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Research on the ground improvement for the construction of highways on alluvial areas of Romanian rivers

Recherche sur l'amélioration du sol dans les zones alluviales des rivières roumaines utilisées pour la construction d'autoroutes

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ABSTRACT: The need for fast development of communications routes in Romania for economic reasons has led to the launch of a major program aiming at the construction of highways and expressways, continued through the construction of urban centers bypasses.
Staring from the intention not to affect agricultural land and in particular to avoid a major impact on the environment, new road routes have been chosen in areas that are partially unfavorable from a technical point of view.
This has created a challenge for geotechnical engineering. Thus, it has been decided to opt for arid areas, areas affected by landslides, high erosion areas or areas near alluvial river beds.
One of the greatest challenges was the construction of high embankments for highways in alluvial areas with soft and very soft soil, specific to the wetlands of the Mures River floodplains.
Poor foundation terrains suffer from large and often uneven deformations under external loads and therefore need improvements if they are to be used as support ground.
The design of embankments on such lands is related to the need to study and analyze the factors that have an influence over resistance, deformability and general stability. In engineering practice, several solutions for the improvement of the supporting ground have been developed, such as: drainage columns, lime columns, ballast / stone columns, dynamic compacting, dynamic replacement, stone blocking, digging and substituting soft layers, improvements with various hydraulic binders, rigid inclusions, improvements with geosynthetic materials.
Case study presentation of two different areas of the Mures major river bed treated differently by dynamic replacement and rigid inclusion.

RÉSUMÉ: La nécessité d'un développement rapide des voies de communication en Roumanie pour des raisons économiques a conduit au lancement d'un vaste programme de construction d'autoroutes et de voies rapides, poursuivi par la construction de voies de contournement de centres urbains. Dans le souci de ne pas affecter les terres agricoles et en particulier de ne pas avoir d’impact majeur sur l’environnement, de nouveaux itinéraires routiers ont été choisis dans des zones totalement défavorables du point de vue technique. Cela a créé un défi pour l'ingénierie géotechnique, optant pour les zones arides, les zones touchées par les glissements de terrain, les zones à forte érosion ou les zones proches des lits de rivières alluviales. L'un des plus grands défis était la construction des surplombs d'autoroutes dans des zones alluviales présentant une consistance de sol molle et très molle spécifique aux terres humides de la plaine inondable de la rivière Mures. Les terrains de fondation médiocre, soumis à des charges externes, souffrent des déformations importantes et souvent inégales, et leur utilisation doit être améliorée. La conception des remblais sur ces terres est liée à la nécessité d'étudier et d'analyser les facteurs qui influencent sur la résistance, la déformabilité et la stabilité générale. Présentation dans l'étude de cas de deux zones alluviales du bassin de la rivière Mures, traitées différemment, en remplaçant de manière dynamique l'oreiller de ballast par des matériaux géosynthétiques et des inclusions d'oreillers rigides en matériaux cohésifs améliorés avec des liants hydrauliques.

Keywords: embankments, dynamic replacement, rigid inclusions, improvements

1 INTRODUCTION

The Mures River and alluvial areas

The Mures River basin is located in central and western part of Romania and originates from the Eastern Carpathians, Hasmasul Mare Mountains. The total area of the river basin is 28310 km2, representing 11.7% of the country's surface, and the hydrographic network comprises 758 cadastral water courses with a total length of 10861 km and an average density of 0.39 km / km2. The river basin is divided into 3 zones: the River Mures higher, the Mures River middle and the Mures lower Corridor. The studied areas are located in the middle part of the Mures River, located in the central area of the Transylvanian Plateau, which due to the neotectonic movements of the quaternary is located in three large strips, being spread over 8 levels of terraces and the terraced warehouses are of alluvial origin.

Alluviums or sediments are solid particles in the form of particles (granules) which, after their separation from the earth's crust through the action of forces of any nature, are entrained by water currents. Erosion is strong in mountain and hilly areas, while sedimentation occurs especially in field and plain areas. The transport phenomenon is accompanied by the phenomenon of particle weathering, which results in a decrease in the diameter of the grains from the mountain to the plain areas. According to their size, that is, according to the velocity of the current they transported, and the distance they were transported, these alluviums are classified into: boulders, gravel, pebbles and banks

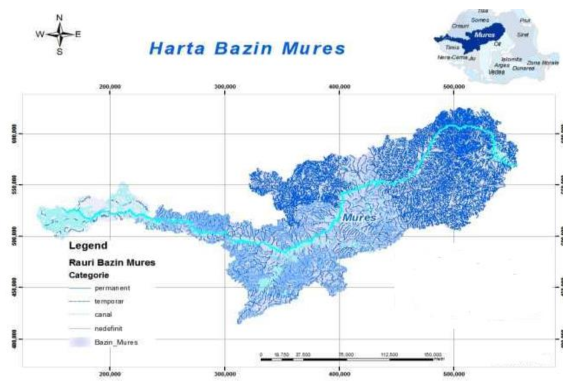


Figure 1. Map of Mures basin

2 DESCRIPTION OF APPLIED SOLUTIONS. CASE STUDIES

In Romania there is an extensive program of construction of highways, expressways and bypass roads, like "Greenfield", along the trans-European corridors.

