Monitoring of the Active Landslide during Excavation of Slopes for the Svračkovo Dam Stilling Basin

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Abstract The Svračkovo dam site is located in western Serbia, on the Veliki Rzav River, 8 km upstream of Arilje town. About 26 million m³ reservoir capacity shall be formed by construction of an embankment dam with a clay core - 60 m high and with the dam crest elevation of 423.60 masl. The narrow area of the dam site and appurtenant structures comprises an area of about 0.4 km^2. For the requirements of construction of the stilling basin, i.e. the outlet from the diversion tunnel on the left abutment, bench slopes from access roads S1 and S3 are excavated. During excavation of slopes beneath the access road S3, contemporary scars resulting from terrain movement were detected on the upper access roads and in the vicinity. In addition to investigation works, geodetic surveys were also carried out for the purpose of landslide monitoring in conditions of ongoing remedial measures.

Keywords Svračkovo, investigation works, geodetic surveys

Introduction

The main purpose of the „Svračkovo“ dam construction is a certain, sustainable water supply to the broader area of this part of the Republic of Serbia, encompassing the towns of Arilje, Požega, Užice and Ivanjica (Fig. 1).

In addition to its basic hydrotechnical purpose, this structure is designed as a hydropower facility, too, so that apart from water supply, its function will be to generate electric power as well (HPP Svračkovo).

Figure 1 Geographic position of the Svračkovo dam

By construction of the first access road to the construction site in 2010, the works related to the execution of the HPP Svračkovo structure commenced. For the requirements of construction of the stilling basin, i.e. the outlet from the diversion tunnel on the left abutment, bench slopes from the access roads S1 and S3 are excavated. The access road S3 is hypsometrically lower (~elevation masl) than the access road S1 (~elevation masl). During excavation of slopes beneath the access road S3, contemporary scars resulting from terrain movement were detected on the upper access roads and in the vicinity. Active scars on the terrain have been identified almost at the peak elevations of the terrain above the road S1 (Fig. 3).

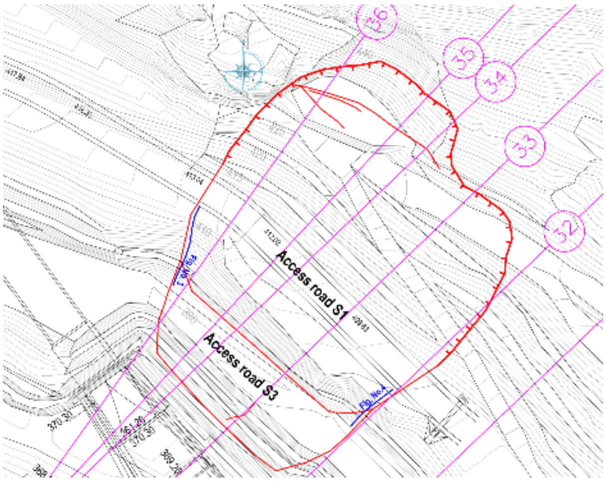

Figure 2 Active scars on the terrain

The boundaries of contemporary geodynamic phenomena, which are presented in Fig. 2, have been geodetically surveyed. The frontal scar of the landslide was identified up to the peak elevation of 420 masl, in the zone of limestone blocks. Lateral landslide scars were clearly identified on already executed slopes covered with shotcrete. The gap of the lateral landslide scars on shotcrete is even up to several cm, Fig.3 and Fig. 4.


Figure 3 Active scars on the terrain

Figure 4 Active scars on the terrain

The presented landslide is one of the two major landslides registered at this site during execution of excavation works for the stilling basin. The other, downstream landslide, is described in detail within the earlier submitted paper at the 5th Regional Symposium on Landslides, Rijeka, 2022.

Upon detection of contemporary geodynamic phenomena on the terrain, extensive measures of investigation works with appropriate computational analyses of terrain stability were implemented.

Presentation of the Results of Geological/Geotechnical Field Investigations

Within the investigation procedure for the requirements of remediation of the activated landslide, detailed engineering-geological mapping of the slopes of service-construction access roads, exploratory drilling of 7 boreholes to the depth of 50 m, and geo-electric probing of terrain were carried out. Based on the analysis of obtained data and investigation results, it was concluded that the narrower investigation area is built up of Lower Triassic and Middle Triassic sedimentary rocks, and Quaternary formations, Fig. 5.

