MODERN SOLUTIONS FOR EARTHWORKS WITH DIFFICULT SOILS FOUNDATIONS

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A B S T R A C T

The locations intended for engineering constructions are selected based on certain conditions required by the constructions’ function and integration facilities within the economic-social network of that area. On these lines, there are multiple situations in which difficult foundation conditions are pointed by the presence of some special behaviour soils on that respective location. Either a reduced bearing capacity or an excessive deformability are relevant indicators for a clear decision regarding the necessity of foundation soil improvement in a certain regions.

Keywords: Transilvania Motorway, Foundation Improvement, Difficult ground

INTRODUCTION

The traffic routes are construction works performed for achieving various nature transportation infrastructure of large requirement for supporting the current and prospect development of a community and its integration into the macro-economic and social arena and into the human society rhythm of life. More than construction works generically called civil and industrial, the ones for traffic routes have difficult placement conditions, especially due to their necessity of adapting to the soil conditions both in terms of road course and of traffic route structure. Moreover, they include art works (like tunnels, retaining walls, bridges, etc.), architectural perfect connections, stability and resistance to the imposed conditions of routes and their associated traffic. The soils that form the foundation ground or those that are employed as material for new engineering constructions are identified and classified based on their physical-mechanical characteristics. These are determined by laboratory tests upon samples extracted from the road location by means of boreholes,

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pits or by means of in-situ trials or else ground tests with special equipment, which bear on large volumes of rock.

Brasov-Oradea Motorway has a length of approximately 415km. It starts from the junction with Bucuresti-Brasov Motorway, before Codlea locality, and spans up to the Romanian-Hungarian border, at the North of Bors locality. When correlated with Bucharest-Brasov Motorway, Brasov-Oradea Motorway will ensure a direct connection between Romania and the Central and Western Europe. Therefore, this motorway will attract not only the traffic from Moldova region, through the rehabilitated national roads network or the ones encompassed in the rehabilitation program, South-Eastern area (that is the connection with Constanta harbour) by Bucharest-Constanta Motorway and Northern area, but also that generated by the large urban centres situated in the motorway area of influence. The construction of this motorway will generate a development of the area crossed by its route, new employment opportunities, advancement of the raw materials industry that supplies various construction elements for building the motorway, and, at the same time, by attracting the through-traffic from the inhabited area, it has a positive impact in terms of transit traffic pollution. In addition, the motorway will become an available gateway for tourists from Central and Eastern Europe.

MATERIAL AND METHOD

1. Considerations Regarding the Geology of the Ground

The geology of the ground belongs to that of Transilvanya Depression, with inter-mountain functions, outlined in Paleocene after the Laramica phase, and finalized in Neocene. It is represented by deposits of Paleocene, epi-continental origins and Neocene molasse. The Paleocene deposits contain varved clays (lilaceous and red clays) with intercalations, which are subordinate to green and bluish sands and conglomerates between which a level of sweet water limestone (Rona limestone) is interpolated. And above this, an arrangement of sandy slate, inferior harsh limestone, superior varved clays, typical Cluj limestone, and marls can be found. At the superior side, sandy slates, marls and clays, sandy marls, and sands were intercepted.

The formations underneath the soil layer that will be the “support platform” for the future earthworks, are represented predominantly by different types of clay (mainly silty) and the consistency is generally “plastic consistent” or “solid plastic”. Organic material content established from the drillings executed on the alignment is lower than 5%. CBR tests (Californian index of bearing capacity) shows values lower than 8 for all the lithological types of formations that will be the “support platform” for the
future earthworks. This value classifies the formations as “very bad” and “bad” foundations grounds. According to Casagrande nomogram from STAS 2914-88, the surface formations fit “4b” type, which confirms the “mediocre” quality of soils to be used as fill material for earthworks, and “4d” type, which confirms the “bad” quality of soils to be used as earthworks material. As per STAS 1709/2-90, the surface formations are “very susceptible” to freeze. The studied interval crosses two distinct areas. The first one is the inter-stream region formed by Hasdate brook and a right hand side tributary stream of Fenesu (Racos) brook, with deluvial and alluvial deposits of Holocene age, fine silty-clay or coarse deposits. The meadow of Racos brook is flat, with depression regions, grassed and/or partially afforested with frequent excessively humid and hydrophilic vegetation areas. In order to obtain additional information about the geological, geotechnical and hydro-geological nature of this interval, two open pits were performed up to a depth of 2.50m. The lithological sequence identified from the two pits executed is:

- in P1 pit: 0-0.30m top soil, 0.30-2.50m plastic stiff red brown sandy clay;
- in P2 pit: 0-1.00m yellowish brown, plastic stiff, gradually consistent sandy clay, 1.00-2.50m saturated ballast with decimeter-like intercalations of banks.

