Geotechnical Consideration of the Cut-and-fill Slope Problems Related to the Struma Motorway Construction

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Abstract. The forthcoming construction of the Struma motorway which is part of the Pan-European corridor IV is one of the most challenging geotechnical assignments in Bulgaria nowadays. The road trace is situated in a region of high seismic activity where the topography reveals mostly areas with steep mountain slopes. Geotechnical considerations of the road construction including cut-and-fill works and building of different supporting structures as pile founded retaining structures, anchor systems and reinforced soil embankments is needed. Numerical solutions based on the limit equilibrium theory and the finite element method are applied. This paper analyses and summarizes the design options and the results of the different numerical models of preferred structures.

Keywords: Cut-and-fill, slope stability, motorway embankment, reinforced soil, numerical solution.

1 INTRODUCTION

“Struma” is the name of a Bulgarian river situated in the south-west of Bulgaria which flows through a long valley and finds it way to the Aegean Sea. “Struma” motorway is named not only after the valley itself, but also after the river parallel to which it runs. The last and the hardest part of the motorway is expected to be finished in 2022, since the construction has already begun. Most of the construction difficulties are concentrated in the “LOT 3.1” Blagoevgrad – Sandanski Fig.1, where the relief is highly inclined, and the PGA (Peak Ground Acceleration) for 475 years is 0.32 g (gravity).

Figure 1. Location of the Struma motorway.

2 GEOLOGY

The alignment of the motorway runs through quaternary clay with depth 0 – 10 meters, neogene sandy silty clays with gravel and rock blocks, rock blocks and hard rock (gneiss). Due to the difference in the geology and the low investment in geological investigation, it is not possible to precisely define the geological profile. For whole sixty kilometer section soil layers as those given in Fig. 2 are presented, but depths and thicknesses vary highly.

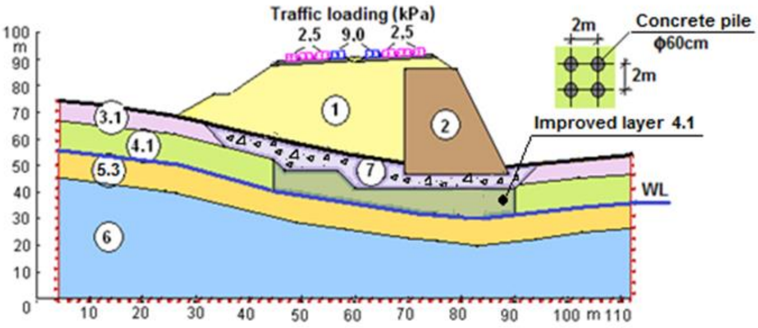


Figure 2. Soil layers, defined based on geology and construction requirements.

Table 1. Margin settings for A4 size paper and letter size paper

Soil Layers, №	Type	γ	φ	c	E
		kN/m^3	deg	kPa	MPa
1	Embankment	20	30	15	80-100
2	Reinforced Soil Embankment	21	35	30	120
3.1	Clay	18	22.5	33	6
4.1	Clay	19	20.5	20	10
5.3	Sandy Clay	21.7	32	19	23
6	Sandstone	24.5	37	100	100
7	Gravel-infill	20	35	5	80

In today´s motorways and railways construction in Bulgaria, it is rather common that the actual geology is revealed as late as during the construction excavation. This often leads to wrong preliminary design and redesigning the structures is unavoidable. Another typical problem for geotechnical designers comes with the ungrounded underestimation of soil properties.

3 CUT ANT FILL DESIGN

As introduced, cut and fill works predominates in the geotechnical design all over this section. Typical cut and fill designs are shown on Fig. 3.

