THE CONSOLIDATION OF SOFT CLAY FOUNDATION GROUND USING GEOSYNTHETICS COMBINED WITH THE ELECTRO-OSMOSIS PROCESS

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ABSTRACT

In the last decade, the construction of communication routes has intensified in Romania. As a result, many case studies related to the presence of saturated clayey soils in the foundation ground have emerged. In order to speed up the execution of highways and railways in a safely manner, the designers use different methods of improving soft clays in terms of compressibility.

The present study aims to evaluate the efficiency of an electrical current used for the vertical dewatering of a soft clay subgrade, through simple physical models. The experimental study is being performed on a laboratory scale model by using electrodes and geosynthetics for drainage, along with the vacuum technique.

The vertical drainage capacity during the electro-osmotic dewatering process, combined with preloading, drainage, vacuum and heat induction is being evaluated.

The integrated effect of these methods on the consolidation process will be analyzed for the final conclusions.

Keywords: *electro-osmosis, geosynthetics, drainage, soft clay*

INTRODUCTION

In engineering practice, a common problem is the high compressibility of the reduced consistency clay soils, having values of the IC consistency index <0.5, according to the technical norms in force. In this context, the problem of reducing the compaction of soft clay deposits arises, because of the settling process under the loads induced by the engineering constructions. Another problem complementary to the one mentioned above is the shortening of the time period in which the settlements registered as a result of the consolidation process reach the values admitted from the point of view of the deformation limit state, as a limit state of the normal exploitation, according to the Romanian norms.

As a result, we started a series of experiments focused on the following objectives:

- study of the electro-osmosis effect on the speed of the consolidation process and implicitly, on the values of the main compressibility parameters;
- analysis of the integrated effect of other measures already known and applied in other countries, which, together with the electro-osmosis,

will lead to the reduction of the time required to complete the primary consolidation; In this way, the aim is indirectly to reduce the period of realization of the railways and road embankments and respectively, to improve the soil in order to execute the direct foundations for different types of constructions.

THEORETICAL ELEMENTS

Terzaghi's theory of consolidation

The main assumptions on which this theory is based and implicitly, the laboratory model, are the following:

- the clay is saturated;
- water and clay particles are incompressible;
- Darcy's law is valid in any horizontal section within the saturated clay layer, the total and effective unitary efforts remaining constant in value;
- during the variation of the Δ_n soil porosity, corresponding to the variation of the effective unitary effort $\Delta\sigma'$, the permeability coefficient k and the volumetric compressibility coefficient mv have constant values;
- the clay within the model is laterally confmed;
- the water circulation within the clay layer occurs only in a vertical direction.

Based on the above assumptions, the time variation of pore water pressure within the soft clay layer is generated by the following differential equation:

$$\partial u \partial z = cv2u \partial z2 \quad (1)$$

, where: c_v = consolidation coefficient; it is determined in the laboratory by compression testing – consolidation [m^2/s]; m_v = volumetric compressibility coefficient [m^2/kN].

$$cv = kmvw \quad (2)$$

$$mv = \Delta VV\Delta p = \Delta HH\Delta p \quad (3)$$

In the classical theory of consolidation [1], the evolution of consolidation is expressed by the U_v degree of consolidation, which is determined by the following relation:

$$Uv = StSf \quad (4)$$

, where S_t [m] is the settlement at the t time, and S_f [m] is the settlement recorded at the end of the consolidation process, which can be calculated with the following relation:

$$St = \Delta n \cdot H = mv \cdot H \cdot p \quad (5)$$

The time required to consume the primary consolidation is determined by the following relation:

$$t=\frac{T_v H^2}{c_v} \qquad (6)$$

, where T_v is the time factor that varies with the values of the degree of U_v consolidation.

After the completion of the primary consolidation process, the settlement continues under the p pressure during the secondary consolidation process. However, this settlement, compared to the settlement from the primary consolidation, is negligible.

The electro-osmosis effect on the consolidation process

In the case of normally consolidated clayey-silty deposits, with low concentrations of electrolytes in the pore water, electro-osmosis is a process by which the depth consolidation can be accelerated, a procedure not very well known and/or applied in our country(Fig. 1).

