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# Experimental assessment of swelling potential in montmorillonite soils

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**Abstract.** The study of the physicochemical activity of clays is essential to understand the mechanical-hydraulic behavior. The experimental analysis of the expansivity of soils is linked to the content of clay minerals present in the tactoid tissue, which affect is directly in proportion to the volumetric change that soil may undergo. This work aims to carry out an analysis to understand the expansive behavior of the proposed clay materials, using different techniques, both conventional and modern. For this purpose, the bentonite clay used with a majority montmorillonite component was analyzed through petrographic tests and images analysis. The samples with a base material and different contents of montmorillonite were prepared. Montmorillonite is a clay mineral with a very high swelling potential because even when it was used in low proportions on a sandy base material, the influence of the material is strong and the expansivity remained high.

## 1. Introduction

Expansive soils present volumetric changes when they are submitted to wetting and drying cycles according to their micro and macro-structural configuration. Due to the uncertainty generated by the presence of these clay soils in a geotechnical structure, it is necessary to know the specialized tests to calculate the volumetric change.

Generally, expansive soils are related to semi-arid tropical climate zones, which does not exclude finding this type of soil in other geotechnical complexities. According to [1], in places where there are few levels of precipitation, added to high evapotranspiration processes, they can contribute to post-deposition patterns of the soil, generating special structures such as montmorillonite [2].

The electronegativity imbalance originally presents in a clayey tissue in a solid-state is balanced when cations of water or even other exchange ions surround the sheet of clay, generating a layer with a certain electrochemical attraction, known as a double-diffuse layer, which is hydration caused by the surface of the clay crystal, adsorbing water molecules. Due to the high value of the specific surface of the clays, particularly in montmorillonite soils, the water can localize and surround the available area between the clay sheets, which can be hundreds of square meters in only one gram of material [3,4].

Understanding this phenomenon involves recognizing the lamellar structure of the clayey tissue. Clay is essentially an aluminum silicate. The silicate-related part is made up of a silica cation and four oxygen anions that form a tetrahedral configuration. The octahedral layer, on the other hand, consists of an Al cation surrounded by six hydroxide anions (OH). The placement of the layers in different combinations is what controls the special structure of each of the clay minerals [3]. Montmorillonite is one of the clays called 2:1 it is formed by a layer of octahedral aluminate, between two tetrahedral layers of silicate [5,6], as can be seen in Figure 1.

According to the changes that soil can present, based on different experimental techniques standardized under international entities that measure the volumetric change of the clay, this research article aims to study the presence of expansive clay minerals artificially added to a base material, under different proportions, using various traditional techniques that allow an adequate understanding of the expansive behavior of a composite soil.

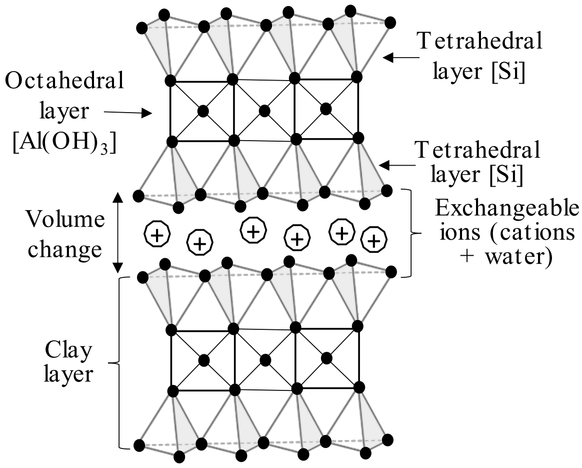



**Figure 1.** Conceptual model of crystalline structure for typical montmorillonite (2:1 clay).

## 2. Background

According to reports generated in the United States, the expansive soils used as the foundation layer, especially lightweight structures, can cause damage close to 2.3 billion dollars annually, which is higher than the damage caused by floods, hurricanes, and tornadoes, even if they are analyzed in combination [7]. Damage to infrastructure caused by the expansive soil's costs about 9 billion dollars per year [8].

