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REMEDIATION OF THE LANDSLIDE AND RETAINING WALL SUČEVIĆ

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Abstract

This paper presents remediation works of the landslide and retaining wall at Sučević, located on the state road DC1, section Gračac – Knin. The remediation of the landslide provided by the design includes the construction of a supporting structure made of reinforced embankment with facing of concrete modular blocks. Stabilization of the existing retaining wall involves the installation of geotechnical self-drilling anchors with a diameter of 38 mm and a length of 15 m. The supporting structure is divided into six cascades, each of which consists of the mentioned system: concrete modular blocks, geogrids, and embankment. Displacements of the structure during construction were measured with inclinometers. Each level of the supporting structure has its own line foundation with dimensions of 0.60×0.20 m, while the lowest level has a line foundation with dimensions of 0.80×0.40 m, under which there are micropiles with a diameter of 180 mm and a length of 6 m, at an axial distance of 2 m. In this project, 11,375 pieces of concrete blocks were installed, with a total mass of 227.5 tons. In total, 4300 m³ of stone material with a granulation of 0-75 mm and 4300 m² of geogrid were installed inside the reinforced soil structure.

Key words

landslide, reinforced earth, stabilization, micropiles, rock anchor

1 Introduction

On the state road DC 1, section Gračac - Knin, instability appeared under the existing reinforced concrete retaining wall in the form of a translational landslide. The landslide covered an area with a width of 60-65 m, a length of 90-115 m, and the sliding surface is at an average depth of 6 m. In total, about 35,000 m³ of material was removed. As a result of this instability, the foundation of the existing reinforced concrete wall was undermined, reducing the stability of the wall and the entire road above it.

This paper presents the initial condition of the landslide, geotechnical investigation works and calculations, and describes each phase of the landslide remediation. The focus of the work is on presenting all phases of the work on the landslide. Additionally, the paper shows the inclinometer measurements that were carried out at the position of the existing reinforced concrete wall during the execution of the works.

Figure 1. The initial state of the landslide, March 2023

The landslide occurred in the spring of 2018 during extreme rainfall.

2 Methods

This chapter presents the chronological sequence of activities for the purpose of landslide remediation: geotechnical investigation works, landslide remediation design, and implementation of landslide remediation works. The focus of this work is on presenting the performance of works on the remediation of the landslide, along with the challenges that arise during the remediation of landslides, especially on inaccessible terrain.

2.1 Geotechnical investigation works

Geotechnical investigations were carried out at the location of the landslide in October 2020. The list of geotechnical investigation works and the number of locations where they were carried out can be found in Table . Geophysical surveys were conducted as part of the research for the development of the landslide remediation project and retaining wall. From the results of seismic and geoelectrical geophysical tests, it is possible to determine and evaluate: the depth and configuration of the bedrock, lateral and vertical material changes, the positions of more fractured zones in the bedrock, and the appearance of caverns in such zones (Highland & Bobrowsky, 2008; Mihalić Arbanas & Arbanas, 2015).

Table 1. Geotechnical investigaon works on the landslide

Geotechnical investigation work	Number of locations on the landslide
Geological prospecting	over the entire surface
Measurement with a Schmidt hammer	4 locations, 10 measurements per location
Measurement with a geological compass	over the entire surface
Terrain profiling with georadar (GPR, P)	6 profiles
Shallow refraction seismic captures	2 profiles
Geoelectric point recordings	2 locations
Machine drilling	3 drillhole, 20 m depth

During the field investigation work, field AC soil classification was performed, soil samples were taken, and "in situ" tests were carried out on rocks. Additionally, the occurrence and level of underground water were monitored during drilling. For the purpose of conducting geostatic stability analyses, based on the results of geotechnical investigations, the geotechnical profile is divided into two layers: embankment and heavily weathered limestone. The strength parameters of the layers are shown in Table (Hoek & Marinos, 2007).

Table 2 . Strenght parameters of the layers

Layer number	Layer name	φ_{ef}	c_{ef} (kPa)	γ (kN/m^3)
1	Embankment	36°	1,0	20,0
2	Heavily weathered limestone	35°	93,0	24,0

2.2 Landslide remediation design

For the purpose of creating the entire structure of the reinforced soil and ensuring the stability of the retaining wall, the designers conducted geotechnical stability analyses. A global stability analysis was carried out for the initial state of the landslide and for each phase of the construction of the structure. Furthermore, the dimensioning of micropiles, head beams of micropiles, rock anchors, and foundations of each floor of the structure was performed. The usability of the slope, defined as the ratio between destabilizing forces (active forces) and stabilizing forces (passive forces), is 95%. That is a calculation with implemented EN 1997-1, PP3. The maximum foreseen lateral displacement at the top of the structure is 5 mm.