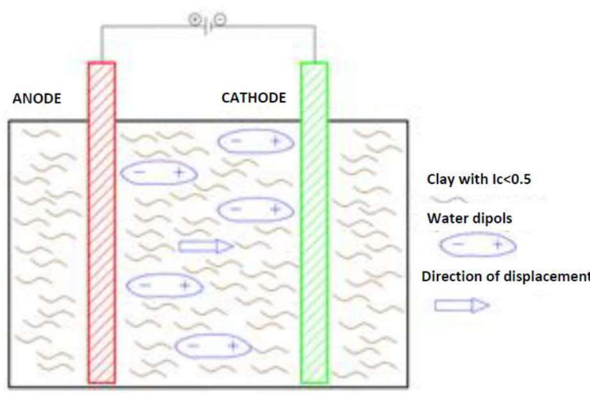


Figure 1. Principle diagram of the electro-osmotic process

If we consider only the hydraulic consolidation, then the flow filtered horizontally according to Darcy's law is:

$$Q_h=K_h i_h \cdot A \quad \left[\frac{m^3}{s}\right] \qquad (7)$$

, where K_h = the permeability coefficient in a horizontal direction [m/s]; i_h = hydraulic gradient; A = the area crossed in front of the moving water (m^2).

The Q_h flow can also be calculated with the following relation [2]:

$$Q_h=K_i \cdot I \quad \left[\frac{m^3}{s}\right] \qquad (8)$$

, where K_i is the flow rate corresponding to the electric current unit between the electrodes ($m^3/s/A$), and I is the current intensity between the electrodes (A).

The flow of water removed from the volume of cohesive saturated soil between the electrodes decreases with time, as the consolidation process unfolds. The reduction of the water pressure from the Δu pores in the area of the anode, compared to that of the cathode area, leads to the start of the filtration process from the cathode to the anode, as a result of the hydraulic gradient that appeared.

Through the measurements made within the laboratory model described in the next chapter, the main specific parameters of the electro-osmosis will be highlighted.

EXPERIMENTAL METHODS

Materials used and their properties

The soil sample used in the experiments consisted of clay-46%, silt-38% and sand-16%.

The sample was grinded, homogenized and mixed with water until a humidity of 46.94% was obtained. The soil sample was then introduced in a plastic container of 27x18x12 cm.

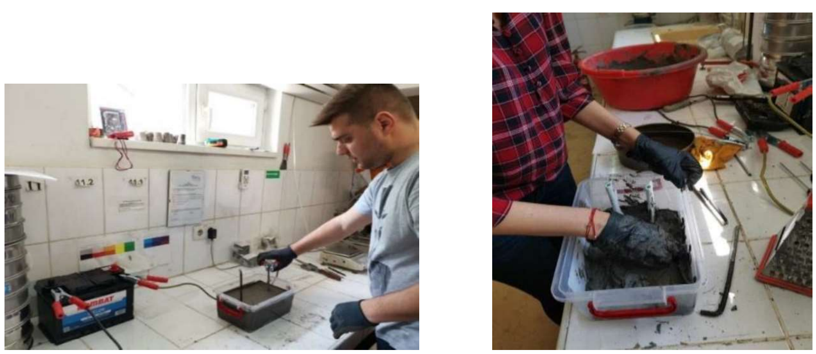
The electrodes used (the anode and the cathode) consisted of two carbon iron bars (OB 37), which were inserted into the ground on the median line of the sample, at a distance of 17 cm, resulting in a voltage gradient of 1.03 V / cm. The power source consisted of a auto rectifier, with power supply at 220 V / 50 Hz, the resulting voltage being 12 V / direct current.

Within the experiments carried out, a series of improvised drains, covered in Polypropylene of 270 g / m^2 and 1.6 mm thickness, were introduced into the soil sample (in the cathode area), to facilitate the drainage process and to accelerate the consolidation..

