MONITORING OF THE BELCA ROCKFALL

MONITORING SKALNEGA PODORA BELCA

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Ključne besede

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Abstract

This paper reviews the monitoring of the rock block above the forest road of Belca Jepca near the village of Belca in the municipality of Kranjska Gora, Slovenia. A rockfall in part of the block occurred in autumn 2014. Both classic and some new measurement technologies were used. The new technologies were implemented according to new findings: an unmanned aircraft was used in the hazardous and hardly accessible areas of the observation, a terrestrial laser scanner was used for the comprehensive observation of the rock slopes and large cracks were observed with the installation of invar wires. The deformation analysis uses data between 2014 and 2017, among which airborne laser scanning (ALS) data from 2014 is included. The study also includes a comparison of the airborne laser scanning and the terrestrial laser scanning.

Izvleček

V prispevku je podan pregled monitoringa skalnega bloka, ki se je jeseni 2014 sprožil nad gozdno cesto Belca Jepca v bližini vasi Belca v občini Kranjska gora v Sloveniji. V sklopu monitoringa je bila uporabljena tako klasična kot tudi najnovejša merska tehnologija. Metode dela smo prilagajali novim spoznanjem. Tako smo na nevarnih in težko dostopnih območjih za opazovanje uporabili brezpilotni zrakoplov, za celostno opazovanje skalnih brežin pa terestrični laserski skener. Analiza deformacij obsega podatke med letoma 2014 in 2017, med katerimi so uporabljeni tudi podatki aerolaserskega skeniranja površja, zajeti leta 2014. V raziskavi je vključena primerjava podatkov aerolaserskega skeniranja in terestričnega laserskega skeniranja.

1 INTRODUCTION

This paper reviews the monitoring of a rock block located near the village of Belca in the municipality of Kranjska Gora, Slovenia. The reason to begin monitoring the area was a rockfall from some parts of the rock block in September 2014 and the possibility of a collapse of the entire block. Geotechnical measurements were used as part of the monitoring process, as well as geolocating measurements, complemented by field geological surveys and observations using an unmanned aircraft. Of the measurement techniques, the following were used: surveys using wire extensometers, tachometry and terrestrial laser scanning (TLS). We have also acquired lidar data from the summer of 2014, using airborne laser scanning (ALS), showing the status of the area before the rockfall. The analysis of the acquired data covers the period from 2014 to 2017. The aim of this research was to assess the risk of another rockfall, as well as finding a solution to achieve the safety and transportability of the road. We have used both classic and the latest measurement technology. In hard-to-reach areas, an unmanned aircraft was used for the observation, while a terrestrial laser scanner was used to comprehensively monitor the rock slopes. The deformation analysis also includes a data comparison between the airborne laser scanning and the terrestrial laser scanning.

1.1 An overview of related works

Scaioni et al. [1] were the first to use terrestrial laser scanning for the monitoring of a rock block in the Alps, together with an interferometric synthetic aperture radar (InSAR), terrestrial photogrammetry and geotechnical measurements. Teza et al. [2] showed the monitoring of a rock block to assess the risk of a rockfall using TLS and infrared thermography (IRT). The first to try TLS for monitoring the movements and deformations were Gordon et al. [3] on an old wooden bridge. Gordon et al. [4] showed that the technology of laser scanning can be more efficient than classic methods for sensing the changes of flat objects due to the large number of acquired points. Alba et al. [5] used terrestrial laser scanning to control the stability of a big dam, while Schneider [6] used it to determine the inclination of a high water tower and the deformations of two dams. Tsakiri et al. [7] researched the required conditions to use a scanner to measure deformations, in the sense of calibrating the scanner and the processes of modelling clouds for movement sensing. The mentioned works are papers from conferences, while we found one article [8] in a scientific journal that describes using TLS for measuring deformations in an incriminating laboratory test. At the ISPRS congress in Beijing in 2008, the authors of [9, 10, 11, 12, 13] presented their work regarding the use of TLS for the measurements of deformations. Berényi et al. [14] used TLS to measure how much large bridges sag in incriminating tests, while Vezočnik et al. [15] tried to determine the movement of a gas line using the movement of concrete columns connected to underground pipes. Abellán et al. [16] dealt with the field of sensing changes in natural environments. De Asís López et al. [17] used statistical methods to compare two clouds of points, accumulated in different ways. Harmening and Neuner [18] use clouds to flatten various 3D planes and compare them with one another.

