Time-dependent behaviour of foundations lying on an improved ground

Temps-comportement dépendant de fondations reposant sur un sol amélioré

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ABSTRACT: The paper presents some aspects concerning time-dependent behaviour of the improved foundation soils. The foundation soils can develop favourable or inappropriate resistance properties under the loads submitted by constructions. Engineers and investors encounter more and more difficult foundation soils, in their desire to efficiently use the construction sites. In this case, physical and mechanical properties of the soil have to be improved, in order to sustain the infrastructure and structure of a building. The paper reviews some improvement methods, after presenting difficult foundation soils from Iaşi area. The paper presents a case study regarding problems caused by difficult foundation soils that are present in the region, during the operating period of structures. The presence of water in the foundation soil created a negative impact in its behaviour, which led to differential settlements and, consequently, the buildings were switching from their initial vertical position. The study also analyzes time-dependent settlements of a construction. Finally the paper presents some conclusions resulting from studies both bibliographic and practical.

RÉSUMÉ : Le document présente quelques aspects concernant le comportement en temps des sols améliorés pour les fondations. Le terrain de fondation peut avoir un comportement favorable ou par contre défavorable sous l'action des charges donner par les constructions. Pour utiliser efficacement les terrains des constructions, les ingénieurs et les investisseurs rencontrent souvent des sols de fondation de plus en plus difficile. Dans ce cas, les propriétés physiques et mécaniques du sol doivent être améliorées, afin d'assurer des bonnes conditions d'appuis pour l'infrastructure et la structure d'un bâtiment. Le document passe en revue les sols de fondation difficiles de la zone de Iaşi et des méthodes de les améliorées. Il est aussi présenté une étude de cas concernant les problèmes qui peuvent apparaitre au cours de la période d'exploitation de structures, a cause des ces sols de fondation difficiles. La présence de l'eau dans le terrain de fondation a eu un impact négatif sur son comportement, ce qui a produit des tassements différentiels, ca veut dire que les bâtiments furent commutés de leur position initiale, verticale. Pour conclure, le document présente des conclusions issues de l'étude bibliographique et pratique à la fois.

KEYWORDS: leaning structure, expansive clay, loess, differential settlement.

1 INTRODUCTION

As a result of the analysis performed over time on a large variety of soils and taking into account soil behaviour in the presence of external factors, the foundation soils can be divided in two categories, considering their capacity to support loads from constructions: good and difficult foundation soils.

The entire existence of the building system depends on the stability and strength of the foundation soil and this is the main reason why a special interest is given to the second category of soils and therefore to the specific issues that must be considered in the design, execution and operating period of a construction.

2 DIFFICULT FOUNDATION SOILS

The sites that have a construction soil with good geotechnical characteristics are rapidly decreasing. Large urban areas are a particular problem because, due to the lack of space, it is necessary to reconsider the possibility of placing a building on a soil that was unsuitable for constructions until now.

2.1 *Difficult foundation soils - classification*

These soils are classified as follows:

- macroporous soils (present large cavities in their structure and have the ability to suffer large settlements when are subjected to a wetting process);
- collapsible soils (are characterised by the fact that when in high humidity develop large deformations);
- liquefiable soils (especially non-cohesive soils consisting of saturated fine sand which under the action of a dynamic load suddenly loose their shear strength);
- expansive soils (cohesive soils such as clays, which change their volume when water content varies);
- soils that during the freezing and thawing phenomena change their structure and properties;
- peaty soils (organic matter is present in its structure, have a high and very high compressibility and a low shear strength);
- eluvium (formed as a result of decomposition and alteration of existing rocks);
- saline soils (are characterized by the settlement phenomena that occurs during a long lasting wetting);
- fillings (occur as a result of unconsolidated alluvial deposits) (Iliesi 2012).

