Compacted soil columns for foundations on collapsible soils. Laboratory and in-situ experimental study

Colonnes de sols compactés utilisées pour des fondations sur sols effondrables. Étude expérimentale menée en laboratoire et in-situ

Burlacu C., Olinic E., Manea S.
Technical University of Civil Engineering Bucharest, Department of Soil Mechanics and Foundations
Uță P.
SC Geosond SA Bucharest

ABSTRACT: Moisture-sensitive or collapsible soils are materials with high porosity that under the loads transmitted by the foundations present additional settlements once the soil is saturated. This category includes loess deposits and other high silt content soils with uneven porosity. A method often used for foundation on these soils is the realization of local loessoid material compacted columns. According to the Romanian legislation, it is forbidden to use granular material in loessoid soils. A compromise may be reached by using a mixture of granular material and local loessoid soil in columns. This paper presents the experimental laboratory program aiming to achieve an optimal mixture of local material (loess) and monogranular sand in order to improve the values of the mechanical soil parameters while keeping the permeability coefficient values as low as possible. This objective can be achieved by adding bentonite. On the experimental polygons, 1:5 scale compacted soil columns were made using a dynamic penetrometer. The aim of the dynamic penetration tests performed in the center and between the columns was to obtain results concerning the improvement of the mechanical characteristics of the columns and the foundation soil.

RÉSUMÉ : Les sols effondrables sont des matériaux avec une porosité élevée, qui, suite à la saturation, présentent des tassements supplémentaires sous l'effet des charges transmises par les fondations. Cette catégorie inclue les dépôts de loess et d'autres sols ayant un contenu élevé de silt avec une porosité irrégulière. Une des méthodes de fondation souvent utilisée sur ce type de sols est la réalisation de colonnes de matériel loessique compacté. Bien que la législation roumaine interdise l'utilisation de matériaux sableux dans des sols loessiques, ceux-ci peuvent toutefois être utilisés pour la réalisation de colonnes dans un mélange avec du sol loessique. Cet article présente un programme expérimental de laboratoire qui vise à réaliser un mélange optimal de matériaux lœssiques avec du sable pour améliorer les valeurs des paramètres mécaniques du sol, en maintenant toutefois les valeurs du coefficient de perméabilité le plus bas possible. On peut atteindre cet objectif par l'addition de bentonite. Dans le cadre d'un programme expérimental, on a realisé des essais à l'aide d'un pénétromètre dynamique sur des colonnes de sol compacté à une échelle de 1:5. Le but des essais de pénétration dynamique a été d'obtenir des résultats concernant l'amélioration des caractéristiques mécaniques des colonnes et du terrain de fondation.

KEYWORDS: collapsible soils, compacted soil columns, dynamic penetration test, soil mixtures.

1 INTRODUCTION

Moisture-sensitive or collapsible soils are unsaturated macroporous cohesive soils that, upon saturation with water, undergo sudden and irreversible changes of the internal structure, reflected by additional settlements with collapsing character and decreases in the values of geotechnical parameters of mechanical behaviour (NP 125: 2010).

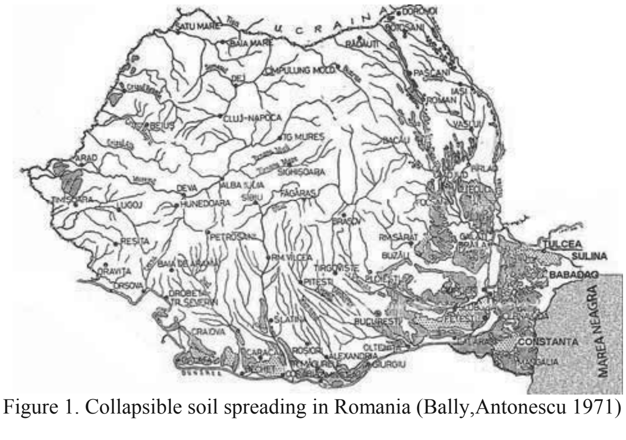

Figure 1. Collapsible soil spreading in Romania (Bally,Antonescu 1971)

In Romania, moisture-sensitive soils cover about 19% of the country's territory (approx. 40.000 km^2) and it is common particularly in the eastern part of the country (Figure 1).