The uplift or settlement of expansive clay soil depends on several factors: mineralogy, composition, the level of water in the soil, and the presence of vegetation at a site. Currently, there is no widely accepted geotechnical testing regime to characterize expansive soils and debate continues current assessment methods [9].

Understanding how the expansivity of soil is obtained qualitatively or quantitatively allows contextualizing the current proposal. The most widespread test in the geotechnical world to analyses the expansion of the soil is developed using the Lambe apparatus. Locally governed by standard INV E-120-13 [10] and the Method for Expansion Index of Soils by ASTM D4829-11 [11]. Lambe's method [12] is considered the most widely used in the world. According to its humidity conditions of the soil, the specimen is compacted, then the sample is mounted on the equipment, the swelling force calculation is recorded, and the cross-sectional area of the test piece is taken.

## 3. Methodology

The characterization of expansive soils is carried out using tests that allow showing specific characteristics of the soil fraction and thus conclude that the tested fraction is a fine and expansive soil. The Atterberg Limits reveal the behavior of fine soils in different moisture states, more details about this knowledge state in [13-27].

In this research, Atterberg limits, particle size distribution by hydrometer, and specific gravity tests were performed. In each of the tests, ten replications were made, to have a representative response of the results. An average was used to take the final value of the analysis. Likewise, within this item results based on less conventional tests such as observation of images analysis in the scanning electron microscope (SEM) and X-ray diffraction (XRD), were included for the montmorillonite clay sample used. Laboratory tests were carried out to obtain a complete characterization of the susceptibility to volumetric changes of the samples used. Table 1 shows the number of replicates tested in each of the tests developed in this study.

The test to determine the volumetric change potential of a soil using the Lambe apparatus is an efficient method of knowing the volumetric change of a soil mass. This test provides high reliability regarding material characterization tests; however, this is directly related to the plastic limit of the sample.

**Table 1.** Specific tests for the obtaining of swelling potential.

| Sample | Lambe | Free swelling | Consolidometer |
|---|---|---|---|
| 100% bentonite | 3 | 3 | 3 |
| 75% bentonite – 25% Guamo sand | 3 | 3 | 3 |
| 50% bentonite – 50% Guamo sand | 3 | 3 | 3 |
| 25% bentonite – 75% Guamo sand | 3 | 3 | 3 |

Likewise, free swelling tests were carried out, which allows us to appreciate the increase in volume suffered by soil without alternate restrictions. This is a qualitative classification test that a priori may present a higher expansion index, considering the unconfined conditions of the sample for this test. Equation (1) is used to determine the free swelling ratio (FSR) which is determined by the quotient between the volume registered in the container when the sample is left in contact with both distilled water ($V_d$) and kerosene ($V_k$). However, the standard used in this study bases the estimation of expansivity using the free swelling index (FSI) determined by Equation (1).

$$\mathrm{FSR} = \frac{\mathrm{V_d}}{\mathrm{V_k}} \qquad \mathrm{FSI}(\%) = \frac{\mathrm{V_d} - \mathrm{V_k}}{\mathrm{V_k}} * 100 \tag{1}$$

The estimation of the probable expansion employing the consolidometer allows determining the amount of swelling under a known axial pressure. This test based on the consolidation of the soil sample, considering the condition of the specimen, aims to show a possible volumetric change to the post-construction flood state.

The method is based on applying a constant seat pressure (1 kPa). The sample is then flooded, and the strain readings are recorded, for various times. Data is continued to be collected until primary swelling is complete. Then, load steps are applied until stress where the sample returns to its initial void ratio. It should be considered that in each increment 100% primary consolidation should be achieved [11]. The free expansion, considering the reference seat pressure, and the initial void ratio can be calculated through Equation (2).

$$\frac{\Delta \mathrm{h}}{\mathrm{h}} * 100 = \frac{\mathrm{e_{se}} - \mathrm{e_o}}{1 + \mathrm{e_o}} * 100 \tag{2}$$

## 4. Results

The early detection of potentially expansive clays in a future foundation soil allows us to foresee pathological problems of structures of all kinds, however, the following results obtained from the different dosages, indisputably show the importance of detection before to the start of a project of construction.