2.2 *Methods of soil improvement*

Given the frequency of soils that present unfavourable characteristics for constructions over time were developed methods to improve their mechanical properties, such as:

- soil compaction which can be made on surface (rolling, dynamic, cushions) or in depth (columns, pre-wetting, dynamic);
- chemical soil stabilization (cementation, silicatization, jet grouting, bentonite etc.);
- electrochemical methods (electrophoresis and electroosmosis);
- thermal treatment of soils.

The case study refers to the problems that can occur with an improved foundation soil. The method used for improvement is soil replacing (soil cushion).

3 CASE STUDY

Within the areas with difficult foundation soils, Iaşi City is the largest urban settlement located in the eastern part of Romania. The city lies at the contact between Jijia Meadow and the Moldavian Plateau. The landscape is varied, forming a region consisting of eroded hills crossed by Bahlui plateau.

3.1 *Soil types in the studied area*

Studies performed over the last decades into the existing terraces of the region show that almost 70% from the current area of the city have medium and low suitability for construction purpose, this reason being more or less a natural barrier for city expansion. Theoretical and practical solutions offered for solving the issues caused by these types of soils present a special interest in the current context (Vieru 2010). Among these types of soils there are two specific categories: loess and expansive soils.

The different types of soils existing in the studied area have either a normal behaviour under loads, or an atypical one.

Therefore, upper and medium terraces consist of a succession of coarser sediments at the bottom followed by a loess soil sensitive to wetting. Loess layer is yellow-brown with variable thickness from 8.00 m to 15.00 m lying in the highest areas of the city. Loess deposits usually consist of silty clay and clayey silt.

The loess of Iaşi region has medium plasticity with the liquid limit LL = 30÷50%. Grain-size distribution is: 25÷29% clay, 43÷47% silt and 24÷32% sand. Regarding the uniformity coefficient, the loess of Iaşi City is considered to have a good uniformity (Ciornei & Răileanu 2000).

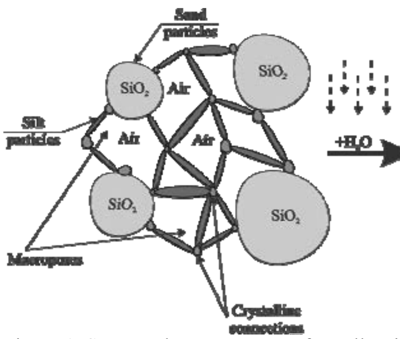

Figure 1. Structural rearrangement for collapsible soils

Bahlui Meadow is characterized as a mixture of sand and gravel layers at the base of the stratification, followed by a layer of fat swelling and shrinking clay. The sand layer has a thickness of almost 4.00 m and the clay is between 5.00 m and 6.00 m. This clay is actually the foundation soil from the area, requiring good knowledge of soil characteristics.

As far as the soil properties are concerned, Bahlui clay falls within the category of high swelling and shrinking soils. Climatic conditions of the area, with temperatures decreasing in the summer with 10ºC...20ºC from day to night and heavy rainfall, lead to changes in soil volume. To avoid foundation deterioration the minimum foundation depth has been set at -2.00 m, as deep as the effects of seasonal variations in moisture content and temperature may not be felt (NE 001-96 1996).

Other factors influencing the volume variation are:

- soil activity – volume variation is influenced by molecular and electro-molecular phenomena reflected by adhesive and capillary water, their size depending on the mineralogical nature of the particles making up the clay fraction and the nature of the absorbed ions;

- hydro-geological conditions – groundwater is present both through deep under pressure aquifers and also through free flow ones. Deep layers have a high mineralization, being intercepted only by drilling. They have an ascending nature, sometimes an artesian one. Shallow drillings revealed the presence of captive water with low mineralization, which can be used locally;

- layer thickness – the thicker the layer is, the bigger its swelling;

- moisturized area – if the wet surface under an existing building is insignificant, the deformations increase and the probability of deterioration grows (Alupoae et al. 2011).

