Geological-Geotechnical Exploration for the Landslide mitigation Section at the Old Cemetery in Smederevo

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Abstract: The slope where the Old Cemetery in Smederevo is situated has been shaped by landslide processes. These are most likely deep but dormant landslides with the failure surface of over 20 m. Active landslides occur in shallow, near surface areas, with the failure surface of about 2 m. In addition to present exogenic processes, human activities such as cutting, filling, land development etc. also impact the landscape. The study microlocation occupies the slope section in the Old Cemetery northern boundary area from Karađorđeva Street to Koče Kapetana Street. The slope gradient in this section is about 45°. The slope stretches to the Danube river alluvial plain, with elevations ranging from 74 to 74,5 m, whereas the elevations in the slope section under consideration range from 77 to 90 m. Overall stability of the slope is ensured by an RC retaining system – a concrete diaphragm wall built at the slope toe, whereas traces of active landslide and failures with their effects are clearly visible in higher sections of the slope. The study area is made up of the sediments of various compositions and ages. The bedrocks represented by the Neogene sediments are overlain by the Quaternary delluvial sediments. The proposed solution involves construction of the retaining system comprised of Ø800 mm piles with a capping beam. The piles will be 10 m long, with the pile base elevation at 72,0 m. The capping beam elevation will be at 83,0 m. The spacing between the piles depends on the static calculation, with an assumption that Ø800 mm piles with the spacing of 2,0 m can provide stability. The gap between the piles (from the surface of the ground to the capping beam) will be protected by horizontal sheet piling. Drains that will allow water drainage should be provided for at the sheet piles. The pile retaining wall length is 54 m. Terramesh gabion wall filled with sand will be constructed after the pile retaining wall has been completed. The gabion walls will be supported by the pile capping beam and installed by stepping back by 0,5 m. In case the gabions have cross section of 1,0 x 1,0 m, the retaining wall face will have a gradient of 2:1. The elevation of the top the Terramesh gabion retaining wall will range from 86,0 to 89,0 m, depending on the elevation of the slope in the back. The surface layer of the sand fill should be covered with topsoil and grassed.

Keywords: the Old Cemetery, Smederevo, landslide, piles

Geomorphological characteristics

The study area occupies the border between southern Banat plains and the hills of Smederevo. Present landscape patterns have mostly been shaped by the Danube river together with present exogenic landslide processes. A number of landslides is a one of the outstanding characteristics of the right bank of the Danube river along its entire flow through Serbia. The tendency of the river course to shift southward is the primary cause of the landslide processes.

The slope where the Smederevo Old Cemetery is situated has been shaped by landslide processes. These are most likely deep landslides with the failure surface of over 20 m however, with the suspended landslide process. Active landslides occur in shallow, near surface areas, with the failure surface of about 2 m.

In addition to present exogenic processes, human activities such as cutting, filling, land development etc. also impact the landscape.

The The study microlocation occupies the slope section in the Old Cemetery northern boundary area from Karađorđeva Street to Koče Kapetana Street. The slope gradient in this section is about 45°. The slope stretches to the Danube river alluvial plain, with elevations ranging from 74 to 74,5 m, whereas the elevations in the slope section under consideration range from 77 to 90 m. Overall stability of the slope is ensured by an RC retaining system – a concrete diaphragm wall built at the slope toe, Figure 1, whereas traces of active landslide and failures with their effects are clearly visible in higher sections of the slope, Figure 2.

Figure 1. A section of the existing retaining system at the slope toe

Figure 2. Landslides and failures in higher sections of the slope

Geological characteristics

The study site is made up of sediments of various composition and ages. The Quaternary diluvial sediments overlie the Neogene bedrocks.