1.2 The area of research

The area of interest is the right rock slope above the river Belca, which is above the forest road Belca Jepca, near the village of Belca. In the autumn of 2014 a rockfall with a volume of between 5,000 and 10,000 m^3 was launched over the forest road. The terrain is rocky with some rockface on distinct slopes. The rock block is made from Upper Triassic rocks: massive dolomite and limestone, strongly tectonized: limited by open cracks. The main area of interest is the independent block between the road and the peak ridge that we call *Main block.* Its volume is estimated to be 150.000 m^3. The most unstable block – *Upper block* – is clearly limited with 0.5-m-wide and 4–6-m deep cracks. The volume is estimated to be 16,000–20,000 m^3. On the side of the main block some significant open cracks determine the *Side block*: 45,000 m^3. The terrain is quite steep. Where there is no rock, the area is covered in a sparse pine forest. There are two distinct screes below the road, up to the valley of Belca, which is the main watercourse.

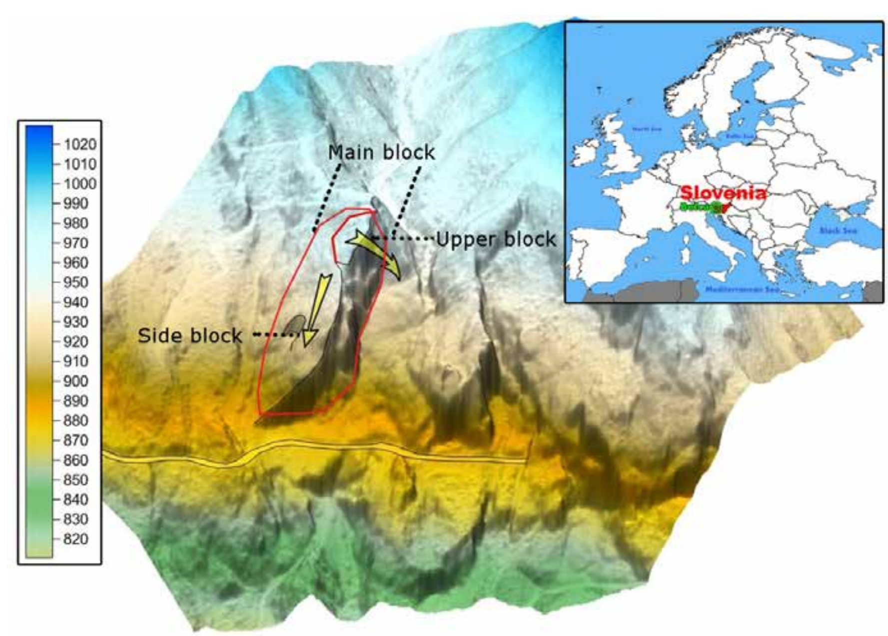

Figure 1. The researched area, view towards the northeast. The construction of the terrain is from lidar data from 2014. Indicated are the main directions of the potential falling and the main fallen blocks of the slope.

After the rockfall in autumn 2014, the area of the road was completely covered by rock to a length of 45–50 m. The waterways of the unnamed stream were also completely ruined.

There were many activities during the redevelopment that provide a safe commute on the forest road:

- Transportability of the road was provided by widening the road. On the wider road rubble and smaller stones can be stopped on the inner part of the road.
- Monitoring during the construction works was also carried out to determine the size of the movement and alert the working crew. With the monitoring, an estimation of the stability of the entire rock block was also achieved.

