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LANDSLIDE STABILISATION AND REHABILITATION MEASURES ON THE REGIONALEN ROAD R-1202 MAVROVO - DEBAR, NORTH MACEDONIA

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Abstract

Tectonic displacements, terrains with cracked and decomposed rocks, climate change and intense rains are the main factors that cause the emergence of new geological processes. These phenomena can cause damage to road infrastructure facilities. Such a phenomenon is registered on the regional road R-1202 Mavrovo-Debar, in the western part of North Macedonia, where on one of the lanes on the side of the slope there is a subsidence of the road construction. In this paper measures for stabilisation and rehabilitation of the landslide on the regional road are presented. This particular terrain is characterised by steep slopes, and in addition to the terrain instability reasons stated above, there is an inadequate maintenance of the drains and canals that are a part of the road structure. Therefore, the problem has been studied and recommendations are given for stabilisation and rehabilitation measures. The proposal is to build a structure to relocate and strengthen the unstable zone consisting of a slab founded on piles that will transfer the load to the lower layers. For this purpose, two software programs are used: "Slide", which analyses the stability by boundary equilibrium methods, and "Plaxis 2D", which is used to calculate deformations and straining. According to the results obtained from "Slide", the safety factor value F_s = 0.988 proves that the slope is not stable and there is a need for slope reinforcement, as well as rehabilitation of the road with reinforced concrete slabs and piles. While the design of the technical solution is simulated in several phases, according to the obtained results it is concluded that valid results are obtained from the last phase of exploitation and the maximum deformations U_{tot} = 14.23 mm are shown and they occur in the pile capping beam. The horizontal and vertical displacements are 4.50 mm or 14.13 mm accordingly. Hence, the conclusion is that the steps taken for stabilisation and reconstruction of the landslide on the road Mavrovo - Debar meet the project-exploitation requirements.

Key words: *landslides, stabilisation measures, safety factor, deformations*

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1. INTRODUCTION

Torrential rains, large temperature changes, tectonic shiftings, as well as the composition of the terrain with steep slopes with cracked and decomposed rocks are the main factors that cause the occurrence of modern geological phenomena: erosion, landslides and the like. Landslides are phenomena of instability, i.e. sliding of soil masses that most often occur on steep slopes and are of great importance in shaping today's relief map.

Inadequate road maintenance and untimely intervention after the landslide's occurrence, especially those occuring in places easily accessible to humans, can cause various material damage and also human losses. Therefore, there is a real urgent need to assess and repair potential unstable zones that have favorable slippery conditions. The most common reason for the occurrence of such geological processes is the inadequate human activity through road construction on unstable soil terrains.

This paper develops solutions for landslide remediation located on the regional road R-1202 Mavrovo - Debar, chainage km 43 + 100 (Fig. 1). It is a route with lots of pronounced problems when it comes to slope stability. This can be a case due to a poorly built road, inadequate drainage of atmospheric waters, tectonic movements and similar.

Figure 1 Landslide on the regional road Mavrovo-Debar

One of the possible solutions for remediation of an unstable zone is through indirect reinforcement of the landslide with the help of reinforced concrete piles and pile capping beam [1-2]. Two analyses were performed, i.e.:

1. Slope stability analysis;
2. Geostatic analysis of the terrain in which the structure is founded.

Global slope stability is analysed in "Slide" software to determine the critical slip surface and the safety factor. The geostatic analysis is performed in "Plaxis 2D" software and includes analysis of stresses and deformations in the substrate during four stages of performance. The analysis refer to the most critical cross section of the geological profile, with the highest height and the steepest slope.

2. GEOLOGICAL AND GEOMORPHOLOGICAL CHARACTERISTICS OF THE TERRAIN

The terrain, subject to this analysis is hilly - mountainous. In one part there are green grassy areas (pastures), and in the other part of the terrain, above the road and below it, there is a forest with low-stemmed and tall-stemmed trees. In the zone of unstable slope, the terrain has an average altitude of 650 m.