The Neogene (Lower Pliocene – Pl_1)

Pl_1(lg, ug, p) – a complex of marly and coaly clays with sand interbeds

A complex of coaly (ug) and marly (lg) clays represented by clays with lenticular interbeds of coal and sands overlie the floor sands. Thickness of coaly clays ranges from 40 to 60 m. Coaly clays are always highly jointed, with a number of tectonic joints dividing the rock mass into irregular blocks. The coal is of a variable thickness. It is faulted and contorted due to tectonic movements. Relatively closely spaced faulting in coals as marking beds virtually produce discontinuities in the horizontal direction of the bed.

In general, the clay-sandy complex is a product of lacustrine sedimentation, where the sand and the clay belong to shallow and deep facies, respectively. Their relatioship corresponds to the shallowing process in the Pannonian Sea accompanied by many movements in the tectonically mobile basin (which is indicated by several beds of coal). The Pliocene lake retreat along its boundary resulted in formation of abrasion terraces. Steep scarps – cliffs and plateaus were formed in sands and marly clay, respectively.

The Neogene sedimentary rocks are gently undulating, dipping northeast at an angle of 5 to 15°.

Two groups of discontinuities are present in a broad area:

The first group includes the faults that strike approximately parallel to the Danube river, with the dip direction ranging from 15° to 205° (with a relatively steep dip westward), along which individual blocks moved up or down).

The second group of faults have the direction of 135° to 315°, with the dip southwestward. Their strike is diagonal to the strike of the first group of faults, and subsequent movements occurred along the faults. Reverse rise of the coaly clays in relation to the roof sands occurred along the faults.

The Quaternary (Q)

The Quaternary sediments are the most widespread stratigraphic member on the surface and are represented by the heterogenous fill material (n) that makes up the surface portions of the slope toe and bottom portions of the site, diluvial deposits (dl) composed of clayey silty-sandy sediments that make up the surface portions of the unstable slope.

Hydrogeological characteristics

Lithology and porosity conditions determine hydrogeological properties of the study site. The diluvial deposits have pseudointerparticle and fine fissure porosity. The fill material and Pliocene sands are mostly of interparticle porosity. Due to their different porosity types and distribution on the site, the identified sediments can be classified in the following groups according to their geologic function:

- hydrogeologic conductors of water – the fill material and diluvial deposists,
- hydrogeologic accumulator aquifers – the Pliocene sands.

In the Pliocene sands, an aquifer has been formed in which the water table was not discovered to a depth of 15 m during borehore drilling. During periods of high precipitation, the water table in the aquifer is always much higher and estimated to be up to 2 – 3 m from the surface of the ground.

Seismic characteristics

No detailed microseismic zoning of the area studied has been performed. The seismicity parameters have been taken from the website of the Seismological Survey of Serbia (http://www.seismo.gov.rs/). The maximum intensity earthquakes can be expected according to the seismic hazard maps for peak horizontal ground acceleration for the bedrock – Acc(g) and a maximum macroseismic intenisty – I_{max} in units specified by the European Macroseismic Intensity Scale (EMS-98) within the return periods of 95, 475 and 975 years and are represented in Table below.

Table 1. Seismicity parameters for return periods.

Seismicity Parameter	Return Period (in years)	
	95	475
Acc(g) max	0.06	0.10
Imax (EMS-98)	VI-VII	VII-VIII

Basic characteristics of landslide

The process of initiation and development of landslide on the location considered is both complex and specific. Main prerequisites for slope instability are the site geologic structure, morphology, hydrogeological properties and poor physical and mechanical properties of the rock masses (marly clays, marls and sands). Human activities such as improper, usually unplanned cuttings, damages to water and sewer systems, and similar activities can be a contributing factor in causing landslides.

The wider area is affected by the process of instability. These are most likely deep landslides with the failure surface of over 20 m however, with the suspended landslide process. Active landslides and failures occur in shallow, near surface areas in the top portion of the steep slope spreading along the Cemetery northern boundary. The estimated failure surface is about 2 m, and the landslide future activity can directly threaten and restrict the use of the Cemetery area.

Landslide mitigation measures

The engineering solution to the repair of the part of the Old Cemetery landslide in Smederevo has been proposed taking into account the results of investigations and surveys.

