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APPLICATION OF RETAINING STRUCTURES IN REHABILITATION OF LANDSLIDE ON STOLICE – KRUPANJ REGIONAL ROAD

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Abstract: *Landslides can be triggered by different factors including changeable weather conditions, prolonged heavy rains, complex terrain, traffic loads, etc. This paper deals with the problem of landslide rehabilitation on the Stolice-Krupanj regional road that resulted from vehicle loads and soil saturated with water. The technical measures used in the rehabilitation of the landslide included a concrete retaining wall and a geogrid-reinforced soil structure. Based on data related to soil obtained from laboratory tests, slope stability before and after applying rehabilitation measures was tested in the GEO5 Geotechnical software. The stability of the concrete wall was examined analytically by calculating the factors of safety against toppling and horizontal displacement. Both technical measures of given physical-mechanical properties increased the stability of the slope.*

Key words: landslide rehabilitation, concrete wall, geogrid-reinforced soil structure, GEO5.

PRIMENA POTPORNIH KONSTRUKCIJA U SANACIJI KLIZIŠTA NA REGIONALNOM PUTU STOLICE – KRUPANJ

Izvod: *Na pojavu klizišta mogu uticati mnogi faktori: promenljivi klimatski uslovi; velika količina padavina u kratkom periodu; složenost strukture terena; opterećenja od saobraćaja, itd. Rad se bavi problemom sanacije klizišta na regionalnom putu Stolice – Krupanj, koje je nastalo usled opterećenja od vozila i zasićenja zemljišta vodom. Tehničke mere koje su primenjene za sanaciju klizišta su: betonski potporni zid i potporna konstrukcija*

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od tla i geomreže. Na osnovu podataka o zemljištu iz laboratorijskih ispitivanja izvršene su provere stabilnosti kosina pre i posle primenjenih mera sanacije u programu GEO5, dok je stabilnost betonskog zida ispitivana analitičkim proračunom faktora sigurnosti na prevrtanje i horizonatalno pomeranje. Obe tehničke mere, zadatih fizičko mehaničkih karakteristika, povećale su stabilnost padine.

Ključne reči: sanacija klizišta, zid od betona, potporna konstrukcija od tla i geomreže, GEO5

1. INTRODUCTION

Landslides are among the most common hazards both in our country and worldwide. Most landslides are triggered by heavy rain and/or snowmelt, earthquakes and human activities. They can have substantial socioeconomic impacts and often cause the loss of human lives (Mitrović, 2014). Many case studies indicate that landslides can cause extensive damage (Kesseli, 1943; Campbell, 1975; Govi and Sorzana, 1980; Govi and Mortara, 1981; Sidle and Swanston, 1982; Ellen and Wieczorek, 1988).

Landslide rehabilitation requires the engagement of a wide range of resources. There are various measures and means to conduct the rehabilitation of landslides. They can be classified into several categories, such as changes in slope geometry, replacement of existing soil with better physical and mechanical properties, drainage of the terrain, and/or removal of surface water, retaining structures and internal reinforcement of slopes (Popescu, 2002, Mitrović, 2014), as well as the use of vegetation in shallow landslides (Marković et al., 2018). Landslide rehabilitation is often performed to protect a building or road (Marković et al., 2019). The application of technical measures, such as retaining structures made of concrete or geogrid-reinforced soil, is a solution that significantly increases the stability of newly designed slopes (Jotić et al., 2007, Niroumand et al., 2012). If several potential solutions are examined, a multi-criteria decision-making method should be applied to choose the most efficient solution (Cvetković, 2020).

The paper presents the analysis of proposed solutions for the rehabilitation of a landslide with retaining structures and the effects of the measures on the change in the stability of the terrain on the Stolica-Krupanj regional road. The paper aimed to elaborate on applying modern and traditional technical solutions for the rehabilitation of landslides in this locality.

2. MATERIAL AND METHOD

2.1. Material

A landslide on a section of the regional road R-211 Stolice-Krupanj in western Serbia at km: 0+578.6 - 0+605.690 was selected for the research area (Figures 1a and 1b).

The most important data on the landslide, including slope geometry, lithological layers, geotechnical profiles and results of physical and mechanical parameters of the soil, were taken from the “Elaborate on geotechnical conditions of landslide rehabilitation”, hereinafter –Elaborate (Institute of Geotechnics).