From the hydro-geological viewpoint, in the pits carried out in the region the groundwater level was identified starting from a depth of 1.0m up against the levels of the excavtions on the right hand side, stuck in ballast deposits. The physical and mechanical characteristics for each ground layer were tested in laboratory. For embankment fill, some tests were run to determine the average of the physical and mechanical characteristics, taking into account the amount of layers from the soil sources. In the cases when
The geotechnical borehole did not correspond to the chainage of the cross section, an interpolation was made between two geotechnical boreholes adjacent to those cross sections [2].

The geotechnical investigation works on the terrain of the designed motorway route consisted in semi-mechanical boreholes (of about 548), manual boreholes of Ø2” and open (exploration) wells (of about 128) and the dynamic penetrations type “STANDARD” (SPT). The samples taken (unsettled or settled) were analyzed in the geotechnical laboratoires in Bucharest (SC IPTANA SA, ISPIF-SA UTCB, The Laboratory of the Geology and Geophysics Faculty Bucharest, The Central Laboratory CCF SA Bucharest), Cluj (The Laboratory of the Technical University Of Cluj Napoca, The Central Laboratory DRDP Cluj), Savadisla (Bechtel site Laboratory). Mathematical statistics were employed for establishing the characteristic values of the geotechnical parameters. The assurance level of $X_K$ values were of 95%. The geological elements, for which the characteristics values of the geotechnical parameters were established, are determined based on geotechnical investigation works on site. These were performed in accordance with the requirements of SR EN 1997/2-2009 and NP 074-2007. The typical values of the geotechnical parameters were established based on the specification in SR EN 1997/1 and on the recommendation of R.Frank studies [9]. The typical values of the geotechnical parameters for studied section and soil type are showed in Table 1.

<table>
<thead>
<tr>
<th>Layer</th>
<th>$l_c$</th>
<th>$l_p$</th>
<th>$U_L$</th>
<th>$W$</th>
<th>$e$</th>
<th>$\gamma_k$</th>
<th>$\varphi_k$</th>
<th>$c_k$</th>
<th>$n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>0.78</td>
<td>39.3</td>
<td>25.9</td>
<td>26.5</td>
<td>0.77</td>
<td>21</td>
<td>14</td>
<td>35</td>
<td>40.9</td>
</tr>
<tr>
<td>Heavy Clay</td>
<td>0.79</td>
<td>57.2</td>
<td>33.1</td>
<td>27.3</td>
<td>0.87</td>
<td>19</td>
<td>13</td>
<td>39</td>
<td>46.2</td>
</tr>
<tr>
<td>Sandy Clay</td>
<td>0.82</td>
<td>28.7</td>
<td>33.1</td>
<td>20.1</td>
<td>0.52</td>
<td>21</td>
<td>18</td>
<td>21</td>
<td>34.2</td>
</tr>
<tr>
<td>Silty Clay</td>
<td>0.78</td>
<td>35.2</td>
<td>22.6</td>
<td>50.9</td>
<td>0.74</td>
<td>21</td>
<td>13</td>
<td>39</td>
<td>40.8</td>
</tr>
<tr>
<td>Clayey Sand</td>
<td>0.73</td>
<td>14.2</td>
<td>17.2</td>
<td>16.4</td>
<td>0.54</td>
<td>21</td>
<td>18$^\circ$</td>
<td>15$^\circ$</td>
<td>32.5</td>
</tr>
<tr>
<td>Gravel with sand</td>
<td>-</td>
<td>-</td>
<td>6.35</td>
<td>4.7</td>
<td>-</td>
<td>21$^\circ$</td>
<td>34$^\circ$</td>
<td>0$^\circ$</td>
<td>-</td>
</tr>
</tbody>
</table>

( ) The values are determined based on the correlations of certain trials and documentary data

2. Consolidation Solution for Difficult Foundation Soils

Regarding the consolidation solutions for motorway earthworks, besides the calculation of the geotechnical parameters there were considered also the bearing capacity of the motorway support layer (for cuts this layer...
is the layer of the roadbed level, while for embankments the support layer is represented by their foundation). In these situations, depending on the existing available space for setting the measuring equipment, the bearing capacity was established based on trial board testing (Lucas board), Light Weight Drop Test (Zorn dynamic board) or on Benkelmann Beam Deflection Tests.

In order to control the quality of execution on the studied motorway sector, the bearing capacity measurements were performed on the road section at the top of the embankment before the execution of the capping. They were also performed at the roadbed level, at the subgrade level and at that of the granular materials foundation sub-base, and at the level of the embankments’ soil foundation. Based on the values of geotechnical parameters, for each excavation stage were established measures to consolidate and stabilise the slopes, as well as to consolidate the earthworks of the motorway. The improvement methods for foundation ground are grouped according to the following purpose:
- temporary improvement of the foundation ground by: lowering of the underground water level, surface compaction;
- permanent improvement of the foundation ground with or without addition of extra material.

