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LANDSLIDE REMEDIATION ON LOCATION ČOLE, THE SETTLEMENT ŽELJEZNO POLJE, ŽEPČE MUNICIPALITY

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ABSTRACT

The aim of this paper is to present a landslide's remediation conducted on the basis of research and testing of samples, and 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 paper analyzes the phenomenon of instability and its causes, and presents the results of research at site in question before and after the remediation of instability. The geological profile and remediation methods will be determined after the presentation of the results.

Key words: *landslide, retaining wall, geological profile, remediation*

INTRODUCTION

A very important and challenging activity in the field of construction is determining the stability of slopes, because material damage and all other forms of damage are associated with it [1]. The paper presents the analysis and remediation of landslides in the Čole locality, Željezno Polje settlement, Žepče municipality [2].

In 2014, landslides and floods caused serious problems in Bosnia and Herzegovina, which, in addition to numerous previous inadequate actions, culminated in huge damages and losses. Some of the problems that had accumulated up to that time were the execution of works in areas where no research and studies had been carried out beforehand, the reconstruction of roads where adequate research for the basic conditionshad not been carried out beforehand, poor maintenance of river banks and the banks of other reservoirs, poor maintenance of defense floodembankments and other hydrotechnical and infrastructural facilities, along with unfavorable climatic conditions and increased precipitation that lead to the occurrence of landslides.

During the preparation of the project documentation, field investigations are planned, the results of which are the basis for further design. The extent to which legal regulations and rules of the profession are respected can be seen through a series of examples in practice related to research and remediation of unstable terrain [3].

Engineering geological and geotechnical research, field tests, elaboration of existing data and research analysis were carried out in advance [2].

Field and office works were carried out in 2020.

The aim of the research was to solve questions and dilemmas such as: identifying problems, interpretation of results of geotechnical research and testing, defining a preliminary geotechnical model of the location, and proposing preliminary solutions for remediation [2].

DESCRIPTION OF THE CURRENT STATE

A landslide was activated in the road scarp on the investigated terrain, which affected the road. The activation of the landslide occurred due to the effect of several factors. The preconditions were the morphology of the terrain, i.e., the large slope of about 45°. Another prerequisite is the physical-mechanical characteristics of the material, i.e., a high degree of brittleness and degradation of materials with low cohesion. With these prerequisites, in a period with high amounts of precipitation, water saturation of surface covers occurred, which led to a complete loss of cohesion and soil breakdown. In addition, the river Željeznica, which flows along the road, overflowed its bed, destroying the body of the road, which lost the already steep slope support. Through geological mapping and investigation work, it was established that the entire width of the road in this section was built on the filled material that originates from the parent rock. In addition, the materials of the base under the embankment were not taken into account. The embankment was placed directly on colluvial deposits, which are themselves subject to sliding in steep terrain [2].

RESEARCH METHODOLOGY

The following activities were performed in achieving the basic goals and tasks of field geological and geotechnical research works [3]:

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

6 boreholes were drilled, with a total length of 56.0 m' as well as 5 exploratory excavations.

During the construction of investigation bore holes, certain activities were performed, such as ''in situ'' tests and observations, as follows [3]:

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

15 soil and rock samples were selected for laboratory tests 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 [7]:

The cover was divided into 3 horizons, 1,2 i 3.

Horizon 1- artificial products

Artificial materials are represented along the local road in the entire investigation area. They are represented by a buffer with fragments of pieces of parent rock that were formed during the road construction and clay debris of melange fragments. The thickness of these deposits varies, and the most significant one is under the road. The embankments were formed during the construction of the local road. These materials were affected by an activated landslide on the entire surface of the site. In conditions of complete water saturation, and the slope load under the road on which they rest, these materials transform to an unstable state. Based on past experience, we can state that these materials have uneven geomechanical characteristics. According to GN 200, the materials of artificial creations belong to the II and III categories of excavation[3].