### *4.1. Images analysis by scanning electron microscope*

Utilizing SEM images, the surface characterization of the organic and inorganic material of the sample is carried out, this offers morphological information and chemical composition, quickly and efficiently. Consequently, it also allows us to observe the porous areas found in the material analyzed.

With the elaboration of the SEM images, the porosity of the montmorillonite clay used was ratified, its macropores range between 25 µm and 50 µm, while the micropores can be less than 1 µm, as shown in Figure 2. Which directly alters the degree of expansivity and fibrous structure of the material.

*4.2. X-ray diffraction*

This section presents the results obtained in the analysis of clay minerals. With this assembly, the clay minerals present in the sample are identified, as well as the presence of an interlayer. Therefore, Table 2 reports the crystalline phases recognized in the oriented aggregate diffractogram and presents a 100% recalculation of the percentage weight only for the minerals of the clay group. The bentonite sample used has a majority amount of montmorillonite, which guarantees the use of a sample with high swelling potential, useful for the research.

**Table 2.** Clay minerals present in the sample obtained from the XRD.

| Clay mineral | Bentonitic sample (%) |
|---|---|
| Kaolinite | ------ |
| Illite | ------ |
| Montmorillonite | 99.64 |

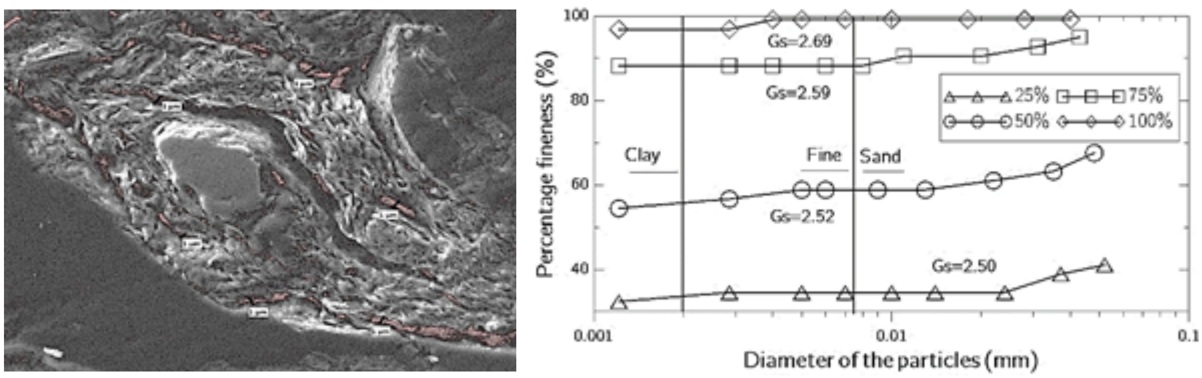
*4.3. Geotechnical parameters*

The basic variables of soil behavior must always be analyzed when clay materials are involved in the analysis. Atterberg limits shown in Table 3, Particle size distribution and specific gravity were considered in this research, not only for the base material but also for the combinations of the composite material.

