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LANDSLIDE REMEDIATION ON THE SCARP ABOVE THE LEVEL, ROAD M-17, SECTION: 007, TOPČIĆ POLJE – LAŠVA

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ABSTRACT

The aim of this paper is to present a landslide remediation based on research and testing of samples, and to list those measures that will help to remediate the landslide or partially mitigate its further effects. These measures include: closing cracks, collecting and draining surface water from landslides, terrain planning, making supports from stone materials, drainage trenches, draining water from traffic areas, repairing water supply and sewerage systems, and establishing monitoring. The phenomenon of instability and its causes has been analyzed, and the results of research at the subject site before and after the remediation of this instability will be presented and discussed. Geological profile and remediation methods will be determined after the presentation of the results.

Keywords: *landslide, retaining wall, geological profile, remediation*

INTRODUCTION

A very important and challenging activity in the field of construction is to determine the stability of slopes, because they are related to both material and damage of all other forms [1]. The paper presents the analysis and remediation of landslides on the main road M-17 section: 007, Topčić Polje - Lašva 0, stationing: km 3 + 880, in Nemila, municipality of Zenica [2].

In 2014, landslides and floods caused serious problems to the state of Bosnia and Herzegovina, which, along with numerous previous inadequate actions, culminated in huge damages and losses. Some of the problems that have accumulated so far are the performance of works on sites where research and studies have not been previously conducted, the reconstruction of roads where adequate research has not been conducted for basic conditions, poor maintenance of river banks, other reservoirs, embankments for defense from floods, and other hydro-technical and infrastructural facilities, which, along with unfavorable climatic conditions and increased precipitation, have led to landslides that need to be repaired.

Field research is planned during the preparation of the project documentation, the results of which would be the basis for further design. The extent to which legal regulations and rules of the profession are respected can be seen through a number of examples in practice related to the research and remediation of unstable terrains [2].

As a precursor, engineering geological and geotechnical research, field testing, elaboration of existing data, and research analysis were performed [3].

Field and office works were performed in January and February 2015.

The aim of the study was to solve issues and dilemmas such as: identification of problems, interpretation of results of geotechnical research and testing, definition of preliminary geotechnical model of the site, and proposalof preliminary solutions for remediation [3].

DESCRIPTION OF THE CURRENT SITUATION

On the main road M17, section: 007, Topčić Polje-Lašva 0, km 3 + 880, there was a landslide on the scarp above the level line on the left side of the road, as well as minor landslides and water leaks from the scarp. Approximately 100 m on the scarp there is a landslide with water flowing out of the body of the landslide, while in the next 130 m, minor landslides and water leaking from the scarp occurred. There is one culvert that collects rainwater and takes it to the recipient at this location.

Displacements and cracks are not visible on the asphalt road, except for the damage that occurred during the loading of the material from the landslide. On the right side of the road is a supporting structure on which no damage is visible. The front of the landslide is about 60 m away from the road, while the height of the scarp where the landslide occurred is 20 m. Directly above is the road leading to the buildings above the landslide. Currently, the traffic is unhindered, but there is a great danger of reactivation of landslides, which would jeopardize the flow of traffic [2].

RESEARCH METHODOLOGY

The following activities were performed in achieving the basic goals and tasks of field geological and geotechnical research works [2].

- Exploratory drilling
- Sampling for laboratory tests
- Photographing and geological mapping of investigacion bore holes and excavations
- Standard dynamic penetration test (SPT tests)
- Geological and engineering-geological research
- Office data processing and preparation of studies and projects

4 investigacion bore holes were drilled, with a total length of 23,0 m.

During the construction of investigacion bore holes, certain activities were performed, such as “in situ” tests and observations, as follows [2].

- Sampling of soil and rock materials. Disturbed samples were taken for standard geo-mechanical analysis. Samples were taken from each investigacion bore holes, when changing lithological members at depths where it is necessary to determine the quality of the material. After sampling, the materials are properly packed and shipped to the laboratory;
- The Standard Penetration Test (SPT) was performed on every 1,5 m of the investigacion bore holes;
- Monitoring of GWL (groundwater levels);
- Placing the drilled core in appropriate crates, marking and mapping the core from the investigacion bore holes and taking photographs before the start of the mapping and after its completion, and taking undisturbed samples.

12 soil and rock samples were selected for laboratory testing at the thematic station.

All tests on gravel, stone fragments and clay were performed according to BAS CEN ISO/TS 17892 standards [4,5,6].