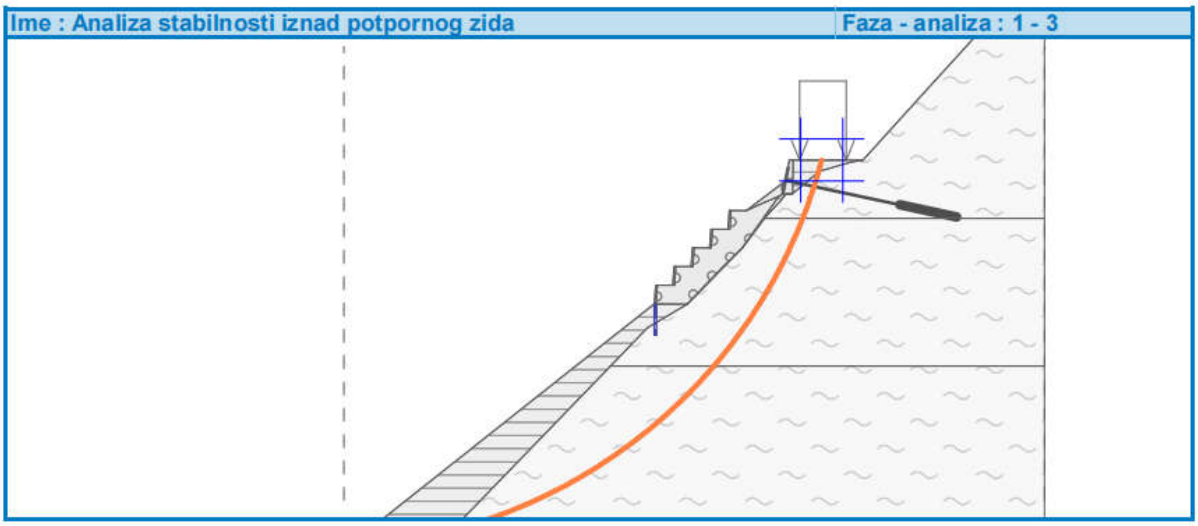

Figure 3. Global stability analyses in Geo5 software Slope Stability

The calculations were carried out using the geotechnical software Geo5, specifically the Slope Stability and MSE Wall software, which are part of the Geo5 software package. The global stability of the landslide was verified using the Slope Stability software. This software is used to perform slope stability analysis for various structures such as embankments, earth cuts, anchored retaining structures, and MSE walls. The slip surface is considered circular or polygonal and analyzed using several general methods. The dimensioning of the component parts of the reinforced soil construction was performed using the MSE Wall software. This program is used for the verification of mechanically stabilized earth walls and segmental retaining walls reinforced by geogrids (georeinforcements). The Slope Stability software enables calculation of global stability using several calculation methods, including Bishop, Fellenius/Petterson, Spencer, Janbu, and Morgenstern – Price (Popescu, 2001). Figure 2 shows global stability analyses in Geo5 software Slope Stability on one of the cross-sections. Figure 3 shows the cross-section of the structure with all elements of reinforced soil, micropiles, rock anchors, geotechnical profile, and the intended inclinometer.

