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THE EFFECT OF MINERAL BINDERS STABILIZATION ON THE PHYSICAL AND MECHANICAL PROPERTIES OF BAHLUI CLAY

BY

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Abstract. The clay in Iaşi City, also known as Bahlui clay, has a highly active character because of its rich montmorillonite/smectite content. The swell potential increases under water content variations by the montmorillonite content, the dry density and, respectively, by the cationic exchange capacity, causing degradations of structures. To realize a direct foundation on these soils, the designer can chose: either to remove the active clay layer with negative effects on the future construction and to replace it (solution that implies high costs), or to use the local available soil with the condition of improving its properties through chemical stabilization with mineral binders. This paper aims to highlight both the physical and mechanical properties of Bahlui clay as a result of chemical stabilization with cement and a lime-cement mixture, following the evolution of grain size, swelling pressure, plasticity index and unconfined compressive strength.

Key words: active clay; cement stabilization; lime and cement stabilization; plasticity; swelling pressure; compressibility; unconfined compressive strength.

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1. Introduction

Many structures (light buildings, roads and highways, earth dams, slopes, underground constructions) are severely affected by excessive volume changes of active clays spread all over the world. Considering the problems appearing as a consequence of volume changes and, respectively, important settlements and heave, comes the necessity of quality improvement of the soil under this type of structures.

One of the most used improvement methods is the chemical stabilization with mineral binders that influences not only the compaction properties through lower plasticity index, transformed structure and texture, but also the strength of the new material resulted from the specific reactions between the added binder and the active soil. Cement and lime have been used in treating expansive clays for some time now and many tests have been conducted on such type of soils, the authors' ones included. Almost all studies that have been made in this field leaded to the conclusion that lime-stabilization is very effective on the montmorillonitic clays compared to the kaolinitic ones (Bell, 1996) due to their higher cation exchange capacity (CEC) that provides a better reaction between soil and lime. On the other hand, cement stabilization as well consists in the formation of bonds between particles following the reactions that occur when the cement and the water in the soil meet.

The improvements of active soil properties when stabilized with quicklime are due to texture changes that lead to a totally different behaviour when wetted. These changes are attributed by researchers to some basic reactions that occur between soil and lime. First of all, quicklime hydration occurs when a large amount of heat is released and the quicklime is hydrated in the presence of pore water of the soil (Bergado *et al*., 1996; Al-Rawas & Goosen, 2006). Second of all, cation exchange, carbonatation flocculation (short-term reactions) are highlighted. Following the short-term reactions, and a long term one is activated, the pozzolanic reaction (a time dependent one) which gives the improved strength characteristics (Al-Mukhtar *et al*., 2012; Hotineanu *et al*., 2012; Al-Rawas & Goosen, 2006; Castro-Fresno *et al*., 2010; Little *et al*., 2000). Although carbonatation is a specific reaction that occurs when adding lime to an active soil, it does not cause a major strength increase, so it can be neglected because the cementing agent formed as a result of the reaction between lime and the carbon dioxide from the atmosphere (during the mixing) is a weak one. This reaction is also considered to be rather deleterious than beneficial to soil stabilization, inhibiting the most important one that is the pozzolanic reaction (Bergado *et al*., 1996). In the case of cement treatment, two types of chemical reactions – hydration and pozzolanic reaction – occur. The hydration takes place between cement and water, resulting in hydrated products which later will interact with the clay minerals during the pozzolanic reaction (Sasanian, 2011).

The products formed as a result of lime–soil reactions bind clay particles together forming a new material consisting in aggregates. These cementitious compounds are similar to the ones that result from cement–water interaction, calcium aluminate hydrates (CAH) and reticular calcium silicate hydrates (CSH), respectively (Rajasekaran & Narasimha, 1997), where C is the represantation for CaO, A for Al_2O_3, H for H_2O and S for SiO_2 (Bell, 1996). The CAH and CSH compounds are responsible for the long-term strength improvement of the soil behavior (Nalbantoglu & Tuncer, 2001; Al-Rawas & Goosen, 2006).

In previous studies, other researchers (Nalbantoglu & Tuncer, 2001; Basma & Tuncer, 1991; Locat *et al.*, 1996; Al-Rawas & Goosen, 2006) also concluded that grain size distribution is severely modified by the addition of lime by the increased percentage of coarse-grain fraction and decreased clay fraction; the plasticity index and swelling characteristics are also decreasing by lime addition; it is also expected an obvious reduction of the compressibility and an increase of the shear strength.