Horizon 2 – eluvial-deluvial deposits

Eluvial-deluvial deposits participate in the structure of the cover above the landslide on the upper forest road, and above the substrate. They were created by the process of decomposition of the parent sediments of the substrate, which were transported down the slope. These deposits are made up of light brown clay powder. The thickness of these deposits is about 1,00 m'. According to GN 200, colluvial cover materials belong to excavation category II - III [3].

Horizon 3 – colluvial deposits

These are materials that have been precipitated by sliding processes. Their origin stems from deluvial-colluvial processes and partly from eluvial ones, which formed the cover of this slope The water saturation of these materials led to a drastic change in physical-mechanical properties, loss of resistance to shearing and movement of mass down the slope. These materials have a heterogeneous composition, consisting of dust, altered rock and debris. They are characterized by a dark blue color and very fine particles, due to which they have a very smooth surface with low resistance to friction. The thickness of all colluvial formations, including these, is highly variable, ranging from 0,30 to 1,50 m. Material sliding occurred in this layer and it includes NPV. This layer is still the most critical in terms of sliding. According to GN 200, these materials belong to the III-IV excavation category [3].

Altered (decayed) geological substrate

In terms of engineering geology, the rocks in which the engineering works are to be carried out are extremely altered. Due to the physical-chemical weathering processes by which they are affected, these rocks have far weaker geomechanical characteristics than in their ‘’fresh’’ state. Alteration (wearing) of rocks generally decreases with depth, so the physical and mechanical characteristics of these rocks improve with increased depth. Under the influence of water and climatic factors, qualitative-quantitative changes take place relatively quickly, and the decomposition products of parent rocks have significantly changed not only structural-textural characteristics, but also water-physical and physical-mechanical properties, compared to the properties of primary rocks. Under the influence of external agents, the rock in the higher horizons (closer to the surface) is highly eroded, disintegrated into blocks of different dimensions, and mixed with dusty and sandy disintegration.

According to GN 200, the rocks of the geological substrate belong to the IV-V excavation category. The foundation of the supporting structures can be performed in horizon 4b, Figure 3, with the condition that the geomechanical parameters of the horizon meet the load of the designed object and landslide rehabilitation [3].

Geological substrate

The material of the geological substrate was determined by drilling deeper boreholes, which was not influenced by external influences and groundwater, i.e., it was not altered and disintegrated under the influence of these agents. However, this rock is cracked and has very low RQD values. For this reason, the quality of the rock mass had to be determined through GSI. The substrate is represented by a Jurassic magmatic-sedimentary formation (‘’diabase – chert formation’’). The magmatic-sedimentary formation represents a very diverse thick complex of rocks which, in addition to different sediments, also includes igneous rocks, the most important of which are ultramafites, with which they occur together, and metamorphic rocks. This complex could not be stratigraphically defined. No fossil remains were found in any sedimentary member. On the other hand, the geological relationships in the area are such that they do not allow drawing conclusions based on superpositional relations. Namely, there is not a single larger or a smaller folded structure based on which conclusions could be made about the floor and roof of the Jurassic magmatic-sedimentary formation [3].

Hydrogeological characteristics

Given that the oversaturation of the material with water led to the activation of the landslide, the clarification of the hydrogeological conditions of the terrain is important for the remediation of the landslide.

Hydrogeological properties are predisposed by the lithological composition, structure and porosity of the rocks, based on which two hydrogeological categories of rocks are distinguished, namely: permeable deposits of intergranular porosity and moderately permeable rocks of fracture porosity [3].

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

An intergranular structure of porosity is formed in unbound and semi-bound rocks, which perform the HG function of a conductor collector and reservoir.

The terrain itself is very rich in surface and underground water. Landslide activation revealed several springs below the landslide front. Water that seeps from streams and springs constantly feeds materials and keeps them in a liquid or borderline liquid state [3].

