ANALYSIS ON SOIL COMPRESSIBILITY CHANGES IN LIME-STABILIZED SAMPLES

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ABSTRACT

In order to manage and control the stability of buildings located on difficult foundation soils, several techniques of soil stabilization were developed and applied worldwide. Taking into account the major significance of soil compressibility on construction durability and safety, the soil stabilization with a binder like lime is considered one of the most used and traditional methods. The present paper aims to assess the effect of lime content on soil geotechnical parameters, especially on compressibility ones, based on laboratory experimental tests, for several soil categories in admixture with different lime dosages. The results of this study indicate a significant improvement of stabilized soil parameters, such as compressibility and plasticity, in comparison with natural samples. The effect of lime stabilization is related to an increase of soil structure stability by increasing the bearing capacity.

Keywords: stabilization; lime; compressibility; bearing capacity

REZUMAT

Pentru a gestiona și controla stabilitatea construcțiilor amplasate pe terenuri dificile de fundare au fost dezvoltate si aplicate la nivel mondial numeroase tehnici de stabilizare a pământurilor. Ținând seama de importanța majoră a compresibilității terenului asupra durabilității și siguranței construcțiilor, stabilizarea pământurilor cu un liant de tipul varului este considerată una dintre cele mai utilizate și tradiționale metode. Prezenta lucrare isi propune, pe baza încercărilor experimentale de laborator, sa evalueze efectul conţinutului de var asupra caracteristicilor geotehnice ale pământurilor, in special a celor de compresibilitate, pentru o serie de categorii de pământuri în amestecuri cu diferite dozaje de var. Rezultatele acestui studiu indică o îmbunătățire semnificativă a parametrilor terenului stabilizat comparativ cu probele naturale. Efectul stabilizării cu var este asociat cu creşterea stabilității structurii terenului prin creşterea capacității portante.

Cuvinte cheie: stabilizare; var; compresibilitate; capacitate portantă

1. INTRODUCTION

Severe damage of structures reported worldwide due to inappropriate soil conditions can be avoided by setting and implementing proper and reliable treatments. The present practice consists in modifying the engineering characteristics of the natural difficult soils in order to gather the design specifications. Construction stability depends on the strength and deformation characteristics of soil foundation. In this regard, geotechnical soil properties have to be determined in order to establish correct measures for assuring the stability and safety of constructions. By adopting soil stabilization solutions, the physical and mechanical characteristics of soil will be improved (Littlle, 1987; Sherwood, 1993; Al-Tabbaa and Evans, 2005) and will assure works durability.

Due to the wide spreading of difficult soils on Romanian territory, including sensitive and shrink-swell soils, and taking into account the effects on structures stability, stabilization solutions are necessary (National Research Council, 1991; EuroSoilStab, 2002) for increasing bearing capacity, shear strength, as well as for the decreasing of compressibility and permeability.

The term “stabilization” directly involves acquiring higher geotechnical soil properties by mixing with various binders in order to sustain the construction surcharges. The development of superior strengths in comparison with initial ones is achieved due to reduction of void volume by replacing the liquid from soil structure with stabilization agents and forming chemical bonds between particles. In the stabilization process, it is useful to evaluate the initial soil characteristics, in order to adopt the adequate technical solution and binders type and quantity.

According to the National Lime Association (2004), soil stabilization with lime represents an efficient and traditional method for improving the engineering parameters of lime-treated soil. The transformations manifested in soil structure after lime treatment (Amiralian et al., 2012; Jawad et al., 2014) are related to cation exchange, flocculation agglomeration, lime carbonation and pozzolanic reactions that lead to mineralogy changes. Lime stabilization is widely used especially for clayey soils, as well as for all types of soils with plasticity index ranging from 10% up to 50%. By adding lime, a plasticity decrease and the stability of volume changes will be obtained. A large number of experimental tests have concluded that the necessary quantity for obtaining the increase of stabilized soil properties can vary between 3% and 10%.

Soil compressibility represents an important parameter that should be considered in the design and execution of constructions, in order to assure their durability and safety. The aim of the present paper consists in analyzing the suitability of soil-lime mixing to the improvement of deformation characteristics of difficult soils (Rao and Shivananda, 2005; Singh et al., 2008; Amiralian et al., 2012). The soil stabilization in laboratory conditions will contribute in the effectiveness assessment of stabilized materials in the field and represents an economical and rapid method to establish the optimum binders and dosages, as a function of soil nature.

2. METHOD USED IN LABORATORY SOIL STABILIZATION

Various natural soil types from the cohesive and cohesionless categories were selected in order to be stabilized by preparing lime admixtures. Grain size analysis was conducted for the identification of soil type, by using the hydrometer and sieve methods. Natural samples were identified as silty clay (SiCl), clayey silt (ClSi) and medium to coarse sand (Sa), based on the results obtained from the distribution of predominant granular fractions. The sand sample is considered to be well-graded and medium dense.

