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# LANDSLIDE ON LOCATION OF WATER SOURCE STUDENAC NEAR BIJELJINA, REPUBLIKA SRPSKA

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ABSTRACT

The landslide is located in the hinterland of water source "Studenac" in the local community Gornja Cadjavica near Bijeljina. The field where the triggered landslide occurred is conditionally stable slope. It is overgrown with forest trees and therefore it was not a subject of interest in terms of its stability until the water source and accompanying local road have been constructed in the lower part of the slope. Additionally the slope was undercut resulting in jeopardizing its conditional natural stability. At first, it was about some slight ground movements requiring no significant interventions.

As the time was passing by site conditions have been changing. During winter and spring time movement of rock blocks is more intense due to large amount of surface and underground water whereby such a process was significantly slower and almost calm in the summer time. Such a cycle was repeated for several years until late 2010 when massive collapse of the unstable zone, which might be called ‘landslide’, endangered not only the local road but also the water source.

For the purposes of overviewing the site and landslide characteristics as a whole, exhaustive researches were carried out within the part of the site affected by sliding at the surface of about 0,4 ha. A field surveying of wider area was also conducted. The landslide is located at relatively steep slope where the height distance between the crown and the toe of the landslide is 14,0 m. General slope angle is up to $10^0$ and in those parts where landslides occur they are up to $25^0$. Sliding plane has been formed at depth of 2,5 to 4 m depending on terrain morphology, in clay of high plasticity (CH groups). The main cause of landslides is surface and underground water.

Within the scope of remediation project two restorative measures were applied. The main recovery measure was placement of AB retaining concrete wall which was intended to accept the pressures of soil mass and to prevent it from slipping, namely to maintain the slope in stable condition. The other remedial measure was construction of an open perimeter canal at the slope above the retaining wall for the purposes of collecting surface water flowing towards the main body of the landslide and its diversion outside the sliding area.

Key words: *landslide, slope, water source, research, rehabilitation*

## INTRODUCTION

The landslide is located in the hinterland of water source "Studenac" in the local community Gornja Cadjavica near Bijeljina. The field where the triggered landslide occurred is conditionally stable slope. It is overgrown with forest trees and therefore it was not a subject of interest in terms of its stability until the water source and accompanying local road have been constructed in the lower part of the slope. Flattened area at the foot of the slope is marshy, previously being rich in smaller springs that supplied local population with water. Over time, an interest for capturing larger quantities of water for the construction of local water supply station had arisen. Dug wells, water-capturing systems, pumps for pumping and transporting water to consumers were built.

Above the water source and towards the slope a local road was extended whereby the slope was undercut resulting in jeopardizing its current natural stability. At first, it was about some slight ground movements requiring no significant interventions. Temporary measures were mostly applied using wooden piles and stone loads.

During winter and spring time movement of rock blocks is more intense due to large amount of surface and underground water whereby such a process was significantly slower and almost calm in the summer time. Such a cycle was repeated for several years until late 2010 when massive collapse of the unstable zone, which might be called 'landslide', endangered not only the local road but also the water source.

Upon the research, a rehabilitation project was compiled and implemented involving concrete retaining walls and open perimeter canals whereby a special attention was turned to maintaining slope stability in order to prevent new sliding of disturbed part of the slope and its extension in the hinterland.

## GEOLOGICAL AND GEOMECHANICAL CHARACTERISTICS OF THE SITE

Wider area belongs to foothill parts, namely "Brcko greda" which in terms of geomorphology makes a plateau of elevation height ranging from 100,00 to 200,00 m, built of Pleistocene sediments. Immediate area is a slope that elevates from height of 179,5 meters above sea level down to the northwest, towards the source Studenac and a valley of a spring that runs near the source at a height of about 154,0 meters above sea level.

The site affected by landslides is of valley shape, with southeast-northwest orientation and very gentle side slopes. Slight inclinations in the higher altitudes and steeper parts in the immediate hinterlands of the road characterize longitudinal valley profile. From the road to the source and further towards the valley of the spring, slope angles are about $5\text{-}6^0$. In the structure of the examined and wider area there are Plio-Pleistocene-Quaternary and alluvial sediments [1,2].