The proposed solution will provide stability of the top portions of the steep slope in the north part of the Cemetery in Karađorđeva Street, and prevent any further slides of the surface portions of the site. In addition, the steep slope will be permanently stabilized and its potential failures prevented.

The proposed solution involves construction of the retaining system comprised of Ø800 mm piles with a capping beam. The piles will be 10 m long, with the pile base elevation at 72,0 m. The capping beam elevation will be at 83,0 m. The spacing between the piles depends on the static calculation, with an assumption that Ø800 mm piles with the spacing of 2,0 m can provide stability. The gap between the piles (from the surface of the ground to the capping beam) will be protected by horizontal sheet piling. Drains that will allow water drainage should be provided for at the sheet piles. The pile retaining wall length is 54 m.

Terramesh gabion wall filled with sand will be constructed after the pile retaining wall has been completed. The gabion walls will be supported by the pile capping beam and installed by stepping back by 0,5 m. In case the gabions have cross section of 1,0 x 1,0 m, the retaining wall face will have a gradient of 2:1. The elevation of the top the Terramesh gabion retaining wall will range from 86,0 to 89,0 m, depending on the elevation of the slope in the back.

Stability of the existing RC diaphragm wall may not be compromised during construction works. This particularly applies to pile driving machine moves on the site. In addition, the use of bored pile walls is proposed because the method of drilling bored piles produces the least vibration.

The back of the gabion wall (the section between the the gabion and the existing slope) will be filled with sand. The sand should be compacted in layers of up to 30 cm by manual vibro compactors (tamping rammer). Sand layers compaction should be minimum Evd = 15 MPa.

The surface layer of the sand fill should be covered with topsoil and grassed.

Slope stability analysis

Geostatic calculations have been used in stability analysis of the soil and the proposed retaining system.

Geostudio 2012 – Slope/W software and *the Morgenstern-Price* limit equilibrium method were used in the analyses. The geoengineering model at the cross section 1-1' was adopted in the analyses (Figure 3).

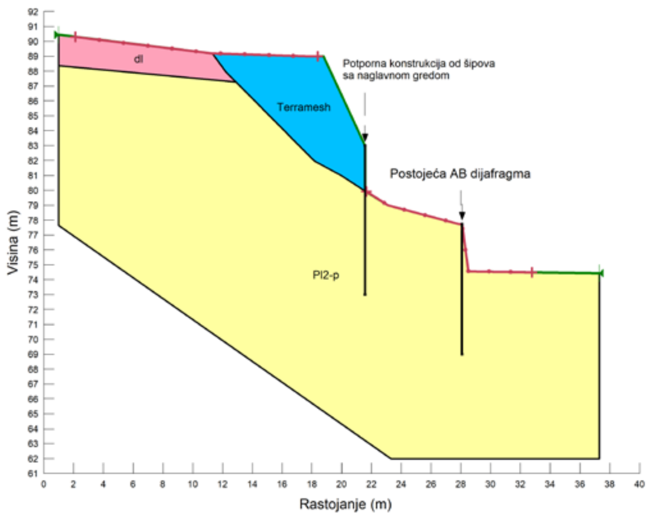

Figure 3. Geoengineering model at GT cross section 1-1’

The first step involved the analysis of the overall stability after the repair that is, construction of the retaining system from the piles and "terramesh" gabion wall.

Strength parameters (for terramesh) for the structure were provided by the material supplier, and they apply to the fill excluding geomesh for reinforcement. The equivalent parameters for the terramesh structure are the following:

- $\gamma = 18{,}5$ kN/m^3;
- $\phi = 35°$;
- c = 10.

The above parameter values apply to the case where sand materials are used for filling.

Shear strength is 300 kN, with the pile spacing of 2,0 m.

Stability analyses have been made for regular conditions and for horizontal ground acceleration of *Acc(g) = 0,1*. The results are represented in Figures 4 and 5.