The chemical stabilization of selected natural soils was performed by preparing admixtures with industrial hydrated lime in various amounts: 3%, 7% and 10%, as shown in Fig. 1. After mixing each soil type with different lime dosages until obtaining a homogenous composition, laboratory tests for the determination of moisture content, Atterberg limits and compressibility were carried out.

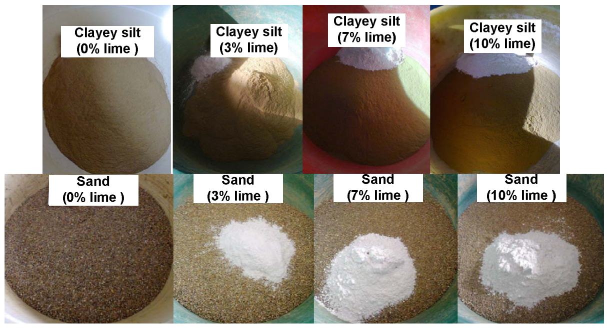

Fig. 1. Admixtures of soil samples with lime

For each natural soil, the average values of moisture content were determined. Then, various water quantities were added to the samples mixed with lime, in order to maintain moisture equilibrium, with small variations around 1-2%, for both natural and stabilized samples, as follows: 23% for silty clay mixtures, 20% for clayey silt mixtures, respectively 4% for sand mixtures.

The Atterberg limits determinations were carried out on admixtures composed from silty clay and clayey silt with stabilizer agent, by determining liquid limit, plastic limit, plasticity and consistency index. The natural soil samples were characterized from the point of view of consistency and plasticity state as medium and highly plastic in the case of silty clay and stiff and highly plastic in case of clayey silt.

By analyzing the values resulting from Atterberg limits on silty clay samples, the following aspects can be observed: a high increase of the plastic limit, varying from 38% up to 65%, a slight decrease of the liquid limit from 1% up to 14% and a significant decrease of the plasticity index from 13% up to 47%, related to the addition of lime content on natural samples, as shown in Fig. 2. The decrease of the plasticity index is linked with the increase of soil workability. The results indicate that the silty clay sample, initially characterized from the point of view of plasticity state as highly plastic, changed to the medium plastic category and from medium to stiff, in consistency terms.

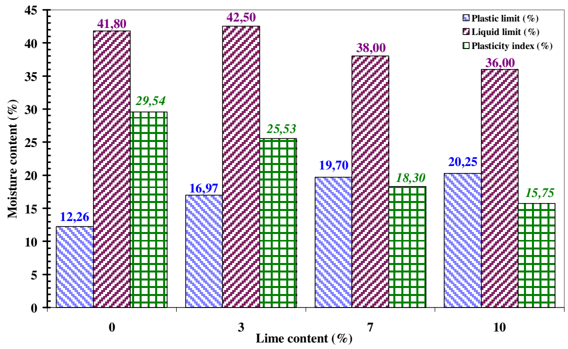

Fig. 2. Variation of plasticity indices obtained for silty clay admixtures

In the case of clayey silt samples, the results pointed out a slight increase of the plastic limit from 14% to 20%, a slight decrease of the liquid limit from 5% up to 19% and a significant decrease of the plasticity index from 20% up to 47%, by adding stabilizer agent to natural samples, as in the chart in Figure 3.

The decrease of the plasticity index is linked with the increase of soil workability. Data obtained from the Atterberg limits indicated that the clayey silt sample, with high plasticity, changed to medium plastic category and remained in the stiff category.

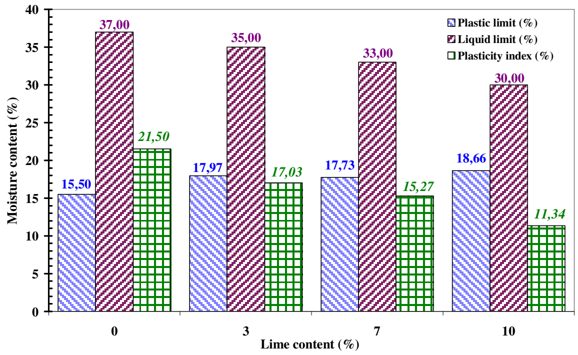

Fig. 3. Variation of plasticity indices obtained for clayey silt admixtures

3. EXPERIMENTAL TESTING FOR DETERMINATION OF STABILIZED SOIL COMPRESSIBILITY

The determination of soil compressibility on admixtures was performed by using oedometer equipment and consists in the measurement of the deformation of cylindrical samples under vertical axial loads (Fig. 4). Based on the settlement-compression curve, mechanical characteristics of natural and stabilized soils related to compressibility indices were obtained: the specific settlement at 200 kPa (ε_{200}, %) and the oedometric modulus for stresses ranging between 200 and 300 kPa ($E_{oed200\text{-}300}$, kPa). Regarding the laboratory testing procedure, it should be noted that the load increments applied to the specimens were set at 25, 50, 100, 200, 300 and 500 kPa and the deformations were recorded before applying each load. Each load increment was maintained until settlement stabilization and then the next load was applied. After applying the maximum load increment, the specimen was unloaded up to the initial load.

