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Second phase of Landslide stabilisation on Cut 3, LOT 1, Motorway E75, section Gornje Polje – Caričina dolina

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Abstract Landslide stabilization works in the zone of Cut 3 were divided into 3 phases. The scope of this paper is to provide detailed information on the Phase 2 of the designed stabilization measures. These works consisted of constructing the Reinforced Soil Embankment (RSE), up to 12.5 m height in the zone of the toe of the landslide. The embankment contributed to the stabilization of the slope as a ballast, as well as redistribution of the mass after the excavation necessary for the road deviation. The design envisaged the use of flexible geogrid which had to be manufactured from high-modulus polyester (PET) yarns with low creep by knitting production technique. The construction of the piles over which rockfill and concrete have been placed up to a height of 5.8 served as stabile foundation for the RSE. After the execution, Reinforced Soil Embankment increased safety factor against sliding of the Cut 3 and, due to its flexible type of construction, complex geometry that fits very well into natural suroundings has been achived. The paper also gives a short overview on related literature and explains the beneficial effect of a high alignment capacity of reinforcement products on the performance of the composite material “reinforced soil”.

Keywords landslide, slope stabilisation, flexible geogrids, interaction flexibility, geosyntehtics.

Introduction

During the execution of works on the E-75 highway, Belgrade-Niš - the border with FYR Macedonia, on section Gornje Polje - Caričina Dolina, LOT 1, on the Cut 3 from km 876+ 325 to km 876 + 825 there was a violation of the stability of a conditionally stable slope that jeopardizes the highway route (Fig.1). By analyzing the results of observing the geodetic benchmarks on the slope, as well as the results of the observation of the displacement in the inclinometer constructions, it can be said that it was a huge landslide with a complex slip mechanism. The sliding process involves the surface sediments, as well as the deeper areas within the shale. Landslide stabilization works in the zone of Cut 3 were divided into 3 phases.

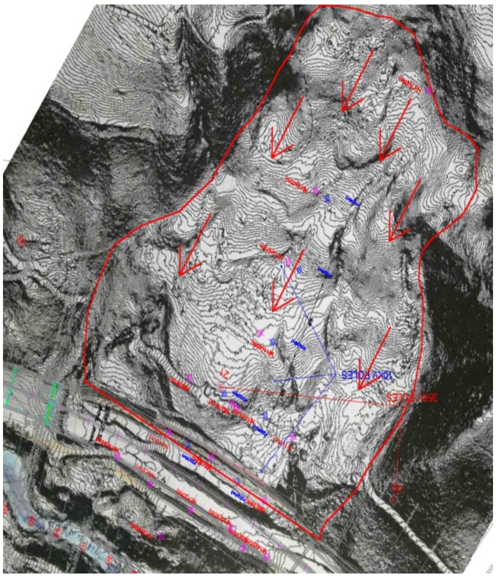

Figure 1 Landslide on the Cut 3

Stabilisation works Phase I

Within the Phase 1 of works for landslide stabilization in the zone of CUT 3 – LOT 1, works on the excavation of the terrain behind the existing structure of micro-piles and works on the surface drainage are foreseen. The excavation works envisage considerable relief of Cut 3, which will greatly contribute to the stabilization of the slope, and the development of surface drainage will provide lower groundwater level.

The design envisaged the construction of transversal drainage trenches (channels) of two different types in several layers and perimeter channel, Also, on every newly formed berm, the precast concrete channels for collecting atmospheric waters has been constructed.

Stabilisation works Phase II

Within the Phase II of works for landslide stabilization in the zone of CUT3 - LOT1, works on the stabilization of the landslide toe in the zone of the left bank of the South Morava River, in the length of 300,50 m, from km 3 + 592 to km 3 + 900.35 (along the axis of the river), or from km 876 + 739,23 to km 876 + 485 (along the axis of the highway) were foreseen. These works consisted of constructing the Reinforced Soil Embankment, up to

12.5 m height in the zone of toe of the landslide. The embankment contributes to the stabilization of the slope as a ballast, as well as redistribution of the mass after the excavation necessary for the road deviation.

As the river is very near the embankment, the embankment was founded on the construction of the piles over which rockfill and concrete were placed up to a height of 5.8 m as a measure to improve the weak subsoil. In this way, a stable base for the embankment was made. The height of the embankment is 10,5-12,5 m, up to the level of the road.

The protective structure from piles has been performed from two rows of bored piles Ø900 mm, 15 m long, on a distance of 2.5 m, transverse and longitudinal. The piles have been connected with a pile cap beam of dimensions 5,0 x 1,0 m and 300,50 m long. Working dilatations on the pile cap beam is on every 9-12 m.