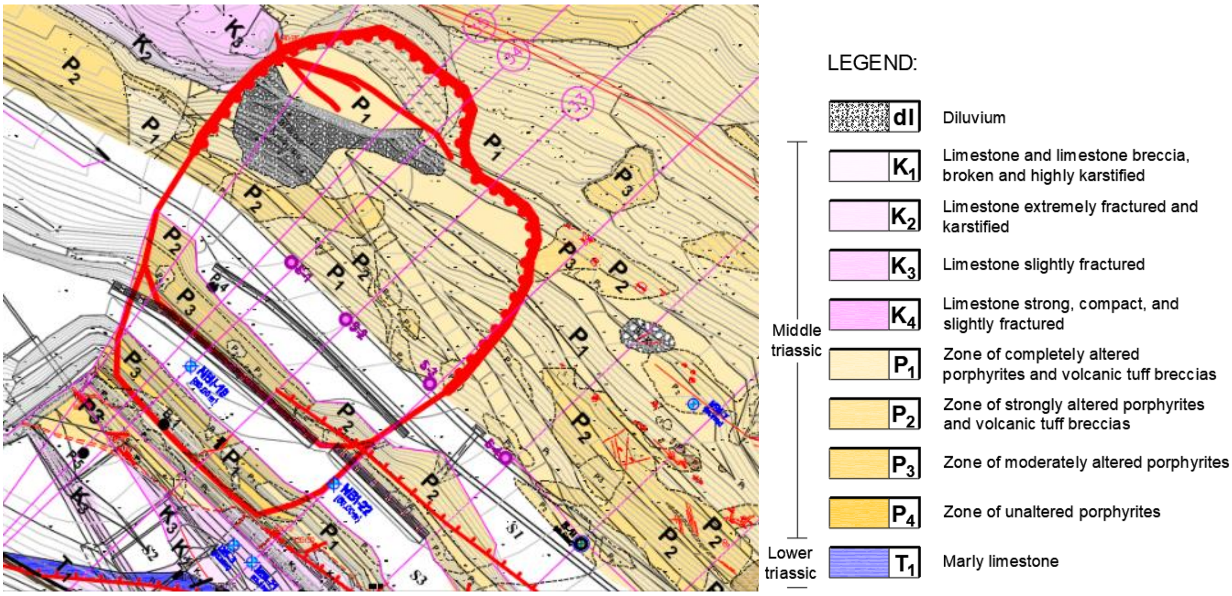

Figure 5 Engineering geological map of the investigation area

The Lower Triassic rocks are relatively poorly exposed, outcropping is identified along the riverbed edge and sporadically in the proximity of access roads. It is represented by *bioturbatic formation* composed of marly limestones of pronounced laminated structure. The rock mass is of medium to low strength, with pronounced fracture systems, their walls being smooth and flat. On the Basic Geological Map of SFRY (Brkovic and Malesevic 1977), it was believed for a long time that the Lower Triassic sediments were in a normal relationship with the Middle Triassic sediments, all until the extensive investigation procedure conducted for the requirements of remediation of this instability. In fact, during execution of access roads to the higher exploratory boreholes NBI-10 and NB-4, it was noted on fresh outcrops that the Lower Triassic sediments were in a reverse relationship with the Middle Triassic sediments. The contacts have mild slopes, with mandatory presence of a thin layer of hydrothermal altered rocks of red colour in the contact zone. This data indicates to high pressures during the block overthrust of older geological formations over younger ones. The described procedure is also identified in the exploratory drilling cores. The expert confirmation of such a geological composition of terrain in conditions of intensive block overthrust was supported by the results of the executed investigation procedure, and documented within the structural-tectonic Study (Trivić, 2019). Based on the mentioned study, block overthrusts are generally dipping northeast, with mean statistical dip elements EPkr 21/44. In Fig.6, the Lower Triassic sediments are marked T1.

Middle Triassic sediments spatially dominate in the investigation area, and are composed of limestones of sparite structure, massive texture, partly or completely recrystallized, in some places irregularly dolomitized, and in some places with lenticular intercalations of sedimentary breccias. The slopes structured of massive limestone are steep, and in some places turn into vertical sections, which was noted immediately above the frontal scar of the active landslide. On limestone outcrops, sets of fractures stand out, dividing the rock into monoliths of different dimensions. According to the degree of jointing and degree of karstification, the massive limestones are divided into four media:

- K1 – Limestone and limestone breccia, broken and highly karstified;
- K2 – Limestone, extremely fractured and karstified;
- K3 – Limestone, slightly fractured;
- K4 – Limestone, strong, compact and slightly fractured.