Under external loads, weak foundation ground suffers large and often non-uniform deformations which requires improvement measures for their use.

In engineering practice several solutions for land improvement can be applied. Among the most commonly used are those that provide for the reduction of excess humidity (drained columns, drenched slopes, lime columns) and land improvement (ballast columns, jet-grouting, dynamic compaction, vibrating tamping, dynamic replacement, excavation and replacement of soft layers by intake of granular material improved with geosynthetic materials).

2.1 Area I Dynamic replacement

2.1.1. Emplacement

The experimental sector was established in a swampy, floodable area, very close to the Mures River, near Deva city in Hunedoara County.

At the level of the floodplain in the area where the site is located, it is worth noting:

• the meandering course due to both the maturity stage and the solid flow input from the major tributaries, as well as the anthropogenic changes caused by the exploitation of the materials or the evolution thereof;

•Aggressiveness of the watercourse to flood flows.

In addition, the area is at the confluence of a valley, a right tributary of the Mureş River, near drainage channels which are currently clogged by suspensions from the former upstream mines and which, when spilled into the emissary, favor puddles water.

2.1.2. Characteristics of the foundation ground

Following geotechnical investigations carried out on site, the following stratification resulted:

- fine alluvial deposits (N) represented by fine sands with powdery binder, passing to sandy plastic soft, brown-yellowish, saturated belowe 2.00 m depth
- recent alluvial deposits (P + N) from the Mureş River bed and meadow beneath the fine alluvial layer;
- Base rock: Marl / Marly clays (M), very hard and compact, intercepted under the layer of coarse alluvium. The geotechnical lithology highlighted in the succession investigated in the first two layers lead to the conclusion that the terrain does not allow direct foundation, being defined as a difficult terrain according to norm NP 074/2014.

Figure 3 alluvial deposit

Figure 2. Area I

2.1.3. Description of the applied solution

Dynamic replacement has been developed as an extension of dynamic compaction and is a semi-mechanical technology to improve the mechanical properties of the soil. It began to be widely used in the early 70s, with the appearance of cranes capable of withstanding large cyclic loads. The principles of dynamic compaction are outlined in detail by Menard (1975), essentially improving by dynamic compaction is accomplished by ground spreading by shear stresses obtained from high energy impacts applied to the surface of the soil.

According to the technical instructions for the design and execution of the low soil foundation improvement works with the dynamic replacement method by plowing with local input materials (raw stone, river boulders, coarse cement rejection), this solution can apply to foundation ground made up of low consistency clay and / or underconsolidated fills. Good improvement throught this method is not conditioned by the need for optimal compaction humidity and is not influenced by groundwater levels.

This improvement solution can be applied for maximum thicknesses of the weak layers of 3-4 m. The maximum depth at which the improvement is achieved as a result of the cladding depends on the dimensions of the materials used and the compaction characteristics, respectively the geometry of the weight, its mass and the compaction energy. For large compaction depths, it is recommended to use large (20-30 cm) intake materials (rough stone, river boulders) that favor punching of the loose terrain and the improvement for an area with greater depth.

The advantages of this technology combines the stone columns and dynamic compaction, through deep and side-fill intakes, in the final stage result columns whici much larger sizes.

The improvement of the weak foundation ground by coining with the rough stone is achieved by:

- the creation of an improved foundation ground area consisting of raw stone, broken stone, river boulders, coarse material, with the pouring of dynamic input materials
- the lateral and in-depth effect of the soil (modifying the porosity) as a consequence of the dynamic loading (the heavier tapping) of the input material.
- bringing a material replacement ratio of up to 20-25%.

