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BEHAVIOR OF EXPANSIVE SOILS TREATED WITH ECO-CEMENT

BY

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Abstract. The swelling behavior of expansive soils often causes unfavourable effects, such as differential settlement and ground heaving. The understanding of the characteristics of soil mixture leads to increasing the confidence level before applying such materials in the field. This study investigates the influence of eco-cement addition on the behavior of expansive soil from Iaşi. A wide range of eco-cement content varying from 0 to 10% of the unit weight of soil was used. For the testing program, the water content used for the soil–eco-cement mix was selected as the optimum water content determined from the Proctor tests. All these specimens were tested for the shear stresses in triaxial apparatus to determine the effect of eco-cement on UU (unconsolidated-undrained) shear strength for different values of the cell pressure. The outcomes of this study can provide important conclusions concerning the mechanical properties of eco-cement treated soil.

Key words: expansive soils; undrained shear strength; eco-cement content; soil stabilization; optimum water content.

1. Introduction

In the world there are more than 40 countries where expansive soil exists, spreads on six continents. The problem of expansive clay is a worldwide issue. Expansive soils are known to cause damage mostly to light construction

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structures, such as residential dwellings and road pavements. There are two conditions that once they met on site, expansive soils on that location become a problem: expansive potential existing in that soil and the soil moisture condition should vary. Volume changes in expansive soils can be reduced or eliminated by the addition of various amounts of lime or Portland cement, providing the lime or cement is thoroughly mixed with the expansive soil end properly compacted. Other chemical additives might be developed to serve the same purpose. Consequently, if not treated, expansive soils cause damage to structures founded on them. Therefore, research into the treatment theory and techniques for expansive soils geotechnical disasters has the significant economic significance.

This study was carried out to expand the knowledge on the behavior and treatment of the Bahlui clay as the expansive soil from Iaşi.

2. Treatment Methods of Expansive Soil

Soils can be stabilized by the addition of a small percentage of cement or lime. Such stabilization processes enhance many of the engineering properties of the treated soils and produce an improved construction material.

The methods of expansive soil improvement can be divided into two types: one is represented by the physical property improvement methods, for example by adding non-expansive coarse sand, and the other represents chemical property improvement methods, for example: adding lime, cement, gypsum, sodium silicate and so on, in order to reduce the swelling potential of the soil.

Using chemical methods to improve expansive soil will lead to a complex physical-chemical reaction and change hydrophility of the expansive soil.

In the cement based stabilization the primary reactions with the water from the soil lead to the formation of a cementations material. Cement based stabilization (surface or deep) has been used for various applications including foundations (to reduce the settlement of existing structures), retaining structures, liquefaction mitigation (to cut off water infiltration into excavations and sewer lines), and water control (foundations curtains that reduce water loss under structures) (Al-Rawas & Goosen, 2006).

The growing interest in utilizing waste material in civil engineering applications has opened the possibility of stabilized soil structure realization with new cementation material based on calcium sulphates resulted from waste. The use of Portland cement as a stabilizing binder is uneconomic and non-ecologic, because this cement is a big consumer of non-renewable natural resources and responsible for 7% of the effect of global warming. Replacement of Portland cement from the soil stabilization area represents an area of ongoing research. The eco-cement stabilization with very good results on the foundation soil behavior develops a large range of applications involving the gradual replacement of the Portland cement with eco-cements for the expansive clay stabilization.

3. Experimental Program

3.1. Selcted Soil and its Classification

Tests have been conducted on expansive soil, obtained from different parts of a new residential area, located in Iaşi, near the Palace of Culture (Fig. 1), mixed with different percentages of eco-cement, to study the effects of mixtures on free swelling and the variation of the shear stress immediately after mixing in a undrained triaxial tests. Also the effect of molding water content and variation of densities are studied.

Laboratory tests have been performed on soil samples and various properties of these soils such as liquid limit, plastic limit, plasticity index, shrinkage limit, grain size distribution, unconsolidated undrained shear strength, and free swell index were obtained and discussed.

