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THE SWELLING PRESSURE OF ACTIVE CLAYS ACCORDING TO VARIOUS TECHNICAL NORMS AND PROCEDURES

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Abstract

The main geotechnical parameter indicating the presence of active clays is the swelling pressure, which is globally determined using at least three different methods. In Romania, however, the swelling pressure is determined using only one method (through the compressibility test in oedometer on initially saturated samples). Regardless of the method used, the initial moisture content significantly influences the results. Two types of moisture content are typically considered: natural moisture content (according to STAS 1913/12-88) and the shrinkage limit (according to NP 126-2010). In current practice, the initial moisture content is usually the natural moisture content. However, by saturating the sample, only the swelling characteristics of the soil are identified, not the shrinkage characteristics. This article aims to synthesize the methods for determining the specific properties of active clays, based on international technical standards and norms.

Key words: *active clays, swelling pressure, technical norms, laboratory tests.*

INTRODUCTION

Expansive soils, characterized by their ability to undergo significant volume changes upon moisture variation (to shrink and/or swell), are found across many regions globally. They are particularly prevalent in semi-arid and arid climates, where the formation of smectite clay minerals (montmorillonite and illites) is geologically favoured (Diaz & Tomas, 2025). In Romania, expansive clays are frequently encountered, especially in the southern and eastern regions, where their geotechnical behavior is rigorously classified and evaluated under NP 126-2010, which sets the national standards for identifying and testing swelling pressure.

In geotechnical engineering, the determination of the swelling pressure (p_s, kPa) is critical for the design of shallow and deep foundations, retaining walls, underground structures, and linear infrastructure (Fredlund, 1996). This pressure quantifies the force exerted by a clayey soil when its volume is restrained during wetting (Chen & Ng, 2013).

The swelling pressure (p_s) is defined as the equilibrium pressure required to prevent volumetric expansion of an initially unsaturated clay soil when its moisture content increases to full saturation under constant volume conditions (Jones et al., 2020; BS 1377-5: 1990).

Various laboratory techniques such as: the one-dimensional oedometer (NP 126-2010; Feng et al, 1998), CBR and triaxial tests (Chen & Ng, 2013) are commonly employed to measure p_s directly.

Also, a wide array of empirical and semi-empirical correlations has been developed to estimate p_s from more readily available soil parameters. Extensive research has explored how p_s varies with clay fraction, dry unit weight, water content, liquid limit, and plasticity index (Mowafy & Bauer, 1985), affirming that such index properties can serve as reliable predictors under certain conditions.

The determination of the p_s is essential to reduce construction risks, limit post-construction deformations, and minimize maintenance costs, thereby enhancing the sustainability and safety of engineering projects (Jones et al., 2020).

MATERIALS AND METHODS

This study is based on an extensive review of the scientific literature, supported by a critical analysis of national and international standards and regulations relevant to the geotechnical characterization of expansive soils. Key references include normative documents such as NP 126-2010 (Romania), STAS 8942/1-89, as well as international standards like ASTM

D4546, BS 1377, and other globally recognized testing protocols.

The primary objective is to synthesize the most representative laboratory methods for determining swelling pressure (p_s), focusing particularly on one-dimensional oedometer tests (constant volume and free swell methods), triaxial testing procedures, and empirical correlations derived from index properties. The methodology involves a comparative and integrative analysis of procedures, test conditions, and parameters influencing p_s, as presented in both peer-reviewed scientific publications and engineering practice documents.

Wetting-after-loading tests on multiple specimens

The most complex method for determining the behaviour of active clays is the "wetting-after-loading tests on multiple specimens" or "Deformation versus Vertical Stress, Method A" from ASTM D4546. The tests are performed on several specimens from the same sample which, initially at natural moisture content, are loaded in the oedometer to different pressures and subsequently saturated. The final specific settlements of the sample at natural moisture content and, respectively, after saturation are recorded. Thus, compressibility curves are obtained for the material at natural moisture content (red dotted line from Figure 1) and in the hypothesis that, after being subjected to a certain compression stress (geological load or geological load to which the surcharge is added), it is saturated (blue dotted line from Figure 1). The swelling pressure is obtained at the intersection of the saturated soil compressibility curve with the zero-deformation line.

This method is a very complex one that identifies, in addition to the swelling pressure, the entire behaviour of the soil at natural moisture content, loaded at different pressures and subsequently saturated.

The method has two major disadvantages: (1) long duration or occupation of several oedometric devices and implicitly significant costs and (2) difficulties in taking quasi-identical samples to obtain accurate comparable results.