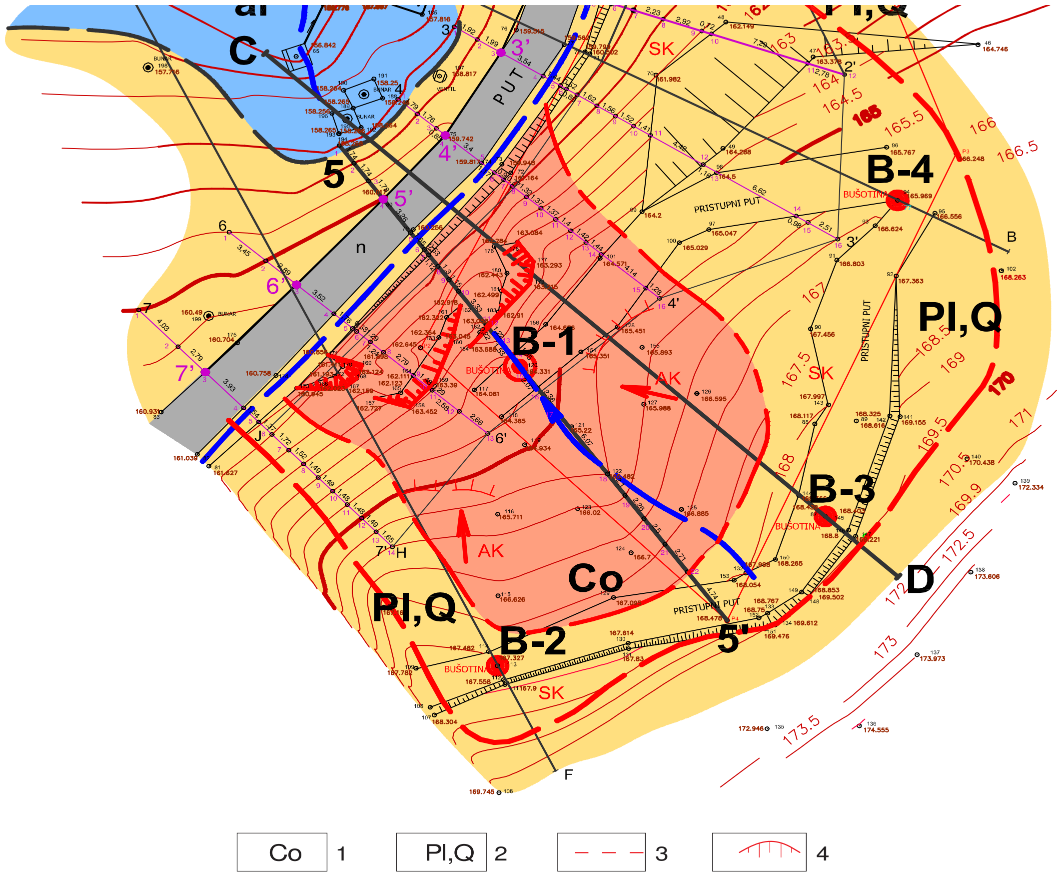
Researched valley and the whole wider area is composed of Plio-Pleistocene-Quaternary sediments (Pl,Q) picture 1. Grey-brown and grey-yellow clays that are extremely rich in calcareous concretions, gravelly sand layers and interbeds that make integral part of Plio-Pleistocene sediments represent them. The depth of research works up to 10 m does not capture their maximum depth.

Alluvial sediments (al) are deposited in the valley of the spring, at the base area of the water source, being contemporary accumulation load represented by gravel and sand with a great share of clay whereby humic clays are found at the surface area.

At the site of the researched slope, four exploratory boreholes were made accompanied with surveys. Samples were taken for laboratory testing followed by determination of parameters for each lithological article.

Two hydro-geological types of rocks were extracted from the researched slope:
Slightly permeable to impervious rocks are of intergranular porosity with dominant share of clay and clay-dust sediments. They have a funciton of rock isolators where the coefficient of filtration for clay ranges from $k = 1{,}15 \times 10^{-7}$ to $8{,}62 \times 10^{-7}$ cm/s.

Semi-permeable to high-permeable rocks of intergranular porosity are built up of gravel and sand of thickness greater than 10,0 m. These rocks have a function of subsurface reservoir of greater range and power. Parts of the reservoir with prevalent gravel component are characterized by good filtration capabilities and coefficient of filtration ranges from $k = 1,10 \times 10^{-2}$ to $1,1 \times 10^{-1}$ cm/s. Recharge is performed from the precipitation in the background of the slope.