Experimental model

Variant 1- the phenomenon of electro-osmosis (simple) – Fig. 2

To limit moisture loss during the experiment, the plastic container was covered and the circuit was maintained for 72 hours.



a) b)

Figure 2. Experimental model: a installation of electrodes and connection to the power source; b) installation of drainage covered in geotextile

Variant 2- the phenomenon of electro-osmosis with preload (Fig. 3a)

For the second variant of the experiment, we chose to perform the phenomenon of electro-osmosis together with the preload. Around the anode we put a preload of 3144 g to speed up the consolidation process.

Variant 3- the phenomenon of electro-osmosis and lime columns (Fig. 3b)

In this experiment we chose to combine the phenomenon of electro-osmosis with the execution of columns of non-hydrated lime. As a result, we used the same material as in versions 1 and 2, with an initial humidity of 59.38%. We made a grid of 16 columns, which we filled with non-hydrated lime. This, by releasing heat, reduces soil moisture.

Figure 3. Experimental assembly a) for variant 2; b) for variant 3 - filling columns with lime in the experimental model

Variant 4 - increasing the efficiency of electro-osmosis by vacuum (Fig. 4)

The vacuum consolidation method has become one of the techniques used worldwide for acceleration dewatering and improvement of soft foundation ground. The suction represents the maximum pressure difference generated by the vacuum pump.

Figure 4. Experimental assembly for vacuuming

EXPERIMENTAL RESULTS AND INTERPRETATIVE GRAPHICS

Variant 1- he phenomenon of electroosmosis (simple)

After about 15 minutes from the beginning of the experiment, the effects of the electro-osmosis phenomenon were visible, forming hydrogen bubbles around the cathode. After almost 2 hours, the process of electroosmosis began to take place, this being observed by the fact that the water migrated from the anode to the cathode, forming a film of water near the cathode (Fig. 5a). During the experiment we introduced at different points a thermometer to measure the temperature variation from anode to cathode (Fig. 5b). The temperature around the anode was 22.3ºC, and around the cathode 24.3ºC (Fig. 6).

a) b)

Figure 5. Experimental model: a) the film of water formed around the cathode; b) temperature measurement in the soil sample

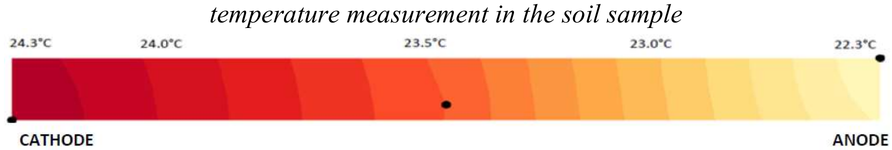


Figure 6. Temperature variation between anode and cathode, measured at the base of the sample

Following the results we can state the following (Fig. 7):

- the humidity difference between anode and cathode is 13.71%;
- the difference of humidity at the anode against the initial humidity is 9.13%;
- at the cathode, the humidity increased by 4.58% compared to the initial humidity.

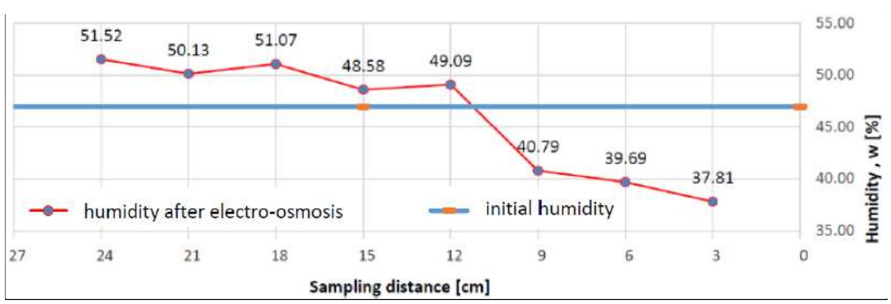


Figure 7. Variation of moisture in the sample

In order to be able to observe the improvement of the foundation ground by the phenomenon of electro-osmosis, we also performed “vane test” tests. We obtained an initial cohesion value of 0.5 kPa and a value of 5.1 kPa following the consolidation process. Also, following the experiment, the anode oxidation was observed, losing 0.36 g, which represents about 0.49% of the initial mass.