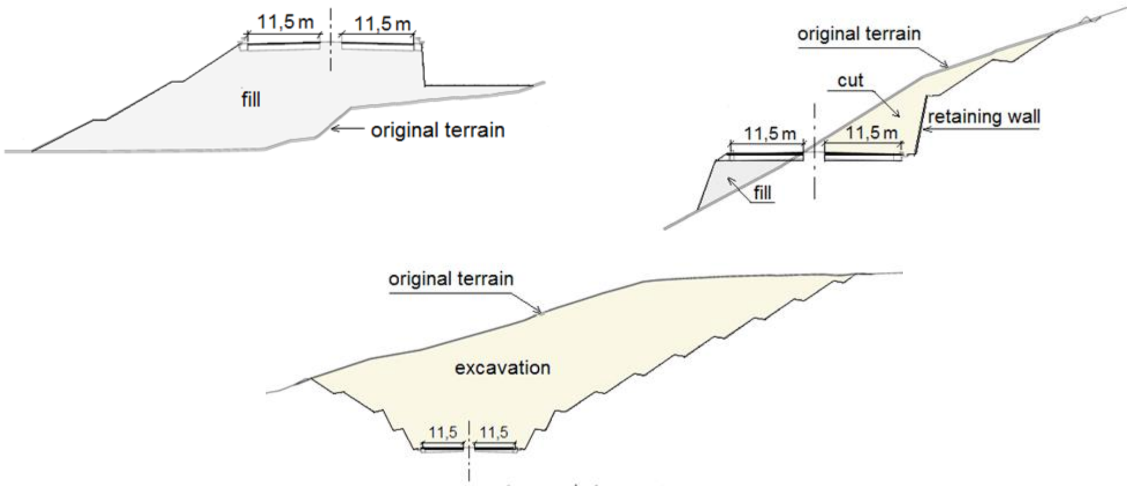


Figure 3. Cut and fill design.

Most of the slope stability as well as earth pressure and structural forces are calculated based on or with Plaxis and GeoStudio. For Plaxis slope stability problems Phi/c reduction method is used. GeoStudio is mostly used for calculating the limit equilibrium solutions for slope stability and anchoring. Solutions according to real physics as well as such using Eurocode 7 (8.5) coefficient are carried through. Results are mostly presented in terms of safety coefficients, anchor and structural forces or structural element bearing capacity and corresponding distance respectively.

3.1 Soft soil reinforcement under high road embankment (km 418+095 - km 418+260)

Due to easement restrictions the road embankment should be 20 m high and not more than 60 m width Slope inclination forces an asymmetric road embankment construction. Right part of the motorway lays on a reinforced part of the embankment (Fig. 2). All boundary conditions determine the following construction steps:

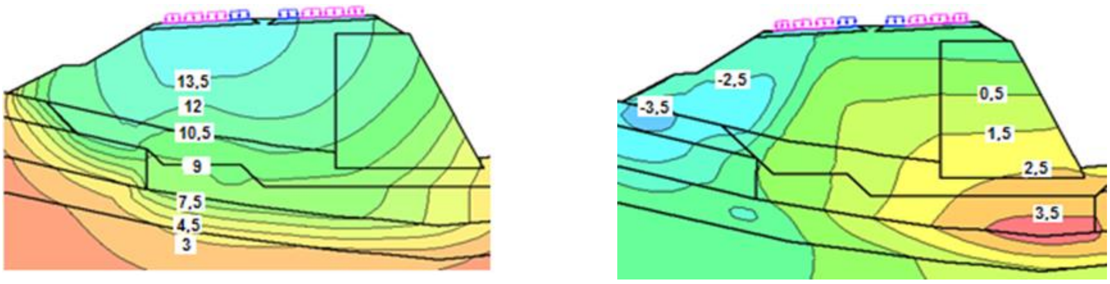
- Reinforcing the soft soil (4.1) layer using orthogonal net of concrete piles with diameter of 600 mm and distance of 2 m.
- Partly removing the clayed soft soil (3.1) layer and replacing with well graded compacted gravel.

The embankment is analysed with a 2D FEM model. Reduced stiffness, shear resistance and unit weight of the pile reinforced zones are used:

$$X = \frac{\left[A_1.X_1 + \left(A - A_1\right).X_2\right]}{A} \qquad (1)$$

Where A is the area of the reinforced soil (plan); A_1 – piles cross section area; X – reduced quantity; X_1 and X_2 – value for the given quantity for concrete and soil respectively.