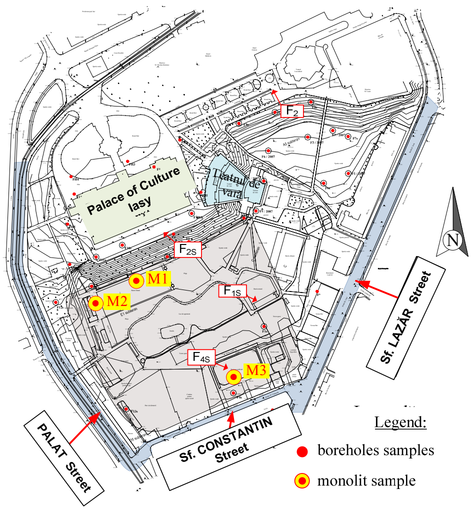

Fig. 1 – Studied area.

Table 1 presents the values of relevant physical properties of the investigated soil.

According to the data given in Table 1 the soil is classified as very high plasticity clay in accordance to Romanian classification (STAS 1243-88). In general, the larger the plasticity index implies greater engineering problems associated with the use of the soil as an engineering material, such as road subgrade, foundation support for residential buildings, etc.

Many other soils properties have been correlated with the plasticity index including the swelling-shrinkage potential. Researchers Holtz & Gibbs

(1956), based on the plasticity values, classifiy the potential swell as presented in Table 2.

Table 1
Properties of Different Soil Samples from Studied Area

Properties	Locations of swelling soil under case study				
	F_{1S}	F_{4S}	M_1	M_2	M_3
Liquid limit, [%]	71.2	83.7	90	65.6	75.9
Plasticity limit, [%]	20.3	24.7	33.35	20.9	22.7
Plastic index	50.9	59	56.6	44.7	53.1
Clay, [%]	71	78	77.5	74.5	86.4
Silt, [%]	29	15	21.5	25.5	10.9
Sand, [%]	0	7	1	0	2.7

Table 2
Classification of the Potential Swell Based on Plasticity (Holtz and Gibbs, 1956)

Classification of potential swell	Liquid limit %	Plasticity index %	Shrinkage limit %
Low	20…35	< 18	> 15
Medium	25…50	15…28	10…15
Hihg	50…70	25…41	7…12
Very high	>70	>35	< 11

Based on the classification from the Table 2, the investigated soil in natural state (untreated with eco-cement) has a swell potential varying from high to very high.

3.2. Indirect Measurement of the Swell Potential in Eco-Cement Treatment

The category of eco-cements, called “green cement”, makes part from the super-sulphate cement.

The manufacturing process takes place at low temperatures and does not involve CO_2 emissions, only water vapours. It is fully recyclable after its storage in the warehouse, without generating waste.

The linear shrinkage of clay soils has been proved to be a better indicator of the swell potential than the plasticity index (McKeen, 1976). The literature indicates that this test may be superior to the plasticity index because it involves a volume change mechanism.

Table 3
The Variation of Soil Shrinkage with the Eco-Cement Addition

Expansive clay	Linear shrinkage %	Volumetric shrinkage %
Natural structure	19.70	131.16
Stabilized with 5% eco-cement	18	94.18
Stabilized with 10% eco-cement	16.19	79.42

Altmeyer (1955) classified the degree of expansion based on linear shrinkage and shrinkage limit. If we compare the obtained results for the investigated soil (Table 3) with Altmeyer classification, for linear shrinkages > 8, it is expected a probable swell of < 1.5% with a critical degree of expansion.

Many criteria are available to identify and characterize expansive soils, such as liquid limit, plasticity index, shrinkage limit, and free swell index (Table 4).

Table 4
Soil Expansivity Predicted by other Measurements

Degree of expansion	Liquid limit, [%]		Plasticity index, [%]			Shrinkage limit %	Free swell index %
	Chen	IS 1498	Holtz and Gibbs	Chen	IS 1498		
Low	< 30	20…35	< 20	0…15	< 12	> 13	< 50
Medium	30…40	35…50	12…34	10…35	12…23	8…18	50…100
High	40…60	50…70	23…45	20…55	23…32	6…12	100…200
Very high	> 60	70…90	> 32	> 35	> 32	<10	> 200

The free swell is reported as the increase in the volume of the soil expressed as a percentage of the initial volume. The Bureau of Indian Standards (1970) proposes many criteria to identify and characterize expansive soil. One of these criteria is based on the soil free swell. Based on this classification the investigated clay (Table 5) has a high degree of expansion (free swell – 100...200%) for its natural structure and for 5% eco-cement mixture, and it changes to medium degree of expansion for 10% eco-cement (Table 5).

