Soft soils improvement solution. Design based on the laboratory test results on scale model

Solution pour améliorer les sols tenders. Calcul basé sur les résultats de l'essai an laboratoire sur un modèle a échelle réduite

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ABSTRACT

The paper refers to a national road sector approximately 5km long that was built on a swamp area. The general slope of the adjacent ground surface lead to the formation of a small concave area where the rainwater gathers and floods both the 1.5-2.0m tall embankment base and subgrade. Thus, due to the field geomorphology, which had not been properly taken into account within the frame of the geotechnical report, during the rainy seasons of the year, autumn especially, the level of the underground water table may rise to a depth of 1.60÷2.00m, very close to the natural ground level. In order to choose and dimension the measures for increasing the subgrade bearing capacity, in the laboratory were performed tests on samples prepared from reduced scale model. From the very beginning risen the solution of micro piles made of a lime, cement and sand mixture. The micro piles fulfilled a double purpose: on one hand they accelerated the primary consolidation process and on the other hand they lead to the improvement of the structured clay physical and mechanical properties. In the paper are presented the laboratory test results both on natural soil and treated one. The parameters obtained from laboratory were used in the model of foundation ground vertical and radial consolidation.

RÉSUMÉ

Le document porte sur un secteur d'une route nationale d'environs 5km en longueur, qui a été construite dans une zone marécageuse. La pente générale du terrain adjacent a entraîné la formation d'une petite zone concave, où les eaux de pluie se ramassent et inondent aussi bien le remblai d'une hauteur de 1.5-2m et le fond de la fouille. Ainsi, à cause de la géomorphologie du terrain, qui n'avait pas été prise en considération d'une manière adéquate dans le cadre du rapport géotechnique, pendant les saisons pluvieuses de l'années, surtout pendant l'automne, le niveau de l'eau souterraine peut se lever à une profondeur de 1.60÷2.00m, très proche du niveau du terrain naturel. En vue de choisir et dimensionner les mesures afin d'accroître la capacité portante du fond de la fouille, des essais ont été effectués dans le laboratoire sur des échantillons préparés à partir d'un modèle à échelle réduite. Dès le début on a envisagé la solution de micro pieux composés d'un mélange de chaux, cément et sable. Les micro pieux ont eu un double but: d'un coté ils ont accéléré le processus de consolidation primaire et de l'autre coté ils ont conduit à l'amélioration des propriétés physiques et mécaniques de l'argile structuré. Ce document présente les résultats des essais en laboratoire sur le sol naturel, aussi bien que sur le sol traité. Les donnés des paramètres obtenues dans le laboratoire ont été utilisées dans le modèle de consolidation uniaxe et radiale du terrain de fondation.

Keywords: soft soils, consolidation, laboratory testing

1 INTRODUCTION

The stabilised soil solution is generally used in road constructions a replacement of ballast or crushed stone layers as the road bed. The classical method consists of mixing a binder as cement or lime with the natural soil in order to make it stronger and stiffer. The bad experience of using high plasticity and expansive fat clays as a foundation ground, risen the solution of soil mixed-in-place with lime. The hydrated lime reduces the plasticity and increases the strength of cohesive soils. The paper shows the geotechnical experiments results obtained on a scale model representing the treatment of a bad foundation soil of a road sector from the Bârlad river catchment area, Galați County, Romania location presented in Figure 1.

2 LOCATION OF THE INVESTIGATED AREA

As can be see in Figure 2 the national road sector is approximately 5km long and it was built on a swamp area. The field geomorphology was not taken into account during the field investigations done for compiling the geotechnical report so that, during the rainy seasons, the level of the underground water table rise up to 1.60÷2.00m deep, very close to the natural ground level accompanied by settlements in the embankment body, both in longitudinal and transversal direction.

From the geo-morphological point of view, the site lays within Bârlad corridor (according to the Romanian Geography – Academy Ed. 1992), which represents one of the most important hydrographical arteries of Bârlad plateau. Bârlad River crosses Bârlad Plateau approximately through the middle, connecting the cities Vaslui and Bârlad, representing at its turn transportation and economic convergence axis.

The alluvium plain of the river has, crosses Bârlad city area over about 3.00km. At the base of the Tutovei hills which border the Bârlad corridor to the west, may be found a strip of glacial deposits which gradually merge into the flood plain full of moist depressions, abandoned branches, pools and dry sandbanks.