Picture 1. Engineering-geological map of the studied site

Colluvial sediments, 2. Pliocene-Quaternary sediments, 3. Landslide ridge, 4. Landslide scars

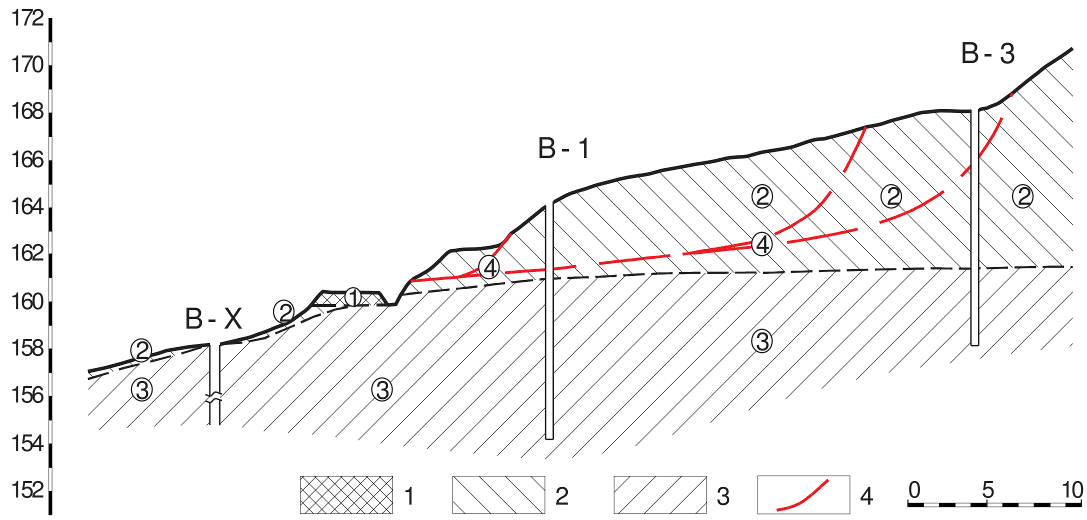
The reservoir was formed in permeable rocks of intergranular porosity only. Locally, reservoirs can be formed in sediments characterized as slightly permeable to impervious, but they are local and restricted in range. That kind of lenses are sandy-gravel but with a high share of clay and that makes the coefficient of filtration $k = 3,2 \times 10^{-6}$ cm/s.

The level of groundwater in the reservoir is of subartesian type and it shows oscillations depending on hydrological conditions. Research works were conducted during the period of drought so the presence of underground water was not observed at the depth up to 10 m.

Composition of the field at the respective location is made of two environments separated as plastic medium presented by clays and bulk medium made of gravels and less of sands, picture 2.

The plastic medium represented by silty clay sediments is extended into the area that is close to the surface part of the site. It is of different power that ranges from 9,0 m in the upper part of the researched site to 1,0 m in the foot part of the slope. A slice of clay sediments, namely of plastic medium, is not uniform both in material composition and in physical-mechanical properties.

Bulky medium represented by gravels and less by sands extends below the clay sediments of plastic medium to the end of the researched depth. The main mass of site material composition is made of sandy, locally clayed, fine-grained to medium-grained, well-compacted gravel (GF). In the foot part of the slope, in the local road area, depth up to the gravel is about 1 m whereby at the far end of the researched slope it is about 7 m.




Picture 2 Geotechnical site profile C-D
1. Technogenic sediments, 2. Silty clay sediments (Cl, Cl-CH, CH),
3. Gravel sediments (GF), 4. Sliding plane

LANDSLIDE DESCRIPTION AND CAUSES OF LANDSLIDES

The entire slope is a part of an old landslide and the active part of the landslide is developed in the slope part of valley shape with the sides of very slight inclination. The research was conducted immediately above the water source Studenac up to the contour lines at height of 170 meters above sea level. The length of the studied slope is about 70 m and the width is about 50 m so the surface of the research field is about 0,35 ha. The foot part of the slope is a spring valley and the most distant part involved in examination works is an isohypse with a height of 170 meters above sea level so at the distance of 75 m the height difference is about 14 m. With the exception of the active landslide area, a value of general slope inclination is up to $10^0$ and along the immediate surrounding terrain at the southeast side slope angles are moving up to $25^0$.

Forehead landslide scar is not clearly visible while the foot part is more obvious and it is positioned within the local road area. Landslide scars and fractures as well as bulges of slipped and re-deposited materials are registered in the main body of a landslip. Sliding scars are clearly visible in the foot area of the landslip, in clays of plastic medium that is separated from the bulk medium by thin bed of undetached material. That is the zone of maximal secondary tensions with the greatest deformations. The height of the scars ranges from 0,5 m to 1,5 m maximum. They are noticeable from the landslide toe and almost to the forehead scar.

Bulges in the landslide body are expressed as morphological shapes in the upper part of the slope. They are partially covered by erosion processes and high forest vegetation. Landslide body is built of colluvial material (Co) represented by low-plastic to high-plastic clays (Cl and CH groups). Gravel conglomerate coming from gravel zone detached by sliding locally appears in the mass. The mass is of fractural and intergranular porosity having uneven water-permeability and water-drainage characteristics. At the time of the research, underground water was not registered at the landslide. Abundance of solution-mined $CaCo_3$ in the area above and below the landslide confirms the presence of water during heavy rains.