2.1.1. Study area

Regarding its configuration, the terrain is mountainous and hilly. This part of the road is located between the absolute terrain elevations of 425-460 m above sea level. Regarding the bedrock, the wider research area belongs to the Jadar tectonic area. The landslide was triggered by the movement of different materials, including the embankment of the road body and the deluvial silty clay to fine-grained surface cover and the physiochemically altered impermeable zone of clay shale in the bedrock. The landslide caused deformations on a section of the roadway and the slope under the road. The average width of the resulting landslide was 20.0 m, and the length was about 30.0 m. The depth to the sliding plane in the central part of the landslide was 4.0 to 4.5 m. The height difference from the top of the main scarp to the foot was 15.0 m. The main scarp was very pronounced, reaching a height of 1.5 m on the roadway itself.

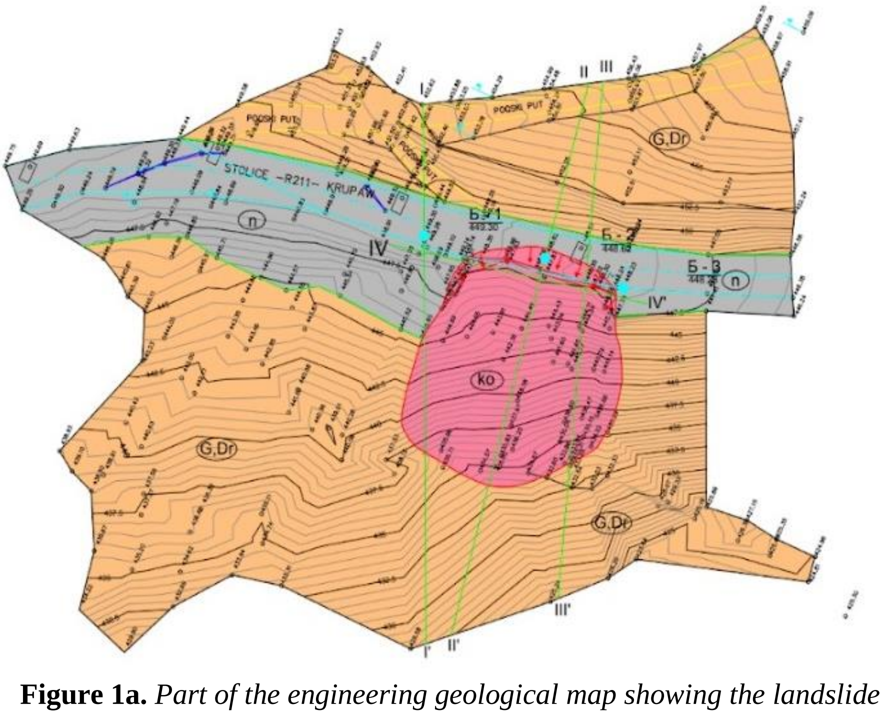

Figure 1a. *Part of the engineering geological map showing the landslide (Source: Elaborate)*

Figure 1b. *Legend for the part of the map shown in Figure 1a (Source: Elaborate)*

The analysis of the slope stability and the calculation of the stability of the applied solutions was performed on profile II - II' (Figure 2). This profile was chosen as typical or critical, as it was the longest and steepest and showed the landslide in the direction of sliding.