The analyzed road is built to the southern part of the plateau, in the middle of the catchment area of Bârlad River and has unfavourable geographic conditions, the most part of it being situated in the oversaturated and easily flooded alluvium plain of the river. The entire ensemble of Bârlad plateau has a temperate climate, strongly influenced by the continental air masses coming from Eastern Europe.

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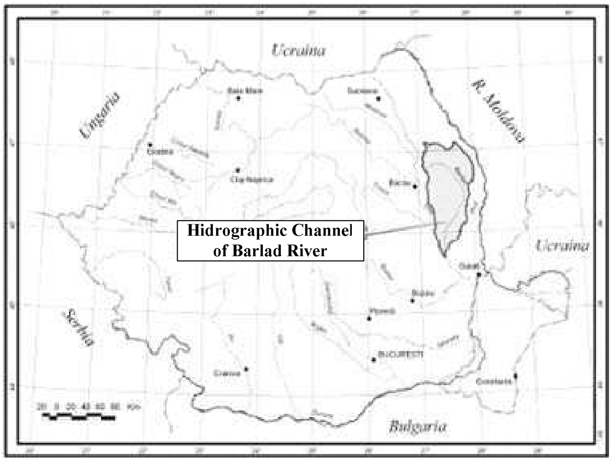

Figure 1. Geographical position of analyzed area

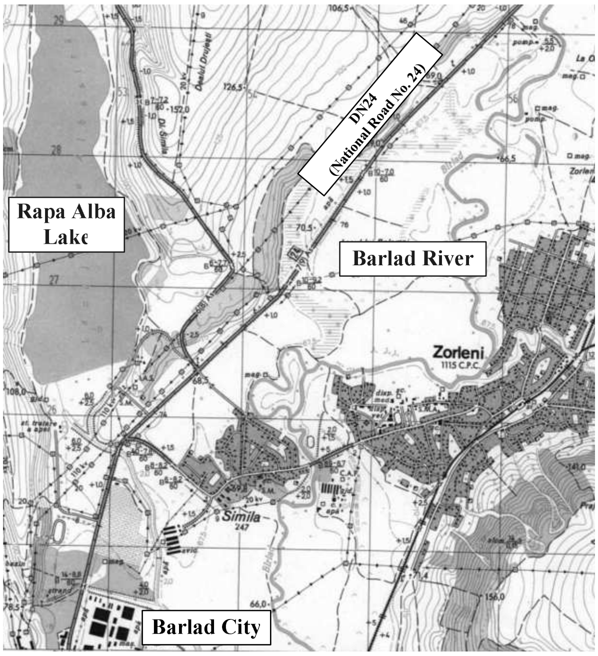

Figure 2. Topographical and hidrogeological details on the road sector

3 CONCLUSION REGARDING THE DEFORMABILITY OF THE EMBANKMENT – FOUNDATION GROUND SYSTEM

From the deformability point of view, two cases may be considered:

- the natural state for which the embankment is well designed, compacted at optimum moisture content while the natural ground is saturated or quasi saturated,
- the flooded case for which the embankment deforms along with the foundation ground; this situation corresponding to the situation appeared after the exceptional rainfalls during August the 12th 2006, when 47.6-60.2 l/sq.m were recorded in the analysed site region.

The second case was recorded during the rainy periods of September – October of the same year appearing due to the fact that the road surface drainage system remained unfinished.

The backfill was flooded and damaged by the water at the lower part of the embankment from the ground water table raised to the soil surface. From the analysis of the transversal profiles it results that there are areas where the anti-capillarity layer of ballast transformed by flooding in a water access path under the backfill, changing the mechanical properties of the clay used for the embankment body and inducing swelling. If the geo-morphology of the area is noticed it may be remarked that the shape is predisposed to such phenomena due to its hollow aspect and the marsh vegetation.

As a result, due to the deformability increase of the backfill-foundation ground system, various traffic-induced cracks appeared along the road. It was necessary to find remedial measures leading to the improvement of the backfill and the foundation ground mechanical properties by increasing the bearing capacity and drainage conditions. These measures were to be taken only after all the water sources of the flooded layer are removed by building a surface drainage system as well as a longitudinal drain to remove the water from the site.