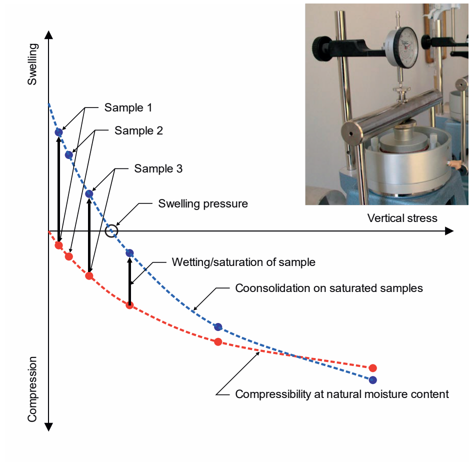

Figure 1. Wetting-after-loading tests on multiple specimens

Wetting-after-loading test on a single specimen

The "Wetting-after-loading test on a single specimen" or "Deformation versus Vertical Stress, Single-Point Test Method B" from ASTM D4546 is a method that only determines the swelling after the sample is loaded with a compression pressure (geological load or geological load to which the surcharge is added) (Figure 2).

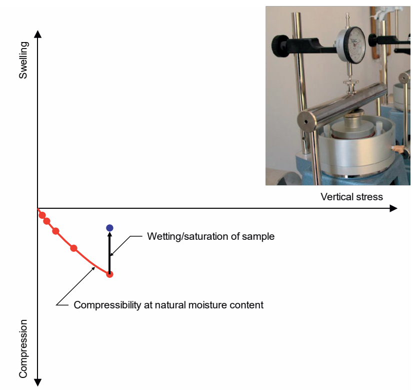

Figure 2. Wetting-after-loading test on a single specimen

This test determines the behaviour of a soil subjected to a certain compression stress and subsequently saturated. Through this test the swelling pressure is not determined.

Loading-wetting-loading test

The "Loading-wetting-loading test" or "Deformation versus Vertical Stress, Loading-after-Wetting Test Method C" from ASTM D4546 is a method in which a soil sample at natural moisture content is loaded to a certain pressure (geological load or geological load to which the surcharge is added) and then saturated and loaded further with different pressures. If the swelling is large enough to exceed the initial height of the sample, the swelling pressure can also be determined at the intersection of the saturated soil compressibility curve with the zero-deformation line (Figure 3).

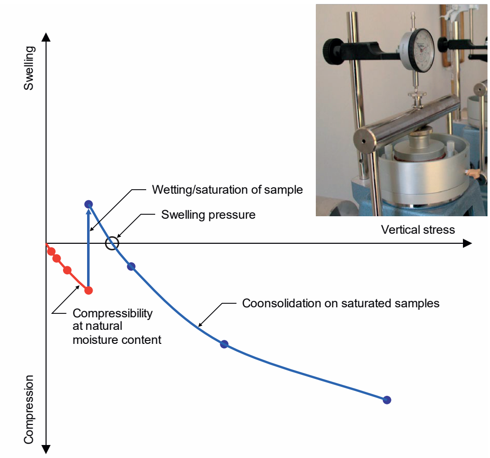

Figure 3. Loading-wetting-loading test

It is a method by which the behaviour of the soil is obtained after it, at natural humidity, is loaded with a certain pressure and subsequently saturated and the loading continues. Basically, it is described the behaviour of a soil loaded with the geological pressure, then saturated and subsequently the construction is built that comes with a certain surcharge.

Loading-after-wetting test

This method is imposed by STAS 1913/12-88 and NP 126-2010 and is almost identical to the "Deformation versus Vertical Stress, Loading-after-Wetting Test Method C" from ASTM D4546, with the difference that the sample is saturated after applying the first loading step, usually equal to 10...25 kPa (Figure 4).

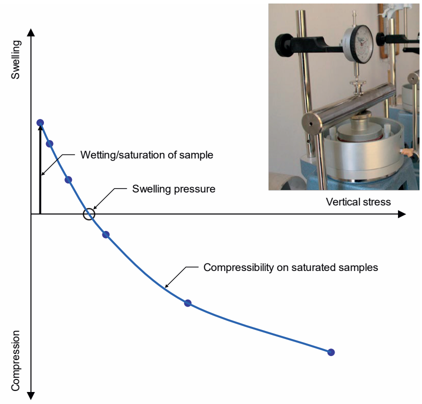

Figure 4. Loading-after-wetting test

According to STAS 1913/12-88 the initial moisture content is the equilibrium moisture content, which is very close to the natural moisture content, while according to NP 126-2010, the initial moisture content should be the shrinkage limit. This technical norm is the only one that refers to the shrinkage limit. In the specialized technical literature, tests are performed starting from the natural moisture content of the sample.