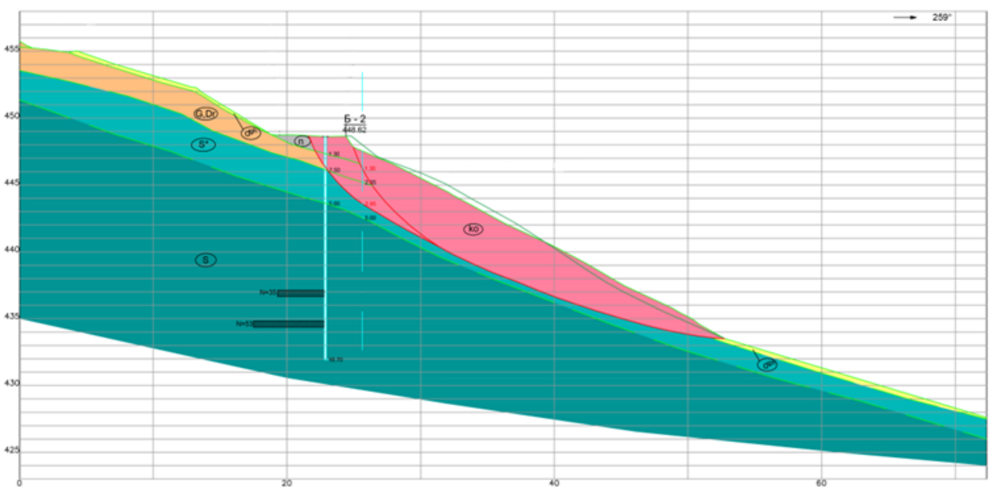

Figure 2. *Characteristic geotechnical section of terrain II-II` (Source: Elaborate) Legend: n-embankment and roadway structure; co-colluvium, G, Dr-clay with crushed fines; S*-clay shale; S-clay shale; dgh-humus clay*

2.1.2. Physical and mechanical parameters of lithological layers

Table 1. *Geotechnical data of lithological layers used in calculations (Source: Elaborate)*

	Layer thicknes [m]	γ [kN/m^3]	φ_{usl} [°]	φ_r [°]	φ [°]	c [kPa]	c_r [kPa]	Mv [kPa]
Embankment and roadway structure (n)	0.2-1.0	21.0			32	0,0		$25 \cdot 10^3$
Colluvium (co)	1.2-3.5	19.0	28	15	22	5.0	3.0	$5 \cdot 10^3$
Clay with fines[1] (G, Dr)	1.1-2.2	18.5		18	22 - 28	5.0 – 20.0	7.0	$1\text{-}3 \cdot 10^4$
Clay shales (S*)	0.5-3.0	21.0		15 - 22	25	22.0	3.0 - 4.0	8
Clay shale (S)	>3.5	23.0			32	30.0		$4 \cdot 10^4$

Legend: 1 – clay with crushed fines to limestone fines in a silty clay base; γ – volumetric weight; φ – angle of internal friction; c - cohesion; Mv – bulk modulus; φ_{usl} – value of mobilised friction angle determined by back analysis; φ_r – residual value of shear stress parameter determined under laboratory conditions; c_r – residual value of cohesion obtained under laboratory conditions.

Table 1 shows the values of physical and mechanical parameters of the lithological layers defined by exploratory drilling. The residual values of the shear stress parameters were adopted because they were disturbed after the landslide triggering.

In order to achieve complete stability of the slope and the road, it is necessary to terrace the slope (landslide body). The adopted values of soil parameters that are required to calculate the stability of designed terraces:

- volumetric weight γ =19.0 kN/m^3,
- angle of internal friction φ= 22˚,
- cohesion c=12.0 kPa

The maximum traffic load expected on a regional road adopted for the calculation amounted to120 kN/m^2.

2.2. Methods

To achieve the optimum solution for landslide rehabilitation, it is necessary to study:

- the stability of the displaced slope (before applying the solution),
- dimensioning of the retaining structures and
- terrain stability with technical measures applied.

We studied two solutions proposed for landslide rehabilitation:

1. traditional – a gravity retaining wall made of concrete and
2. modern – a retaining structure made of geogrid-reinforced soil.

Both solutions required the planning or terracing of the slope under the selected structures. Software package *Geotechnical Software GEO5* (Fine spol. s r.o, Czech Republic) was used to study the stability of the slope before the application of technical measures based on the adopted parameters obtained from the analysis of the existing documentation (Table 1). The same software was used to study the dimensioning of the retaining structure made of geogrid-reinforced soil. After adopting the optimum dimensions for both solutions using the GEO5 software, the local stability of the slope with retaining structures was tested, as well as the general stability of the terrain levelling solution (terracing) together with retaining structures (Solution 1 and Solution 2).

2.2.1. Slope stability analysis

The methods of Bishop and Yanbu were used to estimate slope stability. AW Bishop's method is applied to test the stability of slopes with the slip surface shaped as an arc of a circle. It was applied to test the partial (local) stability of designed slopes. The safety factor for the slip surface is obtained by the following equation (Todorović, 1991):

$$F_s = \frac{1}{\sum W\,sin\alpha} \cdot \sum\{[c'b + W(1-r_u)tg\varphi']\frac{1}{m_\alpha}\} \qquad (1)$$

Wherein:
W_1 – weight of non-submerged part of the slip, α – angle of inclination of the main slip to the horizontal, b – slip width, c – cohesion, φ – internal friction angle, U_s – pore water pressure, F_o – assumed safety coefficient, X_n and X_{n+1} – vertical shear forces along the sides of the slips, E_n and E_{n+1} – horizontal shear forces on the sides of the slips.