4 GEOTECHNICAL REPORT – EMBANKMENT AND NATURAL GROUND CONDITIONS

From geotechnical report issued for the analysed road sector rise the following ground conditions:

- for the backfill it was used a granular material (cobbles and coarse sands); the body of embankment was strongly damaged by traffic loading, improper compaction, insufficient slope protection and poor drainage condition,
- for the natural ground, the upper part (the topmost 1.0-1.5m) a layer of brownish silty clay to fat clay up to 5.0m depth; the cohesive layer was in saturated condition, having large porosity (up to 40%) and plasticity index (I_p>40%); due to nature of soil, the mechanical test shown large compressibility, swelling properties and deformability problems evolving in time; under these cohesive layers is a cohesionless one, represented by silty sand to sand, yellowish to brown, in dense state; the layer represent the bad layer where the ground water level may be intercepted (as a dynamic level in direct correspondence to level of Bârlad river).

From geotechnical tests appear as a major problem of the site the large consolidation coefficient and low bearing capacity due to the soil nature and the improper drainage conditions.

5 RECOMMENDED MEASURES

Taking into account the above mentioned problems and using the results of the in-situ (Lightweight Dynamic Cone Penetration Tests) and laboratory tests, it was recommended the increase of the load bearing capacity of the backfill foundation ground system using cement or lime and sand piles. These piles are used on large scale to reduce the moisture of the soil, to increase the load bearing capacity and the shearing strength. The hydrated lime properties reduce the time required for the consolidation process appeared on site and should be taken into account for limit state computation.

The proposed solution consisted in piles done to a depth of at least 5.0m where they are to be embedded in the sand layer. The soil is treated by anhydrite lime since it produces the replacement of the mono-valence sodium positive ions (Na+) with bi-valence positive ions (Ca2+). It was proposed to form a grid under the backfill (embankment) having the side of 1.0m where the nodes consist of 5m long lime piles.

The cement, anhydride lime and sand mix piles were to be made by mixing in place with the natural soil layers using continuous flight auger equipment pushed in the soil by a screw motion to the desired depth where the resistance to dynamic penetration rises considerably.

When the auger reached the provided depth, the rotation direction is reversed and the anhydride lime with cement and sand mix is introduced in the ground using compressed air, through the openings under the mixing tool.

The withdraw speed should be approximately 10% from the initial speed in order to obtain a good mixing of the components. The low speed is also imposed by the small diffusion speed of the Ca2+ positive ions in the cohesive soils.

The soil is compacted during the auger withdrawal by the inclined shape of the blades.

By flocculation and reduction of the soil moisture as a result of the replacement of the mono-valence positive ions from electrical double layer are replaced by calcium bi-valence positive ions, the stabilized soil becoming less sensitive to the moisture variation influence.

The addition of the binder mix accelerates the stabilization process of the ground and improves its mechanical characteristics. The addition of cement helps to obtain a higher mechanical strength and the acceleration of the calcium ions diffusion in the ground.

The lime and sand piles may be done using recoverable tubing. After the necessary depth is reached (approximately 5.0m below the embankment backfill limit) the lime-sand mixture is be introduced on batches filling about 50cm the borehole and as the mixture is compacted while the tube is withdrawn in steps of 50cm, after which and the procedure is repeated. In the first stage the lime and sand piles are done after which there are made the cement - lime piles.

It is appreciated that by the execution of these piles a global shearing module of $E=200daN/cm^2$ is be obtained for the foundation ground and as a result the settlement of the backfill-ground system decreases considerably.

A general cross section through treated foundation ground and embankment is shown in Figure 3.

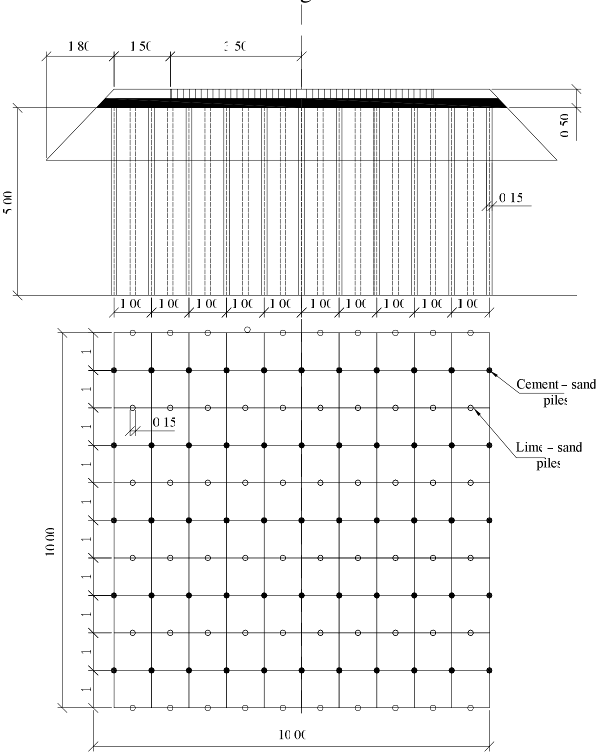

Figure 3. Proposed solution – cross section trough embankment and treated soil foundation

