Effects of Eco-cement (GGBS) on the Expansive Soil Strength

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***Abstract*-The use of eco-cement (GGBS) is well established in many cement applications. The use of eco-cement in expansive soil stabilization is a new process in the geotechnical field. This paper reports efforts to extend the use of GGBS to expansive soil stabilization by determining the beneficial effect it has on the reduction of expansion and improvement of mechanical properties. The paper describes the results of laboratory tests on expansive soil treated with 10% eco-cement (GGBS) and Portland cement. The tests determined the strength development of compacted cylinders at different curing periods. The results illustrated that 50% replacement of Portland cement with eco-cement improved the substantially their strength development.**

Keywords- Eco-Cement; Portland Cement; Expansive Soil; Stabilization

I. INTRODUCTION

The countries suffering from construction damage due to expansive soils include: Argentina, Cuba, Greece, Mexico, Romania, Turkey, Australia, Cyprus, South Africa, USA, Burma, Ethiopia, Israel, Norway, Spain, Venezuela, Canada, Germany, Iran, Oman, Sweden, China, Ghana, Rhodesia and Japan [1]. Expansive soils can be found almost anywhere in the world (Fig. 1) [1, 2, 3, 4].

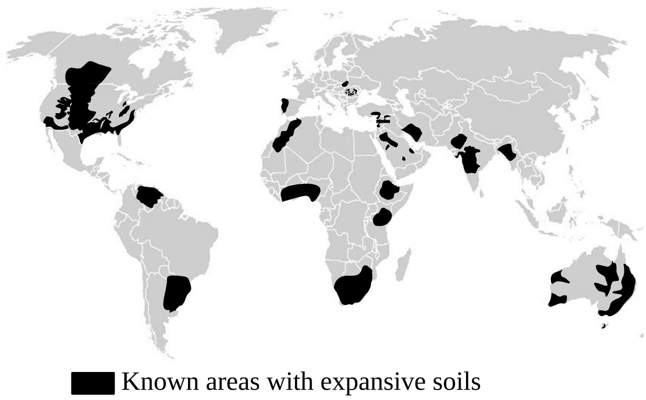

Fig. 1 World distribution of expansive swelling soils

Expansive soils contain a relatively large amount of clay mineral montmorillonite. They are generally found as residual soils from basic igneous rock and montmorillonitic sedimentary rocks or as transported materials derived from the same parent materials.

Several methods can be used to minimize heave of an expansive soil so that difficulties of construction could be overcome. The application of these methods will keep engineering structures, such as buildings, highways, dam embankments and shallow foundation, intact over a long period of time [5].

In the past, soft soils with poor engineering properties such as high plasticity, low bearing capacity, large settlement, etc. were improved with classical stabilizers such as Portland cement or lime. Nowadays, there is a mandatory responsibility in civil engineering that created a new trend in developing and using new materials with low impact on the environment. Reducing volume variations requires mostly a chemical stabilization as improvement method for the expansive soils, such as soil mix with hydraulic binders. These added materials modify the nature and magnitude of the long-term bonding forces between soil particles [6].

The main use of GGBS is in concrete and most ready mixed concrete plants have a silo of GGBS, which they use to replace between 40 and 70% of Portland cement.

On its own, GGBS has slow cementitious properties, mixed with Portland cement provides the alkalinity to activate and accelerate these properties.

The potential of using industrial by-product for soil stabilization, and their use in combination with cement and lime, have been used in soil stabilization, but limited research has been carried out in order to investigate the suitability of using GGBS eco-cement in soil stabilization.

The economic and environmental advantages of stabilisation finally appear to be recognised in the world, where traditionally, low strength or unsuitable materials were removed from sites and imported fill was used.

Soil stabilisation is widely used in road pavement and foundation construction [7]. Soil modification and stabilisation involves the addition of lime or cement to a soil to improve its strength and render it acceptable as an engineering fill.

This study investigated the capability of eco-cement to replace traditional Portland cement used as a stabilizing agent in soils, in this particular situation to control the strength and compressibility of one expansive/active soil [8].