In order to characterize a soil as moisture sensitive, it must meet at least one criterion regarding the physical characteristics and one criterion regarding the mechanical behaviour, the main criteria being the following:

A. Criteria regarding physical characteristics:

- ratio of silt fraction: 50 – 80%
- degree of saturation: $Sr < 0,8$
- porosity in natural state: $n > 45\%$

B. Criteria regarding mechanical behaviour:

- the index of the additional settlement caused by saturation under a loading of 300 kPa (in oedometric test): $i_{m300} \geq 2\%$.

2 IMPROVEMENT METHODS FOR COLLAPSIBLE SOILS

Difficult foundation soil improvement methods are continuously progressing, not only quantitatively, but also qualitatively, as a result of both the development of new technologies and the recognition of economic and environmental protection benefits of modern methods.

A significant number of techniques aimed at improving the mechanical characteristics of difficult foundation soils have been developed. Methods are divided into two wide categories (Schlosser 1997):

- physical methods – soil improvement technologies, by which soil structure is mainly improved in what concerns contacts between particles by additives or by reducing porosity in order to increase the tamping state - physical characteristics improvement methods;
- mechanical methods – soil reinforcing technologies, by which structural elements are introduced in the ground in order to increase the mechanical strength – mechanical characteristics improvement methods.

Classification of results sought by difficult foundation soil improvement (Kirsch, Sondermann 2003):

- increasing density and shearing strength
- reducing compressibility
- influencing permeability in order to reduce infiltrated water flow or to speed up consolidation process
- improving homogeneity.

3 LABORATORY TESTS

In the experimental programme, various mixtures of loessoid material with different natural mineral materials have been proposed, in view of eliminating moisture sensitiveness, improving geotechnical parameters of mechanical behaviour and limiting permeability (Burlacu 2012).

To this purpose, a series of mixtures have been proposed: loess with sand 1-2 mm (Cu = 1.5) and loess with sand and bentonite powder addition in two variants of mixture. The obtained mixtures are presented below:

Mixture 1: 80% loess + 20% sand (1-2 mm);

Mixture 2: 60% loess + 40% sand (1-2 mm);

Mixture 3: 50% loess + 40% sand (1-2 mm) + 10% bentonite;

Mixture 4: 50% loess + mixture from (40% sand (1-2 mm) + 10% bentonite);

The difference between the last two mixtures consisted in the way they were mixed. In the first case, all the three materials were simultaneously mixed and then water was added to reach different degrees of humidity in order to perform the normal Proctor test. In case of the last mixture, the sand was first mixed with the bentonite and with water and then, after this mixture had dried, it was also mixed with the loess (Olinic 2012).

As a first step, the optimal compaction characteristics of the proposed mixtures were determined and then, based on the compacted samples, the compressibility and shearing mechanical characteristics and the possible moisture-sensitivity of the compacted material were determined. The samples used for carrying out the mechanical tests were the ones surrounding the optimum compacted sample. In order to reach uniform results, the variation of the density in dry condition depending on the height of the compacted sample was analyzed and confirmed (Figure 2). This is why a certain sampling order was followed.

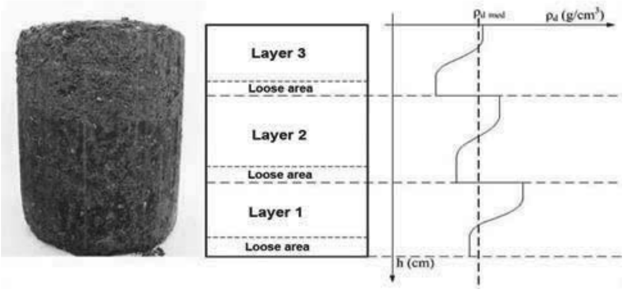

Figure 2. Dry density teoretical variation depending on the height of the compacted sample.

As a result of the Proctor test outcome analysis (Figure 3), it has been observed that along with adding up and increasing the percentage of sand in the mixture (from 20% to 40%), the maximum density in dry condition increases. At the same time, the optimal compaction moisture of the mixtures decreases

The synthesis of the oedometre compressibility tests depending on the oedometric moduli values indicated that the same values $E_{oed\ 200\text{-}300}$ could be obtained for the mixture containing an addition of sand of 20%, at smaller humidity values and at a better tamping state than in case of the natural loess samples. This trend disappeared once the percentage of sand in the mixture was increased (40%). In what concerns samples with bentonite, similar values of oedometric moduli were obtained at a better tamping state that in case of medium loess samples, but at a reduced tamping state than in case of samples with sand, which was also confirmed by the values obtained following Proctor tests.