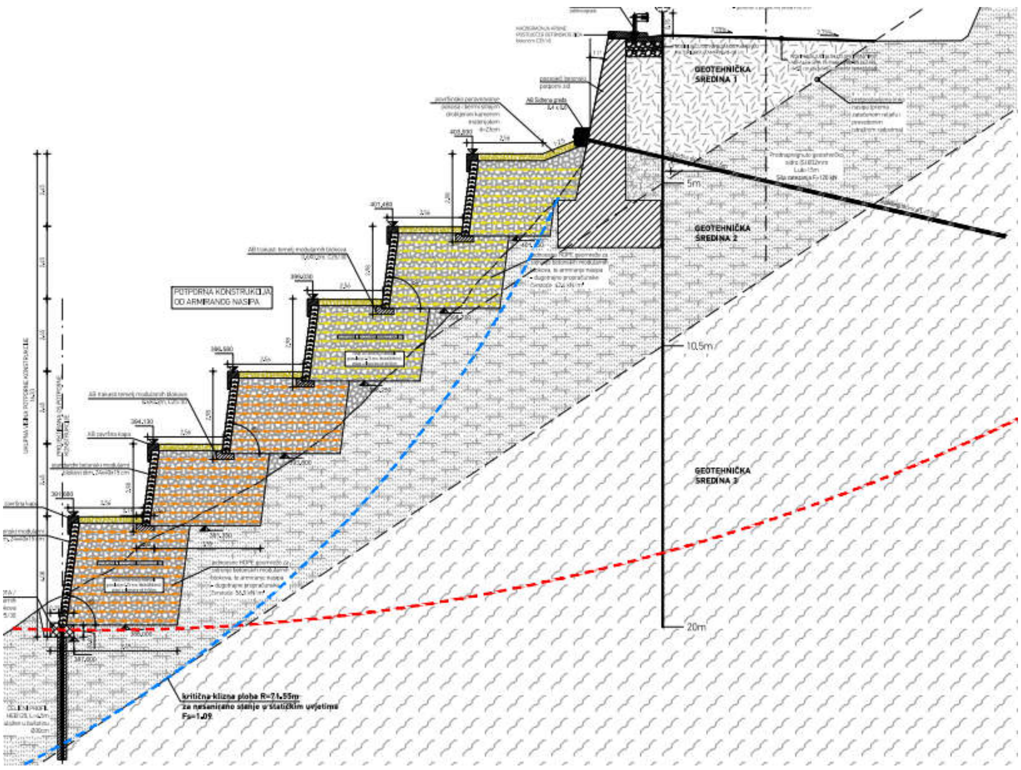

Figure 3. Cross section of the construction

2.3 Implementation of landslide remediation works

In this chapter, each phase of landslide remediation is described in detail. The description of the work chronologically follows the order of execution. All figures show work from the mentioned construction site.

2.3.1 Installation of rock anchors

Before any work on the remediation of the landslide, it was necessary to ensure the stability of the existing reinforced concrete wall with self-drilling rock anchors. Self-drilling rock anchors are installed because there is a layer of fill material behind the existing wall, followed by a layer of heavily weathered limestone.

A total of 34 rock anchors were installed, at an axial distance of 1.50 m. Each anchor is 15 m long and

38 mm in diameter. The diameter of the borehole is 90 mm, and the injection is carried out along the entire length of the anchor. Table 4 shows technical characteristics of self-drilling rock anhors.

Table 4. Technical characteristics of rock anchors

Type of rock anchor	Self-drilling rock anchor
Thickness (mm)	7,1
Ultimate load, (kN)	440
Yield point $f_{y0,2}$, (kN)	360
Average cross section (mm^2)	680
Weight (kg/m')	5,5
Nominal diameter (mm)	38
Thread type	left

Each anchor was tensioned to a force of 130.0 kN, 7 days after injection. The anchors were tensioned using a hydraulic press while monitoring the applied force and displacement in the anchor. Three anchors were tested with a force of 185.0 kN. The anchors are grouted with cement suspension, with a water-cement ratio of 0.42 and 1% swelling additive based on the mass of cement.

Figure 4. Installing of rock anchors

After the anchors have been tensioned and tested, it is allowed to proceed with the remediation works.

2.3.2 Construction of access road

To facilitate work on the sliding body, an access road was constructed from the state road to the lowest elevation of the structure. This road served for the transportation of machinery and delivery of materials. As construction progressed to the level of the state road, adjustments to the access road were necessary. It was always extended to the bottom level of each floor's foundation to provide maneuvering space for machinery.

In total, 840 m^3 of excavation and 50 m^3 of embankment were carried out for the construction of the access road.

Figure 5. The beginning of the construction of the access road

2.3.3 Micropiles instalation

The foundation of the lowest floor of the structure, made of reinforced soil, was constructed in combination with micropiles with a diameter of 180 mm and a length of 6.0 m. The micropiles were installed at an axial distance of 2.0 m, covering a total length of 58.0 m, resulting in the installation of 30 micropiles.

Figure 6. Installation of micropiles

After drilling a borehole with a diameter of 180 mm, HE 120 A steel profiles, 6 m long, are inserted into the borehole. The entire borehole is then injected with a cement suspension with a water-cement ratio of 0.42 and 1% swelling additive per cement mass. Seven days after the completion of grouting, a pile integrity test is conducted, which is a prerequisite for proceeding with the construction of the head beam.

2.3.4 Construction of head beam

The head beam is 60 m long with a cross-sectional dimension of 80×40 cm. For its construction, 19.50 m^3 of concrete of compressive strength class C30/37 and 1500 kg of reinforcement were utilized. The main challenge was the delivery of fresh concrete to the beam's position, accomplished by using an excavator bucket. Concrete was transported to the beginning of the access road by a concrete mixer, and then loaded into the excavator's bucket. The installation with concrete pumps was not feasible due to the considerable distance from the state road to the bottom of the beam, which exceeds 40 m.