- natural humidity BAS CEN ISO/TS 17892-1: 2016
- bulk density BAS CEN ISO/TS 17892-2: 2018

- specific weight BAS CEN ISO/TS 17892-3: 2017
- granulometric composition BAS CEN ISO/TS 17892-4: 2002
- consistency limits BAS CEN ISO/TS 17892-12: 2009 - 12/Cor1:2009
- shear strength BAS CEN ISO/TS 17892-10: 2009 - 10/Cor1:2009
- compressibility BAS CEN ISO/TS 17892-5: 2018

Classification characteristics (moisture content, bulk density and granulometric composition) were examined on all gravel samples, while shear strength and compressibility, as well as classification characteristics were examined on clays [3].

RESEARCH RESULTS

The following field characteristics were defined by the conducted field research and laboratory testing:

Engineering-geological characteristics of the terrain

Taking into account the results of field and laboratory research and testing, a preliminary engineering geological accuracy of the terrain was performed for this site. Thus, the following categories have been singled out in the research area [3].

- cover - surface soil deposits (unbound and semi-bound soil), and
- degraded (decomposed) geological substrate.

Cover – surface layers of soil

Categorization of surface soil deposits was conducted according to genetic origin, material composition and consistency [8].
The cover is divided into 2 horizons, 1a and 1b.

Horizon 1a
In the exploration field, horizon 1a consists of deposits formed by the decomposition process of the parent sediments of the substrate. They occupy the largest area in the exploration area, overgrown with tall and low vegetation. These deposits build humus, clay, and clay fragments of different consistency, depending on the depth at which they are located. The deposits have different thicknesses, the humus has a small capacity, while the surface clay fragments can be found up to a depth of over 2 m. The SPT test was performed in the clay deposits, with values from 5 to 10 N.The average thickness of this horizon is 1,60 m [2].

Horizon 1b
The general characteristic of horizon deposits 1b is the heterogeneity of the material composition. These deposits are built up of silt, clay and clay fragments. They were recorded in the upper part of the landslide. The average thickness of this horizon is 1,70 m. The SPT test was performed in the clay deposits, with values from 4 to 50 N [2].

Degraded (decomposed) geological substrate

The degraded geological substrate is registered under the cover layers in the form of alternating lithological layers of different material structure and degree of alteration, and divided into 3 horizons, namely 2a, 2b and 2c.

Horizon 2a
Due to the different action of exogenous factors, a certain degree of mechanical and physical-chemical change of the parent rocks occurred at the contact between the cover and the substrate. This horizon is presented in the form of deposits of clay fragments, and clay crumbs with gravel (dominance of limestone). The average thickness of these deposits is 0,60 m [2].

Horizon 2b
This horizon is built of broken and clay fragments of limestone, and found in all parts of the landslide. Determination of the RQD parameter of rocks at this horizon was not possible due to the high degree of cracking. It appears at a depth of 2,00 m with 50N and has a hard consistent state [2].

Horizon 2c
Geotechnical horizon 2c is a horizon built by a predominantly marly component, located in a satisfactorily hard consistent state [3].

Hydrogeological characteristics

Since the oversaturation of the material with water led to the activation of the landslide, clarification of the hydrogeological conditions of the terrain is important for the remediation of the landslide.
In hydrogeological terms, the flysch complex builds a heterogeneous environment from the aspect of water permeability. Limestone packages are characterized by a cracked and subordinately less pronounced cavernous structure of porosity.

They perform the function of collectors, conductors and tanks, especially in the near-surface parts of the terrain. Crack porosity is predominant in marls and forms a practically good to poorly permeable part of the flysch complex. In general, Jurassic and Cretaceous flysch rocks form a hydrogeological complex of poorly permeable and watertight rocks that perform the function of floor insulators and side barriers within the terrain [3].

Unbound and semi-bound rocks form predominantly surface coverings of clay-sand-fragment composition. The thickness of these materials is up to 2,5 m.

An intergranular porosity structure is formed in unbound and semi-bound rocks, which perform the HG function of collectors, conductors and reservoirs.

The terrain itself is very rich in surface and groundwater. Landslide activation revealed several sources below the landslide front. Water that seeps out of streams and springs constantly feeds materials and keeps them in a liquid or boundary liquid state [3].

Geotechnical terrain model

The geotechnical model of the terrain at the subject location consists of [3].

- Geotechnical environment GS 1, which is represented by covers – surface deposits of horizons 1a and 1b, i.e., deposits of humus, clay and clay fragments, and horizon 2a in the form of deposits of clay fragments.
- Geotechnical environment GS 2, which is represented by the decomposed geological substrate of horizons 2b and 2c.

