STUDIU PRIVIND EVALUAREA PORTANŢEI PĂMÂNTURILOR NATURALE ŞI STABILIZATE UTILIZÂND LIANŢI CU BENEFICII ECOLOGICE PRIN CORELAŢII PARAMETRICE

STUDY CONCERNING BEARING ASSESSMENT OF NATURAL AND STABILIZED SOILS USING BINDERS WITH ECOLOGICAL BENEFITS BASED ON PARAMETRIC CORRELATIONS

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The assessment of natural and stabilized soils behaviour, using binders with ecological benefits like lime, is based on modelling of the performance characteristics related to the bearing increase of infrastructure works by developing parametric correlations. The value of CBR index represents one of the most used parameters in design, execution and quality control of road structures. Taking into consideration the necessity of a large number of tests and specimens and the long period associated to their execution, a widely used an alternative method based on correlations of CBR value and soil characteristics due to time saving, as well as independent verification and quality control of results, is used. A significant increase of CBR values due to lime stabilization in both natural and soaked conditions has been noticed. The influence of the compaction characteristics on CBR value depending on the index obtained during tests and the derived index expressed by correlation coefficients, has been reflected by good correlations of the analyzed statistical variables. The calibration modelling of data for a simple linear regression has been put into evidence by using comparative analyzes of experimental and predictable parameters.

Evaluarea comportării pământurilor naturale şi stabilizate cu lianţi cu beneficii ecologice de tipul varului s-a bazat pe modelarea caracteristicilor de performanţă legate de creşterea portanţei lucrărilor de infrastructură prin dezvoltarea de corelaţii parametrice. Valoarea indicelui CBR constituie unul dintre parametrii frecvent utilizaţi, atât în etapa de proiectare, execuţie cât şi în cea de controlul calităţii structurilor rutiere. Luând în considerare necesitatea numărului mare de încercări şi probe, precum şi perioada lungă asociată cu executarea acestora, se utilizează frecvent varianta alternativă bazată pe corelaţii empirice ale indicelui CBR cu caracteristicile terenului datorită atât timpului redus pentru execuţie, cât şi a verificării independente şi controlul calităţii rezultatelor. Caracteristicile de portanţă ale structurilor simulate în laborator au evidenţiat creşteri semnificative ale CBR ca rezultat al stabilizării cu var în condiţii naturale şi de inundare. Influenţa caracteristicilor de compactare asupra valorii CBR, în funcţie de indicatorii obtinuţi din încercări şi indicatori derivaţi exprimaţi prin coeficienţi de corelaţie, s-a reflectat prin corelaţii foarte bune între variabilele statistice analizate. Analizele comparative între parametrii obţinuţi experimental şi cei prognozaţi prin relaţii empirice au condus la calibrarea modelelor de regresie liniară simplă dedicate tipului de pământ studiat.

Keywords: bearing capacity, stabilization, parametric modelling, soil structures

1. Introduction

Within the actual scientific context, the improving process of geotechnical characteristics during compaction of natural and stabilized soils shows an increasing interest concerning the solutions for construction foundation on soils with low mechanical strength, road systems and earthworks design with a high safety degree in exploitation [1-5]. The products with ecological benefits used for stabilization of controlled filling layers or road systems present a wide applicability. The scientific studies carried out up to date at national and international level have highlighted the necessity of evaluating stabilized soil behaviour by parametric modelling of the performing characteristics with key role in increasing the bearing capacity of layers, through experimental testing and statistical analysis [1, 3]. By taking into account these aspects, detailed studies regarding the behaviour of stabilized soil under mechanical, chemical, hydric and climatic actions are required. The studies are based on mathematical models development, and their calibration by comparing the experimental bearing capacity values to those predicted by computing empirical equations. The present paper aims to contribute to the assessment of soil bearing performances by carrying out experimental and statistical analyzes. Through this approach, the study is intended to lead to

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perfecting or improving the soil stabilization methodology by using material with ecological benefits for further use in design and execution of infrastructure works (base course and sub grade of road structures as well as filling layers).

