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Factors Predisposing and Triggering the Phenomenon of Shrinkage-Swelling of Clay Soils in the Urban Center of Diamniadio

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Abstract

The phenomena of shrinkage and swelling of clay induce damage to housing structures every year. Precipitation, climatic changes and drought are the cause of wall cracks due to subsidence or swelling of the supporting soil. This movement alters the balance between the soil and the structures. To explain this defection, the soil is made up of three elements: the solid, the liquid and the gas. Sometimes in a natural way or following a human intervention, one of these elements undergoes an abnormal variation that causes the loss of the balance between land and works. It is in this sense that this article deals on the one hand with the factors of predisposition and triggering of the phenomena of shrinkage-swelling of the clay soils of Diamniadio and on the other hand, the factors of aggravation linked to the lithological heterogeneity and the variation in the thickness of the layers susceptible to shrinkage-swelling. The studies carried out have enabled a deeper understanding of the behavior of expansive soils following their interactions with climate, vegetation, hydrology, hydrogeology, constructions among others, but also the influence of lateral and vertical variations of fine soil facies.

Keywords

Swelling Clays, Expansive Soil, Shrinkage-Swelling, Desiccation Cracks, Diamniadio

1. Introduction

Swelling and shrinkage phenomena cause numerous disorders in civil engineering structures founded on the surface of swelling soils and in buried structures. Various disorders have been listed in this area in the Diamniadio, Rufisque, Bargny and Sébikotane sector. Examples of disorders linked to the presence of swelling clay are numerous and varied (Chen, (1975) [1]; Philipponat, (1991) [2]; Vandangeon, (1992) [3]; Djedid *et al.*, (2001) [4]). Research, especially in the last decade, has been carried out by various researchers to provide methods for predicting soil movement over time (e.g., Briaud *et al.* (2003) [5], Vu and Fredlund, (2004) [6] and (2006) [7], Zhang (2004) [8], Wray *et al.*, (2005) [9], Overton *et al.* (2006) [10]). These prediction methods are based on the soil-atmosphere interaction. In the same vein, this article will attempt to relate the importance of climate and the environment (vegetation, hydrology, hydrogeology, topography, constructions, etc.) to shrink-swell phenomena.

The study will focus on two objectives:

Description of the predisposing and triggering factors of shrinkage and swelling present in our study site (Sebikhotane-Diamniadio industrial zone).

Understanding the phenomenon of shrinkage-swelling of clay soils subjected to aggraving factors linked to the heterogeneity and the variation in thickness of the layers susceptible to shrinkage-swelling.

2. Presentation of the Site

The studied site is located in the industrial zone of Sébikotane in Senegal. It is delimited by the coordinate terminals UTM zone 28N. **Figure 1** gives a precise location of the sampling site.

3. Nature of the Phenomenon

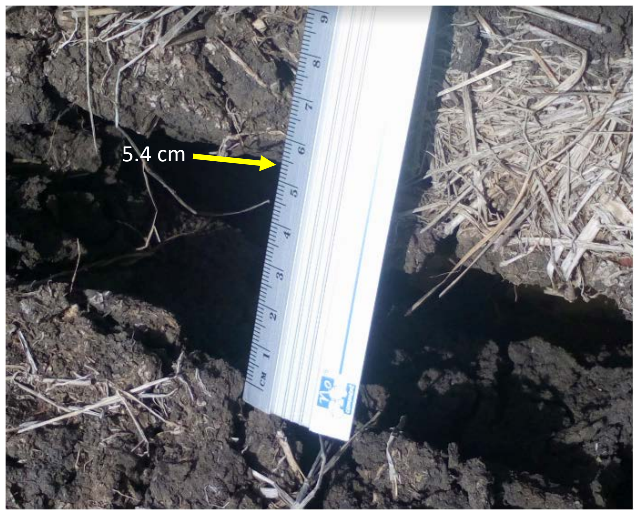
The Diamniadio sector has the particularity of containing very active fine materials in its subsoil (clay, marl, attapulgites, etc.) beyond the modification of their textures, it appears that these natural materials are also affected by variations in volume, directly related to changes in their hydric state: a soil clay moistened under constant stress tends to swell while its drying results in a decrease in volume. The shrinkage cracks that appear in a dry clay soil (**Figure 2**) visually translate the ultimate state of this volume variation which is simultaneously manifested by a vertical settlement of the soil.

4. Manifestation of Shrinkage-Swelling Phenomenon

Differential settlements result in the equivalent of localized bearing defects at certain points of the foundations, mainly house corners, wall posts and other structural elements, which induces tensile stresses in the foundations and facades, in some cases leading to the cracking of the buildings in place (**Figure 3**).

