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PHENOMENA OF INSTABILITY DUE TO THIXOTOPY PHENOMENON

Florin Sebastian MUSTĂŢEA

Scientific Coordinator: Assist. Prof. PhD Eng. Adrian ANDRONIC

Technical University of Civil Engineering of Bucharest, Bd. Lacul Tei nr. 122 - 124, cod 020396,
Sector 2, Bucharest, Romania, Phone: +40 21 242.12.08, Fax: +40 21 242.07.81,
Email: florin-sebastian.mustatea@phd.utcb.ro, andronicadrian@yahoo.com

Corresponding author email: florin-sebastian.mustatea@phd.utcb.ro

Abstract

On the territory of Romania, we find a multitude of soils that have a special character from the point of view of physical and-mechanical behaviors, which can raise real problems without a thorough experience and a particular engineering approach. In Romania there are many regions in which there are found soils of low consistency, more specifically soft clays. The behavior of these clays, under the influence of mechanical stresses, has very distinct characteristics, namely: thixotropy and consolidation. Knowing the physical, chemical and mechanical properties of these soils is very useful in establishing engineering measures that will lead to a source of risk as small as possible. In Romania, during the construction of highways, there have been major phenomena of instability and bearing capacity failure of the foundation ground made of soft clays under the loads induced by the embankments of the infrastructure. The Sebeş - Turda highway, in the sector between km 63 + 700 - km 64 + 000, crosses the Stejeriş Lake through an approximately 500 m long viaduct.Alternatively, to this solution, the builder initiated the construction of a fill in the lake as a platform for the highway sector. The filling was constructed of sand and gravel aggregates, all embedded in a soft clay matrix with insufficient characteristics to bind the blocks together and form a whole. Thus, there have been mudslides and landslides in the lake and in the remaining filling there have been identified active landslides towards the lake.

Keywords: *geoelectric measurements, instability phenomenon, low consistency clays, mineralogical composition, thixotropy.*

INTRODUCTION

Given that the construction of highways in Romania is a sensitive matter, because both designers and contractors are confronted with a wide range of geotechnical problems, the subject of this paper is the presentation of an instability phenomenon that has the thixotopic behaviour as the triggering factor.The instability phenomenon triggered in this area led to the degradation of the embankment designed to overpass the area of the Stejeris Lake (Figure 1).

Figure 1 shows a comparison between the situation in 2013 and 2016. Here, we can see the shape of the lake before the construction of the highway section and after the filling, so by overlapping the two areas it can be concluded that approximately 40% of the lake surface was covered with rockfill.

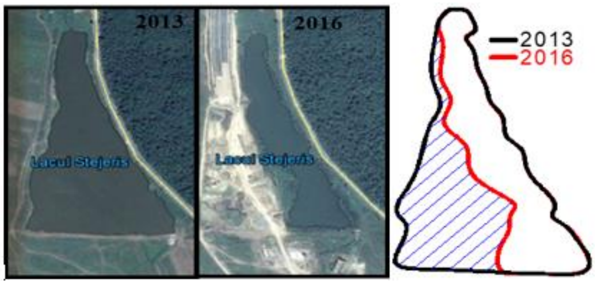

Figure 1. Filling in Lake Stejeris (Google Earth)

For the construction of the embankment cohesive, non-cohesive and even rockfill were used. The implemented technologies induced vibrations both for the embankment and for the foundation ground that later led to the thixotropy phenomenon.

The first to prove the thixotropic and sensitive clay behavior in relation with the engineering works was Karl Terzaghi (1925). A major role in this field was the optical microscopy (Chirică, 1991) and later the electronic one.In order to be able to characterize the phenomenon of geotechnical instability and to take measures to reduce the geotechnical risk generated by the reduction of the cohesion due to the thixotropy phenomenon, the proposed approach is the following: knowing the geomorphological conditions of soft clay deposits, identification of special methods concerning geophysical and geotechnical investigation on site and in the laboratory (eg special sampling techniquesfor low consistency soils), development of physico - chemical methods and computations for the study of thixotropy, special in situ and laboratory tests specific to these soft clays to determine behavioral parameters under mechanical stresses and static and dynamic conditions.