2. Methods in assessment of bearing capacity of foundation layers

California Bearing Ratio is commonly used for quality control of compaction works and evaluation of bearing capacity of compacted layers made of natural and stabilized soil for embankments, foundation layers, base course and sub grades layers,. The CBR test was developed by O.J. Porter for California Highway Department in the 1920s in order to measure load-deformation properties of soils in laboratory and field conditions. This simple strength test is used to determine the thickness of materials to be used in road construction. In laboratory conditions, the test is carried out on undisturbed samples collected directly from the site or restructured samples at natural moisture or other moistures. The test may be conducted in natural or soaked conditions, CBR index value in soaked conditions being determined by experimental tests to reflect soil bearing capacity in the most adverse conditions that may occur during the lifetime of road structures [6]. The test method consists of loading the soil with a plunger (piston) with a specific area of 1935 mm^2 at a penetration speed of 1,27 mm/min. During the test, the applied force per unit area to penetrate in a soil mass at various depths is recorded. Using the resulted values a curve is built, having in the abscissa the piston penetration (mm) and in the ordered the value of the force applied on the plunger (kN). Out of the resulted curve, the values of California Bearing Ratio (CBR) at 2,54 mm and 5,08 mm depth penetration are calculated. CBR values are obtained as a ratio between the corrected force values for 2,54 mm and 5,08 mm penetration and standard values (for crushed stone) at 13,24 kN, respectively 19,96 kN, as shown in equation (1):

$$\mathrm{CBR} = \frac{\text{value of corrected force}}{\text{standard force}} \cdot 100\% \qquad (1)$$

Due to high permeability and reduction of pore water after applying mechanical loading, it is considered that sands and gravels are well-compacted even in saturated conditions. In contrast to cohesion less soils, clay soils are less permeable and pore water cannot be eliminated during short-term efforts applied during compaction process, even at low moisture content. The difficulties occurred in case of excessive wetting clays are also manifested in dry clays. Taking into account the influence of moisture content on clayey soil compaction, it is necessary to study the distinctive soil properties and the presumptive atmospheric conditions within the working area.

The selection of the technology and the equipment to be used is done according to the tests performed to the soil embedded in runways after its exposure at consecutive cycles of various compaction equipment [7]. During these tests the following data is determined: type and weight of optimum compaction equipment, thickness of soil compaction layer, number of passes for equipment required to achieve foreseen compactness.

Regarding clayey soils, the compaction process using equipment with dynamic action is recommended, but only for lower moisture or equal to the optimum moisture, in order to avoid a pronounced disperse structure. Soil compaction at optimum moisture content shows the advantage of forming a more compact structure comparing to aggregate structure. By compaction, an improvement of permeability characteristics, freeze-thaw resistance and durability of soil structures can be obtained. The advantages of intermediate structure formed by compaction at optimum moisture consist mainly in obtaining superior mechanical characteristics and small deformations, implicitly a high bearing capacity [8]. Based on the studies carried out until now [9-13] regarding the importance of determining the California Bearing Ratio for road works, it has been remarked that CBR value depends on a wide range of geotechnical soil characteristics: natural density, dry density, optimum moisture content at compaction, plasticity limits, plasticity index, soil nature, permeability etc. Likewise, the test conditions selected for natural and soaked soil determinations represent a determining factor in variation of CBR values.

3. Experimental and analytical assessment of bearing capacity change depending on compaction characteristics

The experimental program that determined the present research consisted in assessing the performance parameters related to the bearing capacity of layers (CBR index) made of natural and stabilized soils. The Natural soil has been identified in terms of grain size as silty clay (34% clay, 55% silt, 11% sand), characterized by a high plasticity (PI=29,03%), stiff plastic (CI=0,762). In the stabilization process, a traditional material has been used, i.e. hydrated lime. In order to achieve the proposed goals, there were prepared several sets of specimens and structures (single, double and triple layer) while the dosages used for stabilization with 3% and 7 % lime were selected for evaluating the bearing capacity in natural and soaked state. The experimental tests were carried out on different specimens' sets as follows: 3 natural samples represented by silty clay, 3 stabilized soil samples using 3% lime (exposed to

3 days treatment period after preparation), 3 stabilized soil samples using 7% lime (exposed to 3 days treatment period after preparation). The specimens were immersed in water, with the water level maintained at the upper part of the mold. After 3 days, it was noticed that the water level reached the top of the sample. Comparative analysis between CBR index obtained in natural and soaked conditions were performed to quantify the measure where the extreme climatic conditions through water immersion can influence the bearing capacity values. The experimental results were used for the assessment of natural and stabilized soil behavior by parametric modeling of performance characteristics (nature, state, strength), with an impact on the bearing capacity increase for soil mixtures. At the same time, correlations of parameters with decisive role in the bearing capacity estimation for simulated road structures and CBR values obtained on compacted samples at optimum moisture content during 3 day immersion were established. The comparative analyses of experimental and predictable data obtained through empirical equations were aimed at calibrating the simple linear regression models dedicated to the analyzed soil type

In order to estimate the influence of geotechnical soil characteristics on the strength parameters, at individual level, expressed by CBR value, several models for simple regression analysis were proposed. The considered statistical variables were organized according to soil structure in layers and test conditions in two sets of simulated data, as follows: stabilized layer in natural test conditions and immersion in water. In simple linear regression analysis (SLRA), the CBR value determined in natural and soaked conditions was selected as dependent variable and the dry density (DD) and optimum moisture content at compaction (OMC) as independent variables. In Table 1, the models achieved by simple linear regression analysis are presented. The correlations of CBR values and compaction characteristics obtained for stabilized soils in a structure with a single layer exposed to natural conditions (Figure 1 and Figure 2) are represented as average values for each composition.