Yanbu's method is an analytical solution applicable to the slip surface with slips of arbitrary shape. In our study, it was applied to examine the general stability of the slope. The following equation was used to estimate this stability (Todorović, 1991):

$$F = \frac{f_0 \frac{\sum[c' + (p-u)tg\,\varphi']\Delta x}{n\alpha}}{p \cdot tg_\alpha \Delta x + Q} \qquad (2)$$

Wherein:
f_0 and $n\alpha$ – coefficients determined by the diagram, c' effective cohesion, φ' – effective angle of internal friction, p – mean vertical pressure at the base of the slip, Δx – slip width, u – pore pressure, Q – horizontal force (tensile force, horizontal seismic force, etc.)

The safety factor for capital structures is Fs=1.3-1.5 and for other structures Fs=1.1-1.3 (Todorović, 1991). Since the analysed road is regional, we adopted the safety factor of Fs =1.3-1.5 to consider the slope stable.

2.2.2. Dimensioning of the concrete retaining wall

The dimensions of the concrete wall were determined using the static analysis for the toppling stability (Todorović, 1991, Equation 3) and horizontal displacement stability (Todorović, 1991, Equation 4) of retaining structures based on the values of the active pressure obtained by the graphoanalytical procedure (Todorović, 1991).
We obtain the safety factor Fs using the following equation:

$$F_s = \frac{M_W}{M_r} \tag{3}$$

The slope is stable against toppling on the foundation contact if Fs > 1.5.

The horizontal displacement of the retaining wall under the action of the horizontal force component (Rh) can occur along the contact surface of the footing with the ground. It is defined by the stability factor Fs (source):

$$F_s = \frac{R_V \cdot tg_\varphi}{R_h} \tag{4}$$

The structure is stable if Fs>1.5.

If the given analysis shows that the wall is not stable, another stabilisation measure is introduced in the form of bevelling the footing – ω (Jevtić, 1975):

$$S' = \frac{S-0,2Z}{coscos\ \omega} \tag{5}$$

$$N = R_V \cdot cos\ cos\ \omega\ + R_H \cdot sin\ sin\ \omega \tag{6}$$

$$T = -R_V \cdot sin\ sin\ \omega\ + R_H \cdot cos\ cos\ \omega \tag{7}$$

It follows that the safety factor against sliding is:

$$Kp = \frac{N \cdot F}{T} \tag{8}$$

The safety factor is met if Fs > 1.5.

2.2.3. Geostatic calculation of the retaining structure made of geogrid-reinforced soil

To calculate the safety factor, we assume that there is a resisting force at each point of the intersection between the georeinforcement and the potential sliding surface (Mitrović, 2014):

$$F_S = \frac{M_O + \sum_{i=1}^{m} T_i \cdot y_i}{M_S} \tag{9}$$

Wherein:
Ti – resistance force of geosynthetics in layer i, *yi* – arm of Ti force to the center of rotation O,

m – number of geosynthetics layers, Ms – moment of all shearing forces around the center of rotation.

For a circular cylindrical sliding plane, it is assumed that the slope is optimally stable when the stability factor ranges from 1.5 to 2.0.

3. RESULTS AND DISCUSSION

The analysis of slope stability with multiple sliding planes determined the lowest safety factor of Fs=0.86 (Equation 2). Considering the condition of stability of Fs>1.3, the analysed slope was unstable. When analysing the displaced sliding body in the segment of the road body itself (main scarp), the highest values of transfer forces were determined. Taking into account the need to rehabilitate the landslide and protect the road, the retaining structures were positioned directly below the road body (Figures 3 and 5).

3.1. Solution 1 – Concrete wall

This solution included several positions of the wall at different distances from the road, with several geometric characteristics of the wall of simple and complex construction: the width of the foundation from 3.0 m to 4.5 m, and the height of the wall from 5.0 m to 7.5 m. The volume weight of γ =24.0 kN/m ^{3} was adopted for MB30 concrete. Table 2 shows the force values based on which the concrete retaining structure was dimensioned.

The adopted dimensions with which the wall meets the condition of stability are as follows:

- Foundation width B=4.5 m
- The height of the retaining wall H=8.1 m

A simple construction made of unreinforced concrete was selected.