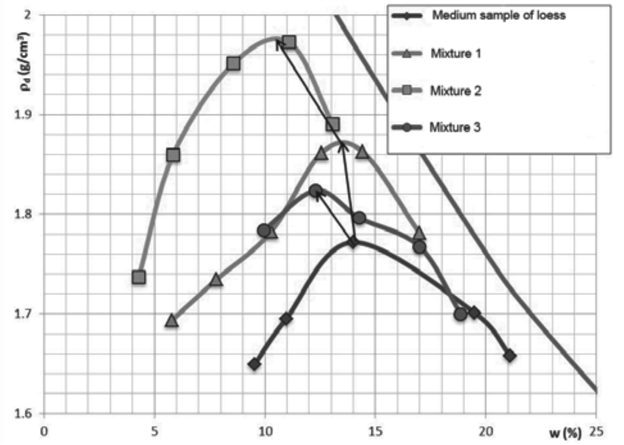

Figure 3. the results of the Proctor trial for all the mixtures obtained.

If, in case of mixture 3, the Proctor diagram has a maximum point (ρ_{dmax}, w_{opt}), in case of mixture 4, the same tamping state was obtained for humidity values between 11% and 15%.

The Proctor diagram resulted for mixture 4 indicated that sample 3 could have represented a maximum point. Therefore, in order to validate the results, tests on this sample were carried out again and similar values were obtained (Figure 4). Given that, humidity plays a key role in the real scale compaction process, the last indication regarding mixture 4 is important because it allows compaction at humidity values belonging to higher humidity domains.

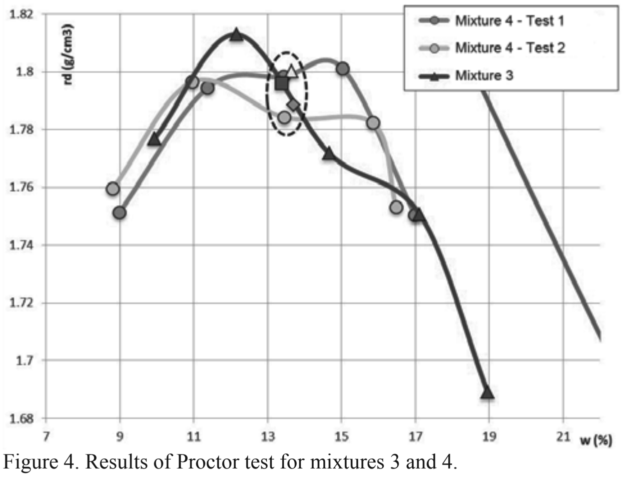

Figure 4. Results of Proctor test for mixtures 3 and 4.

As to the values of the permeability coefficient, these have been of the order of 10^{-5} cm/s for the average loess sample rising up to values of 10^{-4} cm/s in case of the mixture containing 40% sand, while in case of the mixtures containing an addition of bentonite, the measured values were below 10^{-9} cm/s.

4 IN SITU TESTS

In-situ tests first aimed at identifying the effect of the cone shape on: the rate at which the cone advances in the ground, the tamping of the surrounding ground and the compaction degree of the material in the column body. Three types of cones with a diameter of 7 cm were made. (Figure 5).

Figure 5. Cones made: a) C1 – 30°; b) C2 – 60°; c) C3 – hemisphere.

4.1 *Column execution technology*

Collapsible soils improvement by soil columns is regulated by normative C29 - 85. The experimental polygon met the column execution methodology described in the normative but adapting it to the equipment that has been newly proposed for their execution (LMSR-Hk dynamic penetrometer).

Column execution steps are: column hole execution, filling by fill material portions and fill material compaction until rejection.

The fill material portion was set for a column with a diameter of 7 cm and for a height of the compacted material of 21 cm (3 diameters), resulting 1,5 kg of material having optimal compaction humidity.

Successive tests regarding the obtained compaction degree indicated that rejection (compaction stopping) was reached after an advance of maximum 7mm/blow.

4.2 *Optimal cone shape*

On the experimental polygon, columns were executed by using the three types of cones. Figure 6a presents the blow number variation per an advance of 10 cm in DPM tests performed in the centre of the columns and Figure 6b presents the same tests carried out at a distance of 2 diameters towards the column.