Most likely, the idea behind performing this test starting from the shrinkage limit is to identify the behaviour of the soil after it experiences significant drops in moisture content and subsequently becomes saturated. It is the worst-case scenario, but it does not consider the fact that shrinkage occur both vertically and horizontally (visible by cracks in the soil).

Performing the compressibility test in an oedometer on samples brought to the shrinkage limit involves major difficulties in soil sampling doe to its solid state.

Constant volume test

This method can be applied in two variants: (1) as described in "Deformation versus Vertical Stress, Loading-after-Wetting Test Method C" from ASTM D4546 in which small loading steps are applied to maintain the sample around zero deformations or (2) in a CBR type device through which the sample is kept at constant volume and by means of a dynamometric ring the force that the soil sample develops, following saturation, is measured (Figure 5).

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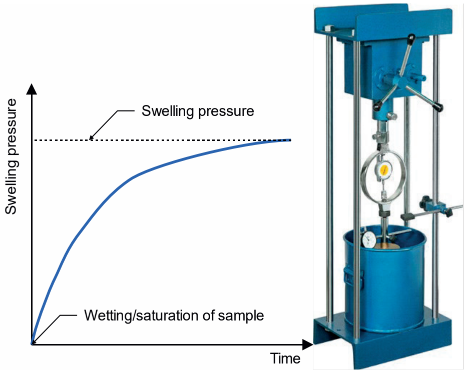


Figure 5. Constant volume

The swelling pressure is an indicator of whether a soil has swelling behaviour when saturated. The strict determination of the swelling pressure does not provide an image of the soil behaviour under different compression stresses which is necessary in order to estimate swelling/settlement.

RESULTS AND DISCUSSIONS

The swelling pressure (p_s) is the pressure required to prevent volumetric expansion of an initially unsaturated clayey soil when its moisture content increases to full saturation. In current practice, it is erroneously considered that if a foundation transmits a pressure greater than or equal to the swelling pressure to the foundation soil, then, in the event of saturation of the foundation soil, no swelling will occur.

In Figure 6 it is presented the scheme for the calculation of the foundation soil settlement, and it is the same scheme that should be applied for the estimation of swelling.

This scheme is taken from NP 125-2010 which is used to determine the additional specific settlement upon wetting of soils sensitive to wetting.

A soil element is initially subjected to a vertical stress equal to the geological stress (σ_{gn}) and, after a construction is built, the vertical stress due to surcharge is added (σ_z) resulting the total vertical stress equal to $p_n = \sigma_z + \sigma_{gn}$. If the foundation soil is saturated the geological stress (σ_{gi}) increases due to the unit weight of the soil increases to saturated unit weight and the total vertical stress becomes $p_i = \sigma_z + \sigma_{gi}$.

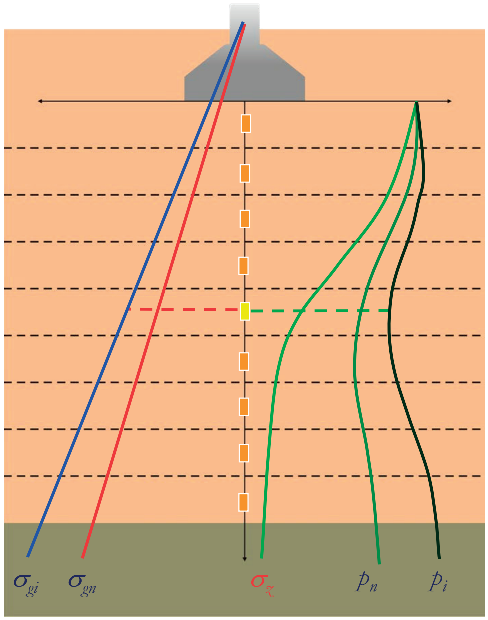


Figure 6. Calculation scheme for foundation soil settlement

In Figure 7 a, b and c are presented different stress-strain curves of soil samples at natural moisture content and initially saturated obtained in different common laboratory tests (cases frequently encountered in current practice).

In Figure 7.a it is presented an example of a soil with a swelling pressure of about 35 kPa.

