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CONSTRUCŢII. ARHITECTURĂ

ON THE ACTIVE AND COMPRESSIBLE BEHAVIOR OF BAHLUI CLAY

BY

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Abstract. Expansive/active soils that consist of reactive minerals (which present unstable networks and thus tend to modify their volume by water adsorption and cationic exchange) raise a major challenge to geotechnical engineers being also considered geological hazards. Studying the potential volume changes of a soil becomes compulsory (because of the degradations that might appear following heaving and settlement) at the outset of future construction projects, especially the low weighted ones and positioned close to the surface and thus subjected to a greater extent of water content variations. This study investigates the swelling and compressible behavior of undisturbed samples of Bahlui clay using a direct method. Indirect methods of estimating the swelling potential are considered as well.

Key words: active soil; Bahlui clay; swelling pressure; compressibility.

1. Introduction

In a continuous developing world, the use of any resource is recommended, especially in the construction field. With the expansion of roads,

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railways and highways networks it is good to know the behavior of soils on which works are to be made.

In the world, clays are present on 42% of the earth crust, therefore the need to study their behavior when used as building material or foundation soil is justified (Hotineanu *et al*., 2012; Stanciu *et al*., 2013). In Iaşi County, there is an extended area in which one can find the soil with a special behavior, namely Bahlui, clay which, over the years, presented a research interest for the geotechnical engineers due to its active/expansive characteristics.

It is well known that active soils cause numerous heave and settlement problems all over the world, hence the necessity of identifying and correcting this behavior. In 1978, Boți, presented a detailed study in his Ph. D. dissertation regarding the chemical-mineralogical composition of Bahlui clay and 20 years later, in the same context, Plătică, (1994), continued those studies in his Ph. D. dissertation.

The active clays in Romania (Fig. 1) belong mostly to formations from late Tertiary and early Quaternary temperate area. The Danube Delta and some lower course river clays and organic deposits belong to hot-climate formations which mean their active behavior is more pronounced than those from a temperate zone. The majority of Romanian active clays are derived from basic igneous and montmorillonitic sedimentary rocks (Popescu, 1979).

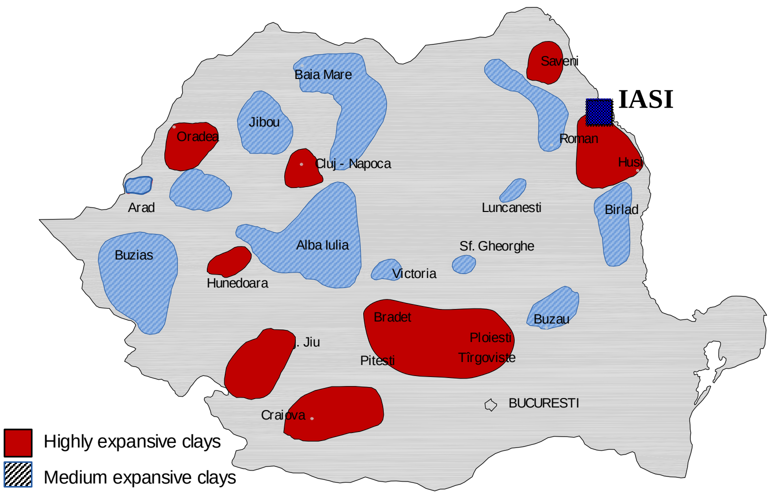

Fig. 1 – The distribution of active clays on Romanian territory.

In Fig. 1 a territorial distribution of active clays in Romania, is presented. In Iaşi, active clays are found along the Bahlui River, and it is said erosion is the occurrence cause of these soils (Aniculăesi, 2009).

The minerals that influence the most the active (high swelling potential) behavior of a soil are smectites, namely the dioctahedral ones (montmorillonite, beidellite, nontronite) and trioctahedral (saponite, hectorite, sauconite) (Stanciu *et al*., 2013).

The interest given all along the years to this category of soils starts with the damages provoqued by its swelling and shrinkage on water content variations, especially in the case of light structures like houses, roads, pavements, etc. Water content variations are a consequence of climatic changes but also of vegetation presence/absence and the position of the water table. Besides this, volume changes (swelling/shrinkage) are due to the chemical-mineralogical composition of the soil, its initial physical properties (Stanciu & Lungu, 2006, 2012; Al-Rawas & Goosen, 2006).