Table 2. *Forces acting on the retaining wall; Safety factor*

Active earth pressure	Ea=377.83 kN/m2
Horizontal component of the resultant	Rh=370 kN/m
Vertical component of the resultant	Rv=671 kN/m
Stability of retaining structure against toppling	Fs = 2.23
Stability of retaining structure against horizontal displacement (without bevelling)	Fs = 0.77
Bevelling of footing	8°
Stability of retaining structure against horizontal displacement (with bevelling)	Fs = 1.58

The analysis of the stability of the concrete retaining structure built to reduce the risk of toppling (Equation 3) resulted in a safety factor of Fs = 2.23, which means that the stability condition was met, and the retaining wall was stable. However, the stability of the structure against horizontal displacement under the effect of the horizontal force Rh (Equation 4) was not confirmed. For this reason, the footing (ω) was bevelled by 8˚, so the height of the structure was now 8.1 m. The safety factor thus amounted to Fs = 1.58 (Equation 8) and the structure was stable regarding the horizontal displacement (Fs > 1.50).

For the rehabilitation of the part of the landslide that extended under the concrete structure terracing was proposed. The proposed width of each planum was 3 m, and the inclination of the planum to the horizontal was 3˚ (inclination down the slope). The height of the planum differed, and going in the direction from the retaining wall to the bottom of the slope, the heights were 3.0 m, 2.0 m, 2.0 m, and 4.4 m (Figures 3 and 4).

The general stability of the slope was Fs=3.55 (Figure 3), which meant that the newly designed slope was stable. The analysis of the second sliding plane that passed directly through the structure produced a safety factor that met the stability condition Fs=11.88 (Figure 4).

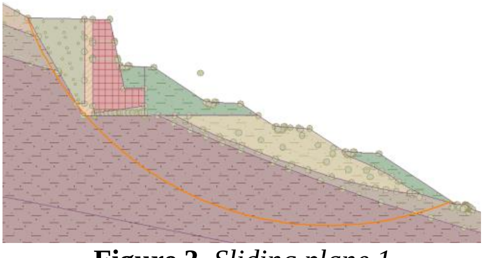

Figure 3. *Sliding plane 1*

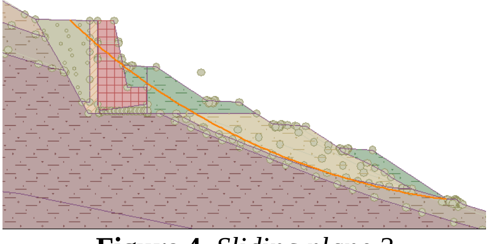

Figure 4. *Sliding plane 2*

3.2. Solution 2 – Retaining structure made of geogrid-reinforced soil

The stability was determined based on the primary geo-reinforcement that provides tensile resistance in the soil. Geogrid layers were placed at a vertical spacing of 1 m, which made the total height of the retaining structure from the ground and the geogrid amounted to 5 m. Table 3 shows the characteristics of the geogrid proposed for landslide rehabilitation.

Table 3. *Geogrid characteristics*

Ordinal number of the geogrid	Geogrid length [m]	Tensile strength Rt [kN/m]
1.	6.5	50.0
2.	7.0	50.0
3.	7.5	50.0
4.	8.0	50.0
5.	8.5	50.0

The tensile strength of the geogrid adopted for the calculation was 50 kN/m.

Table 4 shows the results of testing the local stability of the slope with a retaining structure using Bishop's method (Equation 1).

Table 4. *Local slope stability test*

Sum of active forces	Fa=527.45 kN/m
Sum of passive forces	Fp=893.96 kN/m
Moment of displacement	Ma=6424.29 kNm/m
Moment of resilience	Mp=10888.42 kNm/m
Safety factor	Fs=1.69 > 1.50

The safety factor obtained from the stability analysis (Table 4) met the stability condition (Fs>1.5), which indicates that the part of the slope covered by the sliding plane was stable (Figure 5).

Terracing was proposed as the most suitable measure to stabilise the entire landslide. The proposed width of each planum was 3 m, while the slope of the planum to the horizontal was 3° (inclination down the slope). The heights of the planum differed, and towards the bottom of the slope, they were 3.0 m, 3.0 m, 3.0 m, and 4.0 m.

The general stability of the slope for the tested sliding plane (Figure 6) was Fs=2.12, which means that the stability condition was met (Fs > 1.3), and the newly designed slope was stable with the applied measures.