In Fig. 6, massive limestones are marked K1 to K4.

Porphyrites are present in the central and southwest part of the investigation area. Their genesis is associated to submarine-type volcanism in synsedimentary conditions. These volcanic rocks, according to most authors, represent a product of the Triassic rift area. On the Basic Geological Map, sheet Užice (Mojsilovic and Baklaic 1977), they are treated as an integral part of the volcanogenic-sedimentary unit where it was noted that they appear in the form of porphyritic tuffs, breccias and porphyrites, alternating with crystalloclastic tuffs. Based on additional petrologic tests, it was determined that these exact volcanogenic-sedimentary rock masses are present at this location. Porphyrites are volcanic rocks formed by lava outflow, thus they are initially of higher strength than the volcanic tuff-breccias, and in addition to that, the volcanic tuff-breccias, as softer rocks, are more susceptible to the process of hydrothermal alterations. Chloritization and calcitization were registered on most samples from volcanic tuff-breccias, and sericitization on one sample.

Based on the degree of alteration, these volcanic-sedimentary rock masses are divided into four categories:

- P1 – Zone of completely altered porphyrites and volcanic tuff-breccias;
- P2 – Zone of strongly altered porphyrites and volcanic tuff-breccias;
- P3 – Zone of moderately altered porphyrites;
- P4 – Zone of weakly altered and unaltered porphyrites.

It may be stated that the zones of completely (P1) and partly altered porphyrites (P2) are mixed with tuff breccias, provided that the processes of hydrothermal alterations have masked the mutual geological transitions and boundaries. The processes of chloritization, calcitization, and especially sericitization, play the key role in the rock material degradation. On representative samples from these materials, very low values of physical-mechanical properties were obtained.

It may be concluded on the basis of conducted geological analyses that the sliding planes are formed on unfavourable systems of fracture sets (EPsm1 – 225/68) in weakened geological zones of completely altered porphyrites with tuff-breccias, Fig. 6.

Fracture systems EPsm1 with mean dip elements 225/68 are assessed a very unfavourable set of fractures in terms of slope stability. The spatial position of the strike of these fracture sets is almost parallel to the strike of executed slopes. Apart from the foregoing, the fractures of this set are slickenside and undulatory along the angle of dip, so that they may form very unfavourable sliding planes in relation to other fracture sets.

Slope Stabilization Measures in the Active Landslide Zone

Based on conducted computational analyses of terrain stability in operating conditions, two terrain stabilization phases have been defined.

Terrain stabilization Phase I – reduction of the slope inclination, i.e. slope relief in the form of removal of overburden and moved rock material. Slope relief was performed from elevation ~445 masl to the access road S1, approximate terrain elevation 410 masl. About 25 000 m^3 of rock material was removed. The slopes are executed at 1:1 gradient with berm width up to 3 m. The newly executed slopes are supported by three layers of shotcrete, 2 reinforcing meshes and passive anchors up to 10 m long. In Fig.8, this remediation measure is marked blue.

Terrain stabilization Phase II – systematic anchoring of terrain using pre-stressed anchors, under the access road S1:

- Geotechnical pre-stressed anchors in the zone of road S1 – the total of 12 anchors, 25 m long each, at the mutual horizontal distance of 4 m.
- Geotechnical pre-stressed anchors on road S3 – the total of 36 anchors, 25 m long each, in two rows at the mutual horizontal distance of 4 m
- Geotechnical pre-stressed anchors from elevation 375 masl – the total of 36 anchors, 25 m long each.
- Geotechnical pre-stressed anchors from elevation 369.20 masl – the total of 36 anchors, 25 m long each, in two rows, at the mutual horizontal distance of 4 m.

The length of geotechnical anchors is 25.0 m, while the anchoring section is 10 m long. The maximum pre-stressing force is 1300 kN. In Fig. 6, this remediation measure is marked green.

The works on execution of this terrain stabilization phase were performed in the period from January 2016 to the end of 2017. For the requirements of continuous monitoring of works, and slope monitoring during execution of the envisaged remediation works, benchmarks were systematically executed on the slope. The benchmarks were executed in the broader zone of works and continuously monitored during execution of the terrain remediation.