Most of the disorders observed in this area are attributed to periods of drought during the lack of rain and surface evaporation cause desiccation which progresses downwards. On the contrary, rainy periods can reverse the trend and lead to (partial) closure of the cracks. The clay rehydrates and swells. The paving is raised which can cause the partitions on the ceiling to punch through. **Figure 3** gives some illustrations of these disorders.

Figure 1. Location of the study site.



(a)

(b)

Figure 2. Desiccation cracks in clay soil: (a) Slot width, (b) Slot depth.

Figure 3. Disorders attributed to the shrinkage-swelling of clays near the study site.

Most of the cracks are in the form of stairs and start at the level of the posts, walls and areas where the sag is more felt because of its high weight. Depending on the dynamics of the movement (shrinkage-swelling), other secondary cracks are added, thus creating a cracking network leading to total instability, the ultimate stage of which is the collapse of the building (**Figure 3(a)**).

5. Predisposing Factors

The predisposing factors are those whose presence induces the phenomenon of shrinkage-swelling, but is not sufficient on its own to trigger it. These factors are fixed or change very slowly over time. According to the work of IFSTTAR, (2014) [11] a distinction is made between the internal factors which are linked to the nature of the soil and the environmental factors which rather characterize the site.

5.1. The Lithology of the Site

The lithological nature of the soil constitutes a predominant factor predisposing in the shrinkage-swelling mechanism: the more a subsurface geological formation is rich in fine elements, of a clayey nature, the higher its ability to shrink-swell. All clay soils are a priori subject to the phenomenon of shrinkage-swelling, but the magnitude of the volume variations induced is highly variable depending on the mineralogical composition of their clay phase. The soils encountered on this site to a depth of 10 m are mainly composed of sandy-clay with calcareous concretion, friable marl and attapulgite laminated marl.

In the laboratory, our three samples were subjected to a series of tests aimed at highlighting their physico-chemical and mechanical properties. The results of the laboratory tests are grouped in **Table 1**.

Water Content Measurements	[NF P 94-050]
Determination of the density of fine soils	[NF P 94-053]
Determination of the density of solid particles	[NF P 94-054]
Sieve Size Analysis	[NF P 94-056]
Particle Size Analysis by Sedimentometry	[NF P 94-057]
Limit Tests	[NF P 94-052-1]
Determination of Soil Methylene Blue	[NF P 94-068]
Casagrande Box Shear Tests	[NF P 94-071-1]
Oedometer Swelling Tests	[NF P 94-090-1]

Table 1. Geotechnical characteristics of soil samples.

Samples	Marne to crumb	White laminated marl with attapulgite	Sandy clay with calcareous concretion
Depth (m)	**3.2 - 3.4**	**3.4 - 10**	**1.1 - 3.0**
w_n (%)	13.47 - 48.33	13.03 - 15.24	2.99 - 18.57
γ (kN/m^3)	18.6	18.9	21.9
γ_d (kN/m^3)	16.3	13.5	21.1
γ_{sat} (kN/m^3)	22.6	22.4	25.4
γ_s (kN/m^3)	27.0	27.10	26.90
W_l (%)	178.15	266.2	73.30
W_P (%)	50.15	120.32	32.16
I_p (%)	128.00	145.88	41.14
V_b (%)	6.39	7.17	3.10
e_0	0.682	1.008	0.274
% < 2 mm	99.72	100	95.20
% < 0.5 mm	99.11	100	89.94
% < 0.1 mm	97.36	100	60.15
% < 2 µm	40.29	31.61	23.23
A_c	3.17	4.61	1.77
C (kPa)	81.5	236.72	119.67
φ	3˚	4˚	3.6˚
A_{cl} (%)	6.39	7.17	3.10

The values of the plasticity indices reveal that the sandy clays with calcareous concretion are plastic while the crumb marls and the flaky marls with attapulgite are very plastic.