Over the years, many methods have been developed in order to estimate the shrink-swell potential of soils; one can classify these methods as indirect ones (they use soil properties and classification schemes such as plasticity index, activity ratio, cation exchange capacity) and direct ones (that provide actual physical measurements from soil lab tests such as the free-swell test, the expansion test, the CBR test, the oedometer test, etc.) (Stanciu & Lungu, 2012; Thakur & Singh, 2005).

This paper continues other research on the identification and characterization of Bahlui clay, aiming principally to determine the swelling pressure and other geotechnical indicators of its active behavior.

2. Materials and Methods

2.1. Chemical-Mineralogical Composition of Bahlui Clay

It is well known that Bahlui clay is a montmorillonitic soil (Boți, 1974; Plătică, 1994). In this kind of soil, the exchangeable interlayer cations are located on the surface of the layers or in the hexagonal holes of the tetrahedral sheets (Madsen & Muller-Vonmoos, 1989). Due to the particles negatively charged surface and weak van der Waals attraction forces, the cations hydrate upon contact with water and attract other ions in order to compensate the electrical charge. Conducting a series of studies on Bahlui clay from different location around the city of Iaşi, Boți, (1974), concluded that the clay chemical composition is the following: 51.06…56.63% SiO_2, 17.20…21.37% Al_2O_3, 2.20…4.77% Fe_2O_3, 4.70…8.25% CaO, 1.03…2.54% MgO, 0.038…0.81% Na_2O, 1.54…2.31% K_2O, 3.68…6.17% H_2O and 7.88…10.87% losses. From those specified in the literature (Al-Rawas & Goosen, 2006), one can notice that Bahlui clay has a similar composition to the one from Montmorillon (France), the one from Colony, Wyoming (USA) and San Diego, California (USA).

The laboratory tests, in order to physically and mechanically characterize the active clay present along the Bahlui River, were conducted on undisturbed samples prelevated in form of monoliths.

2.2. Grain Size Distribution and Atterberg Consistency Limits

In order to establish the grain size distribution and the Atterberg consistency limits, the specifications from ASTM D421-85, (2007), and ASTM D4318-10e1 were followed. For the water content determination, the samples were dried in the oven at 105°C for 24 h. For the grain size distribution test, 50 g of dry soil was treated with a dispersing agent for 24 h. The hydrometer test was subsequently used in order to establish the diameters of the particles.

The classification of the swelling potential on the basis of the liquid limit and plasticity index values can be made according to Table 1**Table** (Stanciu *et al*., 2012).

Table 1
Swelling Potential by Liquid Limit and Plasticity Index

Parameter	Reference	Swelling potential			
		Low	Medium	High	Very high
Liquid Limit (LL) %	Chen, (1975)	< 30	30…40	40…60	> 60
	IS, 1498	20…35	35…50	50…70	70…90
	Mohan & Goel, (1959)	20…35	35…50	50…70	70…90
	Daksanamurthy & Raman, (1973)	20…35	35…50	50…70	> 70
Plasticity Index (PI) %	Chen, 1975	0…15	10…35	20…55	> 55
	Holtz & Gibbs, (1956)	< 20	12…34	23…45	> 45
	Holtz, (1959)	< 18	15…28	25…41	> 35
	Williams & Donaldson, (1980)	< 12	12…24	24…32	> 32
	Mohan & Goel, (1959)	< 12	12…23	23…32	>32
	IS, 1498	< 12	12…23	23…32	> 32
	Seed *et al.*, (1962)	< 10	10…20	20…35	> 35
	Holtz, (1959)	> 15	10…16	7…12	< 11

2.3 Shrinkage Limit and Linear Shrinkage

The shrinkage limit and the linear shrinkage can be determined on a soil paste brought to the liquid limit (according to ASTM D4829-11), slowly dried at ambient temperature and then in a drying oven (Stanciu *et al*., 2012). The classification of the swelling potential on the basis of the shrinkage limit and the linear shrinkage values can be made according to Table 2 (Stanciu *et al*., 2012).