The geotechnical works employed revealed that under the layer of soil fill, on a thickness of about 4.00 - 6.00 m the soil consists of muds, followed by cohesive or poorly cohesive soils (clays, silty clays, sandy clays), found in variable consistency states. The proper foundation soil was identified at a depth of 13.00 - 15.00 m from the base of the fill and is represented by clays and silty clays, plastically stiff to firm.

MATERIALS AND METHODS

For the geotechnical investigation, the following were carried out: 5 geotechnical drills with a depth from 19.00 m to 25.00 m (from the boreholes, undisturbed samples were taken in Shelby tubes from which mechanical parameters were obtained), inclinometric measurements indicating the possible depths of the sliding surface, geoelectric measurements and, last but not least, diffractometry analysis to determine the mineralogical nature of the analyzed soils.

A SISGEO digital inclinometer was used to monitor land movements (Figure 2).

Figure 2. SISGEO inclinometer

Inclinometer is a tool for measuring angles (inclination) in relation to the vertical (gravitational direction), so itis used to monitor lateral movements of the soill mass in areas with landslides, overflows, deep excavation walls, etc.

Geophysical investigations were conducted through geoelectric surveys. These include all methods of the earth's crust investigation based on the study of the dependence between electromagnetic phenomena and physico-geometric parameters (depth, resistivity, thickness, porosity, etc.) of the component rocks. In this project, one of the best-knownmethods - Electrical Resistivity Tomography (ERT), was used. The ERT method consists in determining the resistivity along the observation profile with a succession of measuring devices, at which the equidistance between the electrodes increases successively, depending on the depth of investigation that is intended to be reached.

The measuring device used in the measurements is Wenner + Schlumberger (Figure 3).

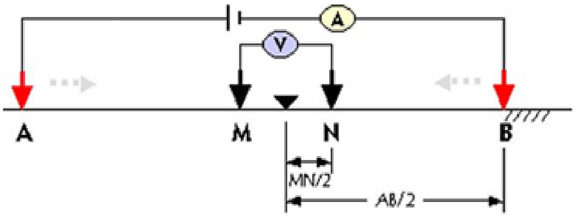

Figure 3. The Schlumberger device

This multi-electrode cable with active sockets consisting of 64 electrodes equidistant from 2.00 to 3.30 m is mainly used for prospecting horizontally layered terrains. The equipment is characterized by the fact that the distance between the MN electrodes is much lower than that between the AB electrodes (MN <AB / 5).

It is imperative to know the mineralogical nature of the clays because it depends on thixotropy. It is known that among the clay minerals, montmorillonite exhibits the highest thixotropy, thus explaining the strong tixotropic properties of bentonite. For the optical analysis of these minerals it is extremely important to refer to the treatment of the mineralogical composition, so that depending on the role played by each of the main constituents in the textural structure we can have an overview of the definition of the physico-mechanical properties.To determine the mineralogical composition, a XRD diffractometer (Figure 4) was used in which the radiation source and the detector were located on the circumference of a circle (goniometer) to control the incidence angles, the sample to be analyzed occupying the center of the circle (Bragg-Brentano geometry). Peak positions occur if the X-ray beam has been constructively diffracted by the crystalline network. The unique set of interplanar d spacings can be used to identify the mineral.

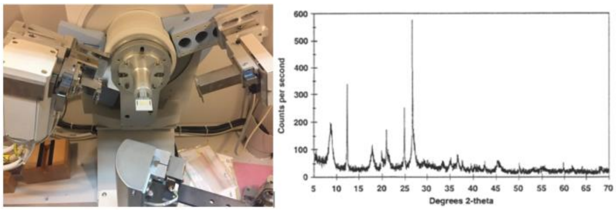

Figure 4. XRD diffractometer and diffractogram

RESULTS AND DISCUSSIONS

As a result of the laboratory tests, the land intercepted in geotechnical drilling granulometry falls within the field of clays, fatty clays (Figure 5), these being in a state of "plastically soft" and "plastically consistent", 0.25 ≤Ic <0.75, with very high plasticity Ip>35%.