Regarding soil–water-binder interaction, it is known (Sasanian, 2011) that cement stabilization of smectitic materials is less effective than in the case of coarse or other less reactive clays because of their affinity to calcium ions (whose quantity is smaller than in the case of lime addition) and pH reduction of the aqueous phase, leading to a decrease of calcium silicates and aluminates solubility (leading to an interruption of secondary reactions).

Knowing that highly reactive minerals inhibit the cement–clay interaction, it is recommended either lime stabilization only, either a lime pre-modification before cement treatment . The paper aims to establish in which manner cement stabilization is less effective than lime and cement stabilization, by comparing the values of the physical, mechanical and swelling properties of the natural and modified Bahlui clay. Lime stabilization of Bahlui clay was approached by the authors within the pale of other papers (Hotineanu *et al.*, 2014; Stanciu *et al.*, 2013; Hotineanu, 2014).

2. Materials

The soil used in this experimental program is the clay (AB) found along Bahlui River – Iaşi City, which is a montmorillonitic one with the chemical composition consisting of 51.06%…56.63% SiO_2, 17.20%…21.37% Al_2O_3, 2.20%…4.77% Fe_2O_3, 4.70%…7.80% CaO, 1.03%…2.54% MgO, 0.063%…0.81% Na_2O, 1.54%…2.31% K_2O, 3.68%…6.17% H_2O (Boţi *et al.*, 1993). The quicklime was procured as lumps with 95% CaO. This type of lime, when mixed with the active clay, releases Ca^{2+} ions which coagulate clay particles and increase pH that will allow the pozzolanic reaction to develop in optimum conditions (Castro-Fresno *et al.*, 2010). The Portland cement chosen for the stabilization is a high initial resistance one (CEM II/A-LL 42.5R) and contains 80%...98% cement clinker and 6%...20% limestone. This type of cement was chosen for its reduced heat of hydration that makes possible the better compaction of the mixture and for its reduced frost susceptibility. When lime+cement stabilization solution is chosen, 2.5% lime is added first, then completed with 2.5%, 5% or 7.5% Portland cement.

3. Experimental Procedures

The samples were prepared at maximum dry density (1.56 g/cm^3) and optimum water content (24.8%), using 0%, 5%, 7.5% and 10% binder, reported to the dry mass of clay. After mixing, the material was left 1h at rest (mellowing time) before compaction. The samples were statically compacted at a 1 mm/min. velocity and cured for 7 and 28 days before testing (Bell, 1996). ASTM standards for establishing the grain-size distribution ASTM D421-85 (2007) and the Atterberg limits (ASTM D4318-10e1) were used in order to physically characterize the natural soil and the stabilized one.

For compressibility and swelling tests, cylindrical samples were compacted at maximum dry density and optimum water content. 71.4 mm diameter and 20 mm height molds were used to prepare minimum two samples for each mixture (0%, 5%, 7.5% and 10% binder). The swelling tests were carried out according to ASTM 4546-08, Method A. The coefficient of compressibility and the oedometer modulus were calculated for the 200…300 kPa pressure range.

The unconfined compressive strength was studied using specimens having 40 mm diameter and 80 mm height, statically compacted at 1 mm/min. velocity. Two specimens of every binder-soil mixture were tested at 0.5 mm/min. velocity until failure. ASTM 2166-00 specifies that the diameter should measure a minimum of 30 mm and the height-to-diameter ratio shall be between 2 and 2.5; the samples used in this experiment respect this prerequisite.

4. Results and Discussion

4.1. Cement and Lime–Cement Treatment Effect on the Physical Properties of Bahlui Clay

As mentioned above, through stabilization the clay particles are united into aggregates. The modification of the grain-size distribution allure is presented in Fig. 1.

The Atterberg limits and plasticity index of Bahlui clay (AB) have modified/improved values as shown in Table 1, Figs. 2 and 3. From these values it is obvious that pre-treating the Bahlui clay with lime before adding cement is a more suitable option from the plasticity point of view. The plasticity