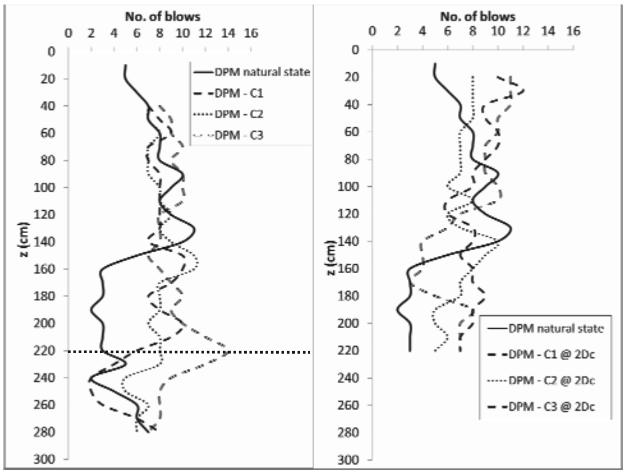

Figure 6. Results of DPM tests carried out in the centre of the columns and at a distance of 2Dc (14cm) towards the columns.

In case of DPM tests carried out in the centre of the columns, the results obtained were similar for all the columns. Therefore, an optimal shape of the cone that leads to a better compaction of the column body could not be found.

Then, for determining the cone with a wider influence radius, DPM tests were carried out at a distance of 2Dc=14 cm towards the columns. These tests indicated [as expected given its shape (the smallest angle at the top)], that cone no. 1 (30^0) had the greatest influence on the tamping state of the soil around the column.

The tests indicated that cone 1 shape (30°) was optimal for soil columns execution.

4.3 *Compacted loess columns*

Therefore, 2 m long columns were executed, arranged as an equilateral triangle network (Figure 7) with a distance of 3Dc - 21 cm between the columns.

After finishing the group of columns, average dynamic penetration tests were conducted both between the columns and at different distances towards them.

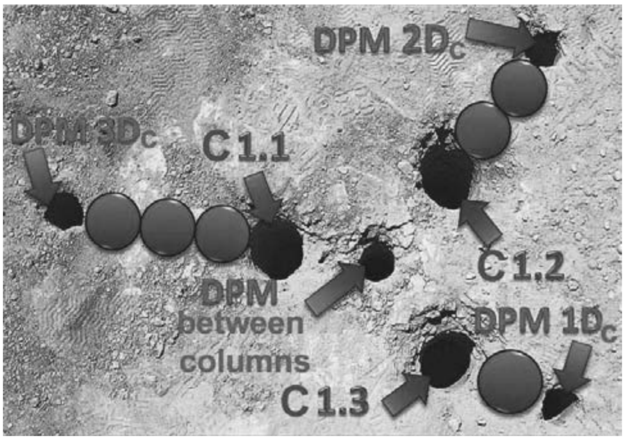

Figure 7. Columns and DPM tests disposal.

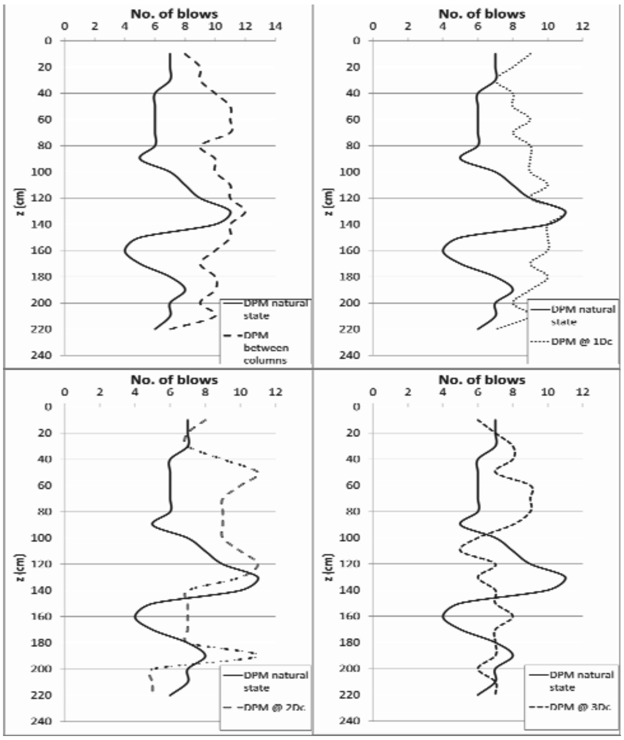

Figure 8. DPM tests results: a) between the columns; b) @ 1Dc; c) @ 2Dc; d) @ 3Dc.