Table 5
Free Swell for the Investigated Soil at Different Eco-Cement Content Varying from 0 to 10% of the Dry Unit Weight of the Soil

Laboratory testing	Natural structure, [%]	Stabilized with	
		5% eco-cement, [%]	10% eco-cement, [%]
Free well	113.33	101.28	92.41

Using the Cassagrande's chart (Chleborad *et al.*, 2005) (Fig. 2), the investigated natural clay plots in the zone typical for montmorillonite, above the A-line. Consequently, the behavior of the investigated expansive clay will be similar with the behavior of montmorillonite. When soil is mixed with 5 to 10% eco-cement, the values of the liquid limit and plasticity index becoming smaller by the increase of eco-cement content. The new plot position of the soil if founded in the zone for illites and kaolinate (Fig. 2).

Another way of identifying the expansive soil is the use of activity method quoted by M. Cartel and S.P. Bentley (1991). The proposed classification chart is shown in Fig. 3.

By mixing the expansive clay with eco-cement it can be noticed that the swell potential decreases from very high (natural structure), to high, in the case of mixing with 5% eco-cement, and reaches a low potential for 10% eco-cement reported to the dry mass of clay (Fig.3).

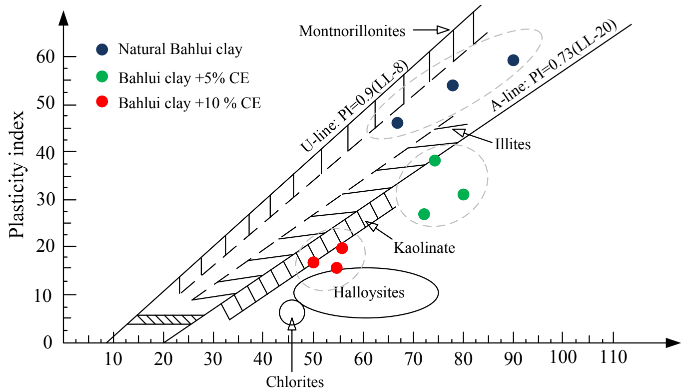

Fig. 2 – Plot of clay minerals on the Cassagrande's chart.

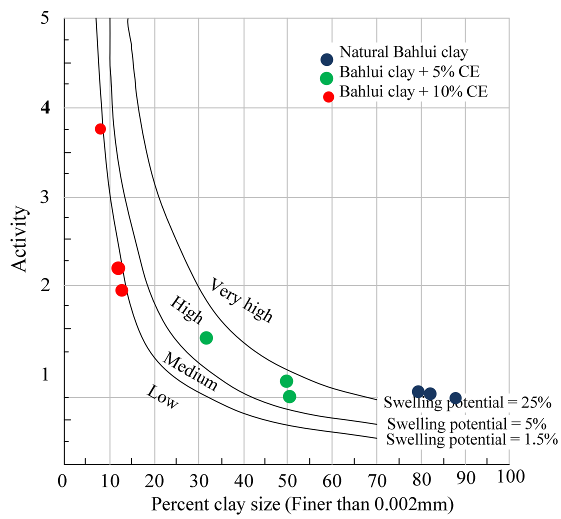

Fig. 3 – Classification chart for swelling potential proposed by Cartel.

4. Soil Mix Preparation for Undrained Triaxial Compression Test

4.1. Initial Testing States of Water Content and Dry Density

Because the swelling potential of an expansive soil depends on the soil's initial condition, it was necessary to test the soil samples at different water contents. In this study, seven different water content at the same dry density were utilized, in order to investigate the effect of water content on the unconsolidated undrained (UU) triaxial compression test of the utilized soil in its natural (untreated) and treated with 5% to 10% eco-cement. The undrained triaxial tests were performed on specimens compacted at different dry densities (Fig. 4) established in a Standard Proctor test (Germaine & Germaine, 2009).

For both types of tests, an amount of air dried soil required was weighed and mixed with the specified cement content (0%; 5%; 10% by the dry mass of the soil). The water needed for any particular water content was also weighted.

All the specimens were tested immediately after preparation except the case of linear shrinkage and free swell.