Variant 2- the phenomenon of electroosmosis with preload

We followed the same steps as in variant 1 with only one difference, namely, the initial humidity of the material was 80.21%. Following the results we can state the following (Fig. 8):

- the humidity difference between anode and cathode is 56.99%;
- the difference of humidity at the anode against the initial humidity is 40.58%;
- at the cathode the humidity increased by 16.41% compared to the initial humidity.

Comparing the results obtained in both cases, we can say that the results obtained in case 2 are more favorable. Water drainage around the anode is performed faster, accelerating the consolidation process.

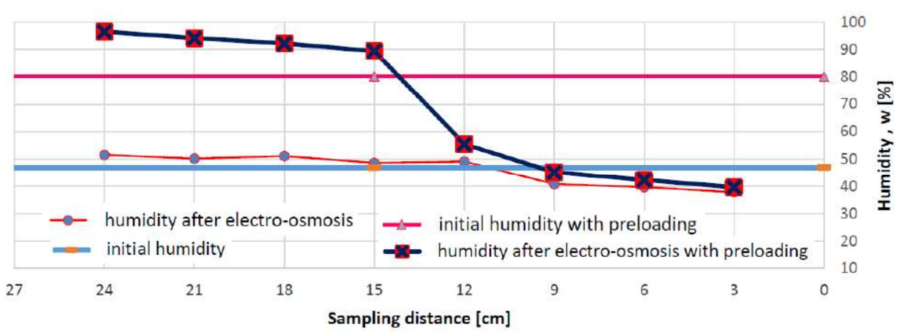


Figure 8. Variation of moisture in the sample

Variant 3- the phenomenon of electro-osmosis and lime columns (Fig. 9)

Around the anode, the humidity in the columns was very close to the initial humidity of the sample, respectively 59.24%, and in the cathode area, it was 87.26%. In this variant, compared to the two above, the humidity obtained in the 8 measurement points did not exceed the value of the initial humidity, so the lime brings an increase of the bearing capacity. Following the results we can state the following:

- the difference of humidity between anode and cathode is 10.40%;
- the difference of humidity at the anode against the initial humidity is 17.03%;
- at the cathode, the humidity decreased by 6.62% compared to the initial humidity, in the case of the two variants above, the result being an increase in humidity.

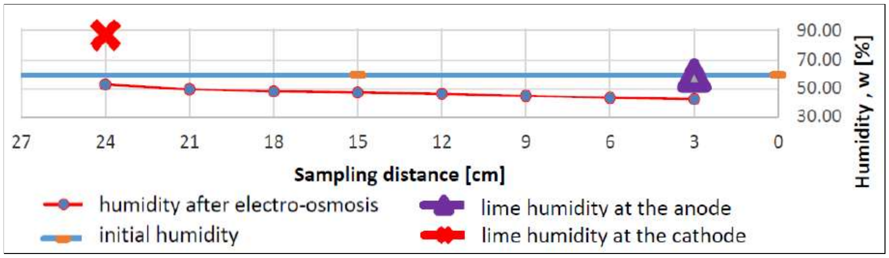
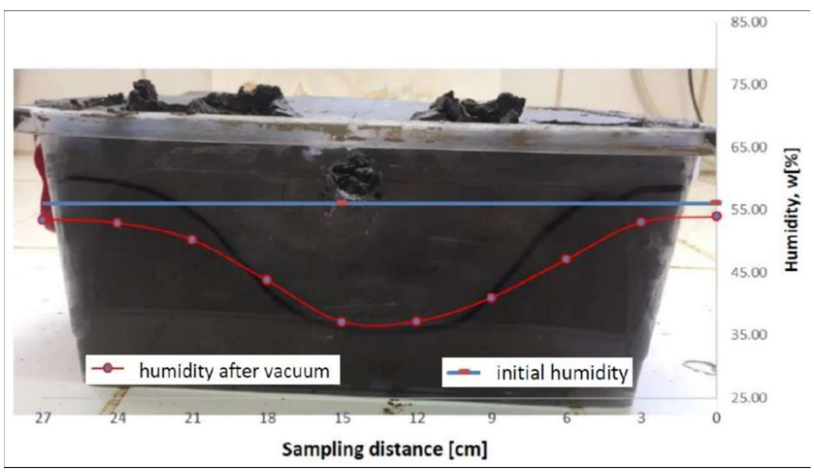