The research focused on the stabilization solution of a soil named the Bahlui clay that is present in the city of Iasi, situated in North-East of Romania with GGBS eco-cement and Portland cement in proportion of 10%. Many geotechnical problems in constructions with the expansive Bahlui clay were triggered by the possibility of heavy soil expansion and shrinkage with wetting and drying cycles [9].

This study investigated the capability of GGBS as an additive in controlling the resistance and compressibility of Bahlui clay.

II. MATERIALS AND EXPERIMENTAL PROCEDURE

A. Expansive Soil

To accomplish the objectives of this work, expansive soil from Iasi-Romania, which is classified as CH according to the Unified Soil Classification System (USCS), was taken from Bahlui river bed. The engineering properties of the clay are shown in Table 1.

TABLE 1 PHYSICAL PROPERTIES OF THE BAHLUI EXPANSIVE CLAY

Property	**Bahlui clay**	**Standard method**
UCS	CH	ASTM D 2487
Colloidal clay content, (%)	89	ASTM D 422-1963
Liquid limit, (%)	86.03	ASTM D 4318-84
Plastic limit, (%)	28.2	
Plasticity index, (%)	57.83	

According to IS 1498, STAS 1913/12-88, USCS Classification, based on the index proprieties from Table 1, the investigated clay displays a very high degree of expansion, leading to serious problems in geotechnical design.

The grain size distribution of the soil is shown in Fig. 2, for the three samples, S1, S2, and S3 [10].

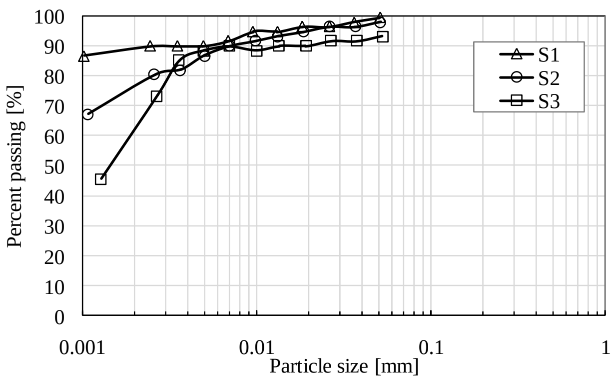

Fig. 2 Grain size distribution of the Bahlui clay

Colloidal clay content (<0.002mm) was assumed to be one of the factors that influence the shrink-swell potential of a soil.

The degree of expansion of a clay can be identified indirectly using the physical properties. The most used physical properties for this purpose are liquid limit (LL) and plasticity index (PI). Based on these parameters Chen and Holtz classified expansions into degrees from low to very high (Table 2) [10, 11, 12].

TABLE 2 SOIL EXPANSIVITY PREDICTED BY OTHER MEASUREMENTS

Degree of expansion	Liquid limit (%)		Plasticity index (%)		
	Chen	IS 1498	Holtz	Chen	IS 1498
Low	< 30	20÷35	< 20	0 ÷ 15	< 12
Medium	30÷40	35÷50	12 ÷ 34	10 ÷ 35	12 ÷ 23
High	40÷60	50÷70	23 ÷ 45	20 ÷ 55	23 ÷ 32
Very high	> 60	70÷90	> 32	> 35	> 32

Based on the properties of the Bahlui clay presented in Table 1, the degree of expansion of the clay, according to the classification presented in Table 2, is very high (LL > 60%; PI > 32).

B. GGBS Eco-cement

The GGBS eco-cement used in this research was made from a by-product of the production of iron in a blast furnace where iron ore, limestone and coke are heated to about 1500 ℃. The eco-cement comprises mainly of CaO, SiO_2, Al_2O_3, MgO, and contains less than 1% crystalline silica [5, 9, 13].

C. Portland Cement

The Portland cement (PC) was purchased in open market, labelled CEM II/B-M 32, 5N. The manufacture of ordinary Portland cement represents one of the largest industrial sources of CO_2 and NO emission [13]. The use of filters in the industrial process of PC reduces pollutants by maximum of 20%, while the concrete consumption for civil engineering works worldwide increased to 3.5 billion tons in 2012, with an estimated yearly increase rate of 4.7% [13].

The chemical constituents and emissions for Portland cement and eco-cement are given in Table 3.