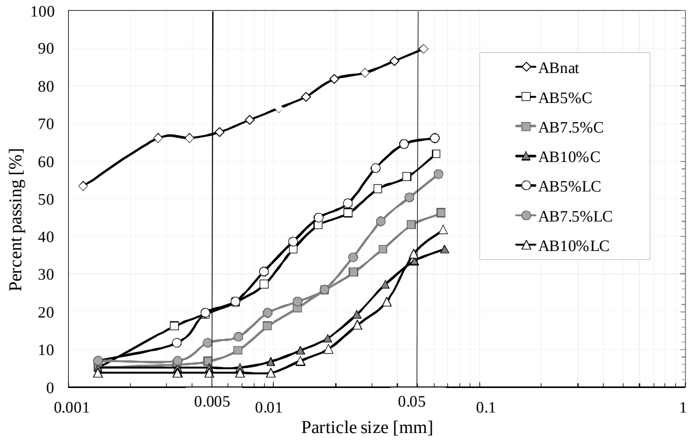

Fig. 1– Particle size distribution of treated and untreated Bahlui clay.

Table 1

Physical Characteristics of Bahlui Clay (AB) Before and after Stabilization with Cement (C) and Lime+Cement (LC)

Material	Coloidal clay content, [%]	Liquid limit, [%]	Plastic limit, [%]	Plasticity index, [%]
Natural Bahlui clay	61.3	69.7	24	45.7
AB 5% C	9.6	61.6	27	34.6
AB 7.5% C	5.4	59.5	29.7	29.8
AB 10% C	5.1	56.3	30.3	26
AB 5% LC	8.9	51.6	33.1	18.5
AB 7.5% LC	6.9	50.1	33.2	16.9
AB 10% LC	3.8	49.1	34.6	14.5

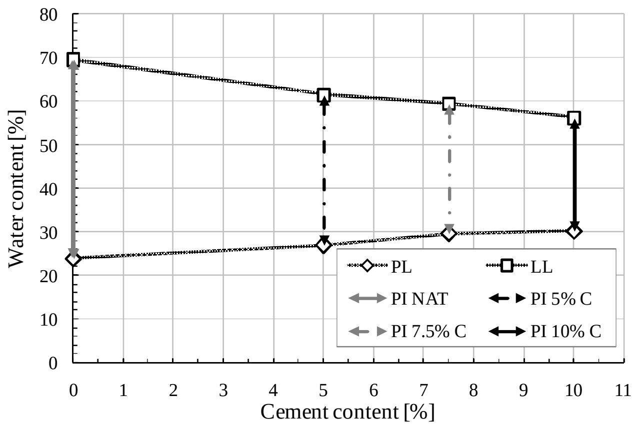

Fig. 2 – Liquid limit, plastic limit and plasticity index variation due to cement stabilization (C).

index decreases almost down to 32% from the initial value in the case of 10% lime and cement treatment, while in the case of cement stabilization the value corresponding to 10% binder is only 58% from the initial value. A continuous decrease can be noticed with the increasing percentage of binder, more pronounced being always in the case of lime+cement stabilized Bahlui clay.

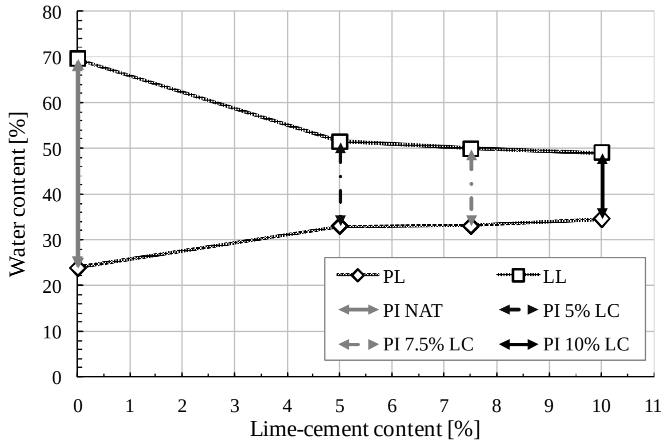

Fig. 3 – Liquid limit, plastic limit and plasticity index variation due to lime and cement stabilization (LC).

As for the soil activity changes, two graphic representations are presented in Figs. 4 and 5. According to van der Merwe – Fig. 4 (whose method is less restrictive compared to the one of Casagrande) the activity of the clayey soil changes (through stabilization) from "very high" to "low", for all types of mixtures.

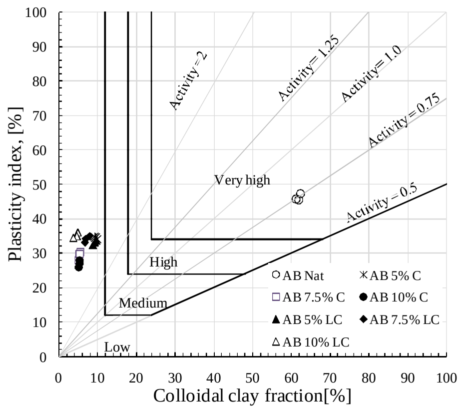

Fig. 4 – Modification of the clay's swelling potential according to van der Merwe.