The geological structure of the terrain (Fig. 2) is defined on the basis of previous research (according to the Elaborate for geotechnical field research and laboratory tests at the location of a potentially unstable zone on the regional road R1202 Mavrovo - Debar), engineering geological mapping and based on conducted exploratory drillings.

Figure 2 Geological structure of the terrain

Based on that, it was concluded that in the geological construction of the exploration area there are: chalks, flysch sediments built of sandstones, clay shales and aleurolites, on which limestone lies. In the surface part there are deluvial creations that are a product of surface physical-mechanical decomposition of rock masses under the action of external (atmospheric) influences [3]. On one part of the slope, a crushing material was found, which was knocked down from the upper parts of the slope and settled on the slope itself. Also, on part of the terrain, presence of embankment material was ascertained, which probably originates from the excavation of the slope during the construction of the road, as well as from slope’s landslide cleaning.

Therefore, the geotechnical profile (Fig. 3) is composed of:

- Flyshoid sediments: on the investigation area they form the base of the field and other lithological units lie above them. They are represented by layers of sandstones, clay shales and aleurolites;
- Limestones: lie perpendicular to the flysch sediments, as smaller or larger masses;
- Deluvial works: they are found on the very edge of the road slope and in the background of the terrain. They are made of raw pieces of crushed limestone material mixed with a finer clay component;
- Waste (deposited) material: in a large part of the investigation area, primarily on the slope under the road, there are thick layers of crushed material deposited during the construction of the road. The material is a mixture of flysch sediments and the limestone above them.

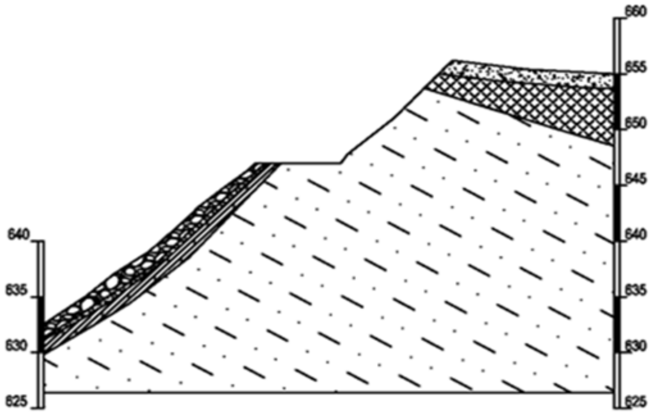

Figure 3 Geotechnical profile

The following table (Tab.1) shows the geomechanical parameters used in the analysis:

Table 1. Geomechanical parameters of materials

Material	Volume weight γ [kN / m^3]	Cohesion c [kPa]	Internal friction angle ϕ [°]
Flyshoid sediments	20	25	31
Compact flysh	23	33	33
Limestone	24	85	40
Diluvium	19	25	25
Spilled material	21	6	36

3. NATURAL SLOPE STABILITY ANALYSIS

Examination of slope's stability is one of the most complex problems that appear in the geotechnics. One of the most important steps in analysing the stability of a slope is to determine the sliding surface with the lowest safety factor [4-5]. Slide software was used for this purpose and the global and local slope stability were calculated using the Bishop method. The geomechanical parameters of the soil were used, adopted in Table 1.

Analysis was performed in static and seismic conditions with K_h = 0.1 and K_v = 0.05. According to the current regulations for slope stability, the safety factor for static conditions should be greater than 1.5, and in seismic conditions should be greater than 1.1. On the assumption that two freight trucks would diverge, the load would have had intensity of 33.33 kN/m^2. Fig. 4 and Fig. 5 show the critical slip surface together with the calculated safety factors, i.e. F_s = 0.988 under static conditions and F_s = 0.842 under seismic conditions.