It may be observed that, at a distance of 3Dc near the columns, the improvement effect has no longer been perceived (Figure 8d). When the DPM test was carried out in the centre of the column group (Figure 8a), the improvement effect recorded an obvious increase.

4.4 *Loess and sand mixture compacted columns*

Finally, on the experimental polygon columns of 60% local material (loess) and 40% sand were executed. For the execution of these columns, cone 1 (30°) was also used as rammer.

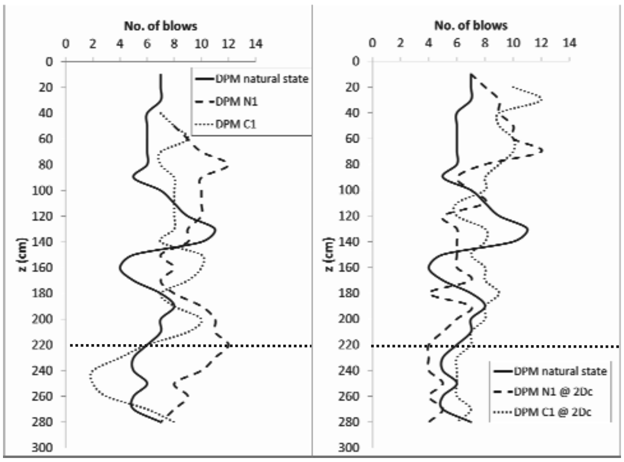

Figure 9. DPM tests results for the column executed from a mixture of loess and sand (N1): a) DPM in the centre of C1 and N1 columns; b) DPM at 2Dc towards C1 and N1 columns

Figure 9a indicates that the results of the DPM tests carried out in the centre of the column executed from a mixture of loess and sand are better that those of the column made entirely of loess. Moreover, it may be noticed that, unlike the compacted loess column, the one made of mixture led to the improvement of the material under the column's body.

Nevertheless, the results of the medium dynamic penetration test carried out near the columns at a distance of 2Dc (~14 cm) indicate that the tamping effect is higher that in case of the loess column.

5 CONCLUSIONS

Laboratory tests aimed at identifying a mixture of loess and natural mineral materials, with better mechanical characteristics and with reduced permeability compared to the one the loess has in its natural state. From all the solutions proposed (compacted loess, mixture of loess and sand and mixture of loess, sand and bentonite) the last one (mixture 4 - sand and bentonite, mixed with loess after drying) seems to be the optimal one due to the wide domain in which optimal compaction parameters are reached.

Concerning mechanical characteristics, no significant differences seem to exist between the analysed mixtures, but one can notice that water sensitivity is significantly reduced and that, compared to the flooded loess, the values obtained are significantly better.

In-situ tests, performed with a penetrometer, simulated the execution of loess columns and of loess with compacted sand columns, at a scale of 1:5. Both the quality of the material in the column body and the effect on the surrounding ground were verified by typical tests. The sand improves the mechanical behaviour of the material in the column body, without significantly exceeding the mechanical behaviour of natural loess that has not been flooded.

By executing columns of compacted local material with natural mineral materials, the mechanical behaviour of the columns - loess complex that has not been flooded does not improve, but this technique leads to some nuclei capable of reducing the negative effect of the accidental flooding of loess.

6 REFERENCES

Bally R.J. and Antonescu I. 1971. *Loessoid soils in constructions*. Tehnica Publishing House, Bucharest. (in Romanian)

Burlacu C. 2012. *Contributions to improvement solutions for weak foundation soils*. PhD Thesis. Technical University of Civil Engineering Bucharest, Romania.

Kirsch K. and Sondermann W. 2003. Geotechnical engineering handbook, Volume 2: Procedures, *Chapter 2.1. Ground improvement*, 1 - 50. Ernst & Sohn, Berlin, Germany.

Olinic E. 2012. Personal comunication.

Schlosser. 1997. *Exposé sur la themè: Améliorqtion et renforce,ent des sols*. Proceedings of the Fourteenth International Confrence on Soil Mechanics and Fountation Engineering, Volume 4, 2445 – 2466, Hamburg, Germany.

NP 125:2010. *Normative for foundation of buildings on moisture –s sensitive, collapsible soils.* (in Romanian)