To determine the relevant parameters of the GS 1 cover material in its natural state, a feedback analysis was performed in the Plaxis software package [9].

The calculation was carried out on the most critical cross-sectional profile. It is assumed that the landslide is in a state of boundary equilibrium, i.e., that the safety factor is Fs = 1,000. Figure 1 shows the most critical sliding surface in the natural state, obtained by calculation based on field and laboratory exploration, engineering geological determination and classification of investigacion bore holes, as well as the results of feedback analysis. The following calculated soil parameters for selected geotechnical environments were determined [3].

- for cover materials of geotechnical environment GS 1: deformation modulus E_s = 12 MPa; bulk density γ = 22 kN/m^3; internal friction angle φ = 27° and cohesion = 30 kPa,
- for materials of geotechnical environment GS 2: deformationmodulus of rock mass E_s=20 MPa; bulk density γ = 22 kN/m^3; internal friction angle φ = 32°; cohesion = 25 kPa.

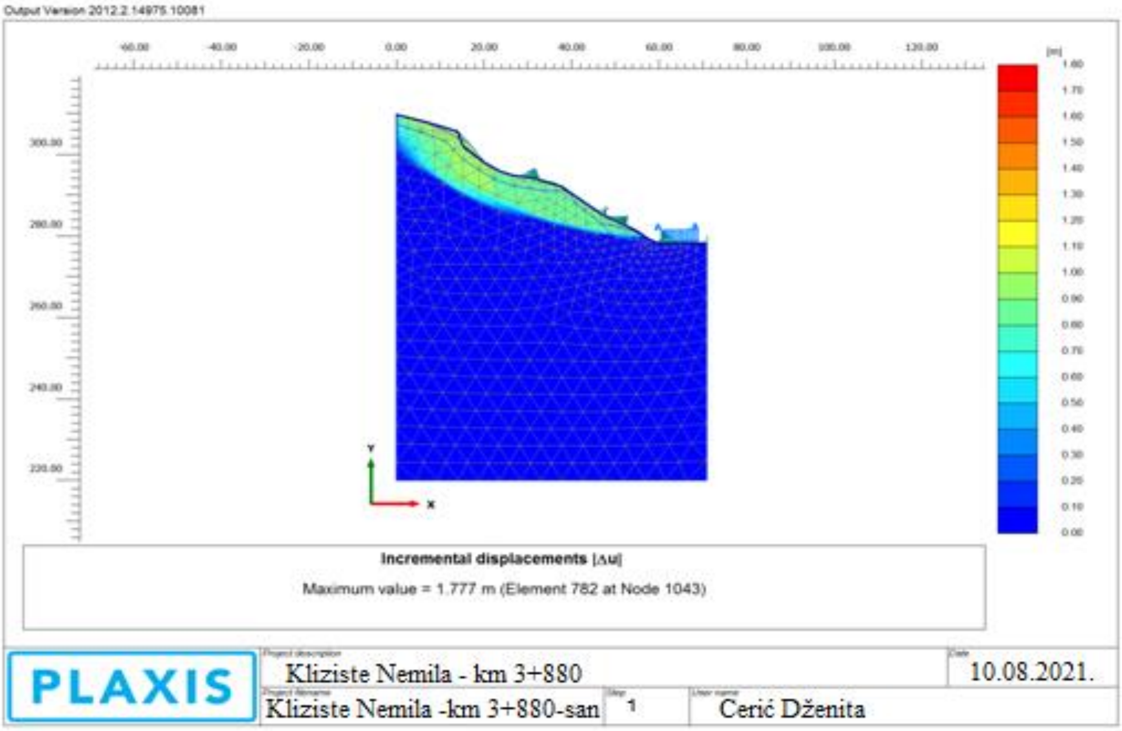

Figure 1. Calculation of slope stability for natural condition Fs = 1,000 [3]

It should be noted that the values obtained by laboratory testing are somewhat lower, but those obtained by feedback analysis in the Plaxis software package were adopted. The adopted values are the same as those in the literature [3].

The numerical model is built in the Plaxis software package and consists of soil elements, static external load conditions and boundary conditions. After creating a numerical model, the initial calculation of the current state is performed. Given the obtained safety factor, it is concluded that the designed structure is stable [10].