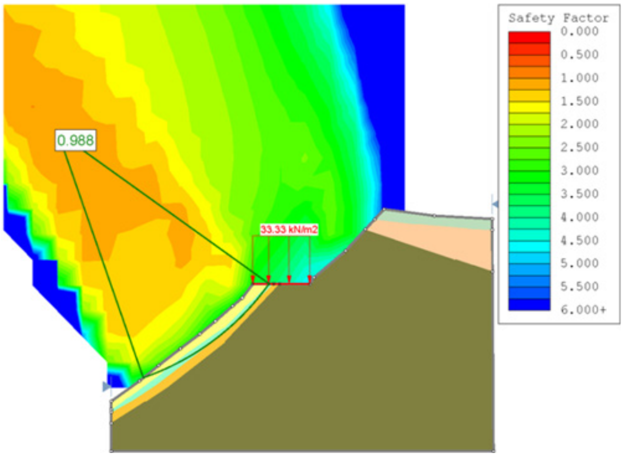

Figure 4 Critical slip surface with safety factor F_s = 0.988 in static conditions

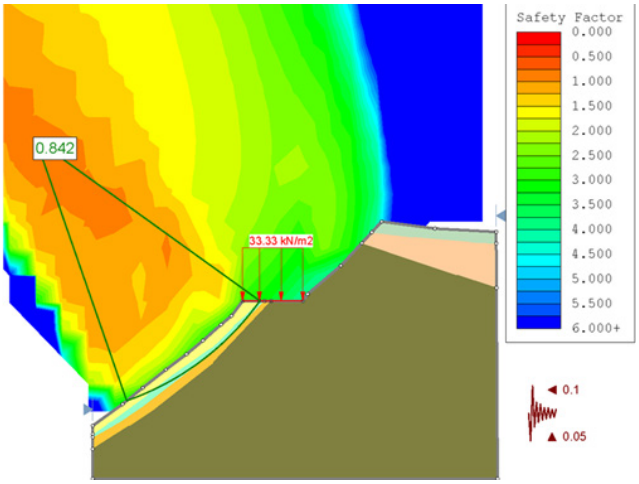

Figure 5 Critical slip surface with safety factor F_s = 0.842 in seismic condition (K_h = 0.1 and K_v = 0.05)

Based on the obtained results, it is concluded that the global stability is not satisfied, i.e. the safety factor in static conditions is F_s = 0.988 (F_s > 1.5) in a situation when the value 1.0 is a labile equilibrium. It is proven that the slope is not stable and there is a landslide.

4. GEOSTATIC CALCULATION

The calculation of the deformations and stresses in the surrounding environment, as well as the displacements of the overpiles structure, is done through a geostatic calculation in the “Plaxis 2D” software. A two-dimensional analysis of the plane state of deformations is performed where the ground as a continuous medium is approximated by the Mohr-Coulomb model. The time dependent behavior of the soils is simulated in several stages, i.e.:

- Phase I: initial condition;
- Phase II: performance of piles;
- Phase III: construction of pile capping beamand
- Phase IV: exploitation of the structure

The ground is defined by its physical-mechanical, strength and deformable characteristics shown in Table 2:

Table 2 Physical - mechanical, strength and deformable characteristics of the ground

Material	Flyshoid sediments	Compact flysh	Limestone	Diluvium	Spilled material
Volume weight γ [kN/^{3}]	20	23	24	19	21
Volumetric weight (water saturated) γ [kN/m^3]	21	24	25	20	22
Modulus of elasticity E_{ref} [kN/m^2]	25000	50000	50000	15000	20000
Cohesion c[kPa]	25	33	85	25	6
Internal friction angle ϕ [°]	31	33	40	25	36

While the figure 6 shows the computational mathematical model with the generated network of finite elements.