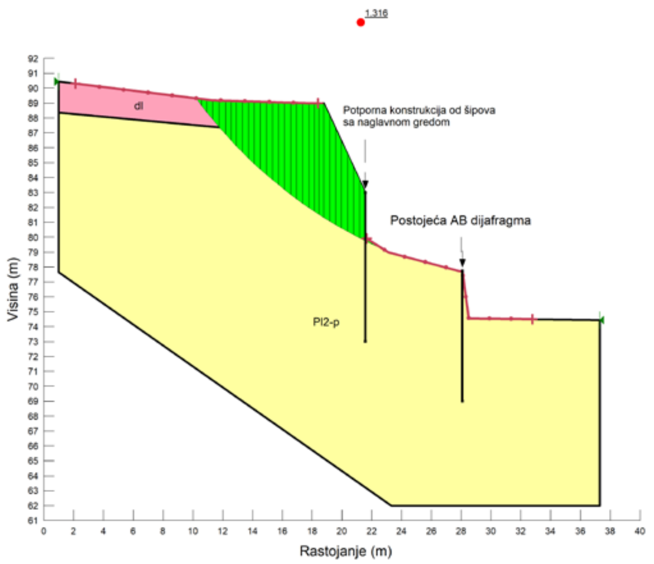

Figure 4. Slope stability analysis in the area of the retaining system

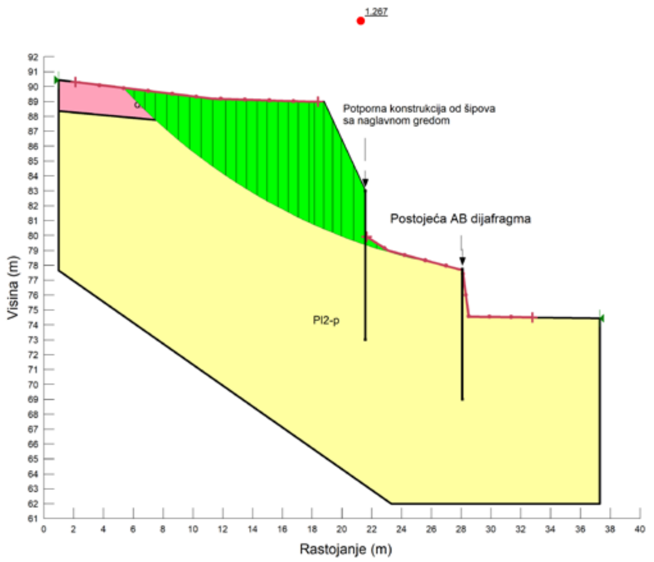

Figure 5. Slope stability analysis in the area of the retaining system – including the peak horizontal ground acceleration for the return period of 475 years

The factors of safety for the critical slip surface are Fs = 1.316 (excluding the ground acceleration) and Fs = 1.267 (including the ground acceleration), respectively. The estimated factors of safety can be considered satisfying for the structure type studied. Since estimation for the cross section analyzed is the most critical given the position of the retaining system in relation to the slip surface, it can be considered relevant for the entire retaining system.

The analysis has also been made for the effects the retaining system has on the landslide in the surface portions of the site (Figure 6).

Since it was not possible to reconstruct the soil conditions before the landslide occurrence, back-analysis has been used to determine stability along the slip surface, with an assumption that the sliding body is currently in the limit equilibrium state (Fs ≈ 1.0).

The analysis resulted in the following conditional strength parameters along the slip surface:

- $\gamma = 21{,}0$ kN/m³;
- $\phi = 11.2°$;
- $c = 0$ kN/m².