Sliding plane was formed at depth of 2,5 to 4 m, depending on site morphology, in clay of high plasticity (CG groups). The inclination of sliding plane in the forehead scar area is steep and further towards the toe it is very mild, up to $7^0$. Further landslide characteristics are as follows:

- according to the depth of sliding surface a landslide is shallow (1-4 m)
- according to the amount of detached soil a landslide is small, up to several thousand $m^3$
- according to the place and cause a landslide is delapsing – it occurs at the toe of the slope and develops upwards along the slope
- according to the time of occurrence a landslide is secondary one, formed within the terrain previously affected by sliding
- according to the structure and the slope composition a landslide is asequent, developed in uniform soils

Causes of landslides are ambiguous: natural and technogenic. Natural causes are basic and they are as follows:

- impact of surface and undergound water
- high values of underground water oscillations throughout the year
- lithological composition
- physical and mechanical properties of individual lithological members
- site construction
- morphological characteristic of a slope

Technogenic causes are sporadic and they are:

- undercutting of the foot of the slope
- weak maintenance or no maintenance of surface water drainage canal at all

The main cause of soil sliding is surface and underground water. During heavy rains, surface water steep into deeper part of the clay layer through humic cover and subsurface clay fractures with lenses of more or less shaly sand and gravel. Prolonged wetting worsens physical and mechanical properties of clay and having in mind site elevation that adds to development of site instability. Presence of water in a bed immediately above the sliding plane area is confirmed by $CaCo_3$ deposits, which are results of chemical wear on the clay.

Underground water also exerts a great impact on the slope stability. During heavy rainfall gravel bed of thickness > 7 is saturated with water. Overlying clay saturates with water due to capillary climbing, than it softens and becomes less resistant to slipping and depending on its inclination, becomes unstable. Apart from this phenomenon, we can assume that there is also a phenomenon of swelling which causes its volume enlargement and causes instability too.

During the drought, water level in the gravel lowers deep down the ground surface. Fluctuations of underground water levels occur in the range of more than 10 m. That high fluctuation values cause changes of the state of stress in the field and given the slope inclination and material composition of plastic medium, they favor development of instability.

Besides natural causes of landslides occurrence, technogenic issues are present to a lesser extent such as small cutting of a slope in its foot and poor or no maintenance of surface water discharge canals built along the road and in the foot of the slope.

## STABILITY ANALYSIS AND APPLIED RESTORATIVE MEASURES

Analysis of the slope stability was done for the terrain conditions shown at the section 5 – 5' where embankment beds, clay and sandy gravel beds are present. Clays are the type CH and Cl, fractured in the surface part and they can accept water that erodes their surfaces. Depth of the bed is from 2,0 to 8,0 m. Below the clay layer there is a substrate made of gravel soil GC. This layer is very resistant and suitable for foundation retaining structures. During the hydrologic maximum, it is possible that the level of underground water rises to the clay layer and then it presses and deforms the lower side.

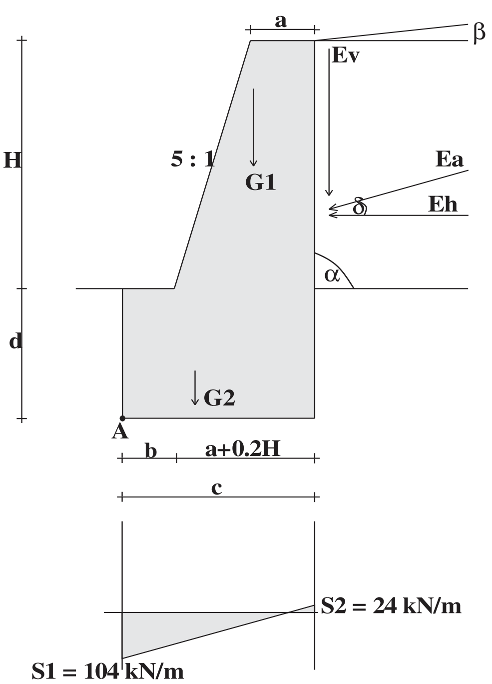
Having in mind that main causes of landslides are surface and underground water, which wet terrain during heavy rain falls, geostatic calculations were performed with the introduction of underground water in the outfield. Following parameters were adopted for the clay layer: $\gamma = 19{,}0$ KN/m$^3$, that is to say 11,0 kN/m$^3$, given the presence of underground water, $\varphi = 13^0$ and c = 0,00 kPa.