By definition, the shrinkage limit can be calculated as follows:

$$w_s = w - \frac{(V - V_d)\rho_w}{m_d} \cdot 100, \qquad (1)$$

where: w_s is the shrinkage limit; V – wet sample volume, [cm^3]; V_d – dry sample volume; m_d – dry sample mass.

Table 2
Swelling Potential by Shrinkage Limit and the Value of Linear Shrinkage

Parameter	Reference	Swelling potential			
		Low	Medium	High	Very high
Linear shrinkage (S_L), [%]	Mckeen, (1976)	< 5 (non-critic)	5…8 (marginal)	> 8 (critic)	
	Altmeyer, (1955)	< 5 (non-critic)	5…8 (marginal)	> 8 (critic)	
Shrinkage limit (w_s), [%]	Holtz & Gibbs, (1956)	>13	8…18	6…12	< 10
	Holtz, (1959)	> 15	10…16	7…12	< 11
	Altmeyer, (1955)	>12 (non-critic)	10…12 (marginal)	<10 (critic)	
	Bureau of Reclamation	>15	10…16	7…12	< 11
	Sowers & Sowers, (1970)	>12	10…12	< 10	


Fig. 2 – Samples during testing for the determination of linear shrinkage.

The linear shrinkage limit is determined using soil samples as half cylinders with a 12.7 mm radius and 140 mm height (Fig. 2)

$$S_L = \left(1 - \frac{B}{A}\right) \cdot 100, \qquad (2)$$

where: S_L is the linear shrinkage [%]; B – height of dry sample [cm]; A – initial height of sample, [cm].

2.4. Swelling Pressure and Compressibility Characteristics

The swelling pressure is one of the most important indices characterizing an active soil. A swelling pressure of less than 20 kPa can be considered as of insignificant consequence (Al-Rawas & Goosen M., 2006). This index can be measured according to a multitude of methods, the most used being the oedometric one following the specifications in ASTM 4546-08. In this study, in order to determine this pressure, method *A*-test (which measures the free swell, the percentage heave for vertical confining pressure and the swell pressure) was conducted on undisturbed soil samples.

Firstly, a vertical load is applied. After the completion of the initial settlements, the specimens are inundated in the oedometric cell, swelling vertically. The specimen is loaded after the primary swell has occurred until its initial void ratio is obtained or even further. The external pressure needed for the sample to regain its initial void ratio is considered the swelling pressure of that soil.

For the determination of the compressibility characteristics, undisturbed and uninundated samples were tested in the oedometer (according to ASTM D2435M-11) with the dimensions of 71.4 mm diameter and 20 mm height. The coefficient of compressibility and the oedometer modulus were calculated for the 200…300 kPa pressure range, both for inundated and natural soil state.

3. Results and Discussion

3.1. Grain Size Distribution and Atterberg Consistency Limits

Following the specifications previously presented, the grain size distribution curves for the Bahlui clay samples were drawn in Fig. 3 (observing that clay fraction is present with the highest percentage). The colloidal fraction percentages and Atterberg consistency limits are presented in Table 3.

Table 3
Physical Geotechnical Indices of Bahlui Clay

Property	Sample 1	Sample 2	Sample 3
$A_{2\mu}$, [%]	58.32	66.96	64.97
Liquid limit, LL [%]	85.75	86.03	85.96
Plastic limit, PL[%]	33.46	32.62	31.68
Plasticity index, PI [%]	52.29	53.41	54.28

According to $A_{2\mu}$ and plasticity values (Fig. 3, Table 3), the Bahlui clay can be identified and characterized as a high plasticity, fat clay (CH category from Unified Soil Classification System). Taking into account the value of $A_{2\mu}$

which is higher than 28, after the criteria of Holtz and Gibbs (Stanciu *et al.*, 2012), the swelling potential is very high.