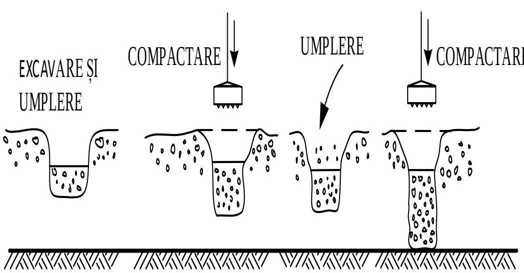


Figure 4. Dynamic compactation

Figure 5. engine of dynamic compactation

2.1.4. Design Principles

In the first phase calculations were performed at ULS and SLS according to SR EN 1997 / 1-2004 and the norms in force by choosing a calculation section from the respective area, a backfill with a maximum height of 6.00 m with a motorway profile.

We made calculations with the geotechnical parameters of the natural land without improvement, the results being in line with the expectations, totally unfavorable. The values of the compaction were tens of inches (24 cm) and the sloping stability of the slope was not satisfactory (Fs = 0.75). Rebuild calculations with improved land and the results indicated compaction values of several centimeters (5-6 cm) and satisfactory sliding safety factors (Fs =1.4).

Calculating the efficiency of compaction with the bucket (weight) must take into account a number of factors:

a. Applied energy - In order to provide a contribution to grounding and ground improvement during compaction, a sufficient amount of energy must be applied which is calculated for the preliminary estimation of the compaction process efficiency before the field machine moves.

b. Area of influence - The area of influence is the area around the crater that feels the efficiency of the plowing and lateral compaction depends on the applied energy, the number of falls, the weight of the bucket, the drop height, the stones compaction, the crater width and the space between them.

2.1.5.Experimental area and technological stages.

a) Excavating the upper part of the soft material over a thickness of 1.00 - 1.50 m

b) Place the first stone layer in the excavated pit on a 50-80 cm thick filled with a split coat.

c) Pouring the first layer of intake by the free fall of the compation bucket. The kicks are

applied at the beginning from a lower height, then the drop height is progressively increased;
d) The tapping of the other layers was done in the same way as for the first layer;
e) Making a granular cushion (ballast) over a thickness of about 30 cm to flatten the ram pressure;

2.1.6. Results

The linear deformation module was determined with the Lucas plate according to the standards in force, by two loading cycles with the plate ø = 300 mm, in the first phase on the natural ground without any improvement the values were Ev1 = 8 MPa respectively Ev2 = 12 MPa

The dynamic compaction was done on a single 3-foot print at a height of 20 m with a weight of more than 18 tons. The results are summarized in Table 2

Location	Number of blows	Settlement (cm)	width (cm)	Volume
1	1	51	235	1.89
	2	80	254	3.24
	3	104	274	4.61

The dynamic replacement was done according to the material specifications with the excavation material, the addition of the rough stone and the split layer. Table 3 summarizes the results obtained from compacting on the 3-stroke fingerprint from a height of 20 m with a weigh of 18 tones.

Table 2

Crater	Nr. lovituri	Tasare (cm)	Lățime (cm)	Volum
A1	1	26	226	0.92
	2	45	235	1.67
	3	58	242	2.22

The final test was performed over the ballast layer, the one for the determination of the linear deformation mode and the results revealed the module Ev1 = 76.27 MPa, Ev2 = 90 MPa and the ratio Ev2 / Ev1 = 1.18.

2.2 Area II Rigid inclusions

2.2.1. Emplacement

The studied area is located in Mures County near the Bogata locality on the depression corridor in the meadow areas and the lower terrace of the Mures River, which is of tectonic origin, located in the central-western part of Romania. Besides, the area is characterized by the presence of lands with a potential for contraction and medium swelling, and a difficult foundation ground. This finding is confirmed by the presence of autohydromorphic and alluvial soils with excess humidity. The experimental sector was selected on the site of the future autostrasite, in a meadow area, in the Mures riverbed, a flooded area characterized by hydropower vegetation , set aside and known in the past as a fish pond.

2.2.2. Characteristics of the foundation ground

The chosen area crosses holocene age-old quaternary formations. These deposits are meadow deposits, of the nature of gravel and sand according to geological maps. These deposits are usually covered on the surface by a cohesive and poorly cohesive soil characterized by swampy areas of different thicknesses. Following geotechnical investigations carried out on site, the following stratification resulted:

- Fine alluvial deposits (N), represented by slimy clay, solid plastic, brown-yellowish sands, saturated at a depth of 2.50 m with roots and plant debris up to a depth of 3.00 m.
- recent alluvial alluvial deposits (P + N) from the Mureş River bed and meadow beneath the fine alluvial layer, made of sand and gravel, with medium saturation;
- Base rock: Marly clays / Marl (M) gray, very stiff, with fine sand lenses, partially cemented, from 10.00 m depth hard.