Geotechnical terrain model

The geotechnical model of the terrain at the location in question consists of [3]:

- Geotechnical environment GS 1,represented by covers - artificial formations: modulus of deformability E_s = 30MPa; bulk densityγ = 19 kN/m^3; internal friction angle φ = 30° and cohesion= 0 kPa.
- Geotechnical environment GS 2,represented by covers – eluvial-deluvialdeposits: modulus of deformability E_s = 5MPa; bulk density γ = 19 kN/m^3; internal friction angleφ = 26° and cohesion = 6kPa.
- Geotechnical environment GS 3,represented by dark blue clay decomposed rocks: modulus of deformability E_s = 5MPa; bulk density γ = 18 kN/m^3; internal friction angleφ = 20° and cohesion = 4kPa.
- Geotechnical environment GS 4,represented by decomposed substrate – upper decomposition zone: modulus of deformability E_s = 34MPa; bulk density γ = 21kN/m^3; internal friction angleφ = 33° and cohesion = 21kPa.
- Geotechnical environment GS 5,represented by decomposed substrate – lower decomposition zone: modulus of deformability E_s = 44MPa; bulk density γ = 22kN/m^3; internal friction angleφ = 46° and cohesion = 30 kPa.
- Geotechnical environment GS 6,represented by undisturbed geological substrate: modulus of deformability E_s = 98MPa; bulk density γ = 22 kN/m^3; internal friction angle φ = 40° and cohesion = 66kPa.

The numerical model was built in the Geo5 software package, and consists of soil elements, static external load conditions and boundary conditions. After creating the numerical model, the initial calculation of the current state was conducted. Considering the obtained safety factor, it is concluded that the designed structure is stable [8].

Proposal of preliminary remedial measures

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

- arrangement of the slope in levels, i.e., the terrain of the landslide. This would imply the removal of the cover layer (3) and the creation of levels with broken stone with a diameter of approx. 400 mm, at a slope of approx. 35°. The number of levels should be adapted to the morphology of the terrain, in relation to the height of the supporting structure, and adjusted when analyzing the stability of the terrain,
- drainage of groundwater from landslides is mandatory. Water as the primary cause of instability must be drained on the entire surface of the terrain. The simplest thing would be to lay drainage pipes along the upper and lower road with supporting structures and lead the water into the river in a controlled manner,
- creation of a retaining wall on buttresses. The foundation of the buttresses can be performed in the layer of decomposed substrate, the lower zone of decomposition. Considering the unevenness and heterogeneity of the lithological composition and the degree of disintegration of the substrate material, it is necessary to accept the excavation of each buttress foundation.

Calculation of the stability of the remediated slope

An analysis of the remediated slope was performed using the Spencer method and the utilization rate was 21.2 %. Figure 1 shows the most critical sliding surface of the repaired slope [3].