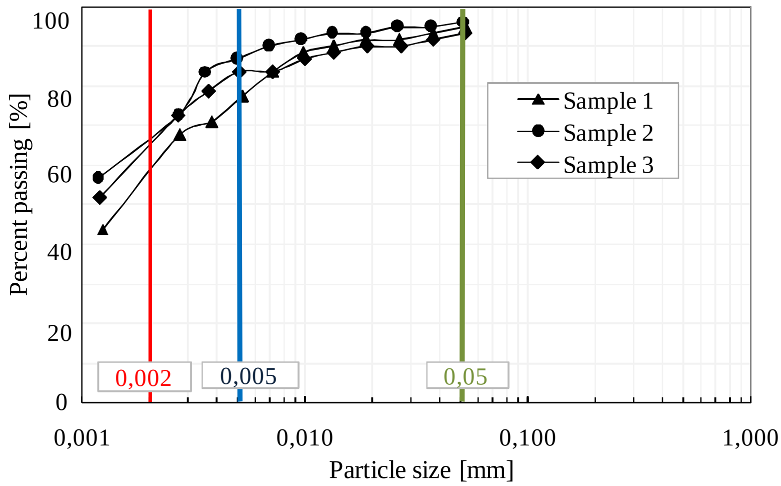

Fig. 3 – Grain size distribution of Bahlui clay.

3.2. Shrinkage Limit, Linear and Volumetric Shrinkage

The results of the tests conducted on Bahlui clay regarding linear shrinkage and shrinkage limit are presented in Table 4.

Table 4
Values of the Shrinkage Limit and Linear Shrinkage for Bahlui Clay

w_{nat}	w_s , [%]	S_L, [%]
30.17	13.20	16.78

Following the characterization given in Table 2 and considering the values from Table 4, the swelling potential of the Bahlui clay is appreciated as high and medium. Although, if it is to consider the range of values of LL and PI (Table 1), the swelling potential of Bahlui clay can be appreciated as very high.

Many researchers around the world developed methods in order to identify expansive soils based on their clay content, shrinkage limits (both volumetric and linear), plasticity index, liquid limit, etc. (Al-Rawas & Goosen, 2006). Two of these methods, graphically objectified (van der Merwe and Casagrande (Stanciu *et al.*, 2012)) were used to characterize Bahlui clay (Figs. 4 and 5). As per van der Merwe graphic representation, the swelling potential of Bahlui clay is very high, enclosing its activity index ($PI/A_{2\mu}$) between 0.75 and 1. Drawing the soil chart designed by Casagrande with the Bahlui clay liquid limit (LL) and plasticity index (PI) values, one can also see that the soil has a very high swelling potential, being placed between the *A*-line and *U*-line, the zone for CH (inorganic clays of high plasticity, fat clays) or OH soils (organic clays of medium to high plasticity, organic silts).

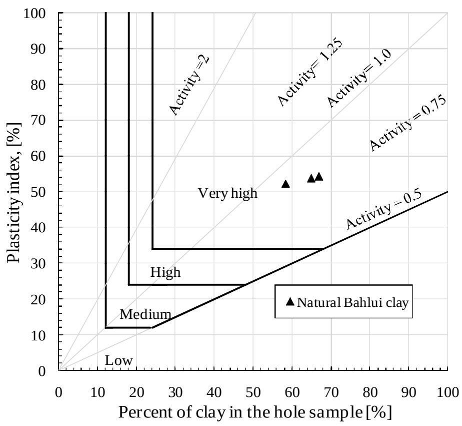

Fig. 4 – Graphical identification of the swelling potential of Bahlui clay according to van der Merwe.

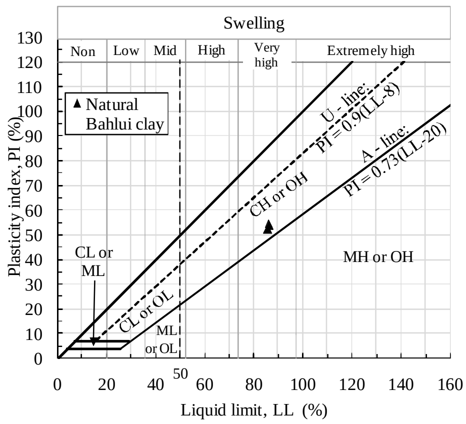

Fig. 5 – Graphical identification of the swelling potential of Bahlui clay according to Casagrande.