The geotechnical types highlighted in the investigated succession in the first two layers combined with the height of the construction lead to the conclusion that the land is not a good foundation ground, being also defined by norm NP 074/2014 as a difficult foundation ground.

2.2.3. Description of the applied solution

The concept of building a foundation on a reinforced earth with rigid inclusions is one of the modern techniques of land improvement, strengthening with this type of inclusion provides a new and efficient technique. However, in fact, this technique has already been used throughout history to build on difficult places, such as swampy areas, without clearly understanding the mechanism and behavior.

The land improvement technique with rigid inclusions has the role of reducing the compressibility of the land. It is not intended to completely avoid this or to create pilots that directly support the entire structure. The objective is to reduce general and differentiated settlement, reducing the effort transmitted directly by the structure to the foundation ground.

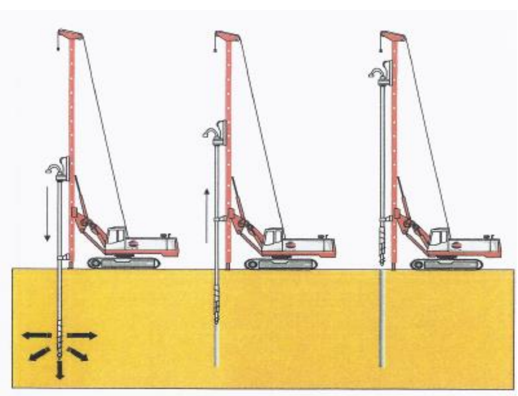


Figure 6 The improvement process

According to its fundamental principle, the reinforcement technique using rigid inclusions introduces a whole sequence of complex interactions from the structure that is sustained to the layer below the layer:

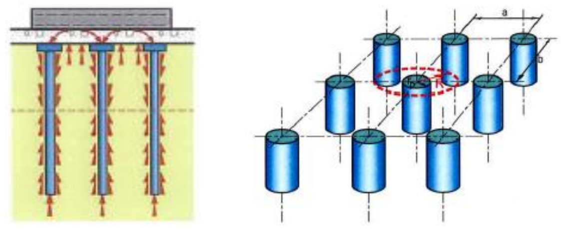
a) Interaction between structure and load transfer platform, depending on both platforms thickness and rigidity of the foundation;

b) Interaction between the transfer platform and the hardened soil block, consisting of soft soil layer and rigid inclusions;

c) Interaction at the interface between soft ground and inclusions where, with depth, unfavorable or negative friction may develop;

d) Finally, the interaction between the peak of inclusion and the load-bearing soli layer.

The basic principle of rigid inclusions is based on the group effect, and their effect increases as the network becomes more dense



Under evenly loaded structures such as platforms and slopes, load transfer is performed through a load distribution platform between the end of the piles and the structure to be supported. This platform (distribution cushion) is made of local material with hydraulic binders with a thickness of 0.50 m compacted in layers.

2.2.4. Design Principles

Calculations of slope stability were performed at ULS and SLS according to SR EN 1997 / 1-2004 and the current rules by choosing a calculation section in that area, a slope with a height of 10.00 m in cross section.

Calculations were made using the geotechnical parameters of the natural soil without improvement, the results being in line with the expectations, totally unfavorable. The stability calculation was performed by the limit equilibrium method and according to SR EN for the soil failure limit state (GEO) the condition $Rd \geq Ed$ must be verified, provided that $Rd \geq Ed$, thus Fs min. $= Rd / Ed \geq 1$

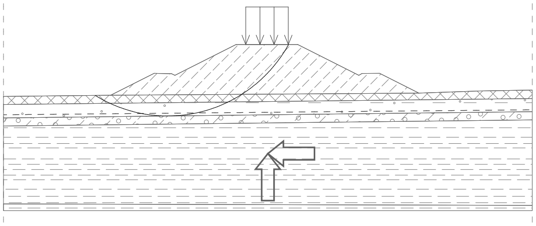


Figure 7. Slope analysis

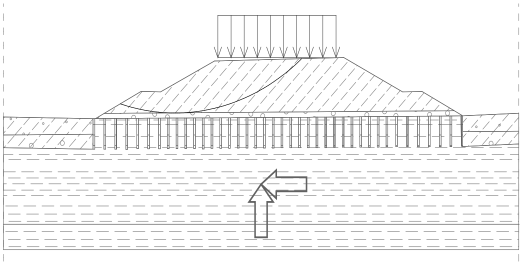


Figure 8. Slope analysis

Calculation of the settlement was made:

- in the first phase with a 2D finite element program by defining the length, diameter and characteristics of each pilot embedded in the earth's stratum according to the geotechnical study.