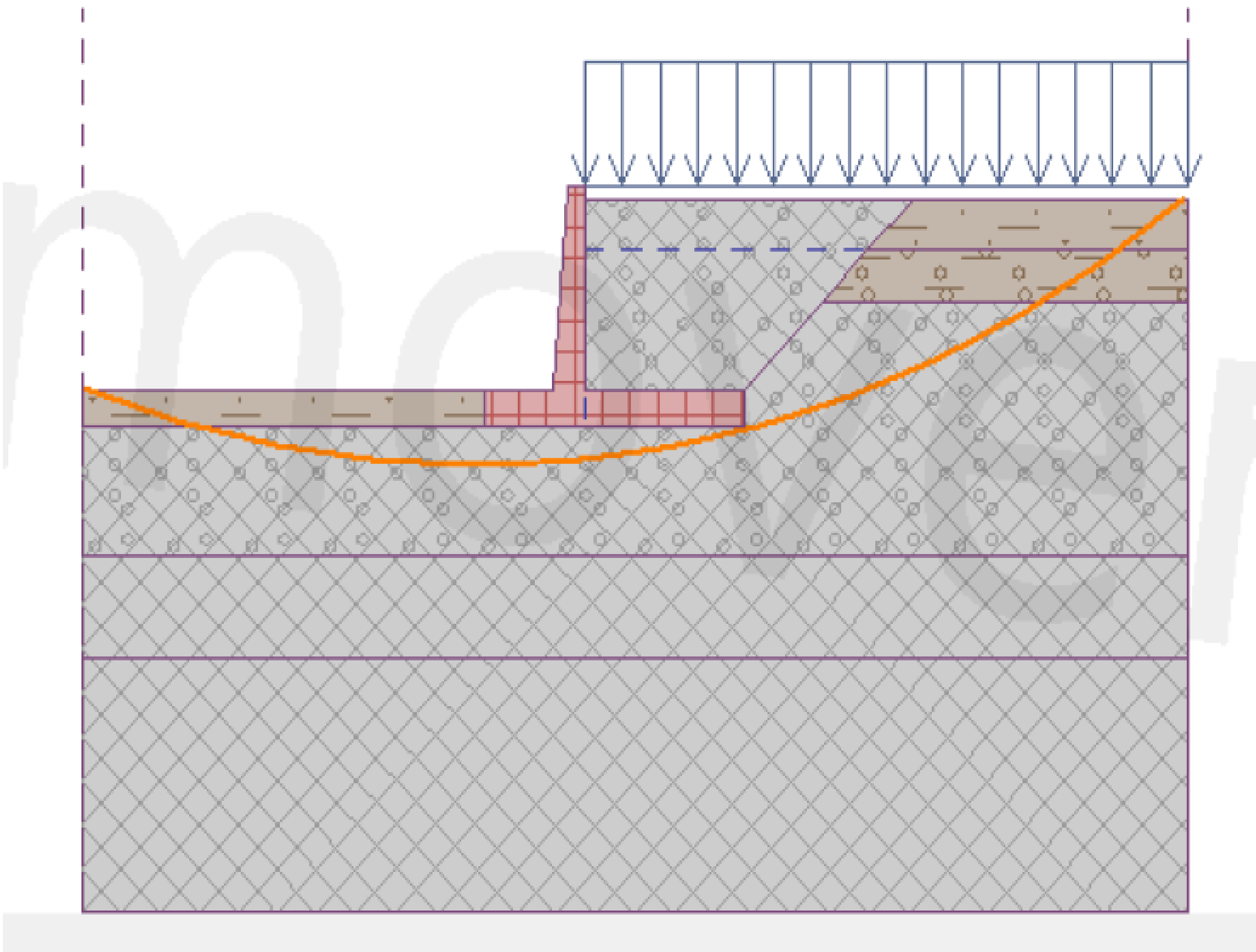

Figure 1. Calculation of slopes tability for repaired condition [3]

Static calculation of the retaining wall

Static calculation of wall 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].

Details below describe the calculation with the Geo5 software package.

Geometry

The calculation was performed in accordance with EuroCode 7, design approach PP1 [5,9] for the adopted dimension of the retaining wall [10,11]. The combination of partial safety factors is given in Table 1.

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}	=	1201	kNm/m
Overturning moment	M_{ovr}	=	97,71	kNm/m

Overturning wall is satisfactory.
Sliding examination

Horizontal resistance force	H_{res}	=	557,7	kN/m
Horizontal action force	H_{act}	=	81,98	kN/m