The analysis was conducted applying the Janbu method for polygonal slip plane. For the field conditions with underground water the obtained safety factor is $F_s = 1{,}02$, it is to say $F_s \approx 1$ showing that the slope is unstable.

The analysis of slope stability based on Janbu method applying rehabilitation measures of AB retaining wall had obtained the safety factor $F_s = 1{,}41$ and that was the reason for choosing this restorative measure.

As a main restorative measure reinforced retaining AB wall made of concrete MB 25 was designed, protected from frost M – 100, picture 3. The wall is based in sandy gravel layer GC. Parameters selected for calculation are:

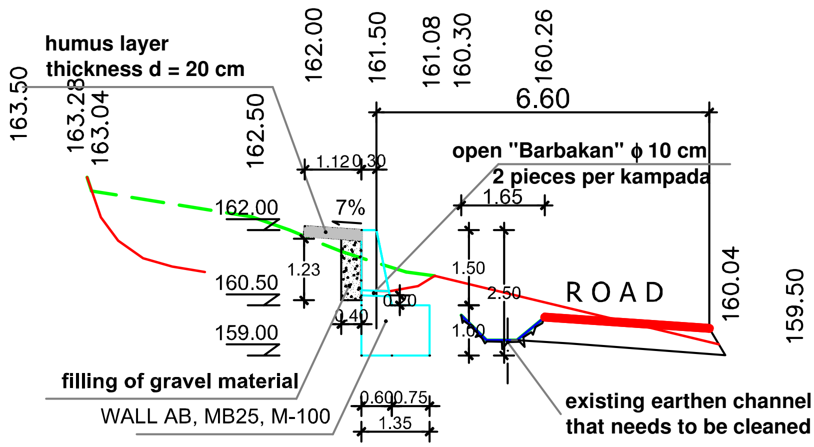
- For the clay layer that pushes the wall: $\gamma = 19{,}0$ KN/m$^3$, $\varphi = 13^0$ and c = 0,00 kPa
- For the wall based layer: $\gamma = 19{,}5$ KN/m$^3$, $\varphi = 34^0$ and c = 0,00 kPa




Picture 3. AB retaining wall at the profile 5 -5'

The wall has a function to accept the pressure of slipping soil mass and to prevent its sliding, namely to keep the slope in a stable condition. The length of the retaining wall is 50,0 m and it was founded on a substrate of sand-gravel formation (GC) throughout its entire length. In order to prevent the retention of water behind the wall, wholes were anticipated in the concrete ("barbakane"), diameter of 10 cm, two of them for each bay, picture 4. Water is further carried by gravitation to the open canal that is situated between the road and the wall.

The other remedial measure was construction of an open perimeter canal at the slope above the retaining wall for the purposes of collecting surface water flowing towards the main body of the landslide and its diversion outside the sliding area. Lining of the canal that remains in the ground is not provided but it requires frequent maintenance and cleaning as needed [7,8].




Picture 4. Transverse profile of the field and the retaining wall 5 – 5'

In order to prevent restorative works to cause new sliding and slope instability their dynamic was determined. Firstly, on open canal without lining was constructed to accept surface water at the slope above the retaining wall. Then excavation works and concreting of retaining wall were performed in planes of 4 m until the retaining wall was completely finished.

## CONCLUSION

The researched landslide is located near the water source "Studenac" in the local community Gornja Cadjavica. It occurred at relatively stable slope because of damage to natural balance due to undercutting its lower part and the construction of the local road. Flattened area at the foot of the slope is marshy, previously being rich in smaller springs that supplied local population with water.

Within the reconstruction of the terrain where landslide occurred some engineering-geological and geotechnical examinations were conducted as well as laboratory testing of samples. The site of examined location is built of Plio-Pleistocene-Quaternary and alluvial sediments.

Slightly permeable to impervious rocks are of intergranular porosity with dominant share of clay and clay-dust sediments with k = 1,15 x $10^{-7}$ to 8,62 x $10^{-7}$ cm/s whereby semi-permeable to high-permeable rocks of intergranular porosity are gravel and sand of thickness greater than 10,0 m with k = 1,10 x $10^{-2}$ to 1,1 x $10^{-1}$ cm/s.

The stability analysis was conducted for natural conditions including presence of underground water where obtained $F_s$ = 1,02, and applying the restorative measure using AB retaining wall, which increases the safety factor to $F_s$ = 1,41. For the purpose of the rehabilitation, two restorative measures were applied and that is: reinforced AB retaining wall made of concrete MB 25 based in sandy gravel layer and construction of the open perimeter canal above the retaining wall in order to collect and drain surface water.

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