After solving the system, results for slope stability, absolute and relative displacement and deformation were obtained. The maximal vertical displacements are 12 cm, and the maximal horizontal displacements – 3.5 cm. Maximal relative settlement of the road is 0.15% (Fig. 4)

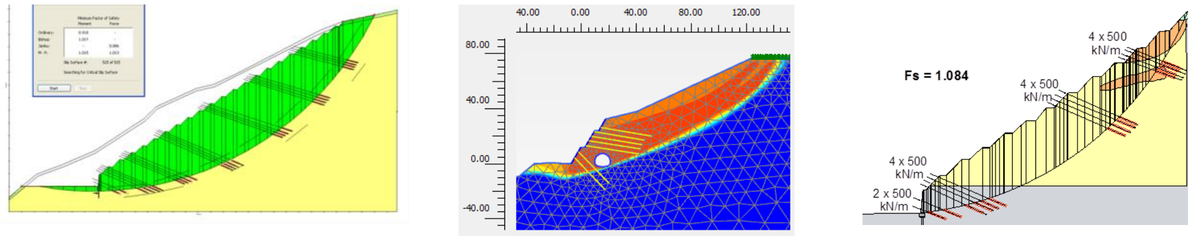


(a) (b)

Figure 4. Displacements: (a) – vertical, (b) horizontal.

3.2 Study of steep slope and anchoring (km 365+500 – km 366+000)

At this point the alignment of the motorway incises into the mountain through a 35° slope and a after few hundred meters enters long tunnel. Based on the “preliminary” but not real geology few general variants were discussed and calculated: a) Excavation for both traffic directions followed by retaining wall with anchoring of the excavated slope; b) excavation for only one direction, while the other enters a short tunnel..

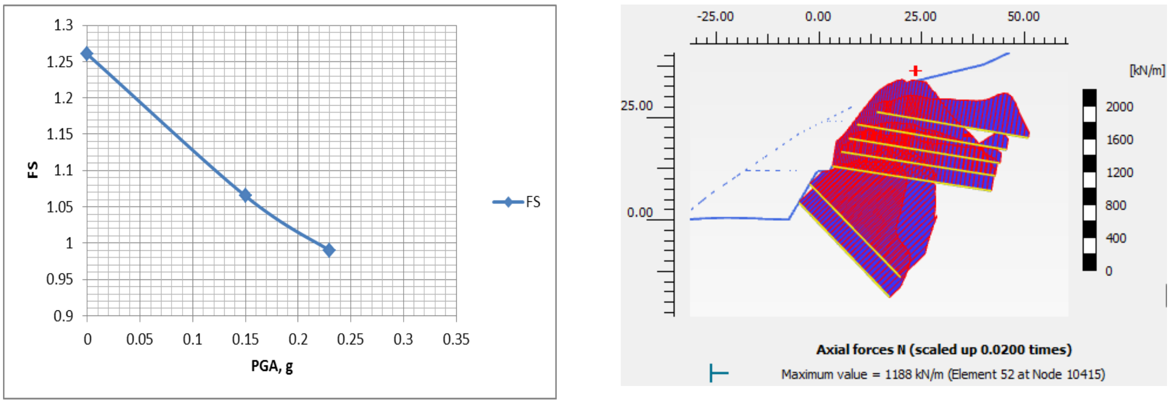


(a) (b) (c)

Figure 5. Variant: (a) – Slope, anchoring – preliminary geology, (b) “half” slope and a tunnel, anchoring – preliminary geology, (c) slope, anchoring – better geology based on excavations.

When calculating the natural slope stability for all variants: a), b) and c) using characteristic (95%) values, the slope appears to be unstable. Hence the further usage of average values for cohesion and friction angle.

For a) it is calculated, that the required anchorage consists of 6 groups of 4 anchors, each with bearing capacity of 1005 kN. Such anchorage demands tremendous investment and were not approved. After that follows variant (b) “half” slope with a tunnel. This variant is calculated based on the same geology and the same soil layers alignment. It is analysed in details and the following safety factors according the DA3 Eurocode coefficients were obtained (Fig. 6).



(a) (b)

Figure 6. (a) – Safety factor according phi/c reduction with respect to pseudo-static PGA, (b) Anchor force in limit equilibrium condition - PGA 0.23g.

Based on the calculations it is concluded that the “half” slope/ half tunnel solution could be stabilized only for PGA lower than 0.23g. The global slope stability problem is still unsolved.

The situation was not changed until a new look at the geology with respect to the nearby excavation process was done. Variant c) includes hard rock on the slip surface and conditioned more realistic behaviour of the slope (Fig. 7).