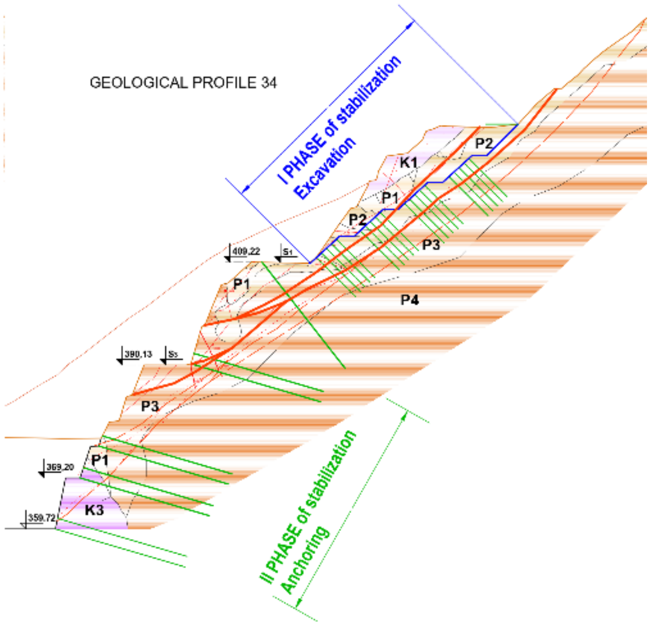

Figure 6 Geological profile 34 with indicated terrain stability measures

Monitoring of the Slope Above the Stilling Basin

In the landslide zone, the total of 25 points are monitored. Out of the total number of monitoring points, 17 points are designed on the landslide itself, and the rest outside this zone in order to observe and monitor the broader area.

The basic 2D and 1D landslide monitoring network consists of 7 points: S1, S2, S3, S4, S5, S9 and S12. Materialization of network points is performed by setting up concrete columns with the height, from tread, of about 1.30 m above the ground surface. The coordinate system in the basic 2D and 1D network is the state reference system.

To determine the horizontal displacement of monitored points, the conventional method was selected, measuring the following quantities: horizontal directions, vertical angles and diagonal distances. For measurement of horizontal directions, the method of measurement in both faces was applied, and the number of rounds of directions was three. Measurement of diagonal distances is to be performed in both positions of the telescope KL and KD. Measurements to determine the vertical displacements of points on the landslide in 1D network were performed by the method of trigonometric levelling. Based on the measurement of all quantities in the basic 2D and 1D network of the specified parameters, the definite values of directions, distances and height differences were calculated.

The basic 2D and 1D network were first adjusted as free ones, and then the fixed points were determined and re-adjustment with minimum trace was performed to the given (fixed) points of the 2D and 1D network.

For each control series, fixed points of the basic 2D and 1D network were determined. The analysis of fixed points in the basic 2D and 1D network was performed by one of the verified methods in the deformation analysis (Pelzer method).

The measurement was performed using an instrument with measurement uncertainty as follows:

- For horizontal and vertical directions 1"
- For distances (1+1*10-6*L) mm, (L in mm)

Total displacement of control points is calculated in relation to the zero measurement executed in December 2015. In the period from February 2016 to August 2017, 12 control series were executed. The value of detectable displacement is smaller than 1 cm, both for horizontal and vertical movements. Assessments of unknown parameters with accuracy assessment and size of detectable displacement at the test rating of 0.80 are presented in the table.

Table 1 Results of laboratory tests in a large scale

No.	Control point	my [mm]	mx [mm]	dpy [mm]	dpx [mm]	mh [mm]	dph [mm]
1	S1, S2, S3, S4, S5, S9 and S12	0.7	0.8	3.0	3.1	1.6	6.2
2	1 to 8	0.7	0.9	2.8	3.5	1.2	4.7
3	9 to 17	0.8	1.0	3.0	4.3	1.2	4.7
4	18 to 25	1.7	1.9	6.8	7.9	1.7	6.5

Wherein:

- my – Mean error in determining the coordinates on Y axis
- mx - Mean error in determining the coordinates on X axis
- mh – Mean error in determining the heights
- dpy – Detectable displacement size on Y axis
- dpx – Detectable displacement size on X axis
- dph – Detectable displacement size on Z axis

The values of changes in movement for the period February 2016 – July 2016 are presented on Fig. 7.