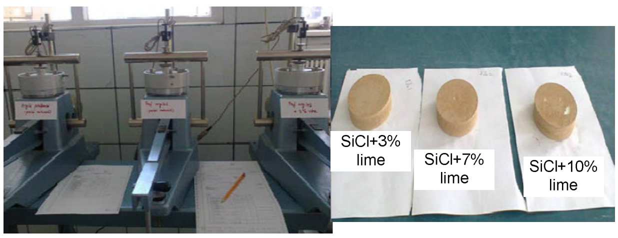

Fig. 4. Compressibility determination of natural and stabilized soil samples

Data collected from oedometer measurements on natural and stabilized soils, including compressibility and physical indices (moisture content, natural density and dry density, porosity, void ratio), are summarized in Table 1.

Table 1. Natural and stabilized soil characteristics resulted from compressibility test

Soil sample	Physical characteristics					Mechanical characteristics	
	Moisture content w,%	Density ρ,g/cm^3	Dry density ρ_d,g/cm^3	Porosity n, %	Void ratio e	Oedometric modulus $E_{oed200-300}$, kPa	Specific settlement ε_{200}, %
SiCl	21,70	2,01	1,66	38,45	0,62	8953	2,95
SiCl+3% lime	19,68	2,02	1,68	37,37	0,60	10050	2,58
SiCl+7% lime	19,08	2,03	1,70	36,69	0,58	12121	2,18
SiCl+10% lime	18,81	2,05	1,73	35,72	0,56	15082	1,92
ClSi	18,30	1,86	1,57	41,06	0,70	8019	2,19
ClSi+3% lime	17,25	1,88	1,61	40,31	0,68	9132	2,02
ClSi+7% lime	16,49	1,91	1,64	39,18	0,64	10989	1,87
ClSi+10% lime	15,26	1,92	1,66	38,16	0,62	12195	1,60
Sa	5,40	1,66	1,58	40,42	0,68	10870	2,40
Sa+3% lime	4,69	1,68	1,61	39,39	0,65	11236	2,22
Sa+7% lime	4,16	1,70	1,64	38,25	0,62	12077	2,07
Sa+10% lime	3,10	1,73	1,68	36,71	0,58	13888	1,90

By processing the data recorded during compressibility tests for silty clay admixtures, a pronounced increase of the oedometric modulus, $E_{oed200-300}$, was observed, starting from 12%, 25% up to 68%, with respect to the untreated soil sample, as shown in Figure 5.

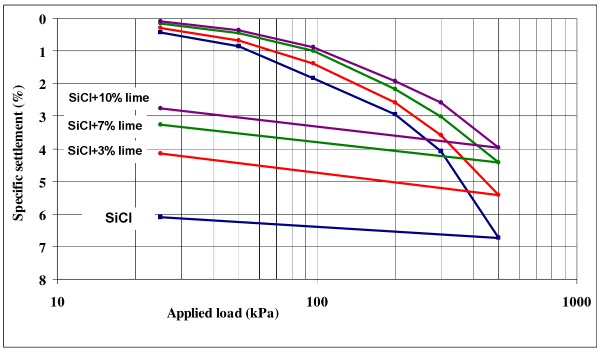

Fig. 5. Compression – settlement curve for silty clay mixtures

According to national regulations, the soil sample in natural state is characterized by a high compressibility. The addition of lime is conducted to obtain a decrease of the deformability characteristics and to pass to a superior soil category, with medium compressibility. Concerning the values of physical indices obtained from the compressibility test, several aspects have to be noticed: a slight decrease of the moisture content up to 13%, of the porosity up to 7% and of the void ratio up to 9% and a lower increase of density for soil samples.

In the case of clayey silt admixtures, the results indicated a gradually increase of the oedometric modulus, $E_{oed200-300}$, with 14%, 37% up to 52% for samples stabilized with lime, as shown in Figure 6. By adding stabilizer agent in mixtures, the change produced in the soil classification, to a superior category – from higher to medium compressibility, can be observed. The variations of physical soil characteristics consist in the decrease of moisture content up to 16%, of the porosity up to 7% and of the void ratio up to 11% and in the increase of density for stabilized samples.