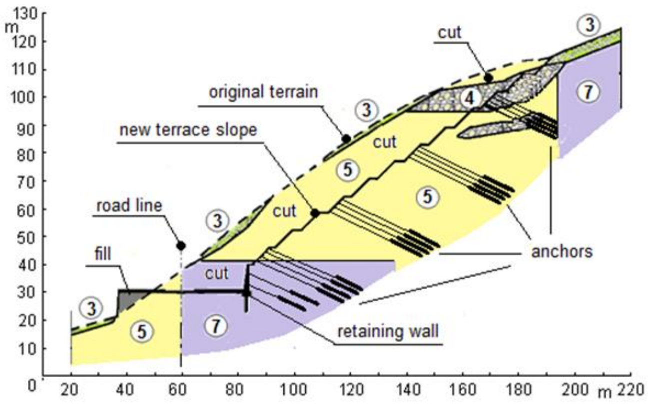


Figure 7. Final variant for km 365+500 – km 366+000.

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According the DA3 calculations the slope is stabilised with 4 groups of anchors, altogether 14 per meter including those of the 9.9 meters retaining wall.

3.3 Reinforced embankments (km 362+500) and (362+820)

For km 362+500 reinforced embankment on a 10 to 30 degrees slope is anticipated. First solution (Fig. 8 a) leads to unstable behavior under seismic loading, hence soft sandy clayed layer (OMN) is presented.

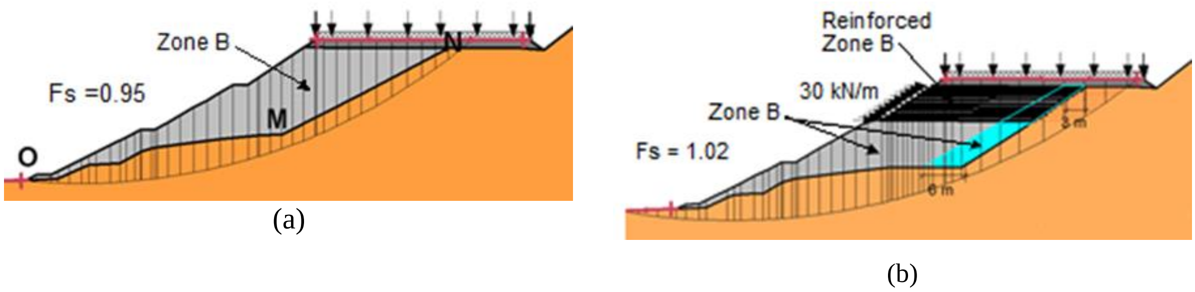

Figure 8. Embankment 365+500 (a) - without soil replacement, without reinforcement, (b) - soil replacement and reinforcement

The slope is stabilised using the following geotechnical solutions:

- Reinforcing of the embankment of zone B 6 meter under the alignment;
- Removing 3 to 6 meters of the soft sandy clayed layer and replacing it with well graded compacted gravel Fig. 8 b).

The steeper slope of km 362+820 leads to more complex solution (Fig. 9). A highly reinforced embankment over the gravel and rock blocks base is constructed. Even so the stability at PGA 0.32 is not approved. Contingency plan anchorage at the bottom of the embankment is anticipated. It is well known that such type solutions, including structural elements with different stiffness and geometry complexity are only solvable using high level FEM models.

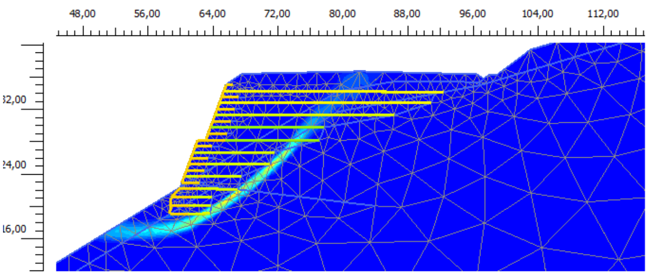

Figure 9. Steep slope embankment design - km 362+820.

4 CUT ANT FILL DESIGN

It is nowadays possible to better describe the geology especially for civil engineering purposes hence soil investigation technique is heavily improved. It is not the case for Struma motorway. Reasons could be found in investment procedures, heavy bureaucracy, outdated soil investigation technique and least but not last geology diversity. Despite lack of modern geotechnical parameters and their determination their estimation based on experience and collaboration is presented. The use of such type of data in modern calculation technique could be crucial, but FEM models are best way to estimate global behaviour of geotechnical structures. Luckily all the geotechnical structures design is reasonable at the end.

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