**Table 3.** Atterberg limits.

| Test | 100% Bentonite | 75% Bentonite + 25% Guamo sand | 50% Bentonite + 50% Guamo sand | 25% Bentonite + 75% Guamo sand |
|---|---|---|---|---|
| Liquid limit | 424.0 | 347.0 | 218.0 | 115.0 |
| Plastic limit | 34.3 | 38.8 | 41.1 | 44.7 |
| Plasticity index | 389.7 | 308.2 | 176.9 | 70.3 |
| Shrinkage limit | 8.0 | 8.2 | 10.3 | 11.8 |

According to Table 3, the LL of the samples is high, even in those with a low amount of bentonite (25%). Analyzing from any point of view [28-30], the Atterberg limit values can be considered as the first point of interest to identify an expansive soil; the degree of expansion of all samples is high and very high. Therefore, the influence of montmorillonite, even in specimens that were dosed with only 25%, is very high. This shows how a very small amount of clay, in this case expansive, can contribute to raising the plasticity values of composite material, even if it is not predominant in the sample.




(a) (b)

**Figure 2.** (a) Image of the bentonitic sample from the SEM, (b) Particle size distribution of the materials.

Figure 2, right, shows the particle size distribution, obtained by the hydrometer technique for the four dosages already presented in Table 3. On the other hand, the specific gravity values are shown in the same way in the figure. The presence of sand in the sample decreases the specific gravity value, something expected since the presence of clay minerals increases the value of this parameter.

### *4.4. Volumetric change using Lambe apparatus and free swelling*

As shown in Table 4, the content of montmorillonite in a soil fragment is decisive for its engineering use, and to detect the presence of expansive soils in time. As suspected before the investigation, the influence of the bentonite content on the samples is significant. Even in the combinations with the lowest bentonite content, the potential volumetric change (PVC) resulted in at least critical conditions, according to the methodology used, which is observed in Table 4.

According to [13] who indicated that it is unlikely that soils with a free swelling less than 50% show expansive properties, while soils with free swelling greater than 50% could present expansion problems. Values of 100% or more are associated with clay that could expand considerably, especially under light loads. The free expansion index (FSI) obtained shows a very high degree of expansion (Table 4), which confirms what was obtained through conventional tests and the Lambe apparatus.

**Table 4.** Average results obtained from the PVC test using Lambe's apparatus and FSI by test tube.

| Sample / Dosage | Swelling index (MPa) | PVC | FSI (%) | Swelling degree |
|---|---|---|---|---|
| 100% Bentonite | 0.10 | Very critical | 645.47 | Very high |
| 75% Bentonite – 25% Guamo sand | 0.09 | Very critical | 416.67 | Very high |
| 50% Bentonite – 50% Guamo sand | 0.07 | Critical | 362.50 | Very high |
| 25% Bentonite – 5% Guamo sand | 0.03 | Critical | 295.23 | Very high |

### *4.5. Swelling by consolidometer*

From the consolidometer test, the curve Time - swelling is obtained. The primary swelling, represented in Figure 3, experienced by the soil, when having direct contact with the water particle, increases the volume of voids by suction of water in partially saturated pores.