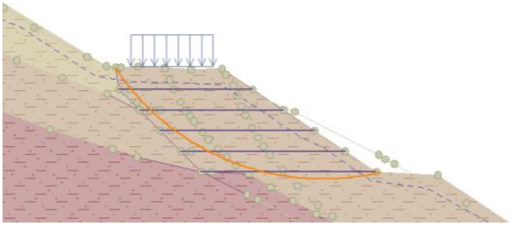

Figure 5. *Sliding plane 1*

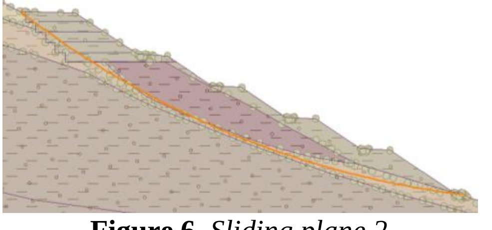

Figure 6. *Sliding plane 2*

3.3. Analysis of proposed solutions for rehabilitation

By comparing the obtained safety factors without the applied measures (Fs=0.86) and with applied measures (Solution 1 Fs=3.55 and Solution 2 Fs=2.12), we can see that a significant increase in the safety factor is achieved. Expressed as a percentage, the application of the first solution increases the safety factor by 313%, and relative to the stability condition 136%. We can say that the dimensions used in this solution are overestimated and calculations should be repeated to reduce material consumption. Regarding the second solution, the percentage increase is 146%, and relative to the stability condition, it is 41%, which means it can be adopted without repeating the calculations.

The retaining concrete wall receives the stress of the road body and the soil behind the wall and ensures their primary stability. The construction with its own weight reduces the active moment of rotation from the earth pressure and thus ensures greater stability (Fs=3.55). The analysis of the second sliding plane (Figure 4) produced a significantly higher safety factor Fs=11.88, which can be explained by the position of the sliding plane passing through the retaining structure. The retaining structure made of concrete has high values of resistance parameters, and thus the entire slope is more stable. The stability of the slope can be further enhanced with the use of vegetation on the planums, the role of which increases with time. For maximum effects of vegetation, planting arrangement should be carefully considered. (Marković et al., 2018).

Considering the current trend towards solutions that follow the concept of "soft engineering" (Popescu, 2002, Prambauer et al., 2019, Wu et al., 2020), the retaining structure made of geogrid-reinforced soil is a more acceptable solution for landslide rehabilitation. Furthermore, when choosing the most effective solution for landslide rehabilitation, it is not enough to consider only the criterion of stability. Methods of multi-criteria decision-making that include a larger number of criteria (e.g., stability, price, length of exploitation, ecological solution, etc.) provide a more reliable way to reach the optimal solution for landslide rehabilitation.

4. CONCLUSIONS

In 2011, deformations were observed on the regional road Stolice - Krupanj, which clearly indicated the existence of a landslide. The landslide also covered part of the road and thus hindered the traffic.

By analysing the stability of the slope, the value of the safety factor Fs=0.86 was obtained, which proved that the terrain was not stable.

The analysis of the stability of the slope with technical measures applied show that Solution 1 – a retaining wall made of concrete and Solution 2 – retaining structure made of geogrid-reinforced soil, together with levelling solutions (terracing) increase the safety factor. Solution 1 increases the general safety factor to Fs=3.55 and Slution 2 to Fs=2.12.

Looking at the achieved safety factors, we can conclude that both technical solutions for landslide rehabilitation meet the condition of stability.

In order to choose the best solution for landslide rehabilitation, it is necessary to conduct multi-criteria decision-making analyses. These analyses would set the criteria how to rank the solutions, for instance according to construction costs, structure lifetime, fitting into the environment, proneness to damage, etc. (Cvetković et al., 2022).

In a broader sense, it is of great importance that, in practice, landslide processes are timely recognised and addressed first with preventive and temporary, and then with long-term measures. In this way, not only do we use resources most efficiently, but also prevent the damage caused by landslides.