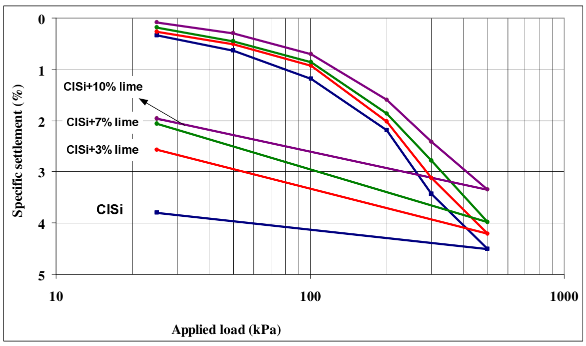

Fig. 6. Compression – settlement curve for clayey silt mixtures

Figure 7 shows the lowest increase percentages of the oedometric modulus, related to stabilized sand samples, of around 28%. In should be remarked that the lime addition to sand samples has no influence in the modification of the compressibility class.

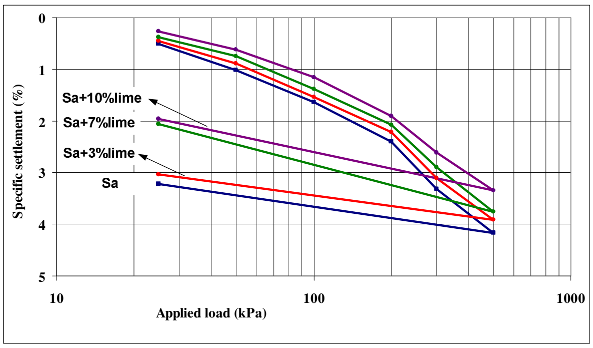

Fig. 7. Compression – settlement curve for sand mixtures

The changes of physical indices obtained for treated sand samples are reflected by a significant decrease of the moisture content up to 42%, a slight decrease of the porosity up to 9%, respectively of 14% for the void ratio.

4. DISCUSSIONS AND CONCLUSIONS

In the research study, laboratory tests were carried out for establishing cohesive and cohesionless soil types, by using lime in admixtures. The research focused on the effect of lime addition on the reduction of compressibility indices, for several soil types. The processing of data obtained for stabilized cohesive soils revealed changes in soil plasticity, reflected by the increase of the plastic limit and the decrease of the liquid limit and of the plasticity index, in comparison with natural samples. A very significant variation of plasticity characteristics was observed for silty clay recipes, due to chemical reactions as cation modifications occurred after mixing clayed particles with lime; this resulted in changes of the plasticity state to a superior category. The effect of the plasticity index decrease was higher soil workability.

For the analyzed mixtures, there is a similar tendency of variation of the physical soil properties resulted from oedometer test as the decrease of porosity, void ratio, density, which linked the chemical reactions with the continuous reduction of values. Regarding the influence of lime on moisture content, silty clay and clayey silt show a slight decrease, in contrast with the more pronounced tendency for sandy samples.

By adding different amounts of lime to cohesive soil samples, the results of compressibility tests showed higher values of the oedometric modulus, corresponding to a superior compressibility category. It was noticed that the oedometric modulus increases significantly in the case of cohesive soils, due to the addition of lime. This increase has a continuous tendency for the oedometric modulus in each combination, as compared with the previous mixture. The compression – settlement curves of the samples with lime showed that the mechanical characteristics of treated soils had a different variation in each combination of binders. Experimental data showed that higher lime content (10%) is associated with a greater value of the oedometric modulus. Regarding the stabilized cohesive samples, the slope of the compression curve highlights a moderate reduction, compared to natural samples, that presents a significant slope decrease. In contrast, the compression slope obtained for sand treated soils has a similar tendency. Thus, it can be concluded that a significant improvement of the compressibility of lime treated soils is more evident in the case of silty clay and clayey silt. The optimum results were obtained for cohesive soils by adding 10% lime.

The research highlighted that lime treatment can be considered as an efficient method for improving compressibility of soils with specific behavior in contact with water. Based on the data obtained from the study, it can be concluded that the addition of an important amount of lime is recommended for the stabilization of clayey soils, yielding to a decrease of soil compressibility. It can be noticed that the influence of the granular fraction on geotechnical characteristics has a strong connection with the effect of lime during stabilization process, reflected in chemical bonds between particles (Dobrescu and Calarasu, 2014).

As a result of the improvement of deformation characteristics, the safety and durability of buildings located on difficult soil types can be ensured. More studies are necessary in the future on soil stabilization using lime treatment in different dosages and on soil types with special behavior.

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