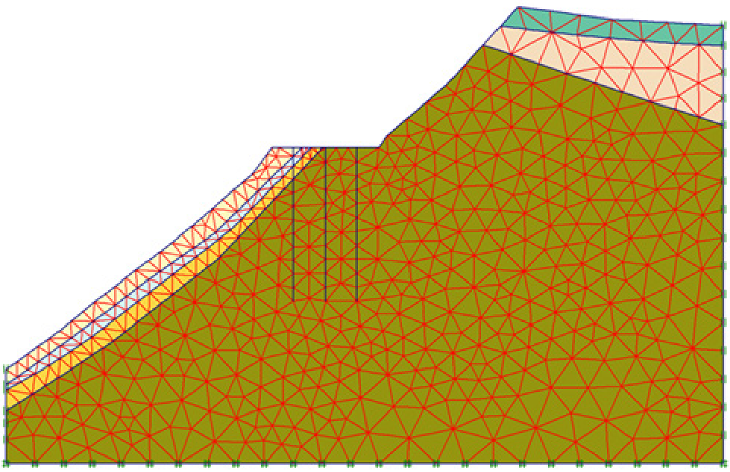

Figure 6 View of the generated network of final elements

From the initial state, it can be seen that the obtained critical sliding surface shown in Figure 7 coincides with the sliding surface from the analysis performed in “Slide”. The obtained safety factor is F_s = 0.988. The small difference in the values of the safety factor between the two analyses is due to the different calculation methods used by the two softwares, i.e. the finite element method and the boundary equilibrium method.

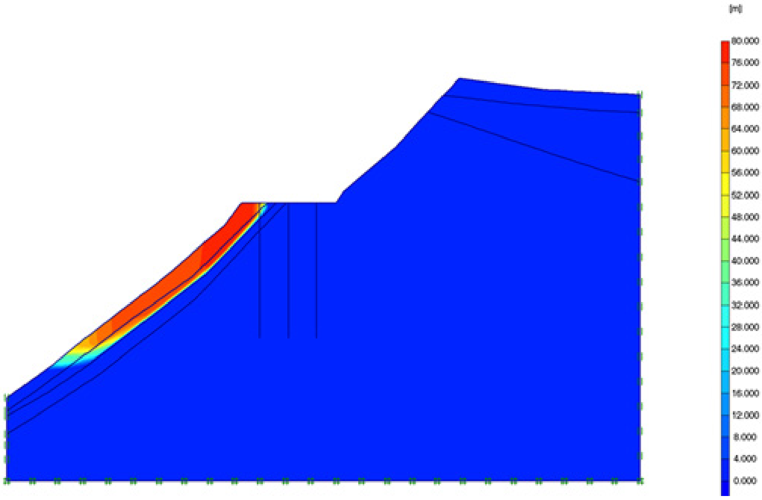

Figure 7 Critical slip surface view

The second phase simulates the performance of reinforced concrete piles modeled as line elements with an equivalent thickness of 0.431 m. The total deformations that occur at this stage are shown in Figure 8 and as expected, the maximum subsidence occurs on the slopes on the side of the slope with the value of U_{tot} = 9.06 mm.

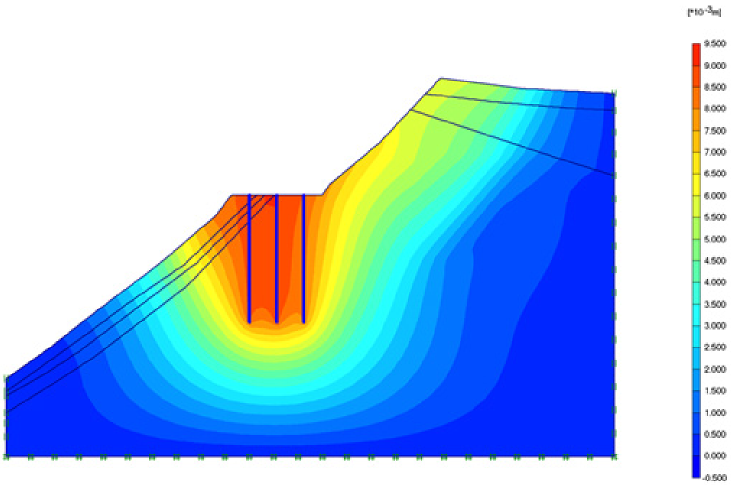

Figure 8 Total deformations of the second phase: U_{tot} = 9.06 mm

In the third phase, a steel reinforced concrete slab is simulated, modeled as a line element with a thickness of 0.50 m. There is a slight increase in subsidence of +1.36 mm due to the own weight of the pile capping beam as per the values obtained from “Plaxis 2D”. The obtained results are shown in Figure 9.