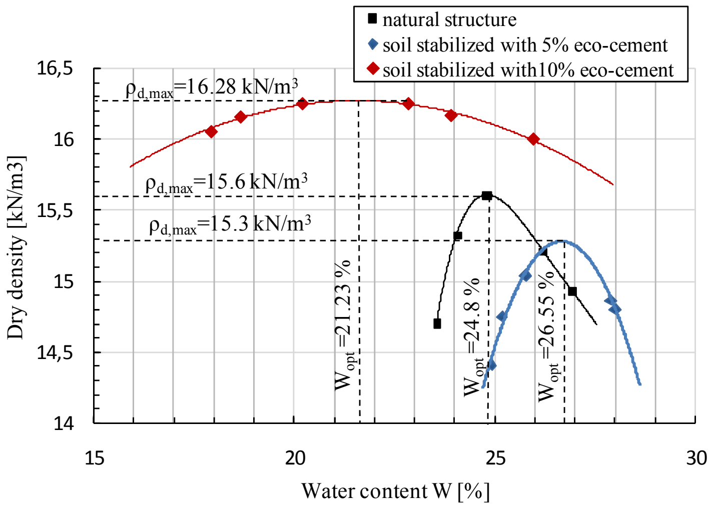

Fig. 4 – Dry density *vs.* water content relationship (Standard Proctor compaction tests) for the investigated clay, showing the correlated states of water content and dry density considered later in this study for the triaxial tests.

4.2. Undrained Shear Strength Obtained from UU Triaxial Test

Shear strength is defined herein at the shear stress peak value of the stress–strain curve obtained from UU tests that were performed at cell pressures of 100, 150, 200 kPa. The specimen was first sealed and loaded to the desired cell pressure, and then the axial load was increased at a rate of 0.5 mm/min until the failure of the specimen. Axial deformation and axial load were recorded during this shearing stage of the test.

In what follows we refer to the influence of eco-cement in the stabilization process immediately after the mixture with the expansive clay. The undrained triaxial test is performed on all the specimens resulted from Standard Proctor tests, therefore variation of shear stress with water content can be represented.

An important influence of eco-cement on the soil cohesion compared with cohesion of the soil of natural structure is observed at 10% eco-cement at which the cohesion has a significant increase.

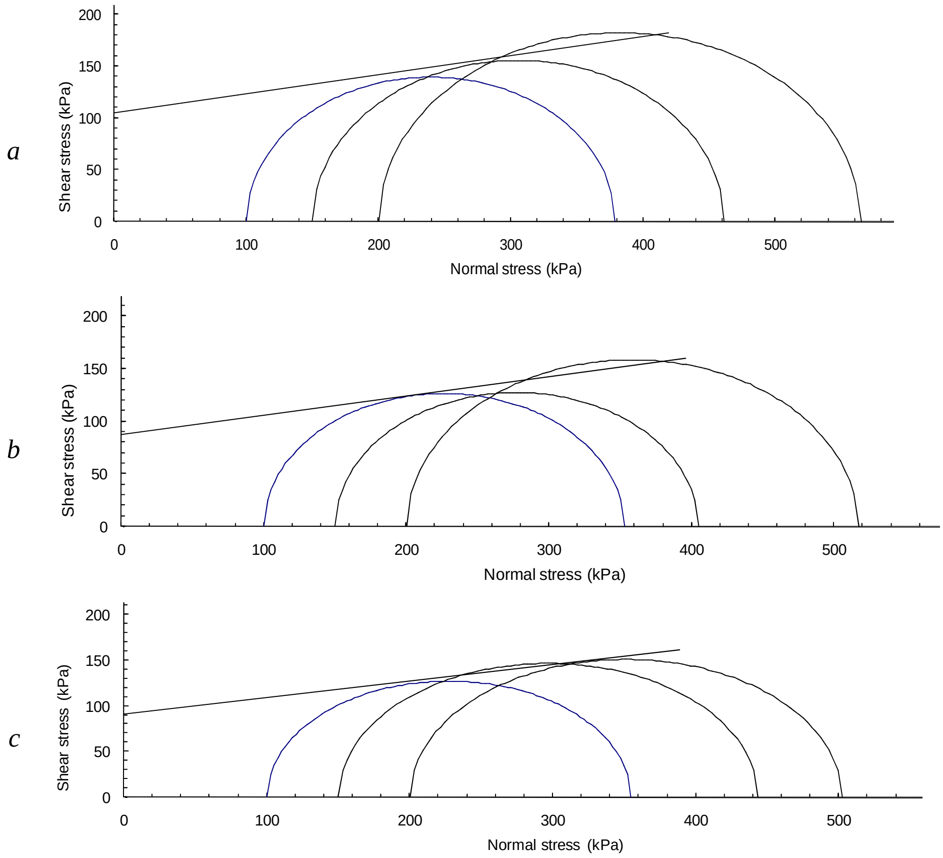

Fig. 5 – Failure envelope from the Unconsolidated Undrained triaxial test on compacted expansive soils mixed with different proportion of eco-cement: *a* – 0% eco-cement and 26.91% water content; *b* – 5% eco-cement and 27.88% water content; *c* – 10% eco-cement and 25.94% water content.