REFERENCES

Campbell, RH (1975): Soil Slips, Debris Flows and Rainstorms in the Santa Monica Mountains and Vicinity, Southern California, Geol.Surv. Prof. Paper 851, 51;

Cvetković J., Vulević T., Gajić G., Živanović N., Rončević V. (2022): Application of the method of additive weighting factors for the selection of the appropriate measure in the rehabilitation of landslides, Book of abstracts of the SETOF International Conference, November 3, Goč, Serbia;

Cvetković J. (2020): Application of technical measures in the rehabilitation of landslides on the Stolica - Krupanj regional road, master's thesis, University of Belgrade, Faculty of Forestry;

Elaborate on the geotechnical conditions of landslide rehabilitation on the road P-211, section: Stolice - Krupanj at km: 0+578.6 - 0+605.90, Road Institute ad, Institute for Geotechnics, Kumodraška 257, Belgrade;

Ellen, SD and Wieczorek, GF (1988): Landslides, Floods and Marine Effects of the Storm of January 3–5 1982, in the San Francisco Bay Region, California, US Geological Survey Professional Paper 1434, 310 pp;

Govi, M., Mortara, G. (1981): I disstesti prodotti dal nubifragio del 10 luglio 1972 nella Bassa Valle Seriana, Bollettino Associazione Mineraria Subalpina, Anno XVIII, 87–118;

Govi, M., Sorzana, PF (1980): Landslide susceptibility as a function of critical rainfall amount in Piedmont basin (North-Western Italy), Studia Geomorphological Carpatho-Balcanica, 14, 43–61;

Jotić M., Jotić S., Milić J., Jevtić M. Ubiparip B. (2007): Geotechnical conditions and methods of remediation of active landslides and other unstable phenomena within the framework of the project of improving the main and regional roads of Serbia, Road Institute ad, Belgrade;

Kesseli, JE (1943): Disintegrating soil slips of the Coast Ranges of Central California, J. Geol. Bull., 51(5), 342–352;

Marković M., Živanovć N., Gajić G. (2018): The influence of bioreinforced soil on the stability of the Raklja landslide, Erosion, Serbia's Dredging Association, Kneza Višeslava 1, 11030 Belgrade;

Marković M., Živanovć N., Gajić G. (2019): Analysis of slope stability next to roads in bioreinforced soil conditions, Bulletin of Faculty of Forestry no. 119., University of Belgrade, Faculty of Forestry, Belgrade;

Mitrović, P. (2014): Rehabilitation of landslides and insufficient load-bearing soil, AGM book, ISBN: 978-86-86363-43-5;

Niroumand, H., Kassim, KA, Ghafooripour, A., & Nazir, R. (2012): The role of geosynthetics in slope stability. Electronic Journal of Geotechnical Engineering, 17(HR), 2739-48;

Popescu, ME (2002): Landslide causal factors and landslide remedial options. In 3rd International Conference on Landslides, Slope Stability and Safety of Infra-Structures (pp. 61-81). CI-Premier PTE LTD Singapore;

Prambauer M., Wendeler C., Weitzenböck J., Burgstaller C. (2019): Biodegradable geotextiles – An overview of existing and potential materials, Geotextiles and Geomembranes, 47(1), 48-59, ISSN 0266-1144, https: //doi.org/10.1016/j.geotexmem.2018.09.006;

Sidle, RC, Swanston, DN (1982): Analysis of a small debris slide in coastal Alaska, Can. Geotech. J., 19(2), 167–174;

Todorović T. (1991): Fundamentals of Geotechnics in Floodplains, University of Belgrade, Faculty of Forestry, Belgrade ;

Wu H., Yao C., Li C., Miao M., Zhong Y., Lu Y., Liu T. (2020): Review of Application and Innovation of Geotextiles in Geotechnical Engineering. Materials, 13(7) 1774, https://doi.org/10.3390/ma13071774.

APPLICATION OF RETAINING STRUCTURES IN REHABILITATION OF LANDSLIDE ON STOLICE – KRUPANJ REGIONAL ROAD

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Summary

The paper presents an analysis of slope stability on the regional road Stolice - Krupanj.

The triggering of the landslide caused deformations on a road section and the slope under the road. The average width of the landslide was 20.0 m and the length was about 30.0 m. The depth to the sliding plane in the central part of the landslide was from 4.0 to 4.5 m. The height difference from the top of the main scarp to the foot part was 15.0 m. The main scarp was very pronounced, reaching a height of 1.5 m on the roadway.

The aim of the research was to show the possibilities of applying modern and traditional technical solutions for the rehabilitation of landslides in the locality.

The following technical measures were proposed: a concrete retaining wall and a retaining construction made of geogrid-reinforced soil. In order to achieve complete stability of the slope and the road, it was necessary to terrace the slope (body of the landslide).