Proposal of preliminary remedial measures

Based on all of the above, the following stabilization measures are proposed: [3]

- construction ofa.b. 75,0 m long wall above the road,
- construction of drainage behind the wall,
- mitigation of the slope at the front of the landslide to a slope of 1: 1,5,
- construction of ''Y'' drainage through the body of the landslide, whose arms extend above the front of the landslide,
- construction a stone throw in the middle part of the landslide,
- cleaning of existing culverts and gutters.

Calculation of the stability of the remediated slope

In the second phase of the calculation, the analysis of the remediated slope was performed, and the safety coefficient F_s = 1.257 was obtained. Figure 2 shows the most critical sliding surface of the remediated slope [3].

Static calculation of the retaining wall

Static wall calculation was performed in Geo5 program. The cross-sectional forces in the wall and the required reinforcement were obtained by calculation. The wall was inspected for overturning and sliding. The calculation was performed for the most critical section of the wall [3].

The details below describe the calculation with the Geo5 software package.

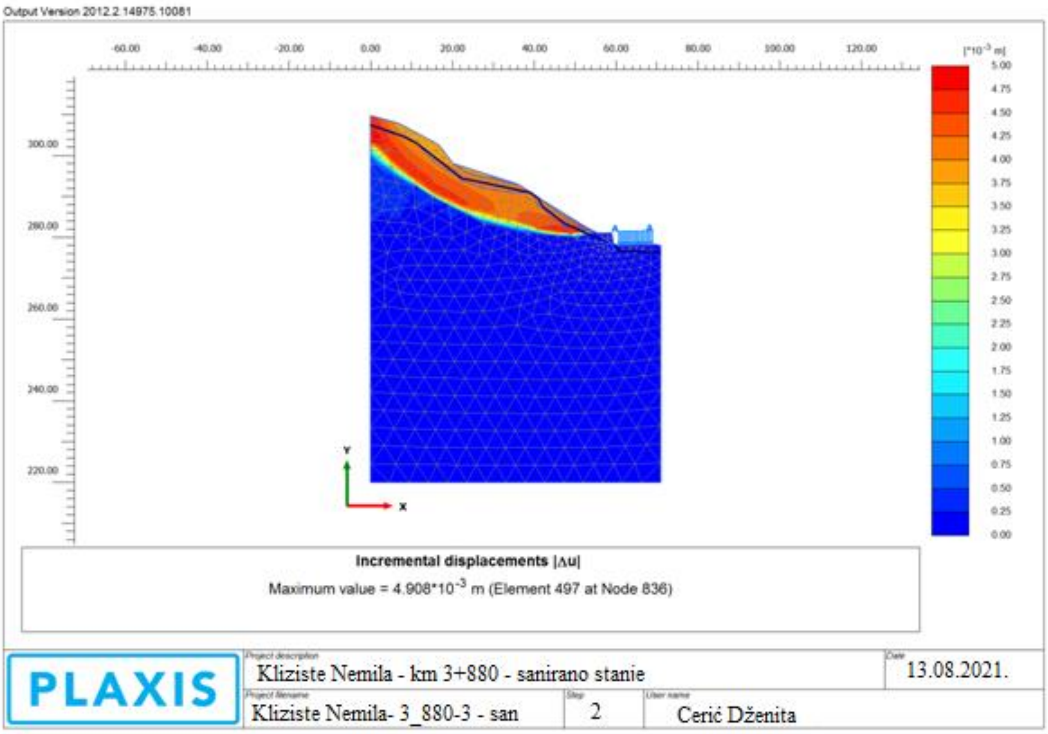

Figure 2. Calculation of slope stability for repaired condition Fs = 1,257[3]

Geometry

The calculation was carried out in accordance with EuroCode 7, design approach PP1. The combination of partial safety factors is given in Table 1. [5,7]

Table 1.EC7 – Partialsafetyfactors

Design approach	Influence and impact		Ground resistance
	Construction		
GEO – PP1 comb. 1	$\gamma_G = 1,35$; $\gamma_Q = 1,50$		$\gamma_\varphi = \gamma_c = 1,00$; $\gamma_{cu} = 1,0$
GEO – PP1 comb. 2	$\gamma_G = 1,00$; $\gamma_Q = 1,30$		$\gamma_\varphi = \gamma_c = 1,25$; $\gamma_{cu} = 1,4$

Control

Entire wall control
Overturning stability examination
Resistance moment M_{res} = 361,7 kNm/m

Overturning moment M_{ovr} = 1,95 kNm/m

Overturning wall is satisfactory.