Table 2 and the graphs shown in Figure 3 and Figure 4 illustrate the proposed models achieved out of simple linear regression analysis for built soil structures during 3 days water immersion as well as average values for each composition

Table 1

Models obtained from simple linear regression analysis corresponding to stabilized soil layers (in natural conditions)
Modele utilizate pentru analiza de regresie liniară simplă pentru straturi de pământ stabilizat (condiţii naturale)

Model	Correlation equation	Correlation coefficient
Model 1 OMC vs. CBR	$CBR_{nat} = -4{,}8751(OMC) + 119{,}20$	$R^2 = 0{,}9943$
Model 2 DD vs. CBR	$CBR_{nat} = 243{,}64(DD) - 399{,}39$	$R^2 = 0{,}9623$

Table 2

Models obtained from simple linear regression analysis corresponding to stabilized soil layers (in soaked conditions)
Modele utilizate pentru analiza de regresie liniară simplă pentru straturi de pământ stabilizat (condiţii inundate)

Model	Correlation equation	Correlation coefficient
Model 3 OMC vs. CBR	$CBR_{in} = -4{,}6575(OMC) + 112{,}8$	$R^2 = 0{,}9874$
Model 4 DD vs. CBR	$CBR_{in} = 235{,}13(DD) - 387{,}01$	$R^2 = 0{,}9751$

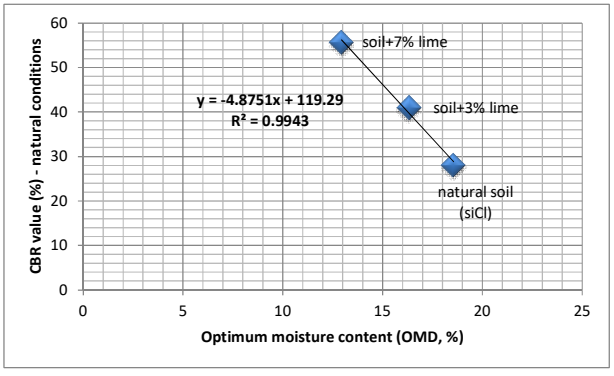

Fig. 1 - Variation of CBR values depending on optimum moisture content (OMC) (natural conditions) *Variaţia valorilor CBR în funcţie de umiditatea optimă de compactare (OMC) (condiţii naturale) .*

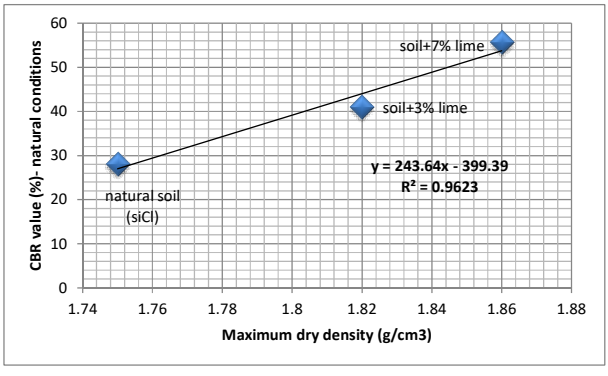

Fig. 2 - Variation of CBR values depending on maximum dry density (DD) (natural conditions) / *Variaţia valorilor CBR în funcţie de densitatea în stare uscată (DD) (condiţii naturale).*

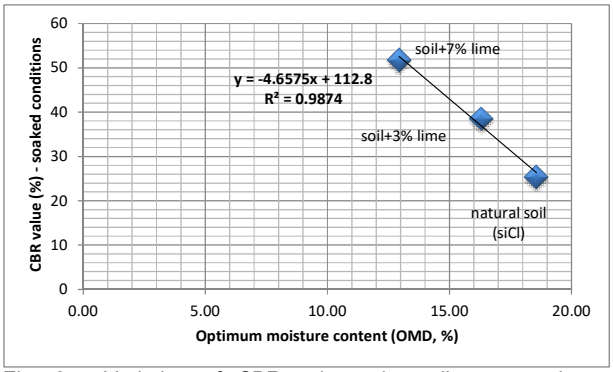

Fig. 3 - Variation of CBR values depending on optimum moisture content (OMC) (soaked conditions). *Variaţia valorilor CBR în funcţie de umiditatea optimă de compactare (condiţii de inundare).*