*Fig.2. Lowering of the underground water level*

**Lowering of the underground water level:** When carrying out the temporary excavations, it is used with high efficiency the induction into the ground of an increased unitary factual exertion state by lowering the level of the underground water (water pumping works) with positive effect on raising the bearing capacity and shear strength parameters. The possibility of applying this method is dictated mainly by the permeability of the layer to be drained, the anisotropy and the potential presence of impermeable ground lenses.
Surface compaction: By this category of works we refer to the compactions carried out for boosting the ramming degree, respectively of the soil specific apparent weight within their circumstantial state and, especially of the relatively small thickness cushions. These compaction activities depend both qualitatively and quantitatively on the characteristics of the machine employed, yet also on the geotechnical characteristics of the soil. The optimal compaction humidity plays an important role. This optimal moisture content varies as per each case according to the granular-metric composition and mineralogical nature of the soil in question. The optimum compaction humidity means that moisture by which is obtained the maximum ramming degree while employing the same mechanical equipment. Once the optimum compaction humidity is established, it should be maintained at the same value for the entire fill to be carried out from that respective soil, throughout the duration of compaction.

For the less permeable soils (cohesive soils), the surface compaction is less efficient, since this artificial ramming is carried out at maximum value only when that respective soil possesses a certain optimal compaction humidity, which is established in the laboratory by Proctor testing (that is a lab trial. Proctor tests can be normal or modified).

The actual depth that sustains surface compaction is very limited. Most equipment cannot perform a successful ramming at depths greater than 0.30-0.50m; however, there are special, very-heavy equipments, with large dimension cylinders, that manage to perform the compaction of the superficial layer up to a depth of 1.50m, and, under certain circumstances, up to 2.00m.

Foundation soil improvement with extra granular material and geo-synthetic materials: The permanent character of soil properties improvement is a guarantee of meeting the demands required by the exploitation of the
new construction on that site in safe conditions in terms of foundation soil resistance and stability. Unlike other methods that improve the foundation soil permanently, without adding subsidiary material, this method benefits from a contribution of extra material, evenly or unevenly distributed in the natural ground. The extra material and the natural ground work together for obtaining an increased bearing capacity and reduced deformability.

Within the studied interval, an embankment foundation improvement with extra granular input and geo-synthetic materials was carried out. Thus, a rock fill dressed in geogrid was accomplished for creating a semi-rigid cushion to take over the load from the embankment and to avoid the transfer of the embankment load on the low consistence support ground. This allowed the embankment load to be drawn off by the geogrid’s tensile strengths that dressed the rock fill layer. Because the geogrid cannot be set directly on the rock fill of sort 0-600mm (due to the lack of clenching), which may cause its breakage, granular material was employed around the geogrid. This granular material acts as a cushion for the rock layer.

![Fig.4. Foundation soil improvement with extra granular material and geo-synthetic materials](image)

The execution of embankment foundation improvement was carried out in several stages as follows:
- an excavation of 2.60m below the natural ground level; Compacted crushed stone fill of 60cm thickness was placed for achieving a working surface to commence the foundation improvement layer execution. A geotextile was laid on the crushed stone surface. Enough geotextile was spared at the edges for reversing it on the improvement layer sides (dressing them) on a 2m length. A 30cm layer of granular material was laid above the geotextile. The geogrid was set on the surface of the well-compacted granular material at a sufficient edge length for encasing the sides and fastening them with the geogrid from above;
- on the top of the geogrid, a layer of 30cm granular material, followed by a layer of 1.00m compacted rubble stone fill was set. Then, another layer
of 30cm granular material was laid, after which a second geogrid followed. The connection between the geogrid from the base and that from the top (superior part) was performed. The last 30cm of granular material are set on the top geogrid surface.

For checking the functionality of the improvement solution, a Benkelman Beam Deflection Test was performed above the improvement layer. The results of the test met the requirements of the Technical Specifications and, at the same time the area was monitored under traffic for a period of six months, while the settlements were consumed.

CONCLUSIONS

Based on the experience gained and on the continuously elaborated research in this field, calculation methods were developed regarding the design of these soil improvement works so that the calculated response and the one measured are, in most cases, in a perfect line both qualitatively and quantitatively.

The domain researches are directed towards achieving both performance technical equipment and creating new materials to enhance the improved ground qualities along with a superior durability and without any environmental impairment.

REFERENCES

3. *** Normative regarding the Geotechnical Parameters Calculation and Characteristic Values Determination.