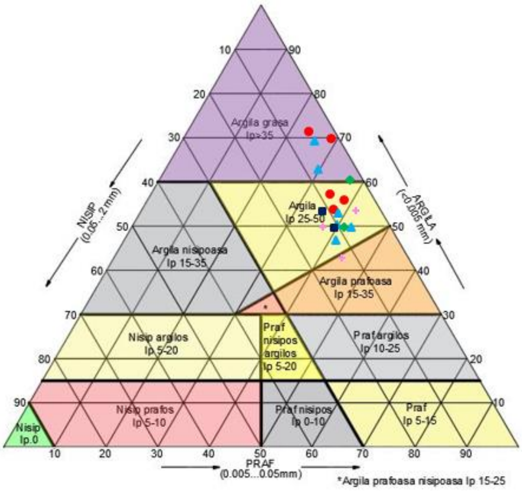

Figure 5. Granulometric distribution

Porosity, noted by n [%], for analyzed samples falls within a large range of values n = (40 ÷ 65)%, these values being specific to unconsolidated deposits. From the point of view of the compressibility parameters, the $M_{200-300}$, the values obtained from the laboratory tests, classifies the lands in the very high compressibility range (M200-300<5000 kPa).

X-ray diffractometry can be applied on monocrystalline or in powder. For the study of clay minerals, due to the standard treatments applied to fraction separation <2µ, dry suspensions were analyzed on the glass blade according to Figure 6.

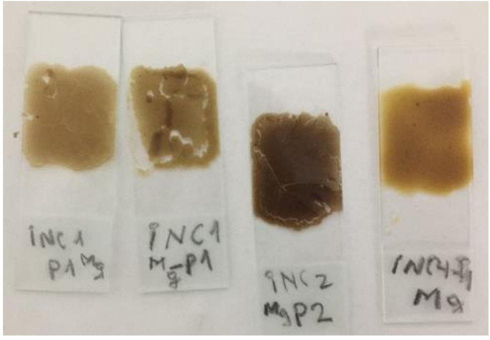

Figure 6. Placing the analyzed samples on the blade

For the analyzed samples, the mineral phases identified in the fraction <2µ are the following montmorillonite, illit, chlorite, kaolinite and iillite / smectite interlayers (Figure 7).

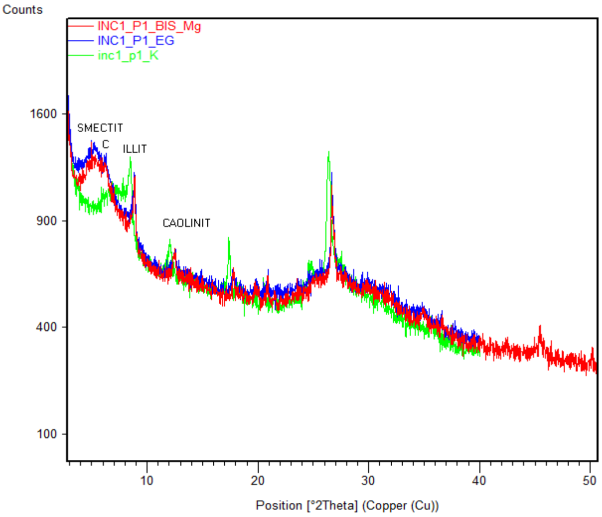

Figure 7. Diffractogram of analyzed samples

Figure 8 shows the semi-quantitative results for each analyzed sample, and we can see how the samples INC1_P1, INC1_P2 and INC4_P1 have a very high content of montmorillonite, which shows us that the soil can be considered thixotropic.