Sliding examination
Horizontal resistance force H_{res} = 183,2 kN/m
Horizontal action force H_{act} = -3,99 kN/m

Sliding wall is satisfactory.
Total examination – the wall is satisfactory.

Control of the entire wall

Overturning stability examination[2]

Overturning moment	M_{res}	=	368,8 kNm/m
Resistance moment	M_{ovr}	=	14,26 kNm/m

Overturning wall is satisfactory.
The wall has the following dimensions: [9]:

Sliding examination

Horizontalresistanceforce	H_{res}	=	148,6 kN/m
Horizontalactionforce	H_{act}	=	4,78 kN/m

Sliding wall is satisfactory.
Total examination – the wall is satisfactory.
Maximum load at the bottom of the foundation: 128,83 kPa

Dimensioning

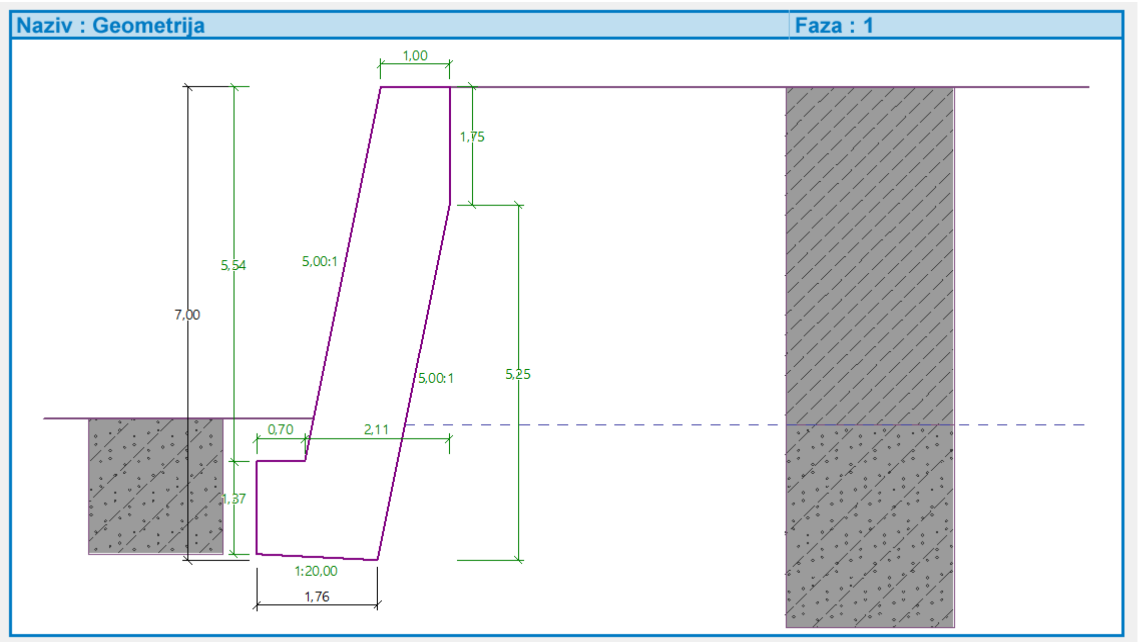

Figure 3. The dimensions of the retaining wall

The dimensions of the retaining wallare given in Figure 3. [3]

Checking the upper part of the wall-front reinforcement

Depth of cross section h=1,35 m

Final shear force	V_{Rd}	=	689,50	kN	>	4,75	kN	=	V_{Ed}
Final compressive force	N_{Rd}	=	4867,6	kN	>	166,1	kN	=	V_{Ed}
Final moment	M_{Rd}	=	-111,0	kNm	>	-81,8	kNm	=	M_{Ed}

Cross section is satisfactory.

Examination of the wall at the construction node 0,10 m from the top of the wall

Depth of cross section h = 1,02 m
Final compressive force

Final compressive force	N_{Rd}	=	12690	kN	>	2,29	kN	=	V_{Ed}
Final torque	MRd	=	-1,17	kNm	>	-0,08	kNm	=	MEd

The cross section is satisfactory.

Following the analysis of geotechnical exploration works, it was concluded that it is necessary to remediate the landslide by making the following stabilization elements:

1. Retaining wall in the central part with length of 50,00 m and height of H = 7,00 m.
2. Primary drainage collector - collects and drains all drainage water further from the landslide zone.
3. Constructionof transverse drainages.
4. Placing a stone throw above the retaining wall – securing the slope.
5. Manholes – used for collecting, cleaning and controlling groundwater overflow.
6. Drainage of water to the existing culvert ϕ 1.,00 m.
7. Construction of gabion walls in order to prevent scarp shelling on P.19 (km 3 + 961,00).