The chemical compositions of these two types of cements are similar, the difference is in the proportion of each component. The reaction of GGBS eco-cement with water is slower compared with that of Portland cement. To reduce this time, GGBS needs to be activated by alkalis (usually $Ca(OH)_2$) released from hydration of the Portland cement [14, 15].

Over the years, there has been an increased interest in the activation of GGBS eco-cement by alkalis other than those from Portland cement, NaOH, Na_2CO_3 or Na_4SiO_4 [14, 16]. This paper presents the results of systematic investigation on the effects of the addition of the eco-cement and Portland cement in the ratio of 1:1 to expansive Bahlui clay from Iasi on the clay's plasticity limit, grain size distribution and the influence of cured time on samples stabilized with 10 % cement (1:1 ratio).

TABLE 3 CHEMICAL COMPOSITIONS AND PHYSICAL PROPERTIES OF ECO-CEMENT (GGBS) AND PORTLAND CEMENT

	Chemical constituent [%]				Ref.
	CaO	SiO_2	Al_2O_3	MgO	
Eco-cement (GGBS)	40	35	10	8	[17,18]
Portland cement	63	20	6	2	[18]
	Emissions [kg]				
	CO_2	NO_X	SO_2	CO	
Eco-cement (GGBS)	40	35	10	8	[17,18]
Portland cement	63	20	6	2	[18]

The experimental program is shown in Table 4.

TABLE 4 EXPERIMENTAL PROGRAM

Name of the additive and dosage (%)	Parameters			
	Physical		Mechanical	
	Grain size	Atterberg's limits	Compressibility	UCS
Without additive	yes	yes	yes	yes
1.25% GGBS + 1.25% OPC*	yes	yes	-	-
2.5% GGBS + 2.5% OPC*	yes	yes	-	-
3.75% GGBS + 3.75% OPC*	yes	yes	-	-
5% GGBS + 5% OPC*	yes	yes	Curing period (days):	
			1, 7, 14	1, 7, 14, 24, 30
(*) OPC – Ordinary Portland Cement				

III. TEST RESULTS AND DISCUSSION

For physical soil proprieties like grain size distribution, Atterberg limit, linear contraction, the soil was stabilized with cement content vary from 0%, 2.5%, 5%, 7.5% and 10% of the dry soil mass, in order to find the optimum cement content (GGBS and OPC), which will be further used in soil stabilization to investigate the mechanical properties of soil (UCS and compressibility) at different curing periods.

Fig. 3 shows the variation of colloidal clay content, resulted from grain size distribution analysis, with the increase of cement content (GGBS and Portland cement in ratio of 1:1).

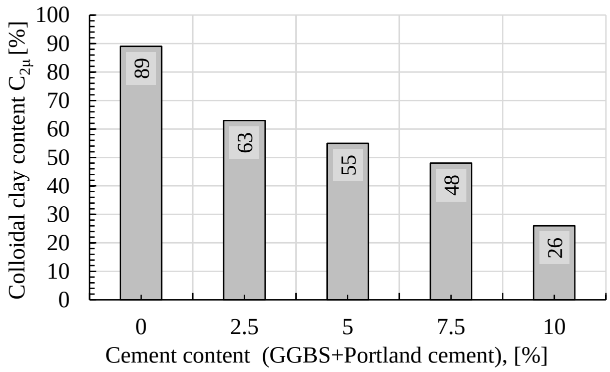

Fig. 3 Grain size distribution of the Bahlui clay

The colloidal clay content started to decrease with the increase of cement content from 89% in natural state to 26% for 10% cement (5% GGBS eco-cement plus 5% Portland cement).

The influence of the amount of cement used in expansive soil stabilization on the Atterberg limits, which are a basic measure of the nature of fine-grained soil, [19, 20], is given in Fig. 4. The chemical reaction between the clay particles and cement reduced the liquid limit (LL) and plasticity index (PI) (Fig. 4).