The reinforced concrete wall of 3 m high and a width of 80 cm, has been constructed over the pile cap beam. The face of the wall is vertical, while on the back it is in an inclination of 10: 1. Behind the wall s a rockfill in concrete in layers have been placed, up to a full height of 5.8 m. For rockfill in concrete, a stone of fractions of 50-100 cm swere used, and filling of caverns between the rock was done by concrete C25/30. The alignment of the protective structure and RSE can be seen on Fig 2.

Figure 2 Alignment of the RSE on top of protective structure

Reinforced Soil Embankment with high flexible PET geogrids

The embankment from reinforced soil has been constructed with a green face in the slope of 60° after the completion of the works on the protective structure from piles and rockfill in concrete. The embankment was constructed using material from the local excavation from Cut No.3 for which laboratory tests have been carried out to prove the material is suitable for the construction of the reinforced soil embankments. The filling were placed in layers up to a maximum of 30 cm, until the total height of the layer is 60 cm, after which the corresponding row of the high flexible PET geogrid has been placed, and this procedure repeated until the full height of the embankment is reached. For this type of construction, compaction of 98% of dry bulk density is required.

The construction of the embankment can be done in a classic way except in the zone od 1.5 m behind the embankment face with spreading by the lightweight bulldozer and compaction with the smooth vibration roller of maximum 8 tons in weight, in layers up to maximum 30 cm. In the zone 1.5 m behind the embankment face, spreading shall be done by hand in 30 cm thick layers. The main compaction will be done by 40/50 cm wide vibration plate near the embankment face. After stabilizing the material, 60/70 cm wide vibration roller of a maximum weight of 1 tone can be used.

The design envisages the use of flexible geogrid which has to be manufactured from high-modulus polyester (PET) yarns with low creep by knitting production technique. According Stability calculations, geogrids with long-term design strength of 34kN/m – 64 kN/m were used. Required length of geogrids varied between 9-12 m. On the face of the embankment, the geogrid has been folded and anchored inside the embankment.

Considering that high embankment was designed on a stabilised landslide, design adopted green facing as the most favorable type of finish for the RSE slope. In general, if there is sufficient available space, green facing is the most flexible and economically advantageous way of finishing RSE slope.

The use of flexible geogrids ie. geogrid without memory effect was of great importance in order to perform the designed geometry of the reinforced embankment with maximum precision and quality. In this way, the construction time of the reinforced embankment is reduced by 30-50% and thus the construction costs by >20% compared to RSE with stiff geogrids.

Importance of Interaxtion Flexibility

It is the general understanding that the three main characteristics of geosynthetic reinforcement products, which dominate the performance of the compound material "geotextile reinforced earth", are the tensile strength, tensile modulus as well as the interaction behavior with the soil.

<u>Interaction behaviour is capability of the geogrid to take forces from the soil and to transfer forces into the soil.</u>

Different publications report on research results regarding the different geosynthetic characteristics influencing the interaction behavior such as geometrical factors, mechanical factors, and adaptability of the geogrid to the soil and all it's particles of a different sizes and shapes. Contribution of geogrid geometrical proprieties were analyzed for more than 20 years, by for example Sarsby (1985th) and Zigler and Timmers (2004th). The importance of geogrid crossmembers and its contribution the pull-out behavior has been emphasized in various papers. The influence of the surface roughness has been noticed and analyzed already at the early days of geosynthetics by Schlosser and Elias (1978th). They found direct correlation between surface roughness and transfer of sheer stresses from the soil to the geogrid, so the higher surface roughness the better transfer of sheer stresses.

O'Rourke et all (1990) concluded that harder surface of geosynthetic decreases shear strength at the contact between geosynthetic and soil. Several other researchers found that increased flexibility and surface friction of geogrids have positive influence on the interaction between geosynthetic product and soil. So it can be said that geosynthetic products with higher Interaction flexibility have better interaction with soil. Positive contribution of Interaction flexibility can be simply explained by Euler Effect as shown on the Figures 3.