The solutions are shown in Figure 4 for normal transverse remediation profile.

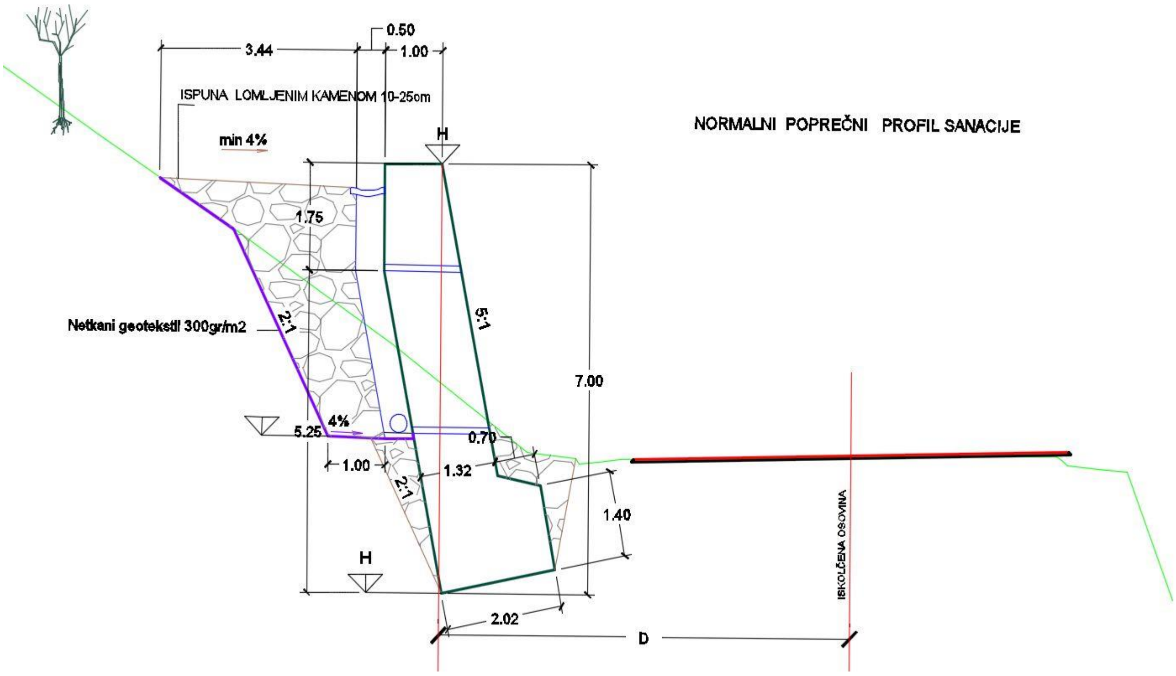

Figure 4. Normal transverse remediation profile

Based on the analysis of the problem at the subject location, the most optimal and safest solution for the remediation of the mentioned slope was given [3].

DISCUSSION

Excavation and stabilization works will begin after the completion of preparatory works, especially geodetic stakes. The terrain is cleaned, after which excavation works, laying of drainages and construction of the supporting structure can start. It is obligatory to perform all works in a hydrologically favorable period [12].

The works must be performed in an order that allows for the continuity of the excavation and the optimal use of machinery.

Excavations to the required depth should be performed mechanically, with gradual lowering, and in segments. Deviations of the excavation geometry from the designed geometry are not allowed.
The excavation of drainage trenches is carried out in segments up to 4.0 m. After that, the next segment is laid [3].

During excavation works, the following should be controlled:
- the excavations are carried out according to the design and elevations of the project,
- to ensure proper drainage during excavation works until the end of the works.

The depth of the excavation is geodetically controlled.

The retaining wall be built in 5,0 meters segments.

Upon the completion of the retaining wall, the embankment of the road trunk is made of stone material. These works are performed in layers with appropriate compaction. It is necessary to compact the stone material to bulk modulus of 60 MPa [13,14].

CONCLUSION

The paper presents landslide remediation conducted based on research and sampletesting, and lists those measures that will help to remediate the landslide or partially mitigate its further effects. These measures include: closing cracks, collecting and draining surface water from landslides, terrain planning, making supports from stone materials, drainage trenches, draining water from traffic areas, repairing water supply and sewerage systems, and establishing monitoring [15].

The landslide remediation solution given in this paper is the most optimal and safest slope remediation solution [3].

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