For cohesive soils, the soils absorb much water during soaking process and then result in increasing of void ratio. The void between soil particles is filled with water and reduces the particle bonds. Consequently, the soil is in a looser condition and results in lower values of shear parameters. These parameters can be shown in Table 6.

Table 6
Variation of the Shear Strength Parameter with the Water Content and Eco-Cement

Soil structure	Sample water content, [%]	Optimum water content, [%]	Cohesion kPa	Internal friction angle, [˚]
Natural structure	23.55	24.80	69	4.6
	24.05		135	10.4
	24.81		98	10.4
	26.18		105	10.4
	26.915		86	10.4
Expansive soil with 5% eco-cement	24.89	26.55	124	10.40
	25.18		92.64	10.39
	25.76		82.76	8.05
	27.88		70.89	10.37
	28		67.99	10.39
Expansive soil with 10% eco-cement	17.92	21.23	247.35	2.29
	18.65		148.25	10.37
	20.2		133.28	10.39
	22.83		142.99	9.20
	23.9		60.27	10.37
	25.94		74.08	10.34

In Fig. 5 the failure envelope is presented for the UU triaxial tests on compacted expansive soils mixed with eco-cement in proportion from 0 to 10%. Each sample is compacted at the same energy in a Standard Proctor test. The water content of the samples presented in Fig. 5 corresponds to the water content higher than the optimum water content. The values of the shear strength parameters decrease with the increase of water content.

5. Conclusions

The performed investigation was carried out to assess the effect of eco-cement on the stabilizing process of expansive soils, as clay deposits from the Bahlui river sediment, in Iaşi. A range of eco-cement content varying from 0 to 10% by the dry mass of soil was used for this study.

The effect of eco-cement on the undrained shear strength were tested on mixed samples immediately after their preparation.

The values of the undrained shear strength generally does not display a significant increase with the increase of eco-cement content, in the case of samples tested immediately after the specimens were prepared. The reaction between the eco-cement end expansive soils is slow. If the eco-cement is mixed with Portland cement in small quantities the instant increase of strength is significant, but this research not represents the object of this paper. The only relevant effect of eco-cement on shear parameters is the increase of the cohesion for an amount of 10% eco-cement.

The variations of the free swell percentage of the expansive soil mixed with eco-cement consist in a reduction from 113% to 101% and 92% of the free swell for natural soils and stabilized soil with 5 to 10% by the dry mass of the expansive soil.

The reduction of the free swell for expansive soil of respectively eco-cement mixture with 10% leads to a predicted degree of expansion from high to medium. This can be associated with the reduction of the expansive clay colloidal fraction (< 2 μ), therefore leading to a significant modification of soil physical properties.

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COMPORTAMENTUL PĂMÂNTURILOR EXPANSIVE ÎMBUNĂTĂȚITE CU ECO-CIMENT

(Rezumat)

Comportamentul pământurilor expansive produce adeseori probleme structurilor fundate pe acestea, cum ar fi tasări diferenţiate şi umflări ale terenului. Înţelegerea proprietăţilor caracteristice ale unui amestec de pământ conduce la creşterea nivelului de încredere înainte de a utiliza acest nou material în exploatare. Studiul efectuat investighează influenţa folosirii cimenturilor ecologice în procesul de îmbunătăţire a pământurilor expansive din oraşul Iaşi. În acest scop s-a folosit ciment ecologic în proporţie de 0 până la 10% din masa uscată a argilei expansive. Pentru programul experimental cantitatea de apă folosită în amestecul de argilă–ciment ecologic a fost egală cu umidităţile necesare determinării valorii umidităţii optime de compactare determinată prin încercarea Proctor. Toate probele au fost încercate pentru determinarea rezistenţei la forfecare pentru a determina influenţa cimentului ecologic asupra rezistenţei la forfecare în condiţii drenate la valori diferite ale presiunii apei din celulă.

Rezultatele acestui studiu pot oferi concluzii importante asupra proprietăţilor mecanice ale pământurilor îmbunătăţite cu eco-ciment, încercate imediat după realizarea amestecului.