2 MATERIALS AND METHODS USED

The main methods for monitoring the rock block consisted of:

- Visual monitoring of the rock block;
- Installing and recording the six measuring points on the slope;
- Installing extensometers on the cracks.

We broadened our monitoring based on the knowledge we acquired while constructing the monitoring system and measuring:

- Using an unmanned aircraft,
- Recording the rock block with terrestrial laser scanning.

2.1 Visual observations

The visual observations are based on geological field overviews [19, 20]. Based on these visual observations, we concluded the following:

- The main part of the material has fallen off (and will probably continue to fall off) the upper part, which is limited by clear rupture cracks. This applies to the so-called upper block;
- We mapped the area that fell off in autumn 2014. It is located on the upper block; the volume of the fallen material is estimated to be 5,000–10,000 m^3 (rough estimate).

On the opposite side of the upper block, a larger volume of rock fell off (estimated at 300 m^3) a few years before. Open cracks are clearly visible in this area. We named this area the side block.

Given the incursions of major discontinuities, we decided for two potential ways of material falling: falling of the upper block, or the possibility of another rockfall of the whole block from the ridge to the road. The volume of the entire block was estimated at 150,000 m^3.

The area is very dangerous for the observation at some points of the terrain change. Some areas are also very hard to reach, even with mountain-climbing equipment. There-

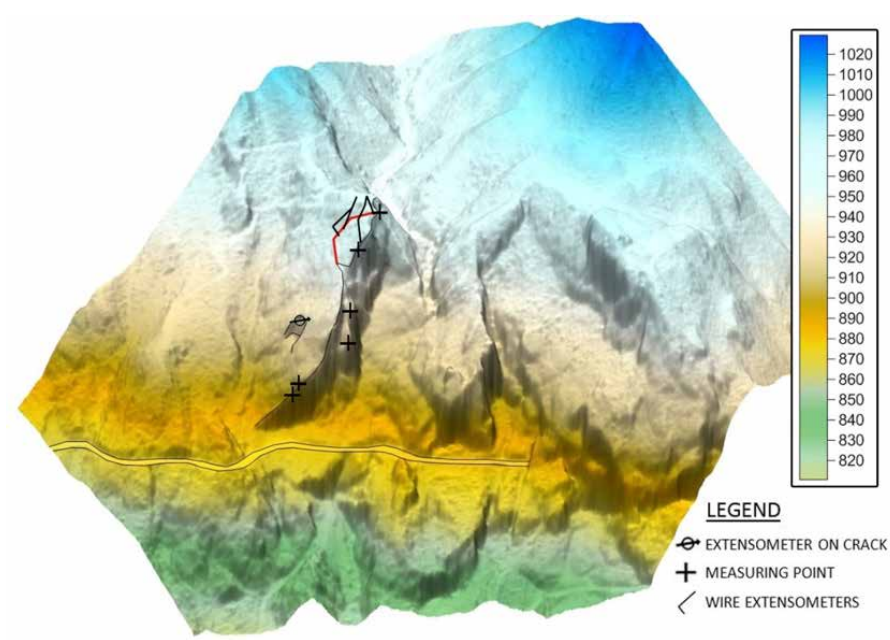

Figure 2. The positions of the extensometers and measuring points in the rock block Belca. The crack that limits the main block is pictured with red.

Figure 3. Left: schematic position of the wire extensometers, based on the upper block and based on the potential direction of movement; Right: a double and triple extensometer.

fore, we used an unmanned aircraft to observe the dangerous and hard-to-reach areas. We captured over 400 aerial photographs. Based on aerial photogrammetry, the aerial photographs were later evaluated. The result is a photo-realistic 3D model of the observed rock block, where the rock block can be viewed from any given perspective. The usability is mainly found in a better spatial orientation of the rock block and in finding a comprehensive image, which makes predicting possible outcomes easier.