date	02/2016			03/2016			04/2016			05/2016			06/2016			07/2016		
CONTROL POINT	V - IV SERIA			VI -V SERIA			VII-VI SERIA			VIII-VII SERIA			IX-VIII SERIA			X-IX SERIA		
	DVY (mm)	DVX (mm)	DZ (mm)	DVY (mm)	DVX (mm)	DZ (mm)	DVY (mm)	DVX (mm)	DZ (mm)	DVY (mm)	DVX (mm)	DZ (mm)	DVY (mm)	DVX (mm)	DZ (mm)	DVY (mm)	DVX (mm)	DZ (mm)
1	-2	0	1	-4	-3	-1	-2	-3	1	-1	-1	0	1	1	0	0	-1	2
2	-4	-2	0	-18	-18	0	-17	-16	1	-11	-11	-2	-2	-3	-1	-3	-2	1
3	-2	-1	0	-10	-14	0	-9	-13	1	-5	-8	1	1	-2	0	0	-2	1
4	-2	1	0	-14	-14	-4	-17	-16	0	-7	-8	-2	0	-1	0	0	-1	1
5	-2	1	-1	-13	-18	-7	-16	-22	-2	-5	-7	-1	0	-1	0	0	1	0
6	-4	-1	0	-16	-21	1	-18	-24	4	-11	-12	1	-1	-2	0	-3	-5	1
7	-4	-2	-1	-22	-25	2	-25	-25	4	-14	-16	1	-4	-5	0	-3	-2	1
8	-5	-4	0	-17	-17	3	-17	-17	4	-10	-9	2	-1	-1	1	4	3	0

Figure 7 Changes in horizontal and vertical movements

Wherein:

- DVY – Change of movement on Y axis between two series.
- DVX – Change of movement on X axis between two series.
- DZ – Change of movement on Z axis between two series.

Fig. 8 shows the summary of vectors of total horizontal and vertical movements obtained after the sixteenth control series in August 2017.

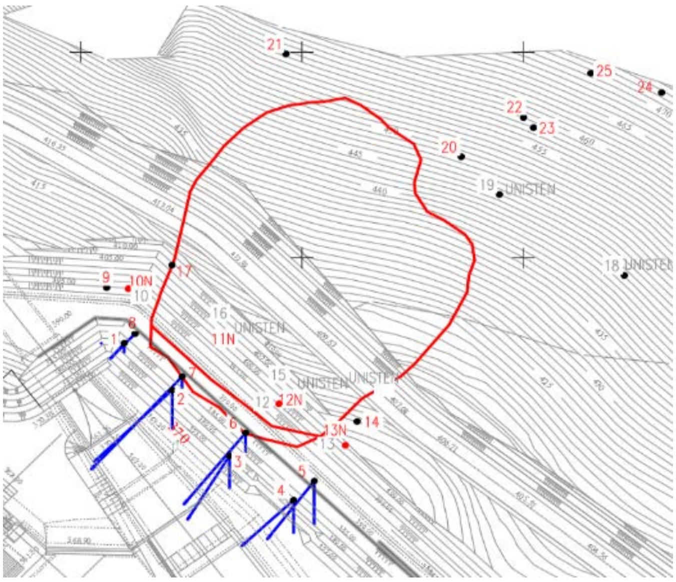

Figure 8 Total horizontal and vertical movements – August 2017

LEGEND:

Total vertical movements – sixteenth measurement series – August 2017

Vector of total horizontal movements – sixteenth measurement series – August 2017

Analysis of the Monitoring Results

As mentioned in the preceding chapter, for the requirements of slope monitoring first the benchmarks 1-25 were installed, on which the zero measurements were performed in December 2015. Surveying benchmarks with serial numbers from 1 to 4 and from 5 to 8 are positioned on the slopes above the road S3, so that they are not damaged during slope remediation and, consequently, they were monitored for the longest time. The results of the monitoring of surveying benchmarks 1 to 4 and 5 to 8 are almost analogous, therefore Fig.No.11 shows the movements on x axis on benchmarks 5 to 8.

The largest movements took place until May 2016, when the removal of overburden above the road S1, PHASE I, was completed. Gradually, in line with the progress of landslide remediation progress, the movements diminished, resulting in the benchmark movement of mm order of magnitude from April 2018 to September 2019.