Proba	smectit (montmorillonit)	clorit	illit/ smectit	illit	caolinit
INC1_P1	44%	27%	9%	18%	2%
INC1_P2	48%	0%	16%	34%	2%
INC2_P2	26%	17%	22%	34%	1%
INC4_P1	38%	15%	17%	29%	1%
Media	39%	14.75%	16%	28.75%	1.5%

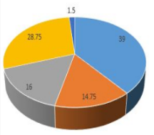

Figure 8. Semi-quantitative results

Montmorillonite (Figure 9) is characterized by a TOT philosophical structure (structural unit consisting of an octahedral layer between two tetrahedral layers) (Zamfirescu et al., 1985). etrahedron positions can be occupied by Si^{4+}in substitution with Al^{3+}in variable proportions, which determines octahedral linkage substitutions (Mg^{2+}ion and Fe^{2+}substituted by Al^{3+}). These substitutions lead to the emergence of negative residual charge on the pack, which are usually neutralized by the adsorption of polar water molecules.

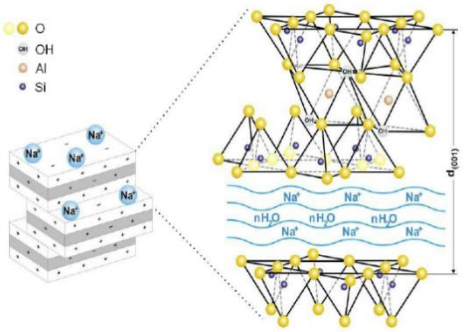

Figure 9. The montmorillonit structure

The electrometric analysis was carried out by means of 4 longitudinal geoelectric profiles and 32 transversal geoelectric profiles located according to Figure 10. Here it should be specified that for the cross-sectional profiles measurements were necessary also on the Stejeris Lake, which represented a national premiere.

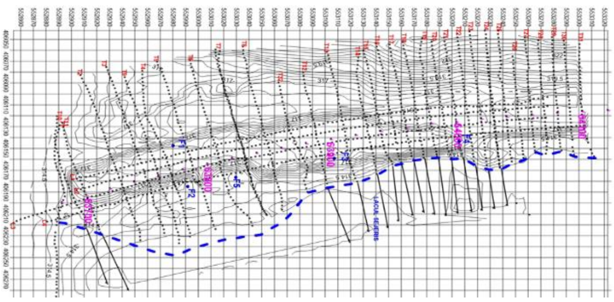

Figure 10. Location of electrometric profiles

From the analysis of the longitudinal geoelectric section (Figure 11), the following conclusions can be drawn regarding the filling and lithology of the foundation ground:

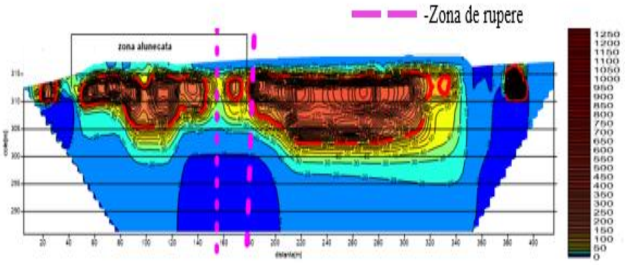

Figure 11. Longitudinal geoelectric section

Under the filler there is a thin layer of 0.50 - 1.00 m with resistances ranging from R = 40 - 60 Ωm indicating a mixture of soil in the ground and less coarse material in the filler. Consequently, we can say that the natural ground (bottom of the lake) can be found from the depth of 6.00 - 8.00 m.

Also, analyzing the thickness of the fillings at different distance intervals (10.00 m and 20.00 m), as shown by the transverse longitudinal sections, the filling did not settle evenly on the bottom of the lake and practically differed from 10.00 m to 10.00 m respectively the foundation conditions will be different.

Analyzing the values of the resistivities measured in the natural depth of the foundation (h = 8.00 - 35.00 m), we can see that they have small values ranging from R = 5-30 Ωm, characteristic of the saturated (flooded) cohesive lands, delimiting the following intervals resistivity, R = 5 - 10 Ωm; R = 10 - 20 Ωm; R = 20 - 30 Ωm.

From the analysis of the longitudinal geoelectric sections, we find that there is a sliding of the filling, a break.

Analyzing the transverse geoelectric sections, we can analyze at sections T5 (Figure 12) and T12 (Figure 13) that they show a pronounced inclination of the filling to the lake with an angle β = 16° - 32°indicating a possible sliding plane. The sliding plan is also confirmed by the existence of small islands formed from the material that has slipped from the filling off the lake.