2.2 Geotechnical surveying

For the verification and quantification of the absolute movements of the rock block, several measuring techniques were used [21, 22, 23]. We installed geotechnical surveying instruments on the cracks, i.e., wire extensometers. We used tacheometry, which we supplemented with terrestrial laser scanning.

- The widening of the cracks on the main block was measured with five wire extensometers, and a wire extensometer with a clock on the side block,
- The whole rock block was measured at six measuring points, installed at several points on the slope: two points on the upper block, with which we assess the possibility of a rockfall of the side block, and four points, with which the stability of the entire rock block is controlled.

2.2.1 Wire extensometers

Wire extensometers were installed on five characteristic parts of the cracks that limit the upper rock block. They were used to transmit the potential movements on the block. We used invar wires, which largely compensated for the influence of temperature.

The measurements were carried out periodically. The results are shown in the table 1, as well as pictured in Figure 4.

The increased increment in 2017 is clearly visible. If we understand the values that are increasing or declining in a *trend* as values worth using, we can state the following:

- *Triple left* is increasing at a constant rate and reaches a value of 2.7 cm. We can conclude that the north

Table 1. Wire-extensometer measurements.

date	DOUBLE				TRIPLE					
	left	diff. left	right	diff. right	left	diff. left	middle	diff. middle	right	diff. right
19. 11. 2015	245.8		245.8				134.1		131.5	
04. 12. 2015	245.8	0.0	245.8	0.0	134.4	-0.1	134.1	0.0	133.0	1.5
22. 01. 2016	245.7	-0.1	246	0.2	135.0	0.5	133.8	-0.3	130.5	-1.0
10. 06. 2016	244.5	-1.3	245.5	-0.3	136.5	2.0	136.0	1.9	116.8	
13. 10. 2016	243.5	-2.3	245.5	-0.3	137.0	2.5	107.0	-27.1	117.0	0.2
27. 10. 2016	243.5	-2.3	245.5	-0.3	137.0	2.5	106.0	-28.1	117.5	0.7
29. 05. 2017	250.8	5.0	248.0	2.2	137.2	2.7	108.0	-26.1	128.0	11.2

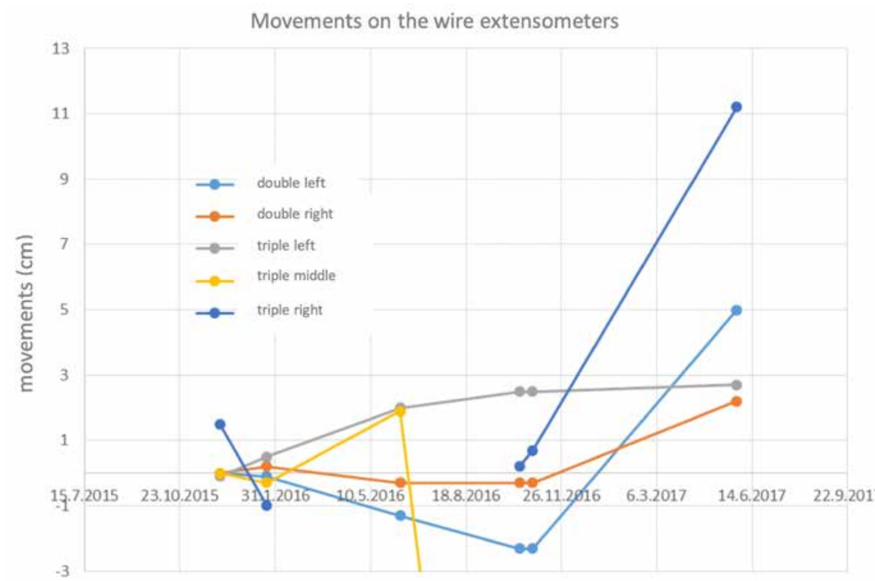

Figure 4. Graph of movements on the wire extensometers.

part of the rock block is moving towards the south at a constant speed.