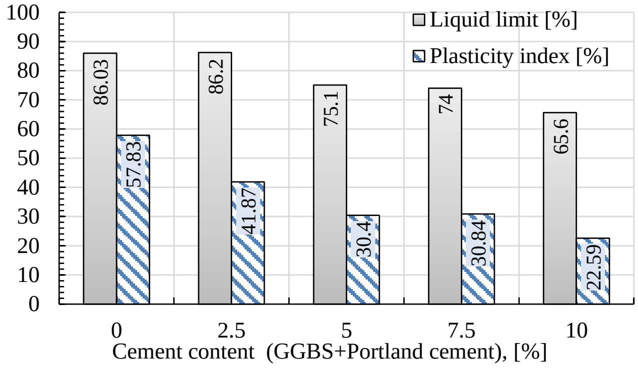

Fig. 4 Variation of Atterberg limit with the cement content

The unconfined compression test is one of the widely used laboratory tests in soil stabilization process. Unconfined compression strength is often used as an index to quantify the improvement of soils due to treatment [18].

Unconfined compressive strength tests on compacted specimens were conducted according to ASTM D2166 and ASTM D698 [1, 21, 22]. The tests were performed on compacted specimen with natural structure and specimen with 10% cement (of the dry soil mass). These tests were performed the stress-strain characteristics of natural and cemented treated clay.

The experiment was conducted with cement content of 10%, out of which 5% was GGBS eco-cement and 5% was Portland cement, in an unconfined compressive tests for curing periods of 1, 7,14, 24 and 30 days. All specimens for the strength tests were prepared at their optimum water content in a standard Proctor test (L=0,6 J/cm3) [23, 24, 25].

The mix and the compaction were completed in less than an hour. The axial load was increased at a rate of 0.5 mm/min and the load displacement curve was determined (Fig. 5). From the load displacement curves it can be seen that the cement treated Bahlui clay exhibited much more brittle behavior than the natural ones.

The peak value of stabilized clay increased significantly in the first 7 days from 95.23 kPa (in natural state) to 380.89 kPa. At the end of the experiment (30 days curing time) the unconfined compressive strength value of stabilized Bahlui clay with 10% cement (GGBS eco-cem + Portland cement) reached a value of 718.63 kPa. (Fig. 6).

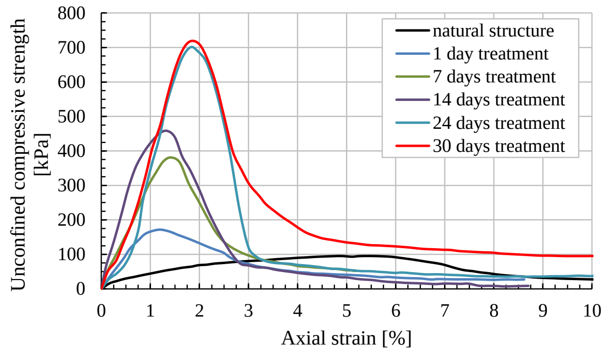

Fig. 5 Effect of curing time on unconfined stress-strain of the Bahlui clay

According to ASTM D 4609 (standard guide for evaluating effectiveness of admixture for soil stabilization), if the increase in unconfined compressive strength is greater than 345 kPa, the treatment is considered to be effective.

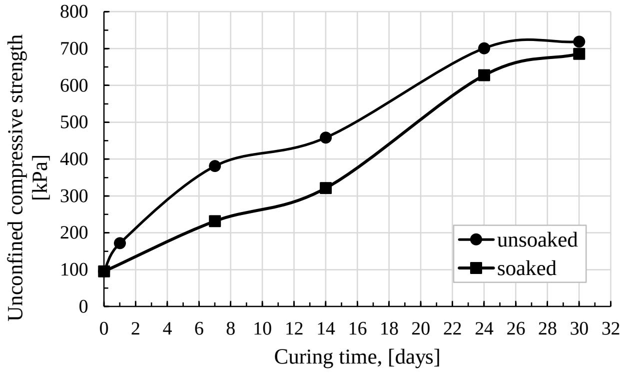

Fig. 6 Effect of curing time on unconfined stress-strain of the stabilized Bahlui clay with 10% cement

The ability of stabilized clay to resist climatic and environmental changes can be studied based on soaking test. If the stabilized soil does not slake during immersion and no significant strength is lost due to soaking, the treatment is effective. For this purpose, one set of samples was immersed in water for two days prior to testing, the unconfined compressive strength of these soaked samples provided an excellent indicator of the durability of the stabilized clay under wet condition [21].