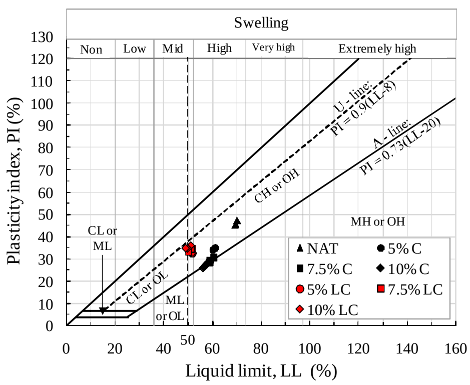

Fig. 5 – Modification of the clay's welling potential according to Casagrande.

On the other hand, if it is to evaluate the modification of the activity of the soil according to Casagrande (Fig. 5), one can see that only the lime and cement mixturesmakes the change to a medium activity zone (from the high one), the cement treated ones remaining in the "high activity" category, because the Atterberg consistency limits only are taken into account. An early conclusion can be drawn with respect to choosing the proper binder for Bahlui clay stabilization and, in this regard, one can say that pre-adding lime improves in a more significant manner the workability properties of the soil.

4.2. Treatment Effect on Swelling Pressure, Compressibility and Strength of Bahlui Clay

As shown in Fig. 6, the swelling pressure the of remolded Bahlui clay is 120 kPa. With the increasing binder content added to the soil, the swelling pressure values decrease down to only 5 kPa when 10% of lime+cement is added and when cured 28 days. Compared to this value, the 10% cement only mixture exhibits a 30 kPa swelling pressure after 28 days of curing. In all the cases the swelling pressure decreases with the increasing binder content and curing time.

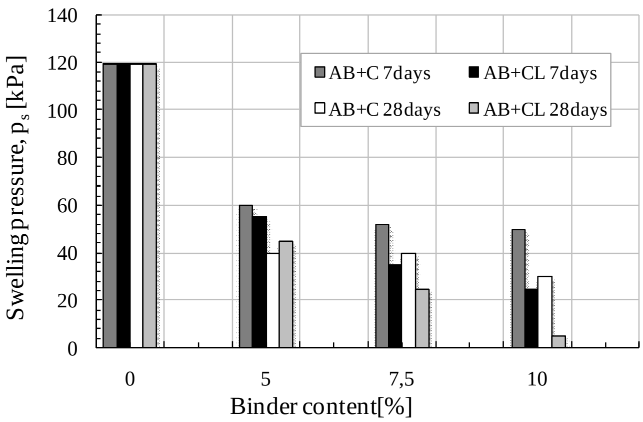

Fig. 6 – Swelling pressure variation in time *vs*. binder content: cement (C) or lime and cement (LC).

When discussed in compressibility terms, the stabilization is as effective in the case of cement only addition as it is when lime+cement is used. The oedometer modulus increases significantly (Fig. 7) when the samples are cured 28 days, its values being almost identical in all the cases. The main peak is when Bahlui clay is stabilized with 5% binder (the value increases up to 7.6 times the initial one), afterwards the increases being insignificant. The same kind of variation is noticed in the case of the coefficient of compressibility as well (Fig. 8), the main peak appearing when 5% binder is added (the value decreased down to 7.3 times the initial one), and the following mixtures exhibiting almost the same values.

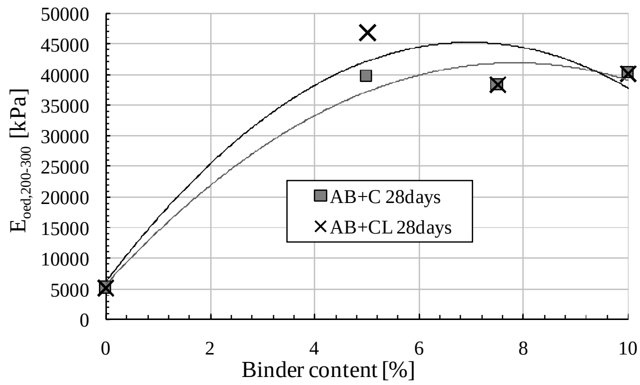

Fig. 7 – Oedometer modulus variation *vs*. binder content: cement (C) or lime and cement (LC).