Beyond this mineralogical composition of the clayey phase of the soil serving as a support for the foundations, other predisposition factors directly related to the nature of the soil can be invoked. The first is the texture of the soil and in particular its state of reworking. The dry density values found and mentioned in the tables above show that the soils crossed by the boreholes, between 0 and 10 m deep, are typical of sparse to dense soils with the exception of laminated marls which are sparse. A second factor concerns the hydrogeological and hydrological conditions that characterize the site. In addition to density, other brittle rocks can undergo deformations under the effect of the lithological weight of the overlying soils or following tectonic movements. The attapulgite laminated marls present micro-fractures which can be created by one and/or the other of these two factors already mentioned. Indeed, the Ponty-kayar fault and the Sébikotane fault are close to this zone and their movements can be the cause of these micro-fractures (**Figure 4**) which favor in other words the infiltration of rainwater. These discontinuities (faults and micro fractures) can promote horizontal displacements

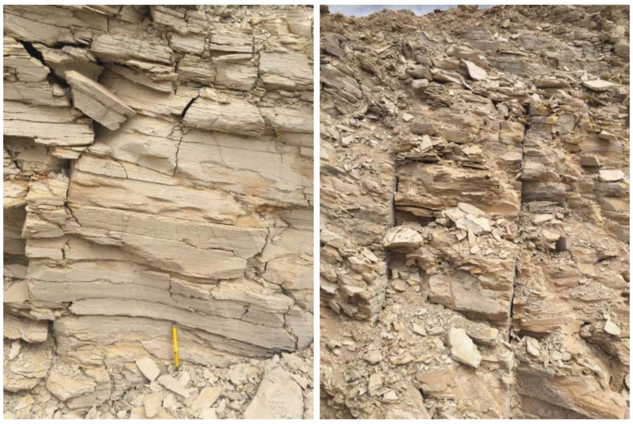


Figure 4. Laminated marls with micro fractures.

during soil saturation because when the swelling soil is cracked, the medium becomes discontinuous.

5.2. Hydrogeology

The Diamniadio sector does not have a permanent shallow aquifer due to its predominantly clayey sedimentation. The hydrogeological structure of the area is the very reflection of its geological structure. The region has been divided into aquifer systems according to stratigraphic and sedimentological criteria. According to the Water Management and Planning Department (DGPE) 2019 [12], there are thus two hydrogeological systems, that of the Quaternary sands and that of the Horst de Diass, separated by the Rufisque graben which does not present of hydrogeological interest due to its predominantly clayey sedimentation from the Maastrichtian to the Lower Eocene and the marl facies—sub-litho-stratigraphic limestones which cover this sedimentation (**Figure 5**). The Diamniadio sector is largely located on the Rufisque graben, so we can say that the water table is almost absent in its basement.

5.3. Hydrology

In this sector, there is a mixed and dense rainfall network according to the National Agency for Civil Aviation and Meteorology (ANACIM) and the Regional Direction of Rural Development (DRDR) 2019 [13]. Precipitation is concentrated over 3 months and fluctuates between 300 and 650 mm from one year to another. This diminishing of the water resources since the 1960-1970 decade (150 to 200 mm) has a major impact on the state of the vegetation cover, the recharge of the water tables... The area is known for its depressions. Over the last million years, it received the waters that flowed from Thiès, Sébikotane towards Bargny and Rufisque thanks to drainage paths see **Figure 6(a)**. The consequence of this runoff is an accumulation of several hundred billion m^3 of clay in the perimeter below the roads and perimeters that will be developed in the years to come. This sector (Diamniadio-Sébikotane) is made up of a succession of small rivers (**Figure 6(b)**) with non-permanent flows in winter.