- *Double left* and *triple right* increased to 5 and 11.2 cm in 2017; therefore, the rock block is moving away from the crack.
- A sudden value change for the extensometer *triple middle* also stands out. The point is directly above a turning point of the slope into a rocky overhang. Therefore, the slope can be so loose that the anchor holding the measuring wire gives way.

An extensometer for measuring the spreading of the larger crack of the rock is placed on the side block (the measuring scale shows movements of up to 65 mm).

The value increased to 5 mm between January and June 2016, after that (between June and November 2016) the value was constant. Between November 2016 and May 2017 the value increased to 11 mm.

2.2.2 Geolocating

We have installed six fixed measuring points using a classic polar method (tacheometry) in the most prominent areas as a part of the observational methods. They were labelled from T1 to T6:

- T1, T2 on the front edge of the rock block; these two points are used to measure the movement of the entire rock block,

Figure 5. Left: view of the extensometer in September 2015; Middle: view of the extensometer in June 2016; Right: view of the extensometer in May 2017. The difference is 11.0 mm. The increase of the value occurred between January and June 2016 (5 mm), as well as between November 2016 and May 2017 (6 mm).

Table 2. Coordinates of points in different epochs.

Measure-ment point	02.09.2015			11.11.2015			28.10.2016		
	X [m]	Y [m]	h [m]	X [m]	Y [m]	h [m]	X [m]	Y [m]	h [m]
T1	416724.048	149131.063	909.662	416724.050	149131.061	909.651	416724.060	149131.057	909.647
T2	416726.666	149133.189	917.702	416726.670	149133.185	917.693	416726.677	149133.175	917.688
T3	416742.017	149171.512	944.830	416742.023	149171.511	944.821	416742.046	149171.508	944.811
T4	416732.672	149181.141	964.918	416732.683	149181.143	964.911	416732.715	149181.150	964.898
T5	416713.598	149207.500	998.636	416713.612	149207.509	998.613	416713.694	149207.539	998.557
T6	416710.956	149234.294	1016.681	416710.978	149234.306	1016.651	416711.081	149234.357	1016.561

- T3, T4 on the side slope, where no distinct movement is expected; they are also used to control the movement of the entire rock block,
- T5 in the middle of the upper rock block; the point is used to monitor the movement of the upper block,
- T6 on the first parts of the upper rock block; this point is used to monitor the movement of parts above the upper block.

Three periodic measurements using a classic polar method (tacheometry) were made in 2015 and 2016. The accuracy of the measurements is 1 cm. The results are shown in the table 2.

2.2.3 Terrestrial laser scanning and airborne laser scanning

The area of the Belca rockfall was scanned with an airborne laser in 2014. This is how, using publicly accessible lidar data through the eVode portal (http://evode.arso.gov.si/), we managed to consider the state of the surface before the rockfall. We managed to do that, because the airborne laser scanning of Slovenia was carried out in the summer of 2014 in that area. We made a digital model of the relief (DMR) with a spatial resolution of 50 cm using the lidar data. Because some details remained hidden (vertical beams of reflection) while scanning and recording from the air (helicopter), we carried out a terrestrial laser scanning of the area from the first measurement on. Doing this we automatically obtained many points from the laser-beam reflections:

- Measurements from 13.7.2015 have 142.4 million points,
- Measurements from 11.11.2015 have 129.1 million points,
- Measurements from 28.10.2016 have 145.5 million points.