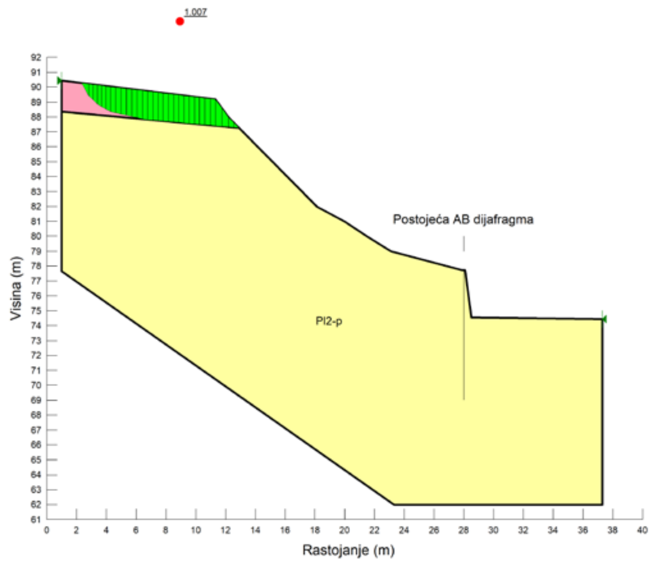

Figure 6. Back-analysis

The effects of the retaining system on the landslide stabilization are demonstrated in an increase of the factor of safety from Fs = 1.0 to Fs = 3.58 (excluding the horizontal ground acceleration for the return period of 475 years) that is, Fs = 2.15 (including the horizontal ground acceleration for the return period of 475 years) – Figures 7 and 8.

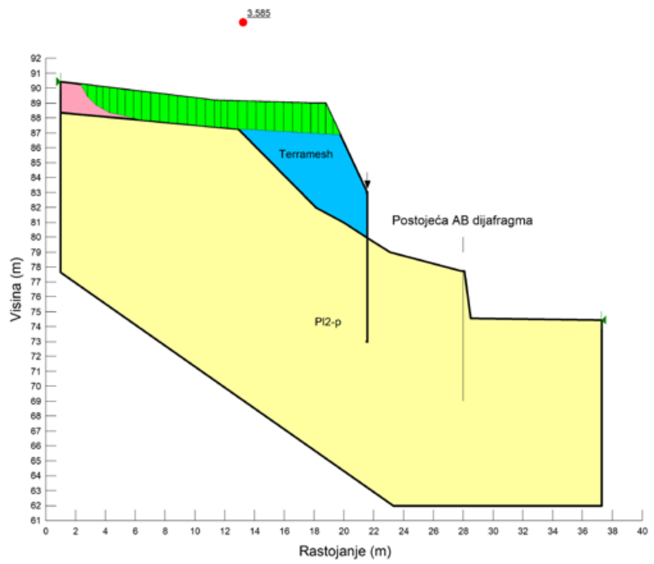

Figure 7. Tha analysis of stability in the landslide area – excluding the peak horizontal ground acceleration for the return period of 475 years

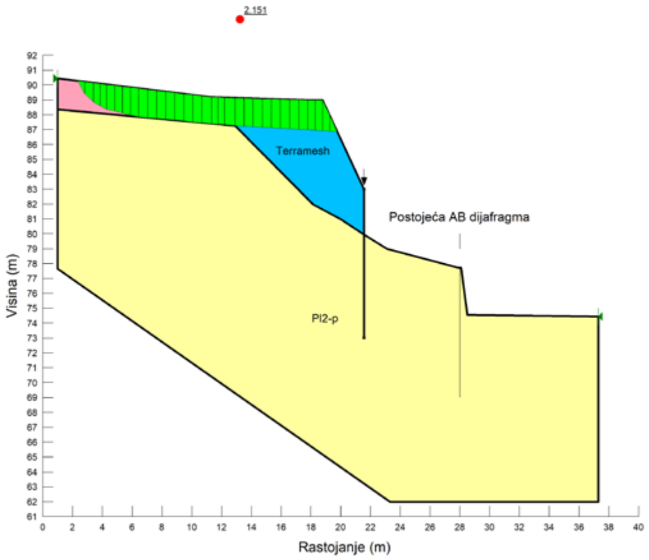

Figure 8. The analysis of soil stability in the landslide area – including the peak horizontal ground acceleration for the return period of 475 years.