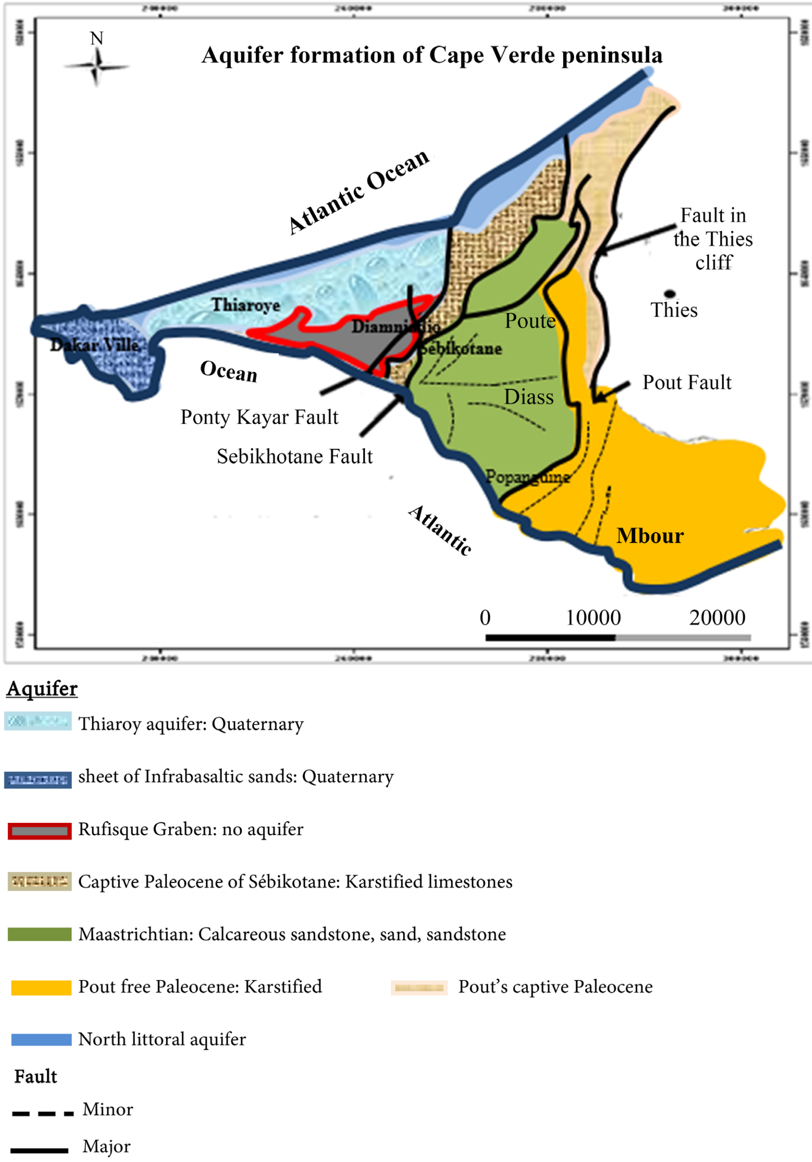


Figure 5. Freshwater groundwater in western Senegal modified.

The dam located next to the district of Guenth and the other dam located next to the industrial area around forty meters from our study area have huge areas and can influence the surrounding areas under the effect of the infiltration.

Morphologically, we see that this area is very rugged and the presence of slopes promotes runoff and therefore drainage, while the low areas will be more likely to capture stagnant water which will slow down the desiccation of the soil during the rainy season. Because of the infiltrations and Figure 7 is a perfect illustration. This site, like several localities in the Diamniadio-Sébikotane sector, has a central basin towards which rainwater flows to reach the dam.

The effect of vegetation will not be taken into account in this study because for the most part, sites under construction undergo complete deforestation before

(a) (b)

Figure 6. Area hydrology: (a) Slope and drainage (b) Low zone and water accumulation.

Figure 7. Topography of the area and sounding points.

construction. This factor will be significant once the city under construction is fully erected and the trees and gardens next to the buildings take part in the water variation of the subsoil.

6. Triggering Factors and Kinetics of the Phenomenon

Triggering factors are those whose presence causes the shrinkage-swelling phenomenon, but which only have a significant effect if there are prior predisposing factors. Knowing the triggers allows to determine the occurrence of the phenomenon (in other words the hazard and no longer just the susceptibility). Meteorological phenomena constitute the main triggering factor of the shrinkage-swelling phenomenon, the seasonal variations of the hydric state of the soil being mainly controlled by precipitation, evaporation and the absorption of water by the vegetation (see climatic data).

In addition to these natural triggerts, there are also those which are not linked to a climatic phenomenon, which is by nature unpredictable in the long term, but to human action. This development works, by modifying the distribution of surface and underground flows, as well as the possibilities of natural evaporation, are likely to lead to changes in the evolution of the water content of the surface layer of soil.

The climatic data of the last ten years were provided to us by the ANACIM, 2020 [14] certain climatic variations according to time are summarized in Figures 8-11. Among the data not represented include the direction prevailing wind, average wind speed (m/s), insolation in hours, minimum average temperature in degrees Celsius and minimum humidity in %.

According to the rainfall data, it can be seen that the shrinkage-swelling alternation is indeed present in this area with a dry season that lasts about nine months followed by three months of rainy season. So, the disorders related to soil drying out last longer than those related to hydration.

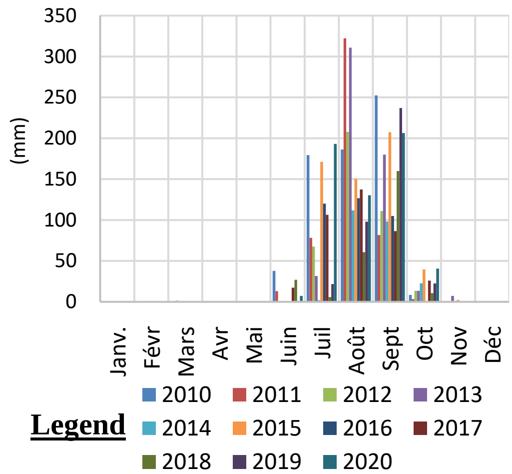


Figure 8. Rainfall accumulation over the past ten years.