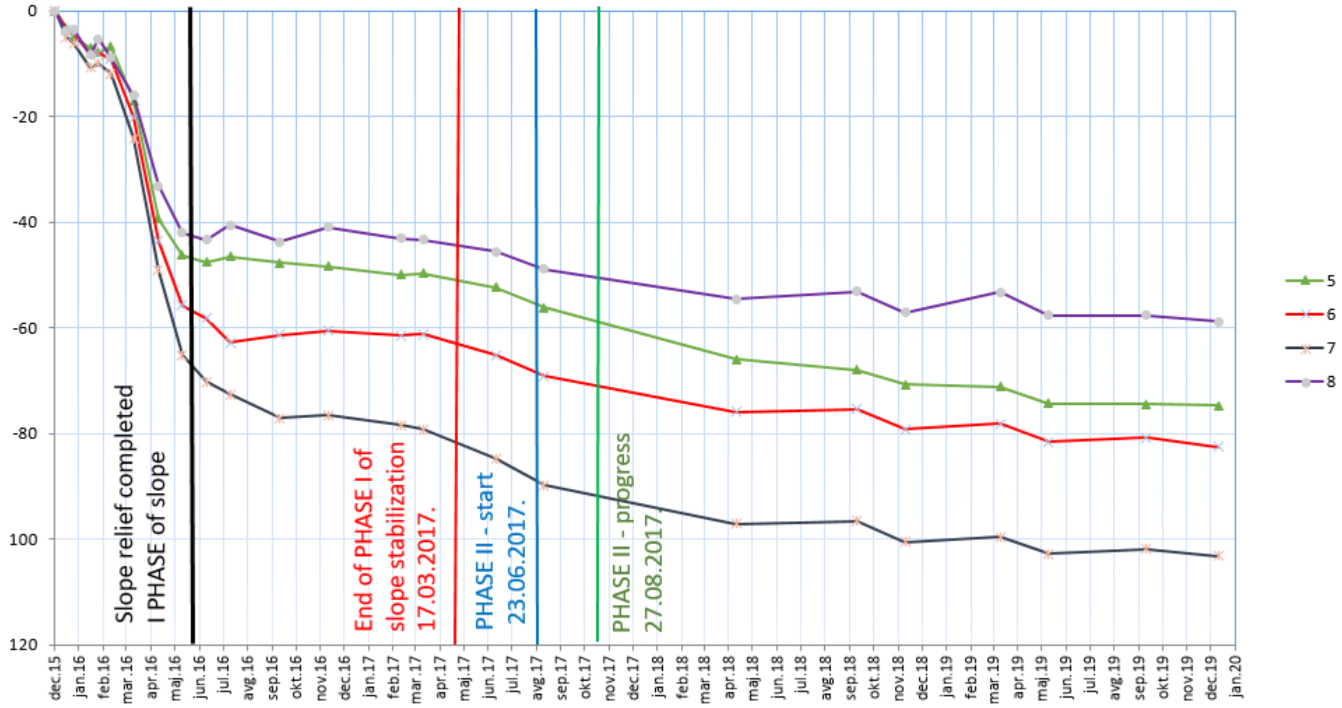

Figure 9 Moving of the benchmark on the landslide in the X direction – II row

Conclusion

For the requirements of stabilization of slopes above the stilling basin, dedicated geological investigations were carried out. Based on conducted investigations, structural analyses were made for the requirements of stabilization of the slope above the stilling basin. The slope remediation design defines two terrain stabilization phases.

Terrain stabilization Phase I – reduction of the slope gradient, i.e. slope relief in the form of removal of the overburden and moved rock material.

Terrain stabilization Phase II – systematic terrain anchoring using pre-stressed anchors, under the access road S1.

The works on execution of these two terrain stabilization phases were performed in the period from January 2016 to the end of 2017.

For the requirements of continuous monitoring of works, slope monitoring during execution of envisaged slope remediation works, surveying benchmarks were systematically executed and monitored during the remediation works.

After analysis of displacements detected on surveying benchmarks, it was concluded that the largest movements took place until May 2016, when the removal of overburden over the road S1, PHASE I, was completed. Gradually, in line with the progress of landslide consolidation, the movements diminished, resulting in the benchmark movement of mm order of magnitude from April 2018 to September 2019.

Acknowledgements

The authors would like to thank the Public Water Management Company “Srbijavode”, for supporting us during the field investigations and approving of the publishing of the presented data.

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