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

Dimensioning

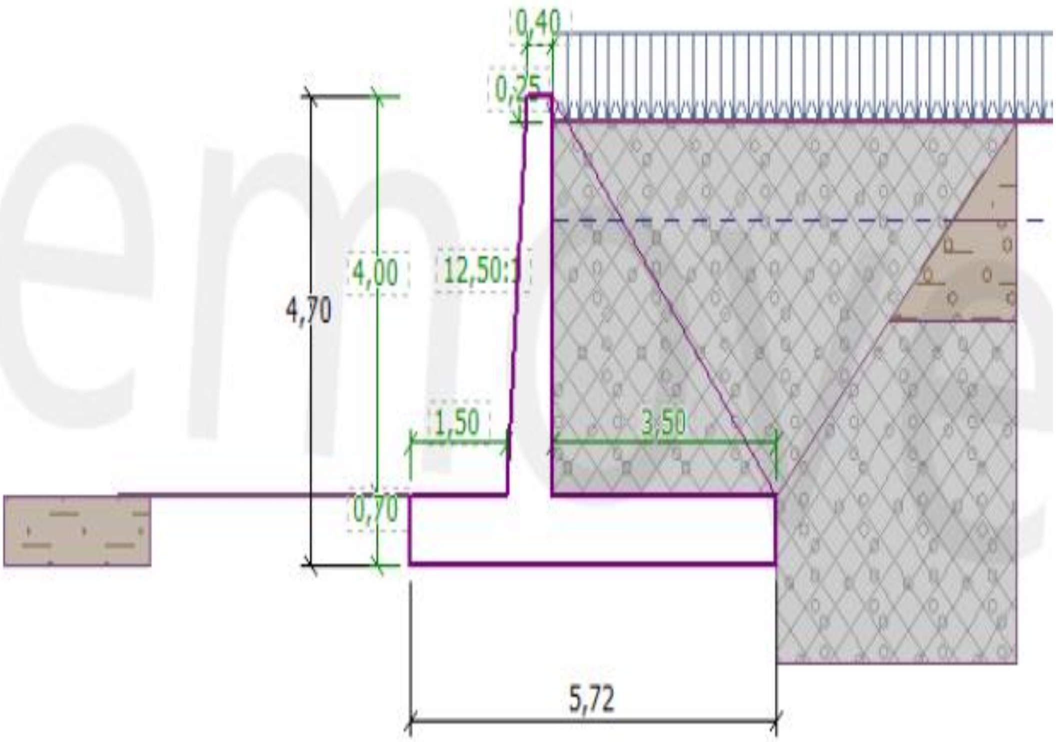

Figure 2. The dimensions ofthe retaining wall [3]

The dimensions of the retaining wallare given in Figure 2. [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	N_{Rd}	=	12690	kN	>	2,29	kN	=	V_{Ed}
Final torque	M_{Rd}	=	-1,17	kNm	>	-0,08	kNm	=	M_{Ed}

The cross section is satisfactory.
After the analysis of the geotechnical investigation works, it was concluded that it is necessary to remediate the landslide by creating the following stabilization elements:

1. Retaining wall with a length of 51.33 m and height H=4.70 m.
2. Construction of drainage and concrete channel. Collected water from the drainage and concrete channel is led down the slope to the nearest recipient (an existing stream) in a full pipe.
3. Placing a stone wall above the retaining wall – securing the slope.
4. Inspection wells – they serve to collect, clean and control groundwater runoff

The solutions are shown in Figure 3, showing the normal transverse profile of the remediation.