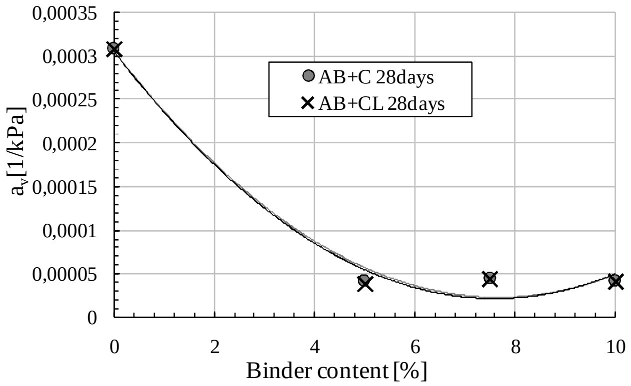

Fig. 8 – Coefficient of compressibility variation *vs*. binder content: cement (C) or cement and lime (LC).

4.2. Treatment Effect on the Unconfined Compressive Strength

One of the most important indices that quantify the effectiveness of soil stabilization is the unconfined compressive strength (UCS), whose variation by binder percentage and curing time is shown in Fig. 9. As expected, the UCS increased with the increasing curing time, but also with the increasing percentage of stabilization agent.

When stabilized with 10% lime+cement, after 28 days curing time, the material exhibits a UCS up to almost 4 times higher than when untreated. The differences between the two types of mixtures, in terms of strength, are not major, although premixing Bahlui clay with lime and then adding cement is a solution that induces higher strengths than in the case of cement only addition.

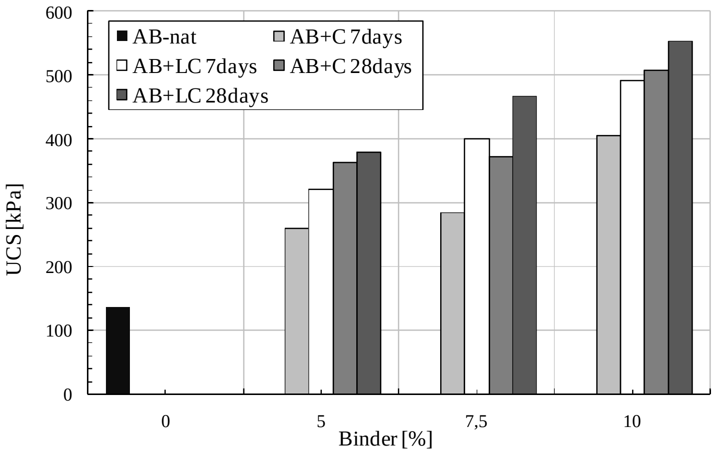

Fig. 9 – UCS variation in time *vs.* binder content: cement (C) or lime+cement (LC).

4. Conclusions

On the basis of the experimental results from this experimental study, the following conclusions can be drawn:

1. Chemical stabilization changes the texture and, implicitly, the grain size distribution of Bahlui clay. With the increasing percentage of binder, the dimension of particle changes, the highest changes being induced by the addition of 10% cement or 10% lime+cement.

2. When 10% binder is added the grain size distribution changes almost in the same manner in both cases. The difference although comes in terms of workability: 10% C mixture has a PI = 26% but the 10% LC mixture develops a PI of only 14.5%.

3. Through chemical stabilization with cement and lime+cement, respectively, the swelling potential of Bahlui clay decreases from very high to low (or medium, depending on the activity chart).

4. The swelling pressure decreases considerably with the increased curing time and binder percentage.

5. The unconfined compressive strength increases significantly through stabilization; the new created material being responsible for this, as well for plasticity and texture changes.

6. The results of this experimental study lead to the general conclusion that lime+cement stabilization is more effective in the case of Bahlui clay than cement only stabilization.

REFERENCES

Al-Mukhtar M., Khattab S., Alcover J.-F., *Microstructure and Geotechnical Properties of Lime-treated Expansive Clayey Soil.* Engng. Geol., *139-140*, 17-27 (2012).

Al-Rawas A., Goosen M., *Expansive Soils. Recent Advances in Characterization and Treatment*. Taylor and Francis Group, London, UK, 2006.

Basma A., Tuncer E., *Effect of Lime on Volume Change and Compressibility of Expansive Clays*. Transp. Res. Rec., **1295**, 52-61 (1991).