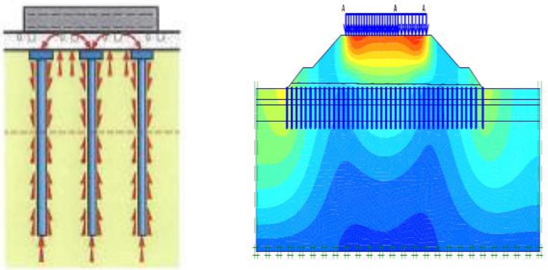


Figure 9. Inclusions

- in the second phase by the homogeneity method. This method takes an improved ground surface and considers it homogeneous and results in the E-mode of linear deformation with the formula

E.A* = (EpAp + EsAs) / A

Ep and Ap: modulus of deformation and cross-section of the inclusions.

Es and As: modulus of deformation and area of the soil.

The differential sliding at the soil/inclusion interface requires the introduction of a correction coefficient, β i.e.:

E.A* = (EpAp / β+ EsAs) / A factor β could easily exceed 10 in some cases

2.2.5. Experimental sector and technological stages

For the experimental sector a plot of 170 square meters was chosen. in an area that is part of the site, with the highest load (the central area, close to the ridge of the bridge with a slope height of 10.00 m) and there were executed a number of 38 inclusions

Stages of the experimental sector were:

a) tagging and drawing the points according to the drawing plan;

b) Auger calibration, drilling speed, refusal criterion, confirmation of geotechnical study stratification, electronic report transmitted by the forehead;

c) Execution of dynamic penetrations before the inclusion and after its execution, at a distance of 10 cm from the edge of inclusion;

d) Load capacity test by application of a vertical force of 500 KN using the utility used as the "reaction mass", with controlled loads at each stage;

e) execution of the local distribution cushion improved with hydraulic binders in different proportions and verification of the bearing capacity with Lucas plate, the quality criterion being Ev2≥45 MN / m2.

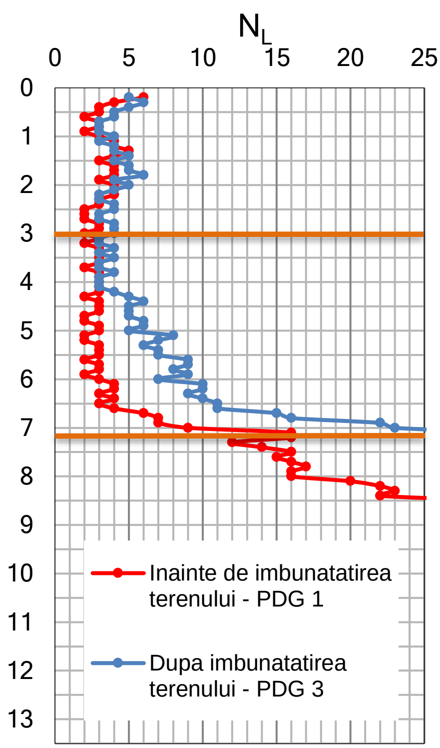
2.2.6. Results

a) Dynamic penetration was performed according to the standards and the results revealed a slight improvement, thus confirming the applied theory.

b) the load capacity test for inclusions was performed according to NP 045-2000 Norm (Field Pilot Testing) according to N3 quality requirements. The compression test with vertical static forces was the type of imposed effortmeasured deformation. The application of loading steps was performed with a hydraulic press, loading up to 500 KN in 8 steps of 62.5 KN and discharging up to 0 KN in 4 steps of 125 KN.

At the maximum load applied by Q = 500KN, the maximum displacement was s = 5.46 mm, and the final unloading Q = 0 KN, the residual displacement was s = 3.39 mm. (the results are in the central diagram.

c) The linear deformation module with the Lucas plate above the distribution cushion was made according to the standards in two loading / unloading cycles using the plate ø = 300 mm. The obtained values were Ev1 = 67.1 MPa, Ev2 = 73.6 MPa and their ratio Ev2 /Ev1=1.09.



3 CONCLUSIONS

Construction of high embankmentes on high compressible terrain is a real challenge for geotechnical engineers. Quality conditions and requirements for limiting settlements on roads or railways require a more detailed analysis and choosing the right solutions. The two solutions applied in the case study had approximately the same site conditions (near Mures River) but different geotechnical conditions. From this observation one can conclude that in the case of very compressible soil (banks) with a smaller thickness (1-3 m), solutions can be applied for their improvemen:; in the case of larger thicknesses (5-6 m) should be analised deeper fundation solutions, such as concrete piles, stone columns, beams, etc.

In both solutions chosen in the two projects, the results were above expectations.

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