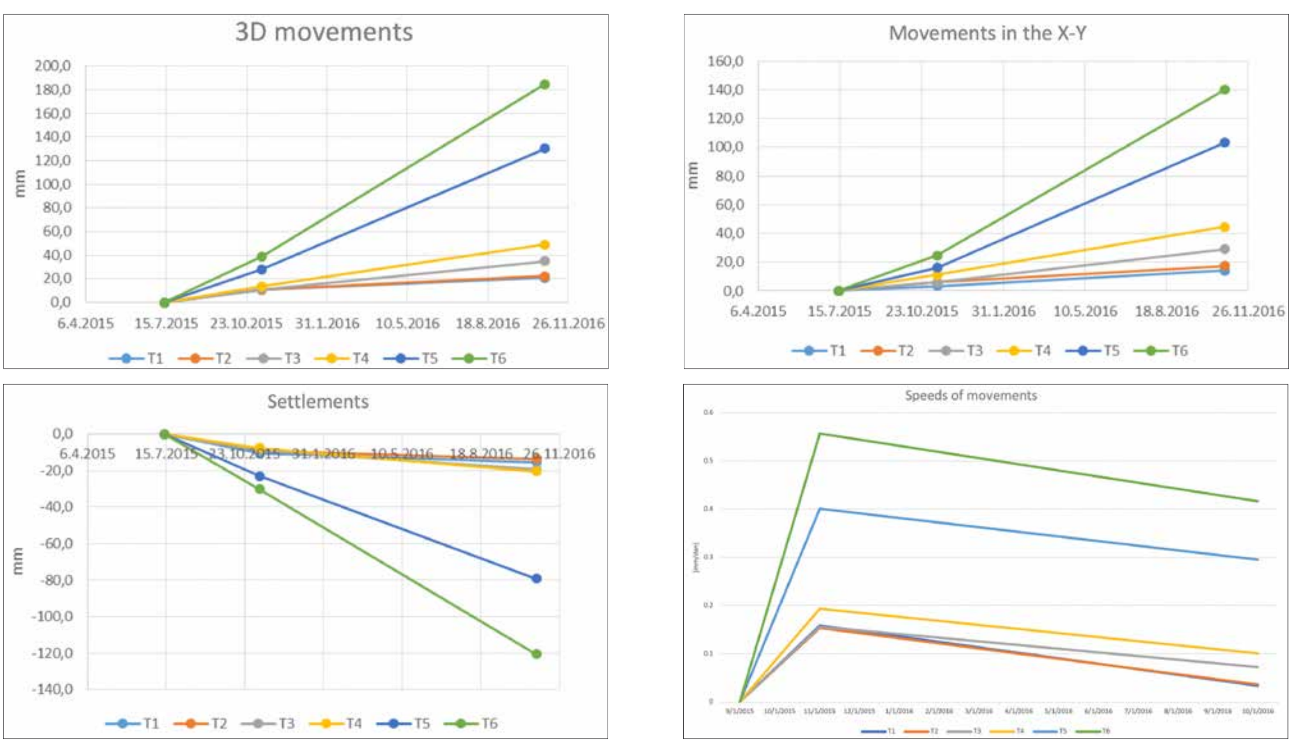

Figure 6. Graphs: size of movements – absolute (top left) and in the X-Y plane (top right); settlements (bottom left) and speeds of movements (bottom right).

The relevant data used in the further implementation is acquired from these points using a variety of software tools. We use these to:

- construct 3D models of the terrain,
- determine the movement by comparing the point clouds of different periods of recording time.

3 RESULTS

3.1 Observation results

Based on two or more periodic measurements of the observations of stabilized measurement points on the rock block with a classic polar method, we determined the size of the spatial movements of the object. Next, based on three or more periodic measurements, we determined the speed of the movements. The analysis of the results is shown in the graphs in Figure 6 (previous page).

The graphs show that the points in the upper part (T5 and T6) clearly stand out while looking at the sizes of the movements. This indicates the intensity and ever-present events on and near the upper rock block. The movement direction clearly shows the possibility of further rockfall around the upper rock block. The values of the other points (T1–T4) also show the movement of the block.

Changes are clearly seen on the upper block and around the lower spree (Figure 8 shows the colour scale going towards red) while comparing the point clouds accumulated with terrestrial laser scanning from 11.11.2015 and 28.8.2016. We attribute the other changes (on the left- and right-hand sides of the figure) to the influence of the vegetation.