Figure 9. The effect of quicklime on the variation of moisture in the sample

Variant 4- increasing the efficiency of electro-osmosis by vacuum

Due to the suction effect on the surface of the soft clay layer and the cancellation of the atmospheric pressure, the drainage of the clay water in a vertical direction was hastened. As a result, the flow of water that is eliminated by electro-osmosis increases considerably. According to previous research [3], the reduction of the humidity for the 17 cm distance between the anode and the cathode, corresponding to the experimental model, is 6%. Figure 10 shows how the moisture in the clay layer varies through this process in the form of a parabolic curve with the maximum value in the vertical direction of the vacuum point. It is important to note that the effect of the vacuuming process is felt in the first stages of an experiment, which helps to release the free water from the land mass. The elimination of bound water content from the land can be done further by applying electro-osmosis.



Figurr 10. Humidity variation in the sample superimposed over the experimental model

CONCLUSION

According to the conclusions of several researches in order to increase the efficiency of the electro-osmotic process, other processes such as vacuuming and lime use can be used complementarily. ÎIn the first case, the major effect consists in the faster elimination of the water resulting from dehydration by producing a section (negative pressure), which will cancel the atmospheric pressure. In the second case, by the chemical reaction accompanying the hydration of the lime with heat release, the moisture in the clay volume decreases and it acts positively on the mechanical properties of the clay (compressibility and shear resistance). During the research on the efficiency of the electro-osmotic process, we also considered these aspects. The granulomeric composition of saturated cohesive soil mainly influences the effect of electro-osmosis. Thus, if the clay fraction component is large (over 50%), the effect is smaller than in the case of silty clays, the initial osmotic pressures being lower. Therefore, according to the model, the efficiency of the electro-osmotic process can be effected by the simultaneous use of the preload with positive or negative pressure (vacuuming) and, respectively, the treatment of the land with lime. According to the graph in figure 11, the positive contribution of the combination of the effect of the electro-osmosis with other processes from at least two more important aspects is evident:

- increasing the flow of water eliminated/consumed by the exogenous chemical reaction typical of lime hydration;
- increasing the shear strength of saturated, soft clay.

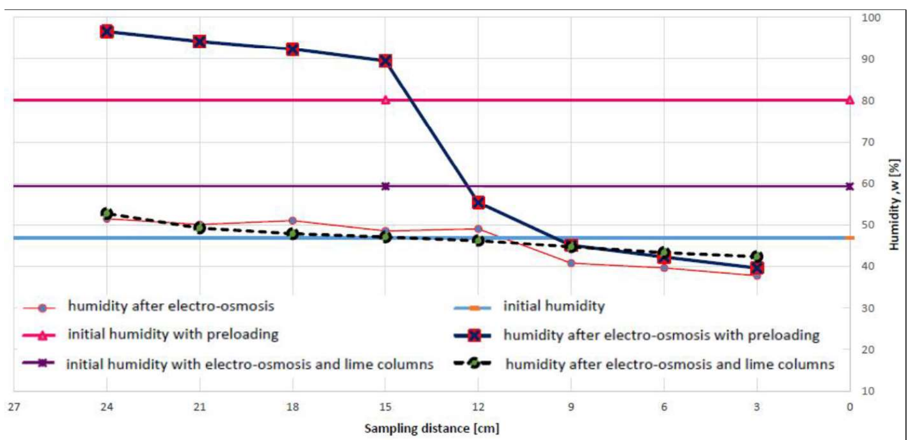


Figure 11. Moisture variation in the sample in the analyzed cases

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