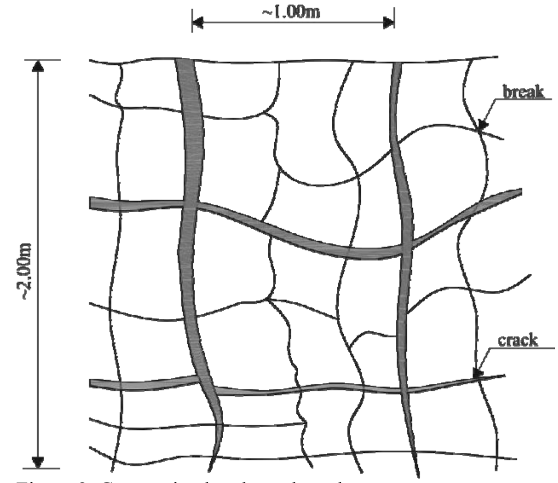

Figure 2. Contraction breaks and cracks

3.2 *On site situation*

The case study follows a residential area placed on one of the hills in Iaşi City, Romania. The increase of water content inside the foundation soil determined a differential settlement and the buildings placed on site were switched from their initial vertical position.

3.2.1 *Data regarding the constructions from the studied area*

The constructions were built during two different time frames:

- Stage 1 – between 1994 and 1998, consists of a two section building 22.0 x 12.0 meters (Section I and Section II), has a total ground surface of 530 m^2, a structure made of reinforced concrete frames placed on network of foundation beams. The foundation rests on a soil cushion, 1.0 meter thick. In 1998 the foundation system was checked and the results showed that the soil cushion placed under the foundation had a degree of compaction of 95.15%. Thus it can be stated that the operations of soil improvement using mechanical means were correctly carried out. On site, a layer of loess, sensitive to wetting, was intercepted in drillings up to 9.0 meters from the ground surface. Under the soil cushion the thickness of the loess layer is about 5.0 ÷ 6.0 meters.
- Stage 2 – the construction of Section III started in 2001, with a built area of about 850 m^2 and a structure and height similar to the initial sections. This section is not entirely finished and the main problem is the fact that no systematization works are carried out. Also, the systems of rainwater collection and disposal are not finished. Because of this, in 2010 a movement was observed.

After the initial observations, measures have been taken to analyze the technical condition of the building and to establish the necessary actions to ensure a proper exploitation for the constructions.

Figure 3. Photos showing on site displacements

3.2.2 *Causes that led to differentiated settlements*

The main cause that led to settlements on the studied case was determined by the increased humidity in the foundation soil. This happened as a result of a deficient vertical systematization: no sidewalks, there were no gradients on site to discharge the water and also there were not built ditches and surface drainage systems. The lack of systematization works led to rainwater infiltrations in the filling layer above the soil cushion used as an improving method for the loss soil on the site. Water bags were formed in the filling layer which supplied the permanent moisture on the layer above the cushion. The humidity of the cushion became 3.14% higher then the optimum compaction humidity (19.40%). Also the filling layer recorded higher values for humidity: 25.07% ÷ 27.52%.

Table 1. Humidity evolution on the site – filling layer

Section	Humidity 1998 [%]	Average humidity 1998 [%]	Humidity 2010 [%]	Average humidity 2010 [%]	Increase of humidity [%]
I	16.98 ÷ 29.16	24.78	19.57 ÷ 30.07	25.83	+4.20
II	17.18 ÷ 24.15	22.45	22.99 ÷ 32.85	26.90	+19.80
III	---	---	18.31 ÷ 33.04	24.40	---

Table 2. Humidity evolution on the site – soil cushion

Section	Humidity 1998 [%]	Average humidity 1998 [%]	Humidity 2010 [%]	Average humidity 2010 [%]	Increase of humidity [%]
I	21.15 ÷ 24.15	21.29	16.37 ÷ 23.81	20.53	-3.70
II	17.11 ÷ 23.69	20.63	18.40 ÷ 24.45	21.77	+5.50
III	---	---	17.61 ÷ 20.64	19.03	---