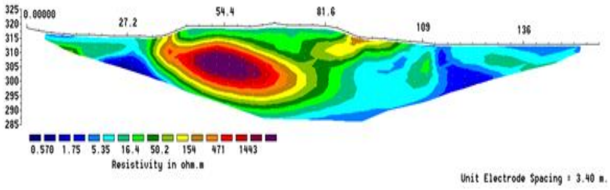

Figure 12. T5 transverse geoelectric section

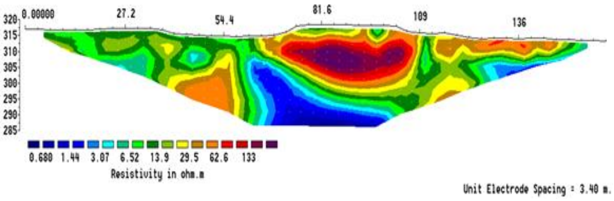

Figure 13. T12 geoelectric cross section

From the analysis of the values of the inclinometric readings, we find the following: the horizontal displacements in each drilling with the direction towards the lake, the largest displacement (+ 8mm) is recorded in the drilling 1 at the depth of 5.00 m respectively in the filling. Also, from the analysis of the data presented in Figure 14, we find the existence of several sliding plans - one in the filling at 5.00 - 6.00 m depth, at the contact between the filling layer and the plastically soft clay layer in the foundation ground. Another plan at 8.00 - 9.00 m depth in the foundation ground at the contact between the plastically soft clay layer and the plastically consistent clay layer. Consequently, it can be concluded that the process of reinforcing the continuous filling and extrusion of the filling is also accelerated by the deposits behind the filling.

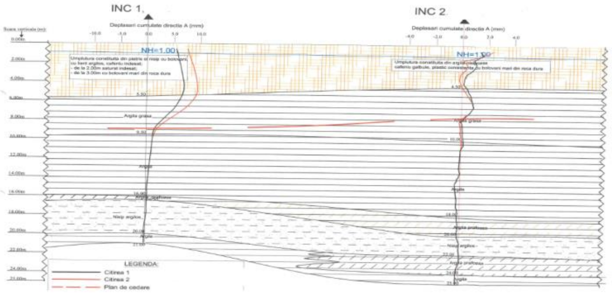

Figure 14. Position of the plan of sliding

In order to highlight this thixotropic behavior (Bancila et al., 1979), we have performed direct UU shear tests immersed on undisturbed samples as well as vibration samples. Before making the shear specimens, I have vibrated the material with a vibrating mass, so I tried to play back the situation on the ground. The shear results lead us to a reduction in cohesion, the ratio of which is 2.26 (Figure 15), which is why this clay is a medium-sensitive soil.

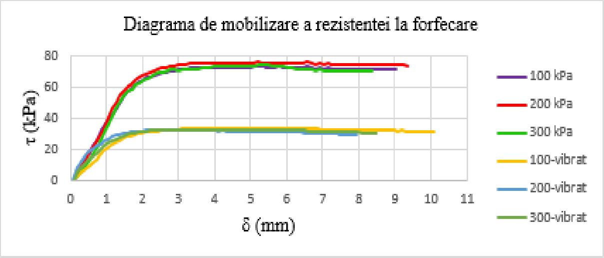

Figure 15. Stress-deformation curves for a clay

The modeling of the instability phenomenon has been accomplished with the help of specialized calculation programs based on both the limit equipments and the finite element method (FEM), programs that solve general stability problems in two-dimensional conditions adapted to allow for stability analyzes for sliding and non-circular surfaces.

For the stability calculation, a cross-sectional profile of the analyzed area was selected, on which geoelectric measurements were performed, in the neighbourhood of which the F1 and F2 drillings were made and these were monitored inclinometrically. In order to highlight the effect of the dynamic compaction of the filling on the soft clay layer, an overload of 200 KN/m3, corresponding to a compaction force of 2 kg/cm2, was applied to the embankment.