6 GEOTECHNICAL LABORATORY PROGRAMME

The proposed treatment solution (applied to natural ground) was tested in laboratory on a 1/20 scale model. From an open pit undisturbed soil sample were taken as shown in Figure 4. The dimensions of transparent boxes are 20x20x25cm and contain natural soil from 1.5m depth bellow natural ground level. The soil nature is mainly represented by firm to soft fat clay, with high plasticity.

One sample was treated using mixed in place piles consisting of two different solutions:

- for cement, anhydride lime and sand piles the following mixed solution is proposed: 13.5% cement, 9.6% anhydride lime and 76.9% fine sand.

- for the anhydride lime and sand piles the proposed mixture was 45.7% anhydride lime, 51.4% fine sand and 2.9% gypsum.

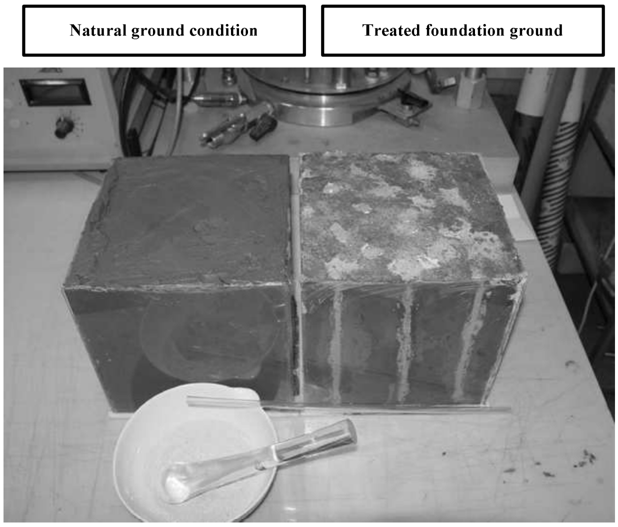

Figure 4. Layout of scale model – natural and treated soil

After 2 weeks from both types of soil (natural and treated) oedometer samples were taken. During the first phase, tests on natural soil were performed in order to compute the compressibility and consolidation processes coefficients.

The tests results for the 5cm diameter oedometer samples are shown bellow and graphically representation of specific deformation versus time, for 50kPa vertical stress, is presented in Figure 5.

$\varepsilon_2=$	20.41	%
$\gamma=$	17.2	kN/m^3
N=	57	%
$S_r=$	0.97	%

Where: ε is the strain, γ is the unit weight, n is the porosity and S_r is the saturation degree.

The compressibility results, in terms of oedometer modulus for various applied vertical stress increments expressed in kPa, are shown bellow.

$M_{25\text{-}50}=$	943	kPa
$M_{50\text{-}100}=$	1302	kPa
$M_{100\text{-}200}=$	2331	kPa
$M_{200\text{-}300}=$	4167	kPa
$M_{300\text{-}400}=$	5587	kPa
$M_{400\text{-}500}=$	9174	kPa

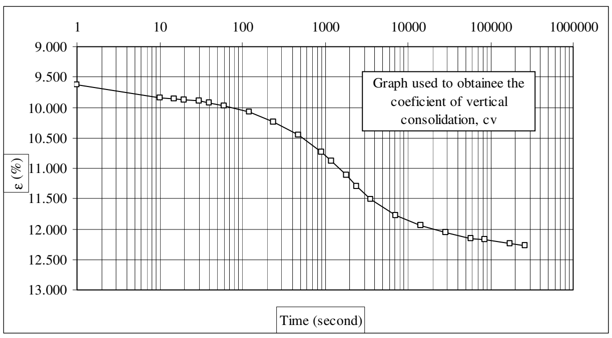

Figure 5: Specific deformation versus time

Table 1 The consolidation tests data

σ (kPa) (kPa)	c_v (cm^2/s)	k (cm/s)	c_v (m^2/year)
50.00	6.256E-04	6.631E-06	1.973E+00
100.00	5.255E-04	4.036E-06	1.657E+00
200.00	4.346E-04	1.864E-06	1.370E+00
300.00	3.455E-04	8.293E-07	1.090E+00
400.00	2.291E-04	4.100E-07	7.224E-01
500.00	3.405E-04	3.712E-07	1.074E+00