Figure 7. Construction of head beam

2.3.5 Construction of reinforced earth

The reinforced earth construction comprises three main elements: the face element, the tensile element, and the backfill material. The construction consists of a total of six floors. Five out of the six floors are 2.56 m high, while the lowest floor is 3.52 m high. Each floor is offset by 2.50 m towards the existing wall compared to the previous floor. Consequently, the total height of the structure is 16.32 m, and its length is 60 m.

The face of the wall comprises concrete blocks measuring 60×20×16 cm. Each block weighs 20 kg, and a total of 11,375 blocks were incorporated into the structure, resulting in a mass of 227.5 tons.

Longitudinal reinforcement, consisting of bars with a diameter of 6 mm, is positioned in each row of blocks. In every other row, a geogrid, serving as a tensile element, is attached around the longitudinal reinforcement. The geogrid is placed 3 m wide behind the wall, with an overlap of 0.50 m over the longitudinal reinforcement. The longitudinal reinforcement is inserted into slots within the blocks.

At an axial distance of 2.40 m, or in every fourth block, a reinforcing bar with a diameter of 20 mm is inserted to vertically stiffen the face of the wall. The rod is anchored into the foundation of each floor by 20 cm, and the rods are continued by overlapping for a length of 50 cm. After the vertical bars are installed, the cavity inside the block is injected with a cement mixture for rock anchor injection. Figure 8 illustrates the components of the reinforced soil construction: wall face, longitudinal reinforcement, geogrid, vertical stiffener, and embankment.

Figure 8. Reinforced earth elements

Stone material with a granulation of 0-75 mm was used as the filling material. The material was compacted using vibrating plates, ensuring a compressibility modulus (Ms) greater than 40 MPa. In total, 4,300 m³ of stone material was installed. Figure illustrates the completed construction after finishing the works.

Figure 9. Completed construction, October 2023

3 Results of inclinometer monitoring

In order to verify the remediation solution, an inclinometer was installed to monitor displacement. An inclinometer tube was positioned near the top of the reinforced concrete wall to monitor displacement on the landslide. An initial measurement was taken in the inclinometer, with two additional measurements conducted during the execution of the works, and a final measurement made after the works were completed. The largest displacement recorded was 1.07 mm, measured after all work had been completed.

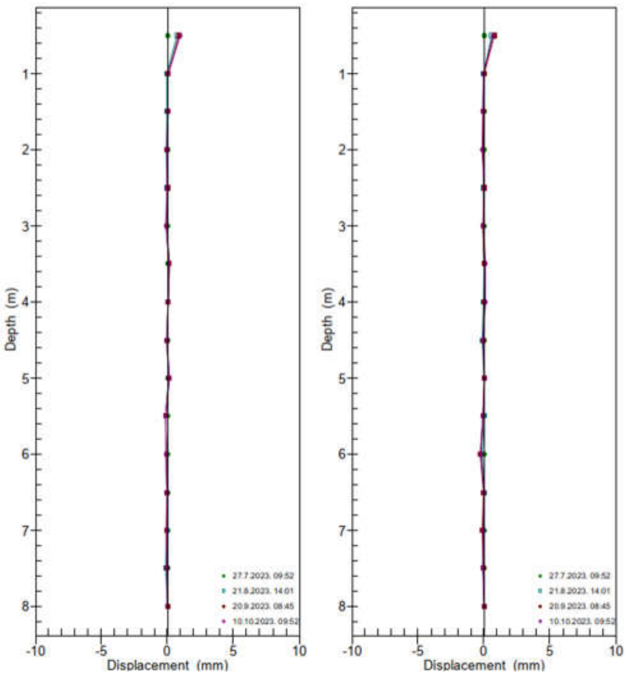

Figure 10. The results of inclinometer measurements

4 Conclusion

Reinforced soil support structures, as a type of backfilled support structures, base their stability on the interaction of tensile elements and the surrounding backfilled soil. They are constructed in such a way that the embankment behind the front face of the supporting structure is combined with tensile elements such as geogrids, tensioners, and the like. The front face of the structure serves to prevent local erosion and has an aesthetic function but does not significantly contribute to the stability of the entire structure.

By undertaking the remediation of the Sučević landslide, it was demonstrated that the construction of reinforced soil is feasible even in highly inaccessible areas with steep slopes. The results of the inclinometer measurements, which will continue to be conducted annually for the next three years, confirm the success of the landslide remediation.

By constructing with reinforced soil, it is possible to utilize materials available on-site, particularly those generated from excavation.

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