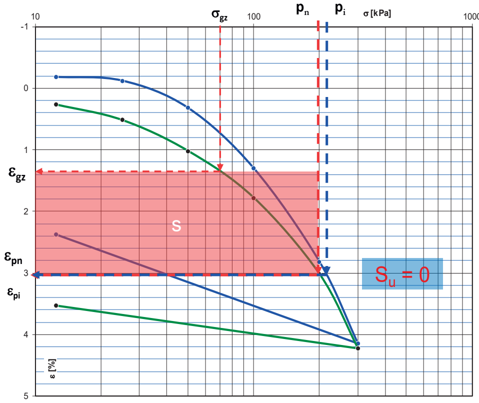
By estimating the geological load of the elementary layer “i” by intersecting with the stress-strain curve of the soil at natural moisture content, the specific settlement ε_{gz} is determined. This is the initial stress-strain state of the elementary layer “i”. After the execution of a construction, a vertical compression stress equal to p_n is transmitted to the same element and, by intersecting with the stress-strain curve of the sample at natural moisture content, the specific settlement (ε_{pn}) under this load is determined. The difference between ε_{pn} and ε_{gz} is the specific settlement of the elementary layer “i” at natural moisture content.

Considering that the foundation soil becomes saturated, at the level of elementary layer "i" the total vertical stress becomes p_i and by intersecting with the stress-strain curve of the initially saturated soil sample the specific settlement ε_{pi} is obtained. The difference between ε_{pn} and ε_{pi} is the specific settlement or swelling of the elementary layer "i" when saturated.

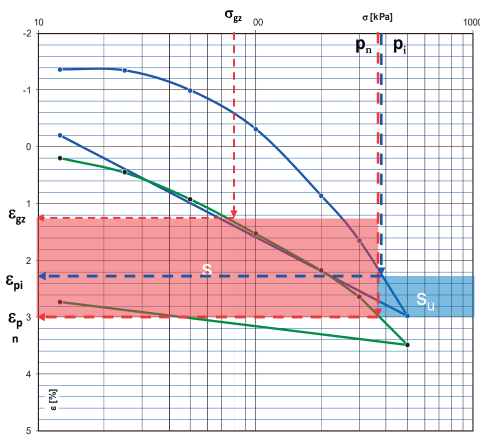
In the case presented in Figure 7.a, it is found that, following the saturation of the foundation soil, neither settlement nor swelling is recorded at the level of the elementary layer "i".

Following the same principle described previously, by which the states of stress and deformation are evaluated from the initial moment, after the execution of the construction, respectively, in the hypothesis of saturation of the foundation soil, Figure 7.b presents a case in which the swelling pressure is equal to 120 kPa but, in the case of saturation of the foundation soil, even at pressures higher than the swelling pressure, a significant swelling of the elementary layer "i" is recorded.

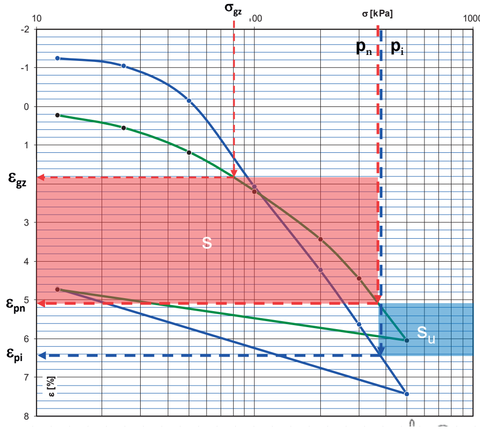
In Figure 7.c, after saturation of the foundation soil, a settlement is recorded.



(a)



(b)



(c)

Figure 7. Stress-strain curves of soil samples at natural moisture content and initially saturated

CONCLUSIONS

The swelling pressure (p_s) is the pressure required to prevent volumetric expansion of an initially unsaturated clayey soil when its moisture content increases to full saturation and is just an indicator of whether a soil has high swelling when saturated.

As in accordance with NP 074-2022, double compressibility tests should be performed on soils with high swelling and shrinkage, on samples at natural moisture content and on samples initially saturated in order to obtain the behaviour of the soil under different vertical loads. The methodology imposed by the Romanian technical norms and standards is very close with the method A from ASTM D4546 but is performed only on two samples, not on minimum 4.

According to the calculation model of additional settlement upon wetting described in NP 125-2010, the stress-strain curves obtained from compressibility in oedometer tests (affected by correction coefficient M_0 used for the calculation of the deformation modulus $E = E_{oed} \cdot M_0$) allow the estimation of the settlement/swelling of the foundation soil.

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