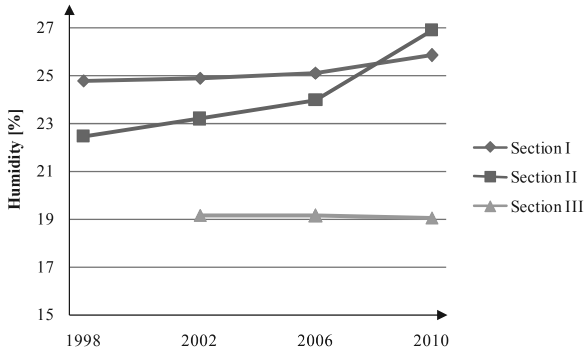

Figure 4. Humidity variation on the site, in the filling layer, for the three sections of the building

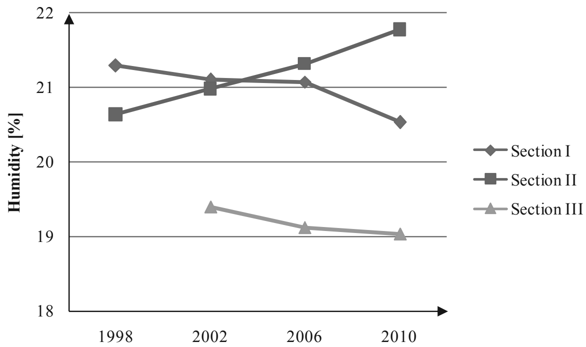

Figure 4. Humidity variation on the site, in the earth pillow, for the three sections of the building

Table 3. Humidity evolution on the site – surrounding area

Section	Humidity 1998 [%]	Average humidity 1998 [%]	Humidity 2010 [%]	Average humidity 2010 [%]	Increase of humidity [%]
I	20.70 ÷ 33.42	26.85	18.90 ÷ 29.36	22.30	-20.0
II	20.70 ÷ 33.42	26.85	18.90 ÷ 29.36	22.30	-20.0

Topographic measurements were made, on the site, for verifying settlements that appeared due to moistening of the foundation soil. By analyzing the results obtained after four cycles of measurements, the following conclusions can be drawn:

- for section I the measured values of settlements are insignificant. This happed because the values fall within the margin of error of the measurements and also because the variations determined at the markers considered stationary must be taken into consideration;
- for section II were found higher values of the settlements at the joint between section II and III. This occurs where the surface water penetrated the ground and produced a pronounced moistening of the foundation soil;
- for section III were also found higher values of the settlements at the joint between section II and III. This occurs where the surface water penetrated the ground and produced a pronounced moistening of the foundation soil.

Established settlements have small values and pose no danger to the behaviour of the building in time. Relative settlements have also small values, $3.65 \cdot 10^5$ millimetres, much lower than the admissible relative settlement, which is, according to Romanian Standards, 0.001 millimetres.

The settlement speed decreases from 0.213 mm/day, after 9 days, to 0.061 mm/day after 22 days and further to 0.006 mm/day after 83 days. This led to the conclusion that settlements are slowing down.

3.2.3 *Proposed solutions*

Continuous monitoring of building settlements and conducting topographic readings at least every three months until the constructions are stabilized.

Efficient vertical and horizontal systematization can be done by making sidewalks, gradients for water discharge, ditches and surface drains.

For stopping water infiltration in the foundation soil is mandatory to check utility networks and repair them where is necessary.

4 CONCLUSIONS

Difficult foundation soils are frequently found on sites located in large urban areas.

Over time, a series of methods and techniques for improving the difficult foundation soils were developed. The implementation of this methods and techniques must take into consideration the soil characteristics intercepted on the site.

In the case of loess soils that are improved using soil cushions a good vertical and horizontal systematization is required to drain the rainwater or the water from other surface sources and to avoid the appearance of settlements.

5 ACKNOWLEDGEMENTS

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