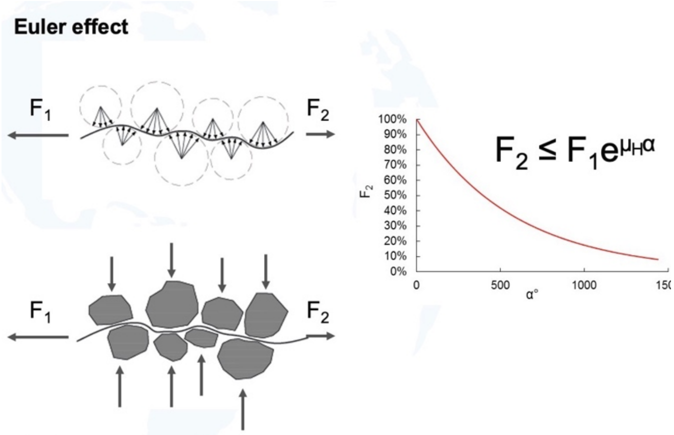

Figure 3 Euler Effect and Interaction flexibility of geogrids

Flexible geogrids allow denser compaction of soil, which results in larger contact surface between geogrid and soil and better transfer of the shear forces among them. This can be explained by the Euler-Eytelwein formula shown on the Figure 3 in which force F2 can be balanced with smaller force F1 due to contribution of friction over contact surface between rope and for example bar or coil.Lower value of Flexural Rigidity of geosynthetic product means higher Interaction Flexibility.

Flexural Rigidity of geosynthetic products can be measured according to ASTM D7748 Standard Test Method for Flexural Rigidity of Geogrids, Geotextiles and Related Products.

Stability Analyses

Stability analysis of slope and protective structure is performed in phases of work execution. Phases are modeled according to the technology of work execution.

For the purposes of the stability analysis, additional geotechnical investigations were performed. Based on the results of these investigations, a geotechnical profile on km 876+625.0 was created. The level of the sliding surface, underground water and layers of soil/rock is imputed in the calculations exactly as the ones measured really. Since there was no laboratory testing in the additional geotechnical investigations, soil parameters that were used for calculations are taken from the original geotechnical report from the main design of Highway. Residual strength parameters for the sliding surface are determined by back analysis search for the safety factor of Fs=1.0 in the phase of excavation for the Highway, which is in accordance with the phase when the sliding started. According to the used methodology, the obtained values for a sliding surface layer and parameters for other layers are presented in Table. 1.

Table 1. Soil/Rock parameters used for the calculations

Material	γ [kN/m3]	ϕ [º]	c [kPa]
S***	22	27	15
S**	24	27	25
S*	26	40	100
Ka	22	19	0

An analysis of internal stability was performed to define the characteristic geometry and type of the geogrid.

This analysis was carried out in accordance with the Recommendations for the design and analysis of reinforced earth constructions - EBGEO [1] and DIN 1054 (1976) [2]. The GGU Stability software is used. To ensure sufficient stability, the degree of exploitation is required $\eta \leq 1$. As a seismic load, the horizontal acceleration kh = 0.15 was taken.

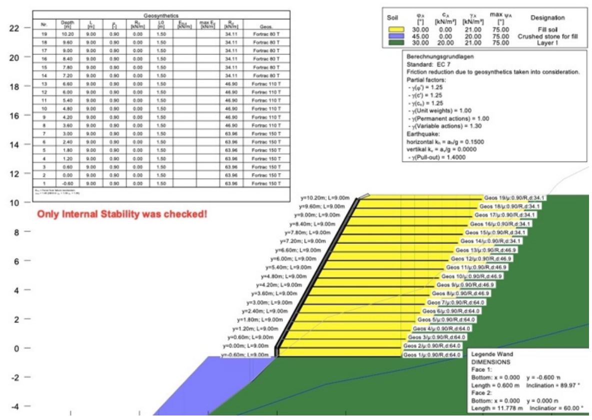

Figure 4 Internal Stability Calculation Results

The maximum coefficient of utilization μ = 0.88 was obtained during the internal stability check using the Vertical slices method for the combination of permanent+variable+seismic loads. The minimum required geogrid length of 9.00m was obtained.

The results of the combined and global stability analysis gave slightly higher minimum required lengths of the most heavily loaded geogrids. The maximum coefficient of utilization μ = 0.98 was obtained by calculation according to Bishop, also for the load combination that includes seismic.

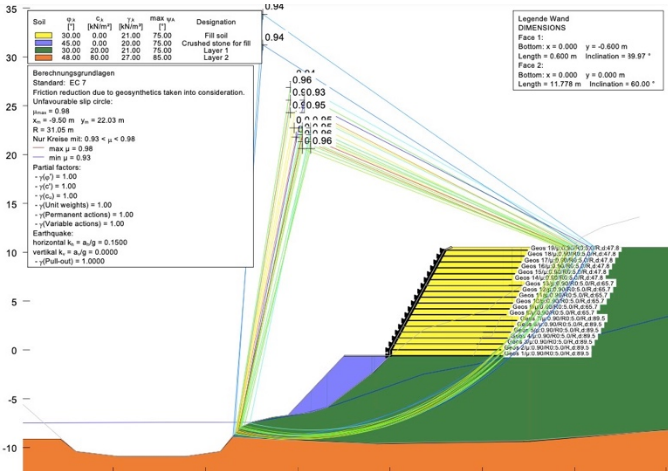

Figure 5 Compound Stability Calculation Results

Three different types of geogrids are adopted, with design tensile strengths ($R_{B,d}$) of min 64kN/m, 47kN/m and 34kN/m, and lengths varying from 9m-12m.