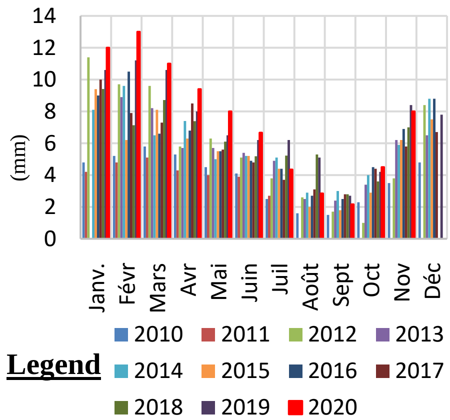


Figure 9. Evaporation of the last ten years.

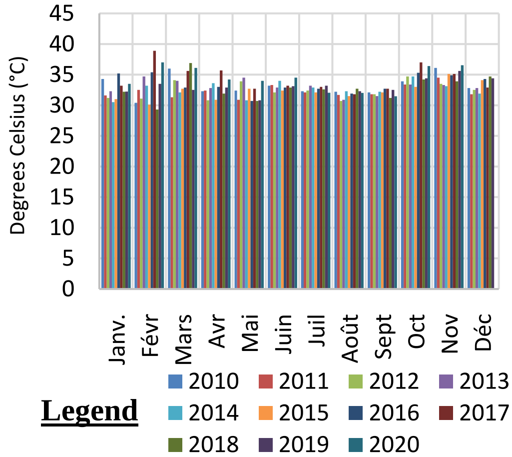


Figure 10. Temperature variation of the last ten years.

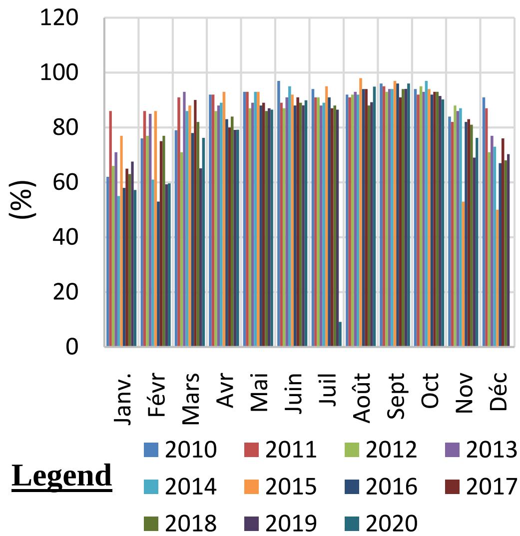


Figure 11. Variation of the maximum humidity of the last ten years.

7. The Heterogeneity and the Thickness of the Layers on the Aggravation of Shrinkage-Swelling

The heterogeneities of the site are linked to the geological history and to any works that it may have been carried out on it (embankment for example). Depending on the geological context, sensitive soil layers can be more or less thick and uniform. Lateral variations in nature (more or less clayey soils) and thickness of these layers are present in this sector, there is a lateral variation in facies. The thickness of these layers will influence the amplitude of the displacements and their heterogeneity will increase the risk of differential settlements. Both of these features exist in our study area; which certainly justifies the differential phenomena of shrinkage-swelling from one place to another.

The soundings carried out on the site reveal a very significant lateral and vertical variation of the facies but also of the thickness of the layers over a very short distance.

8. Conclusion

The swelling of certain soils is a very important phenomenon, as it can be the cause of many disorders both for surface structures and for buried structures. Their understanding and quantification therefore constitute two objectives for reducing claims, but they must be presented by a detailed study of the environment (different types of fine soils, important climatic conditions, hydrogeology, hydrology, topography, etc.). The results obtained on the factors of predisposition and triggering of shrinkage and swelling phenomena showed that this area is very well exposed to this phenomenon. This is added to the aggravating factors constituted by the heterogeneity of the site and the thickness of the fine soils susceptible to shrinkage-swelling, which are also very significant. Ultimately, these studies revealed that the Diamniadio sector presents problematic soils for construction which are both governed by the significant presence of clayey soils susceptible to shrinkage-swelling but also by an environment where the predisposition and triggering factors are also present. These preliminary studies will enable construction engineers to approach this sector with much more precautions and techniques adopted to the behavior of these soils.

Conflicts of Interest

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

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