Results of the unconfined compressive strength tests on soaked Stabilized Bahlui clay samples, for different curing periods, are shown in Fig. 6. If for 7, and 14 days the difference is significant, after the increase of cementing bond between the clay particles the effect of soaking is less significant.

In this study, one-dimensional compressibility test was performed to determine the compressibility characteristics of natural and stabilized Bahlui clay according to Romanian Standard STAS 8942/1-89 [9]. The deformability of soil can be computed based on oedometer modulus E_{oed}. Using the oedometer modulus E_{oed} for the interval of pressure between (200 ÷ 300) kPa, the compressibility of soil can be classified into degrees from low to very high compressibility [26].

The evolution of this modulus with curing time for the stabilized Bahlui clay is shown in Fig. 7, the samples were classified having a medium compressibility (E_{oed} = 10000 ÷ 20000 kPa).

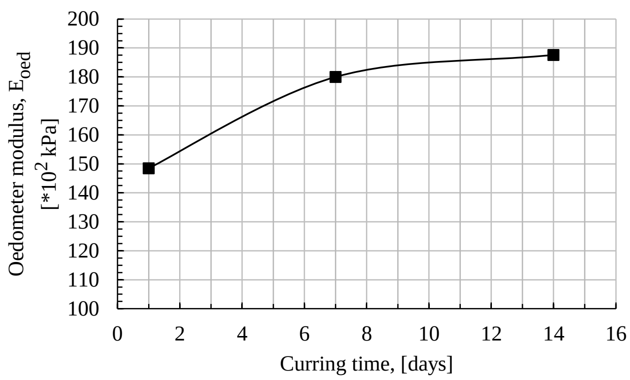

Fig. 7 Variation of oedometer modulus with curing time for (200÷300)kPa intherval

The rate of compression index in a standard consolidation test can be defined by the slope (Cc) of the final part of the void ratio versus logarithmic of load (log p). Fig. 8 presents the compression index (Cc) versus the consolidation pressure for the stabilized expansive soil samples with 10% cement at different curing periods.

From these figure we can see that the compression index Cc decreased with increasing load (log p) and curing time.

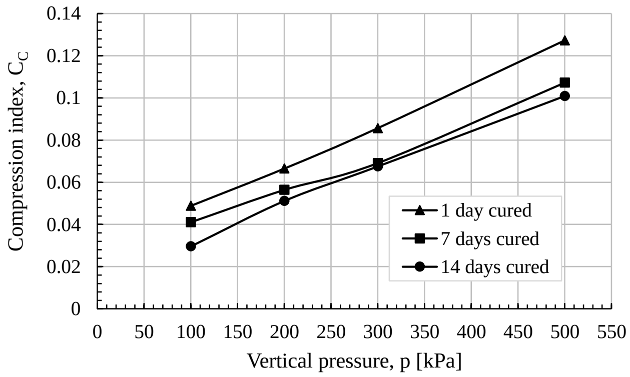

Fig. 8 Coefficient of consolidation versus consolidation pressure

IV. CONCLUSIONS

Engineering properties of cement treated expansive soils were studied through a series of unconfined compression and oedometer tests. From the test results the following conclusions can be drawn:

1. The inclusion of eco-cement and Portland cement (1:1 ratio) changed the grain size distribution and Atterberg limits. Indirect estimation of swell potential of Bahlui clay, indicates a decrease of swelling potential from very high (in natural state) to medium-low.
2. The addition of cement increased the plasticity index, thus the stabilized soils will have a better workability.
3. Cement treatment lead to significant increase in unconfined compressive strength with the increase of curing time. After 7 days of curing time, the unconfined compressive strength reached 50% of maximum strength.
4. Cement treated soils exhibited much more brittle behaviour compared with non-treated soils.
5. The increase in water content in stabilized soil (soaked samples) showed a reduction in unconfined compressive strength compared with the samples treated to a water content equal to the optimum water content.
6. The difference between unconfined compressive strengths of the soaked and unsoaked samples was smaller after 24 curing days.
7. The compression index, Cc, decreased with increasing curing time and consolidation pressure.

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