Bell F.G., *Lime Stabilization of Clay Minerals and Soils.* Engng. Geol., *42*, 223-237 (1996).

Bergado D.T, Anderson L.R., Miura N., Balasubramaniam A.S., *Soft Ground Improvement in Lowland and other Environments.* Amer. Soc. of Civil Eng., New-York, 1996.

Boți N., Stanciu A., Lungu I., *Estimate of the Swelling Pressure*. Proc. of the Constr. 2000 Internat. Symp., Cluj-Napoca, Romania, 1993, 561-570.

Castro-Fresno D., Movilla-Quesada D., Vega-Zamanillo A., Calzada-Perez M., *Lime Stabilization of Bentonite Sludge from Tunnel Boring.* Appl. Clay Sci., **51**, 250-257 (2010).

Hotineanu A., Lungu I., Stanciu A., *On the Behavior of Natural Active Clays or Stabilized with Binders to Freeze–Thaw Action.* Proc. of the First Internat. Conf. for PhD Students in Civil Engng., Cluj-Napoca, Romania, 2012, 340-348.

Hotineanu A., Stanciu A., Lungu I., *The Effect of Freeze–Thaw Cycles on the Lime-Stabilized Active Clays*. DECGE 2014: XV Danube-Europ. Conf. on Geotechn. Engng., Vienna, Austria, Sept. 9-11, 2014, in-press.

Hotineanu A., *The Effect of Freeze–Thaw Action on the Mechanical Properties of the Active Bahlui Clay Stabilized with Lime and/or Cement.* 23rd Europ. Young Geotechn. Eng. Conf. (EYGEC 2014), Barcelona, Spain, Sept. 2-5, 2014, in-press.

Little D.N., Males E.H., Prusinski J.R., Stewart B., *Cementitious Stabilization.* Transportation in the New Millennium: Perspectives from TRB Standing Committees, Nat. Res. Council, Washington D.C., 2000.

Locat J., Tremblay H., Leroueil S., *Mechanical and Hydraulic Behavior of a Soft Inorganic Clay Treated with Lime*. Canad. Geotechn. J., **33**, 654-669 (1996).

Nalbantoglu Z., Tuncer E.R., *Compressibility and Hydraulic Conductivity of a Chemically Treated Expansive Clay*. Canad. Geotechn. J., **38**, 154-160 (2001).

Rajasekaran G., Narasimha Rao S., *The Microstructure of Lime-Stabilized Marine Clay.* Ocean Engng., **24**, *9*, 867-878 (1997).

Sasanian S., *The Behavior of Cement Stabilized Clay at High Water Contents*. Ph. D. Diss., Univ. of Western Ontario, Canada, 2011.

Stanciu A., Hotineanu A., Lungu I., *Physico-Chemical Phenomena in Soil Stabilization for Roads or Highways Infrastructures*. Lucr. Conf. Internaț. a Acad. Oamenilor de Ştiință: Eco-Economia şi Dezvoltarea Durabilă, Braşov, România, 20-21 sept. 2013, 119-131.

EFECTUL STABILIZĂRII CU LIANȚI MINERALI ASUPRA PROPRIETĂȚILOR FIZICE ŞI MECANICE ALE ARGILEI DE BAHLUI

(Rezumat)

Argila din oraşul Iaşi, cunoscută, de asemenea, sub denumirea de argilă de Bahlui, are un caracter puternic activ ca urmare a conținutului bogat de smectite/montmorillonit. Potențialul de umflare creşte odată cu conținutul de montmorillonit, densitatea în stare uscată şi, respectiv, cu valoarea capacității de schimb cationic, la variații de umiditate, cauzând degradări structurilor fundate pe acesta. Pentru fundarea directă pe acest tip de pământuri proiectantul trebuie să aleagă fie îndepărtarea stratului de argilă activă cu efecte negative asupra viitoarelor construcții şi înlocuirea cu un pământ cu proprietăți fizice şi mecanice superioare (soluție foarte costisitoare), fie să utilizeze materialele locale disponibile cu condiția îmbunătățirii acestora prin stabilizare chimică cu lianți minerali. Scopul acestei lucrări este acela de a evidenția proprietățile fizice şi mecanice ale argilei de Bahlui ca urmare a stabilizării chimice a acesteia cu ciment şi un amestec de var şi ciment, urmărind variația distribuției granulometrice, a presiunii de umflare, a indicelui de plasticitate şi a rezistenței la compresiune monoaxială.