3.3. Swelling Pressure and Compressibility Characteristics

Soils that contain a large amount of minerals with a high uncompensated electric charge and, thus, a high reactivity undergo high volume changes when wetted or dried. Adsorbing water molecules in the interlayer spacing, the clay platelets push apart one from another (Al-Rawas & Goosen, 2006) resulting in the development of high swelling pressures when the movement of the particles is restrained. Fig. 6 presents the void ratio variation of three Bahlui clay samples by effective pressure after being inundated in oedometer cells. The vertical swelling pressure has been recorded between 378 and 480 kPa, the differences being mainly because of soil discontinuities of the undisturbed samples.

When inundated, the Bahlui clay exhibited compressibility characteristics calculated for the 200…300 kPa pressure range, (Table 5).

The inundated undisturbed samples developed an oedometer modulus $E_{oed200\ldots300}$ between 4,938 and 5,618 kPa and a coefficient of compressibility $a_{v200\ldots300}$ between 0.00034 and 0.0004 kPa^{-1} (Table 5), indicating (Stanciu & Lungu, 2006) that is a highly compressible soil and it corresponds to plastic consistent clays.

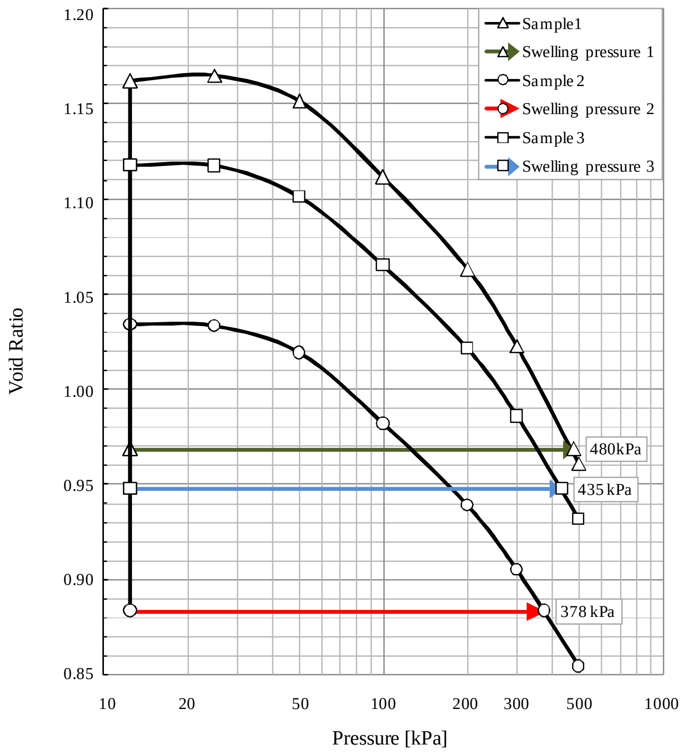

Fig. 6 – Void ratio *vs*. pressure curves and the identified swelling pressure values of the undisturbed samples of Bahlui clay.

Table 5

Compressibility Characteristics for Inundated Bahlui Clay Samples

Compressibility indicators	Sample 1	Sample 2	Sample 3
Oedometer modulus $E_{oed200...300}$, [kPa]	4,938.3	5,618	5,571
Coefficient of compressibility $a_{v200...300}$, [kPa^{-1}]	0.0004	0.00034	0.000354
Swelling pressure p_s, [kPa]	480	378	435

In order to prove the independence of the clay compressibility characteristics of the water content variations, undisturbed samples were tested in the oedometer without being inundated, the void ratio *vs*. pressure being presented in Fig. 7.

Computing the compressibility indicators, there can be pointed out that (as well as in the case of the inundated samples) the Bahlui clay is a highly compressible soil, its oedometer modulus having values between 5,108 and 6,267 kPa and the coefficient of compressibility between 0.00031 and 0.00038 kPa^{-1} (Table 6).