In accordance with EBGEO, the Design tensile strength $R_{B,d}$ is obtained by reducing the nominal tensile strength R_{BKo} by partial factors A_1-A_5 related to the specific geogrid, and a partial safety factor.

$$R_{B,d} = R_{B,ko} / (A_1 * A_2 * A_3 * A_4 * A_5 * g_M)$$

The greatest influence on the tensile strength of a certain type of geogrid for a design life of 60 or 100 years has the partial creep factor A1. Fortrac T geogrids with which the designer performed stability calculations have partial creep factors certified by BBA as well as in accordance with ISO/TR 20432, for different design lives and for different temperatures

An analysis of global stability of the embankment and the protective structure is also performed in phases of work execution according to the technology of work execution. The calculation is performed in FEM software Plaxis 2D. This calculation is based on the finite element method, using an incremental iterative process. As this construction is linear it is justified to analyze it in a cross section in the conditions of a flat state of deformation. The stability factor in the Plaxis 2D program was obtained according to a process called Phi-C Reduction, which was adopted as very good for this type of calculation. For the purposes of this design, one characteristic cross section in the Plaxis 2D program was modeled. After analyses, based on obtained values of safety factors for sliding it can be concluded the proposed and analysed measures with the protective structure and the embankment are satisfactory.

Construction of Reinforced Soil Embankment

Backfilling was done in soil layers up to a maximum of 30 cm, until the total layer thickness of 60 cm was reached, after which the corresponding geogrid was placed and the procedure was repeated until the full height of the embankment was reached. The embankment layers were compacted until a compaction of at least 95% of dry soil density was achieved. The construction of the embankment was done in usual way, except in the 1.5 m zone along the face of the embankment, where fill soil was spread with a light bulldozer, compacted with a vibrating smooth roller weighing a maximum of 8 tons, in layers of a maximum of 0.30 m thickness.

In a zone up to 1.5 m wide from the face of the embankment, spreading was done manually in layers up to 30 cm thick. Primary compaction was done with a 40/50 cm wide vibrating plate directly next to the face of the slope of the embankment, and once the soil was sufficiently stabilized, a light vibrating roller with a width of 60/70 cm and a maximum weight of up to 1 ton was used.

In addition to the Fortrac T geogrid, whose type and length were determined by stability calculations and which were installed perpendicular to the direction of the embankment with 20 cm overlaps, a protective geogrid type HaTe 23.142 GR was installed on the face of the embankment as erosion protection layer, which can be seen in Figure 6.

Figure 7 Installation of geosynthetic materials

The design has envisaged the green face of the embankment. Greening of the face was achieved by the installation of a mixture of humus, appropriate mixture of seed for planting and filling material in the thickness of 20-30cm along the face of the embankment to allow the vegetation growth.

Various mixtures of seeds should be selected depending on exposure to sun, soil, altitude and precipitation. Help of local vegetation specialist was recommended as always in similar cases.

The final aesthetic appearance of the reinforced soil embankment is completely integrated into the surroundings, Figure 7.

Figure 7 Finished RSE with green facing

Stabilisation works Phase III

Within the Phase III of works for landslide stabilization in the zone of CUT3 - LOT1, works are estimated on stabilization of existing support structure on the right side of right half profile, in the length of 300,50 m, from km 3 + 592 to km 3 + 900.35 (along the axis of the river), or from km 876+525 to km 876+725 (along the axis of the highway). These works consist of constructing additional pretensioned anchors, RC beams which are positioned as stiffeners on the slope berm, under the existing structure, gabion wall on the platform above the berm and additional drainage hole.

Conclusions

An embankment built using locally available soil that would otherwise end up in a landfill with all the costs and negative impacts that this brings, reinforced by high strength PET geogrids with very high Interaction Flexibility became instead an integral part of Landslide Stabilization measures. Reinforced Soil Embankment with a green facing due to the flexibility of its structure is also a very good choice in areas where foundation settlements can occur same as in the areas with high seismic activities.

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