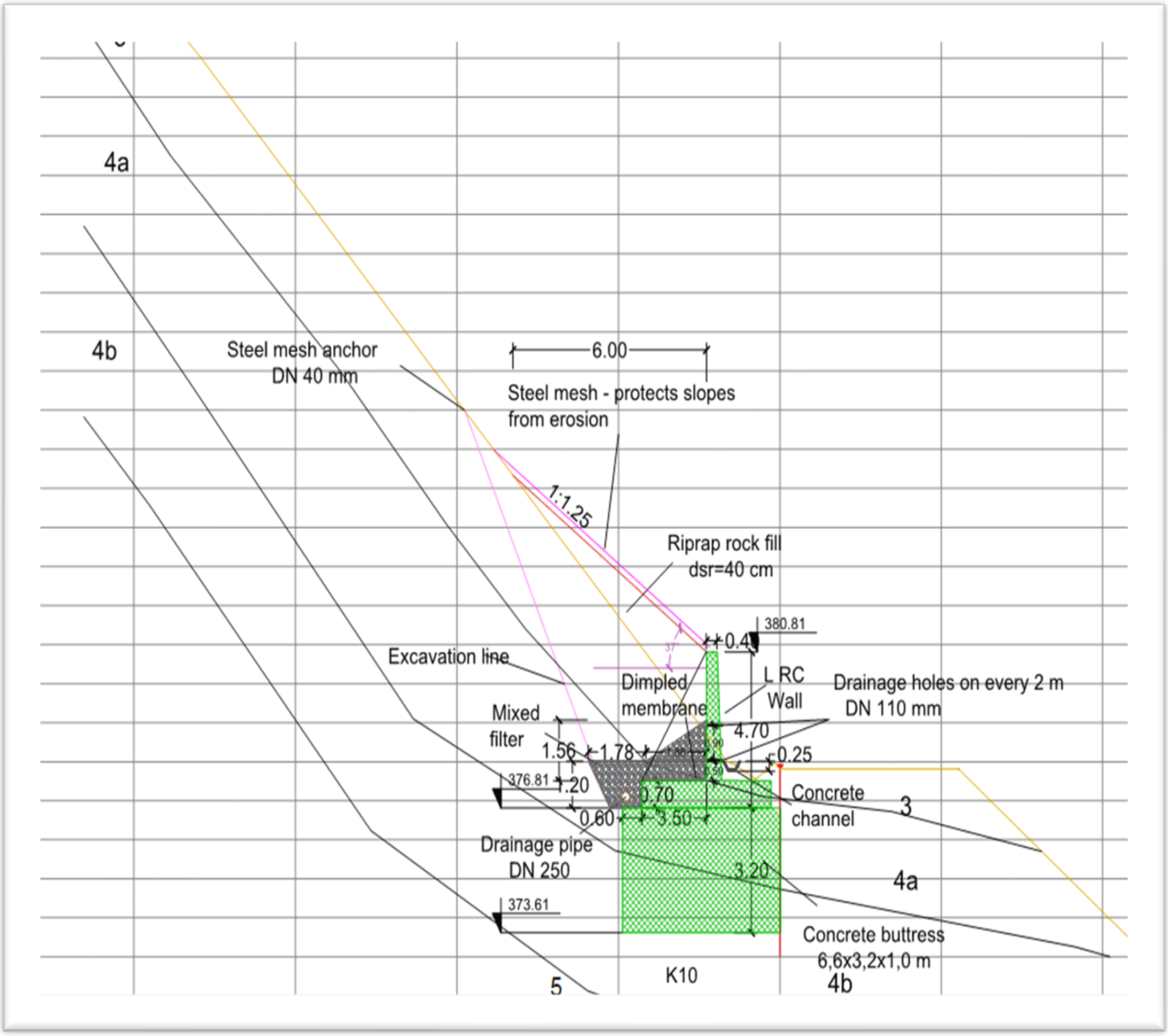

Figure 4. Normal transverse remediation profile

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

DISCUSSION

Excavation and stabilization works will begin after the completion of preparatory work, especially geodetic staking. The terrain is cleaned, after which excavation works, drainage laying and support structure construction can start. All works must be carried out in a hydrologically favorable period [12].

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

Excavations to the required depth should be carried out by machine, with a gradual descent and in phases. Deviations of the geometry of the excavation from the designed geometry are not allowed.
Excavation of drainage ditches is carried out in segments up to 4.0 m. After the completion of one segment, the excavation is performed, drainage pipes are installed and it is filled with filter material. After that, the next phase begins [3].

During excavation works, the following should be controlled:

- that excavations are carried out according to the plans and elevations from the project,
- to ensure proper drainage during the excavation work until the work is completed,
- that excavation depths are geodetically controlled,
- it is planned that the retaining wall will be built in 5.0-meter segments,
- after the completion of the work on the retaining wall, planning of the slope is carried out[13,14].

CONCLUSION

The paper presents the remediation of the landslide, performed on the basis of research and sample testing, and lists the measures that will help remediate the landslide or partially alleviate its further effects. These measures include: closing cracks, collecting and draining surface water from landslides, planning the terrain, making supports from stone materials, drainage ditches, draining water from traffic surfaces, repairing water and sewage systems and establishing monitoring[15].

The landslide remediation solution given in this paper represents the most optimal and safest solution for slope rehabilitation.

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