.

- Permeability

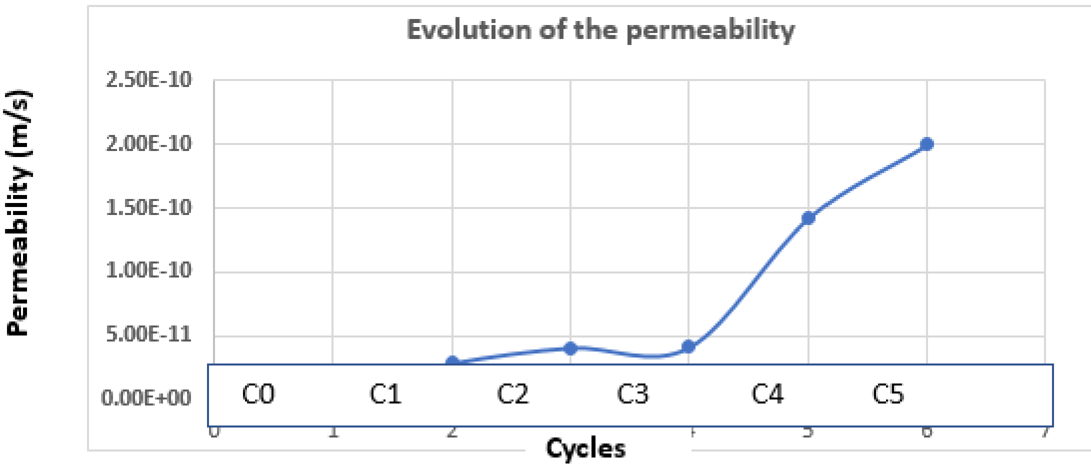

Figure 15: Curve of the evolution of the permeability

Several researchers including **Louati, Fatma et al (2018)** have also studied the impact of cycles on soil permeability.

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The permeability curve shows a growth with the drying-wetting hydric cycles. This trend is confirmed by **(Yasmina Boussafir, Laurent Adbaret (2020))**. The degradation mechanism that develops under the effect of the alternation of drying and humidification phases, irreversibly modifies the microstructure, and this from the first hydric cycles, which is reflected on the hydraulic conductivity.

- **Pre-consolidation stress**

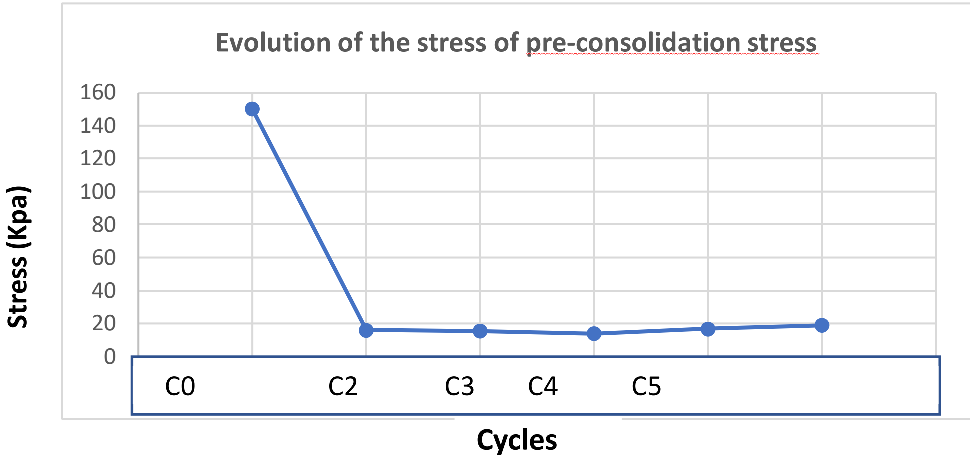

Figure 16: Curve of the evolution of the preconsolidation stress

The curve translating the evolution of the pre-consolidation stress shows a decrease during the cycles. This result is consistent with that of **(Uchaipichat (2010)) cited by (Wahib Arairo 2013)** which states that the pre consolidation pressure increases when the suction increases in other words the pre consolidation stress decreases when the suction drops.

According to the works of **H. Nowamooz & F. Masrouri, the** cycles of imbibition-drying applied on clayey soils of the Deffend site showed that at the end of the suction cycles, the pre-consolidation pressures p0(s) are dependent on the index of the initial voids of the soil and not on the imposed suction. This last result could explain the more or less constant global trend of the pre consolidation stress obtained from the first cycle C1