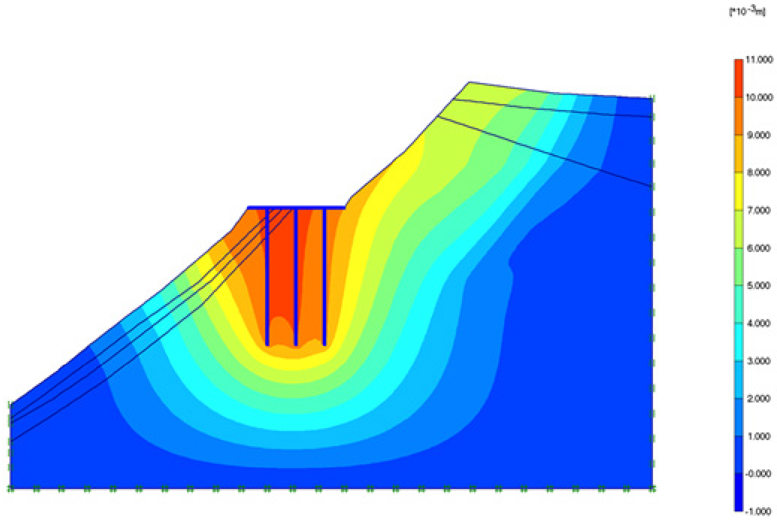

Figure 9 Total deformations from the third phase: U_{tot} = 10.4 mm

In the fourth phase, the fully constructed assembly is simulated and put into use. Therefore, the pile capping beam is loaded with an evenly distributed load with an intensity of 33.33 kN/m^2. The maximum deformations from the conducted analysis are just above the slope, on the left edge of the pile capping beam valued U_{tot} = 14.23 mm. The results are shown in Figure 10. The global stability of the landslide in the section where the construction of piles and retaining wall is above F_s = 1.6.

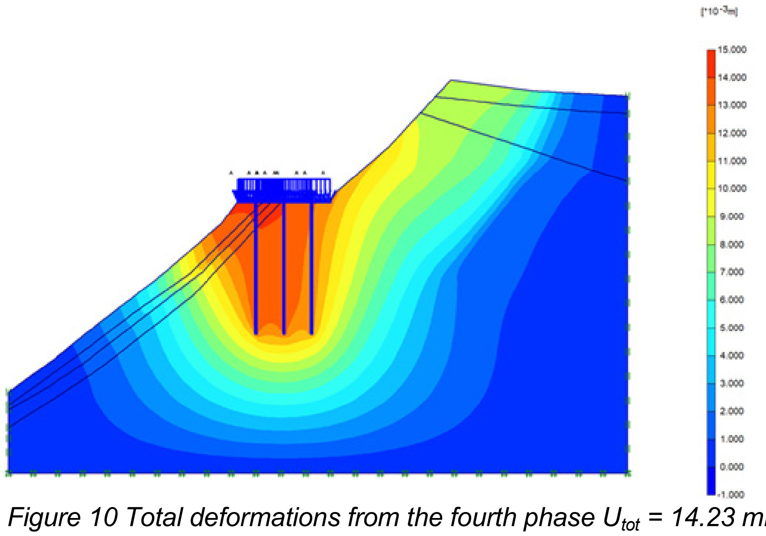

Figure 10 Total deformations from the fourth phase U_{tot} = 14.23 mm

5. CONCLUSION

In this paper, one variant for rehabilitation and stabilization of the regional road's R1202 Mavrovo-Debar landslide is presented. The solution is not a direct remediation of the landslide, but its indirect reinforcement with the help of the piles that serve as a foundation for the slab.

The performed analyses refer to the most critical cross section of the geological profile, with the highest height and the steepest slope.

The dimensioning of the reinforced concrete elements is finished for the limit load capacity and in accordance with PBBA (Handbook of practice for concrete) all controls are satisfied. As expected, the maximum deformations occur in the leftmost row of the piles and the leftmost edge of the pile capping beam. As atmospheric influences are one of the main causes for the occurrence of the landslide in question, special emphasis is placed on ensuring successful drainage of the structure itself during its life span.

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