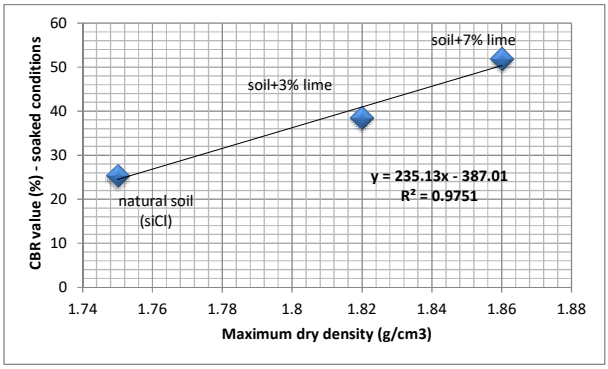

Fig. 4 - Variation of CBR values depending on maximum dry density (DD) (soaked conditions) / *Variaţia valorilor CBR în funcţie de densitatea în stare uscată (condiţii de inundare).*

The correlation equations resulted by application of the simple linear regression models of the quantitative variables taken into consideration emphasized the influence of CBR value on compaction parameters resulted from individual examination. In natural conditions, the values of optimum content moisture for mono-layers decrease up to more than 40%, while for the dry density values an increase of about 6% was obtained. Based on the analysis of links distribution of statistical variables, a good correlation, in a negative sense, influenced by the increase of CBR value as well as a decrease of the optimum moisture content were remarked. A very good correlation, in a positive sense, with linear relations related to the increase of CBR value together with dry density was noticed. For the calibration of the proposed models, available only for studied soil type, based on the correlation equations, a comparison of statistical results for the samples tested in natural and soaked conditions was performed, yielding a correlation coefficient R^2=0.9985, reflecting a very good correlation of the results obtained in calculation (Figure 5). It can be noticed that sample immersion during the 3 days has no significant influence on CBR value. It should be mentioned that the correlation analysis includes the values obtained for soil structures made from single, double and triple layers in different variants of natural and stabilized layers. It has been remarked a considerable increase of CBR for mono-layers by adding lime content and triple-layers with stabilized soil at the top and bottom, allowing to reuse important quantities of local materials in stabilized structures. A moderate increase is noticed for double-layers (stabilized soil at the top), respectively for triple-layers with stabilized soil at the middle. The computed ratio between CBR values in natural and soaked conditions indicates a decrease of 5% up to 7% for soaked specimens, which is considered to be acceptable when dealing with immersion conditions.

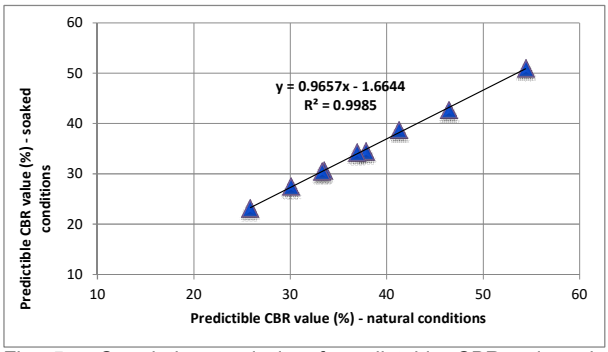

Fig. 5 - Correlation analysis of predictable CBR values in natural and soaked conditions. / *Analiza de corelaţie între valorile CBR în condiţii naturale şi inundate determinate statistic.*

4. Conclusions

The experimental research has lead to a parametric modelling based on experimental and statistical analysis for evaluating the bearing capacity characteristics of the laboratory simulated structures, consisting of natural soils and stabilized soils using 3% and 7% lime content. The correlation and regression analyzes of the values corresponding to geotechnical parameters (compaction characteristics) have allowed to emphasize their significant influence on CBR index and the importance that must be given to detailed studies regarding bearing capacity and behaviour of natural and stabilized soil. The development of empirical correlations as presented in paper are considered items for calibration and validation of quality for laboratory test results in order to assess bearing characteristics as an alternative for cases when such procedure cannot be performed for a large number of tests. In the present work an increase of bearing capacity values of stabilized soils using lime as binder with ecological benefits, for both natural and soaked conditions, has been achieved. For the mono-layer soil structures, the optimum recipe has been obtained for 7% lime content used in mixture, which led to an increase of CBR values of about 114% comparing to the

natural soil. The ratio between CBR values for the specimens maintained in natural conditions and derived values resulted from application of correlation equations in regression analysis varies within acceptable limits, which confirms the calibration of the proposed models available only for studied soil type, internal validation and quality control of results.

The development of such comprehensive studies concerning the assessment of bearing capacity for soils with low mechanical strength during stabilization using materials with ecological benefits, based on a large number of experimental and statistical analyzes is a useful tool in developing innovative solutions with applicability in the private sector dedicated to infrastructure works.

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