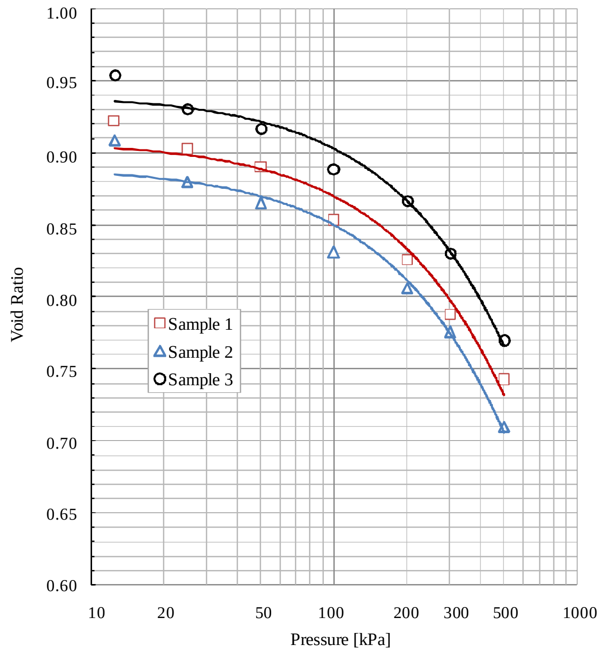

Fig. 7 – Void ratio *vs*. pressure curves of the undisturbed samples of Bahlui clay.

Table 6

Compressibility Characteristics for Bahlui Clay Samples

Compressibility indicator	Sample 1	Sample 2	Sample 3
Oedometer modulus $E_{oed200...300}$, [kPa]	5,449.6	6,267.6	5,108.55
Coefficient of compressibility $a_{v200...300}$, [kPa^{-1}]	0.000364	0.00031	0.00038

4. Conclusions and Final Remarks

The use of active clays in construction works such as roads infrastructures, embankments, and foundation soil for light structures becomes an issue when water content variations are permitted, the volume variations leading to settlements or swellings and, thus, affecting the quality and safety of these construction works.

Following the direct and indirect methods for the characterization of Bahlui clay (which is a typical expansive soil with a high montmorillonite content, its structure governing the active behavior of the clay deposits), it is obvious that it has an active character with a high degradation potential on structures founded on it when subjected to water content variations.

From the tables and figures presented in this paper (as a result of laboratory investigations), one can conclude that the soil is a very plastic one with a high swelling potential. The vertical swelling pressure measured a maximum of 480 kPa and a minimum of 380 kPa in the conventional oedometer cell, depending on the discontinuities in the specimens, if existent.

Some measures can be taken in order to have a proper foundation soil where active clays are present.

1. To limit or even annul the settlements and swellings under water content variations, one can modify the behavior of clay by adding mineral binders, such as lime (proved to be one of the most effective in active clay stabilization), cement, and fly-ash.

2. Another effective solution but more expensive is to replace the active soil with a non-active one (granular processed soils). Besides of the costs, this solution increases the demand of non-renewable materials that affects the environment.

3. Measures implying waterproofing (membranes, draining layers) can be taken regarding the bearing layers in order to prevent infiltrations, as well as to control the influence of vegetation and climatic conditions.

4. When used as sub grade or sub base for transportation networks, measures on the road structure can be taken in order to adapt it to the soil deformations. In practical terms, this solution is not at all economical.

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ASUPRA COMPORTAMENTULUI ACTIV ŞI COMPRESIBIL AL ARGILEI DE BAHLUI

(Rezumat)

Pământurile active/expansive care sunt alcătuite din minerale reactive (care prezintă o rețea instabilă şi deci care tind să-şi modifice volumul prin adsorbția de apă şi schimb cationic) sunt o provocare pentru inginerii geotehnicieni, fiind considerate şi hazarde geologice. Studierea potențialelor variații de volum ale unui pământ este obligatorie (ca urmare a degradărilor ce pot apărea din cauza umflărilor şi tasărilor) înaintea demarării oricărui proiect de construcții, în special a celor unor structuri uşoare, poziționate cât mai aproape de suprafața terenului şi, deci, supuse în mai mare măsură variațiilor de umiditate. Acest studiu investighează comportamentul activ şi compresibil al probelor netulburate de argilă de Bahlui utilizând o metodă directă. Metode indirecte de estimare a potențialului de umflare sunt de asemenea luate în considerare.