In the above σ is the normal stress (geological self weight and the one induced by traffic loads), c_v is coefficient of vertical consolidation (on vertical direction) and k is the permeability coefficient. These results were used to compute the settlement and effective time necessary to consume the consolidation process. Taking into account the following data:

- the width of soft clay layer equal to 4.0m,
- the effective stress in the middle of the layer is

$$\sigma = 2.5\text{m} \cdot 20\text{kN/m}^3 = 50\text{kPa} \quad (1)$$

- the value for the vertical consolidation coefficient, c_v=1.973m^2/year,

Results

$$t_{100} = \frac{2 \cdot (5.0\text{m}/2)^2}{1.973\text{m}^2/\text{year}} \cong 6.4\text{years} \quad (2)$$

which is the time necessary to consolidate in double drainage condition the soft layer. The computed total settlement is the following:

$$s = \frac{1}{1302kPa} \cdot 50kPa \cdot 5.0m = 0.19m \quad (3)$$

It was designed the system of lime – sand – cement piles in order to decrease the time for the consolidation process and also to increase the bearing capacity of the foundation ground. The hypothesis input parameter was the degree of consolidation of 80% to be consumed in one year.

The result shown piles grid 1.0m distance between axes (see figure 3). The results was applied to a scale model and checked on compressibility values using oedometer test on 7.0cm samples as can see in Figure 6. The results displayed an increase, for the same increments of loads as shown in Table 1, by three times.

Complementary, the natural soil became hard due to the strongly exothermic reaction that starts when anhydride lime is used (the diameter of piles on the model, initially equal to 0.8cm increased by 20%).

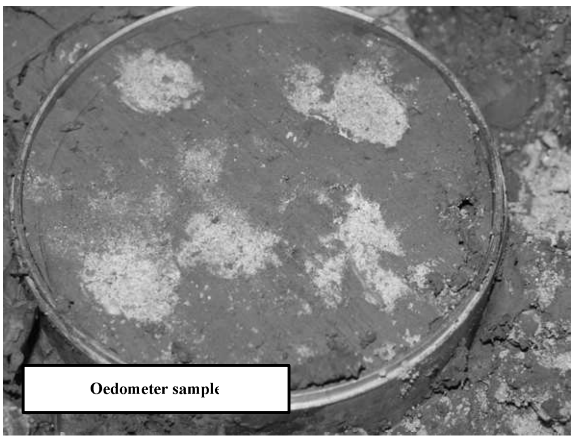

Figure 6. Oedometer sample taken from treated soil

7 CONCLUSIONS

From the laboratory tests performed on soil treated with a binder mixture at scale model reveals the following remarks:

- There is a lateral consolidation process: hydrated lime undergoes an increase in volume which correspond to an increase in the pile diameter; this expansion may induce lateral consolidation of the ground surrounding the pile,
- There is a moisture content reduction: the slaking reaction draws water from the soil in such manner that increase the consistency of the ground,
- There is a reaction between clay and lime: the lime migrate on very small distances around the pile skin,
- There is a hardening of the lime mixture; the experience learnt from the scale model shown that the lime pile becomes stronger than the surrounding soil
- The scale model may be used with good results to assess the consolidation coefficient and find the best recipe of mixture along with the optimum geometry of the piles grid,
- The effect of the piles upon the deformability and bearing capacity of the ground may be easily checked.

REFERENCES

Chirica, A 2006 Technical Report *Expertise on National Road No. 24, Bârlad – Galați*, TUCEB, Bucharest,

Clare, K.E. & Cruchley, A.E. Laboratory experiments in the stabilization of clays with hydrated lime

West, G. & Carder, D.R. Review of lime piles and lime-stabilised soil columns, *TRL Report 305*.

Saxena, D.S. 2007 Soft soils engineering, stabilization and foundation solution – A Case History *60th Canadian Geotechnical Conference & 8th Join CGS/IAH CNC Groundwater Conference*, Ottawa, Ontario, Canada,

Nicholson, P.J. Cement soil mixing in soft ground,

Andromalos, K.B. Hegazy, Y.A. & Jarperse, B.H. Stabilization of soft soils by soil mixing.