- Odometer module

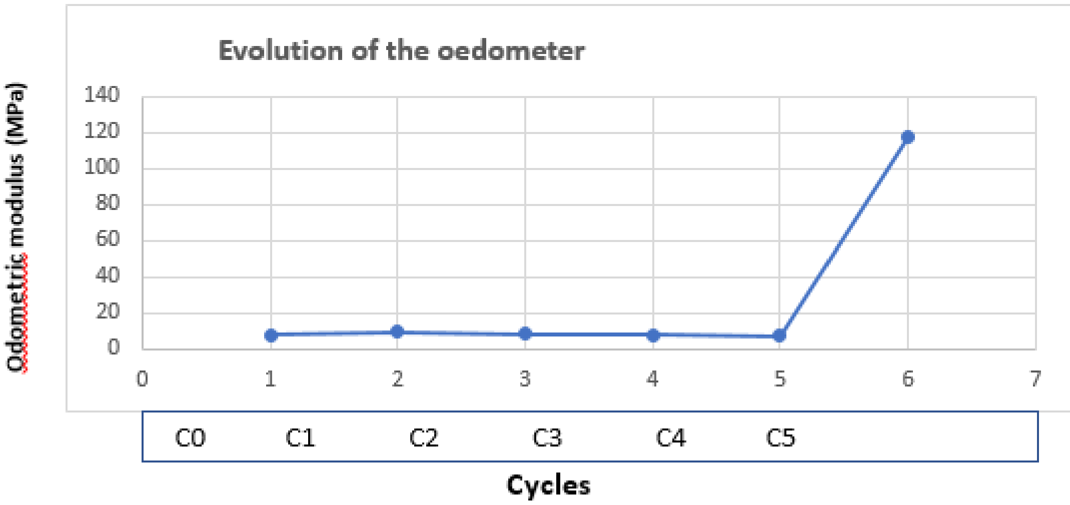

Figure 17: Curve of the evolution of the odometer modulus

The graph of the variation of the oedometric modulus of the material presents globally a constant trend. This result is not the one of **(Cui (1993)) cited by (Wahib Arairo 2013)** obtained with triaxial tests at different levels of

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suction on Jossigny silt and which shows that an increase in suction leads to an increase in the apparent modulus of stiffness of the material.

- **Suction curve**

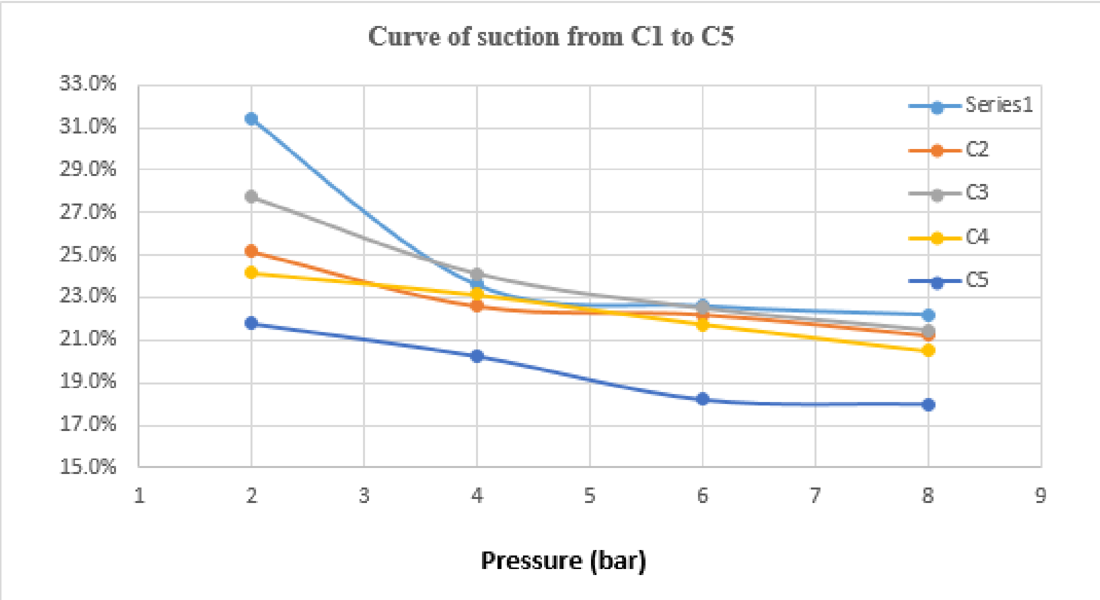

Figure 18: Suction evolution curve

The suction curves obtained after the passage of five (05) cycles of drying-wetting on the soil samples of Tohonou allow us to highlight in a global way the decrease of the water retention capacity of the soil with the cycles. This behavior is explained by the increase of the permeability with the cycles; which is related to the mechanism of degradation which develops under the effect of the alternation of phase of drying and humidification, inducing a modification in an irreversible way of the microstructure, and this as of the first hydric cycle. **Yasmina Boussafir, Laurent Arbaret (2020).**

4. CONCLUSION

The laboratory study of the influence of drying-wetting cycles on the mechanical and hydric parameters of the clayey soil of Tohonou allowed to highlight the effect of these cycles on the compressibility behavior of the soil. This article presents the evolution of these various parameters, namely the compressibility index, the swelling index, the pre-consolidation stress, the odometric modulus of the soil and its permeability.

From the results obtained, the compressibility of the soil increases as the number of cycles increases while the swelling index decreases. The pre-consolidation pressure and the odometric modulus show an unclear variation. They are more or less constant. Soil permeability increases markedly and soil suction decreases with increasing number of cycles. This article shows that the drying-wetting cycles have a certain influence on clay soils. It is thus very important that the mechanical parameters varying under the cyclic phenomena of drying and humidification due to the alternation of the wet and dry seasons, are taken into account in the geotechnical studies to better guarantee the stability of the civil engineering structures whose parameters visibly decrease under the yoke of the hydric cycles.

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