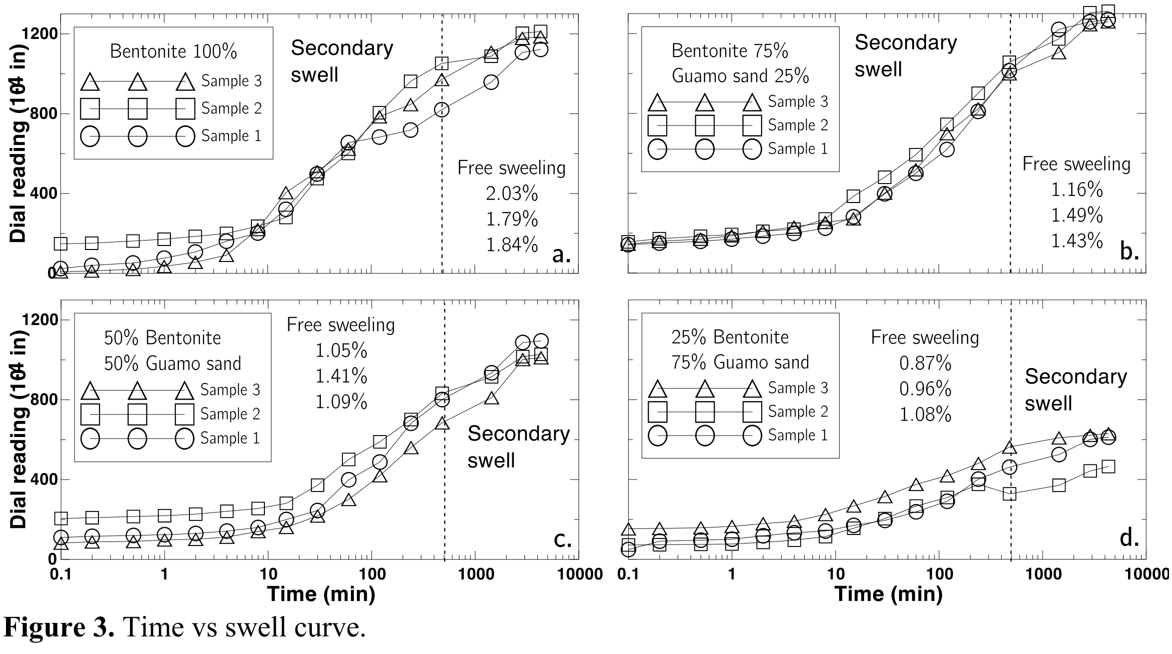



**Figure 3.** Time vs swell curve.

The void ratio present in the bentonite clay generates a potential for water adsorption, therefore, in Figure 3, the free expansion of the sample and the differential relative settlement that it undergoes after the consolidation is evidenced.

## 5. Conclusions

A laboratory test package, consisting of basic, conventional, and specific tests to determine the expansive potential of soil, is the best tool to identify and quantify the expansivity of the soil. It is not only important to detect that the material is expansive. Other aspects such as the probable expansion, swelling potential, expansion stress, among others, are important to analyze this pathology in problematic soils.

The development of image analysis and petrographic tests, to identify the microstructural of the material, as well as confirm the presence of clay minerals, knowing the composition of the soil, ends up being essential when corroborating the swelling potential of soil with another method.

Montmorillonite is a clay mineral with a very high swelling potential. Even when it was used in low proportions, on a sandy base material, the influence was strong and the expansivity remained high. All the specific tests (Lambe, Free swelling in test tube, Consolidometer), showed that the samples had a very high expansive response. Some of them may overestimate the analyzed behavior, so it is always important to develop a test package.

It was confirmed experimentally that the consolidometer test provides important and valuable information regarding the swelling, consolidation, or settlement stages of a fraction of the soil. On the other hand, through the results obtained it was evidenced that this methodology offers accurate information in terms of stress values in terms of soil pressure concerning its void ratio, with this information it is possible to determine the pressure in terms of vertical thrust ground.