The analysis was performed in two hypotheses (variants) depending on the geometry of the filling. In variant 1 the filling layer considered is in the embankment and in the variant 2 the filling (the number 3) was made at an angle of 18° according to the geoelectric measurements. In Figure 16 is presented the calculation model (variant 1), in which it is considered that the layer numbered with 1 is the filler, 2 - embankment body, 3 - plastically stiff clay, 4 - plastically consistent clay, 5 - plastically soft clay, the aquifer level is at the natural ground.

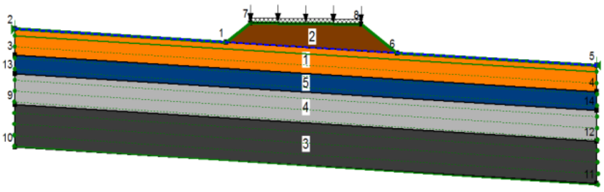

Figure 16. Calculation model-variant 1

Following the model analysis in variant 1 resulted a stability factor of 0.728 indicating the instability of the area at the contact between the plastically consistent clay layer with the plastically stiff clay layer.

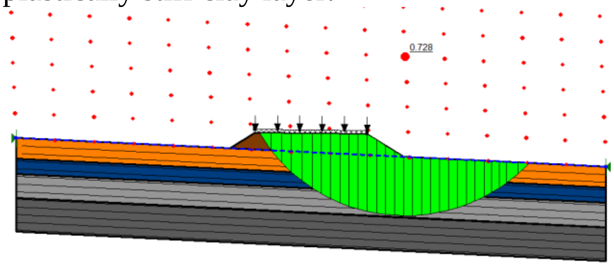

Figure 17. Factor de stabilitate varianta 1

In Figure 18 there is presented the calculation model (variant 2), in which it is considered that the layer numbered with 1 is the plastically stiff clay, 2- the embankment body, the 3-filler, 4-5- the plastically soft clay, 6-7 – plastically consistent clay, and the aquifer level is at the natural ground.

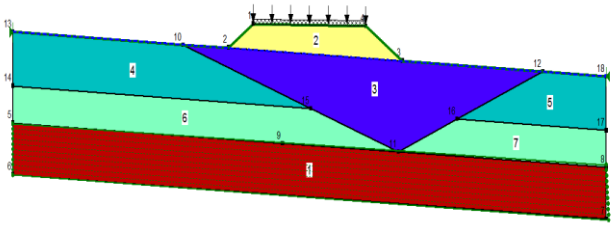

Figure 18. Calculation model-variant 2

Even if the calculation model in variant 2 was different from the variant 1 and in this case we obtained a value of the subunit stability factor, Fs = 0.869, the slip plane being intercepted also at the interface between those of the plastically consistent clay and of the plastically stiff clay.

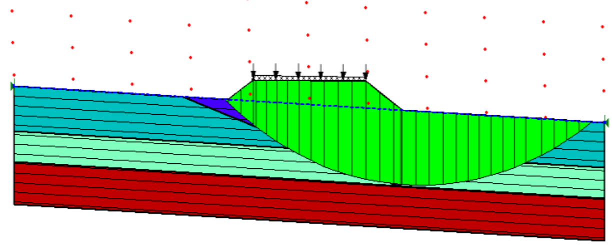

Figure 19. Stability factor variant 2

CONCLUSIONS

Saturated clay on the bottom of the Stejeris Lake has a mineralogical content rich in clay minerals, especially from the smectite group (montmorillonite), about 50%, so they have led to a phenomenon of instability that is hard to explain unless special attention is paid to mineralogical analysis

Due to its manifestation, thixotropy is an important cause of landslides because it can lead to a substantial reduction in shear resistance.

"In situ" monitoring of the instability phenomenon that affected the Sebes - Turda highway in the area of the Stejaris Lake through complex and conjugated methods (geotechnical investigations, geophysical investigations, inclinometric measurements, analyzes in mineralogy and earth mechanics laboratories, and mathematical modeling) allowed a correct understanding of the geotechnical risk induced by the relationship between the future geotechnical structure and the foundation ground.

Following the analysis of all the obtained documentation, design solutions have been adopted to ensure the strength and stability of the construction under normal operating conditions.

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