In order to find the optimal solution for landslide rehabilitation, the following analyses were carried out: analysis of the stability of the displaced slope (before applying the solution), dimensioning of the retaining structures and testing of the stability of the terrain with the applied technical measures.

The analysis of the slope stability as well as the calculation of the stability of the applied solutions was carried out on the profile II - II`. This profile was chosen as characteristic/critical because it showed the landslide in the direction of sliding, was the longest and had the steepest slope.

Having analysed several sliding planes, the lowest safety factor of Fs=0.86 was determined. Considering the condition of stability (Fs>1.3), the analysed slope is unstable. With the measures applied, the newly designed slope becomes stable, and with Solution 1 (a concrete retaining wall) the general safety factor increases to Fs=3.55. The dimensions with

which the wall meets the condition of stability are: the width of the foundation of 4.5 m and the retaining wall height of 8.1 m. If we apply Solution 2 (retaining construction made of geogrid-reinforced soil), the safety factor is Fs=2.12. It consists of primary geo-reinforcement placed at a vertical distance of 1 m. The total height of the retaining construction is 5 m.

It is of great importance that, in practice, landslide processes are timely recognised and addressed first with preventive and temporary, and then with long-term measures. In this way, not only do we use resources most efficiently, but also prevent the damage caused by landslides.

PRIMENA POTPORNIH KONSTRUKCIJA U SANACIJI KLIZIŠTA NA REGIONALNOM PUTU STOLICE - KRUPANJ

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Rezime

U radu je prikazana analiza stabilnosti padine na regionalnom putu Stolice - Krupanj.

Nastanak klizišta je izazvao pojavu deformacija na delu puta i kosini ispod puta. Prosečna širina klizišta je 20,0 m, dužina oko 30,0 m. Dubina do klizne ravni u centralnom delu klizišta iznosi od 4,0 do 4,5 m. Visinska razlika od vrha čeonog ožiljka do nožičnog dela je 15,0 m. Čeoni ožiljak je vrlo izražen, na kolovoznoj traci doseže visinu od 1,5 m.

Cilj istraživanja bio je da se prikažu mogućnosti primene savremenih i tradicionalnih tehničkih rešenja za sanaciju klizišta na pomenutom lokalitetu.

Predložene su sledeće tehničke mere: potporni zid od betona i potporna konstrukcija od tla i geomreže. Kako bi se postigla potpuna stabilnost padine i puta, bilo je neophodno izvršiti i terasiranje padine (tela klizišta).

Za utvrđivanje optimalnog rešenja sanacije klizišta sprovedene su sledeće analize: analize stabilnosti pokrenute padine (pre primene rešenja), dimenzionisanje potpornih konstrukcija i ispitivanje stabilnosti terena sa primenjenim tehničkim merama.

Analiza stabilnosti padine kao i proračuna stabilnosti primenjenih rešenja izvršena je na profilu II - II`. Ovaj profil je izabran kao karakteristični/kritični, s obzirom da daje prikaz klizišta u pravcu klizanja, najveće je dužine i najstrmijeg nagiba.

Analizom stabilnosti padine, uzimajući u obzir više kliznih ravni, utvrđen je najniži faktor sigurnosti koji iznosi Fs=0,86. Imajući u vidu uslov stabilnosti (Fs>1,3), analizirana padina je nestabilna. Sa primenom pomenutih mera novoprojektovana kosina postaje stabilna, pri čemu sa rešenjem 1 (potporni zid od betona) generealni faktor sigurnosti iznosi Fs=3,55. Usvojene dimenzije sa kojima zid ispunjava uslov stabilnosti su sledeće: širina temelja je 4,5 m, a visina potpornog zida je 8,1 m. Primenom rešenja 2 (potporna konstrukcija od tla i geomreže) faktor sigurnosti je Fs=2,12. Rešenje 2 se sastoji od primarne geo-armature koja je postavljena na vertikalnom rastojanju od 1 m. Ukupna visina potporne konstrukcije iznosi 5 m.

Od velikog značaja je da se, u praksi, na vreme prepoznaju procesi kliženja kako bi se blagovremeno reagovalo sa preventivnim, privremenim, a kasnije i završnim merama. Na ovaj način, ne samo da bi se optimalno iskoristili resursi, već bi se sprečile i štete koje nastaju kao posledica pojave klizišta.