## References

[1] Méndez A, Pineda V 2011 *Comportamiento de Cimentaciones en Suelos Expansivos* (México: Universidad Nacional Autónoma de México)
[2] Mašín D 2017 *J. Eng. Mech.* **143(9)** 04017067
[3] Ruge J C, Palacios X, Molina-Gomez F, Rojas J P 2019 *J. Phys.: Conf. Ser.* **1388** 012014:1
[4] Guancheng, J 2018 *Gas Wettability of Reservoir Rock Surfaces with Porous Media* (United States: Gulf Professional Publishing)
[5] Faheem U 2018 *Montmorillonite: An Introduction to Properties and Utilization, Current Topics in the Utilization of Clay in Industrial and Medical* (London: Intechopen)
[6] McKeen R G 1976 *Design and Construction of Airport Pavements on Expansive Soils* (United States: Department of Transportation Federal Aviation Administration, Systems Research & Sevelopment Service)
[7] Kerrane B 2004 *What Are Expansive Soils?* (United States: Kerrane, Storz & Nelson, P.C.)
[8] University of Texas Arlington (UTA) 2019 *Mitigation of Expansive Soils Damage* (United States: University of Texas Arlington)
[9] Indraratna B, Chu J, Rujikiatkamjorn C 2015 *Ground Improvement Case Histories* (United Kindom: Butterworth-Heinemann)
[10] Instituto Nacional de Vías 2013 *Determinación del Potencial del Cambio Volumétrico del Suelo Empleando el Aparato de Lambe, INV E-120-13* (Colombia: Instituto Nacional de Vias)
[11] American Society for Testing and Materials (ASTM) *2011 Standard Test Method for Expansion Index of Soils, ASTM D48219-11* (United States: American Society for Testing and Materials)
[12] Lambe T W 1960 *The Character and Identification of Expansive Soils - Soil PVC Meter: A Technical Studies Report F.H.A.–701* (Washington: Federal Housing Administration)
[13] Abduljauwad S N, Al-Sulaimani G J 1993 *Geotechnical Testing J. ASTM* **16(4)** 469
[14] Altmeyer W T 1955 *J. of the Soil Mech. and Foundations Division, ASCE* **81(2)** 17
[15] Raman V 1967 *Indian Eng.* **11** 7-22
[16] Sowers G B, Sowers G F 1970 *Introductory Soil Mechanics and Foundations* (New York: Macmillan)
[17] Holtz W G 1959 *J. of the Col. School of Mines* **54(4)** 89
[18] Ranganatham B V, Satyanarayana B 1965 *Proc. of the 6th Int. Conf. on Soil Mec. and Foundation Eng.* (London: International Society for Soil Mechanics and Foundation Engineering) pp. 92–96
[19] Snethen D R 1974 *Visit to Kansas Highway Commission. Memorandum for Record. Soil Mechanics Division* (United States: Soils and Pavements Laboratory. US Army Engineer Waterways Experiment Station)
[20] Vijayvergiya V N, Ghazzaly O I 1973 Prediction of Swelling Potential of Natural Clays *Proc. 3 Int. Research and Eng. Conference on Expansive Clays* (Israel: Academic Press) pp 227–234

Journal of Physics: Conference Series **1938** (2021) 012006 doi:10.1088/1742-6596/1938/1/012006


[21] Nayak N V, Christensen R W 1974 *Clay and Clay Minerals* **19** 251

[22] Weston D J 1980 Expansive roadbed treatment for southern Africa *Proceedings Fourth International Conference on Expansive Soils* (Denver: National Institute for Transport & Rd Res S Af) pp 339–360

[23] Snethen D R, Johnson L D, Patrick DM 1977 *An Evaluation of Expedient Methodology for Identification of Potentially Expansive Soils* (United States: Army Eng. Waterways Experiment Station)

[24] O'Neill M W, Poormoayed N 1980 *Journal of the Geotechnical Engineering Division* **106(12)** 1345

[25] Snethen D R 1984 Evaluation of expedient methods for identification and classification of potentially expansive soils *Proc. 5th Int. Conf. on Expansive Soils* (Australia: Institution of Engineers) pp 22–26

[26] Instituto Nacional de Vías 2013 *Relaciones de Peso Unitario-Humedad en los Suelos, INV E-141-13* (Colombia: Instituto Nacional de Vias)

[27] Sridharan A 2005 On swelling behaviour of clays *Proc. Int. Conf. on Problematic Soils* (North Cyprus: Eastern Mediterranean University) pp 499–516

[28] Instituto Nacional de Vías 2013 *Determinación de Suelos Expansivos, INV E-132-13* (Colombia: Instituto Nacional de Vias)

[29] Instituto Nacional de Vías 2007 *Método para Medir el Potencial de Asentamiento o Expansión Unidimensional de Suelos Cohesivos, INV E.173-07* (Colombia: Instituto Nacional de Vias)

[30] Bureau of Indian Standards 1970 *Classification and Identification of Soils for General Engineering Purposes, IS 1498* (New Delhi: Bureau of Indian Standards)