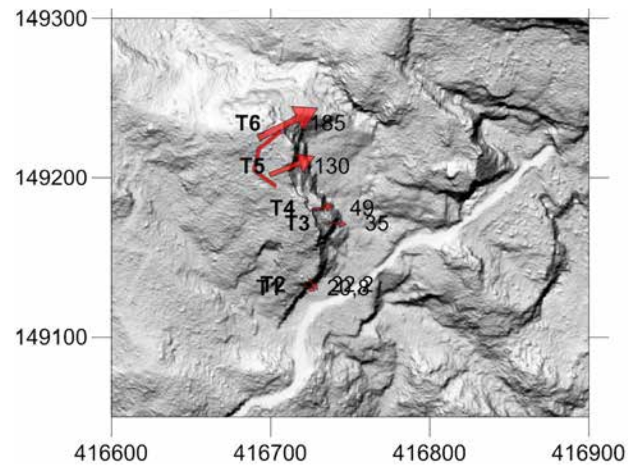

Figure 7. The position and labelling of the measurement points on the rock block. The arrows proportionally show the directions of movement, while the values of the absolute movements between July 2015 and October 2016 are shown on the right-hand side.

3.2 Data analysis of the airborne laser scanning and the terrestrial laser scanning

Airborne laser scanning of the surface was conducted within the LIDAR survey of Slovenia in the summer

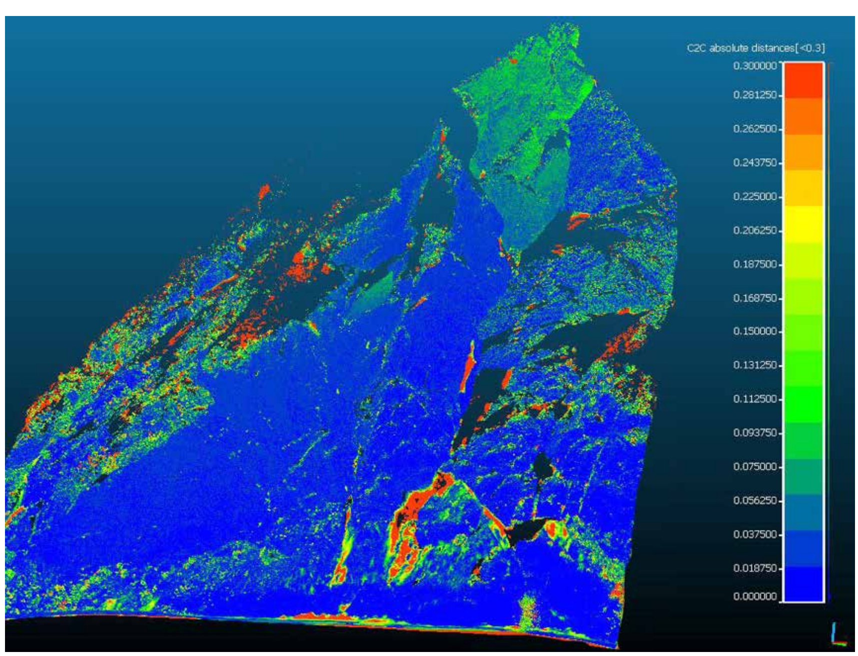

Figure 8. Differences between the terrestrial laser scanning on 11.11.2015 and on 28.8.2016.

of 2014, so a few months before the rockfall in the autumn. This gave us the chance to compare the data from before and after the rockfall. The difference in its surface is visible when comparing the inclination maps (Figure 9).

The biggest fallen block of rock measures approximately 90 m x 20 m in layout dimensions, and is 33 m in height. Based on the 3D analysis of the difference between the surfaces in 2014 and 2015, we have defined the volume of the fallen rock, which measures 6,700 m^3.

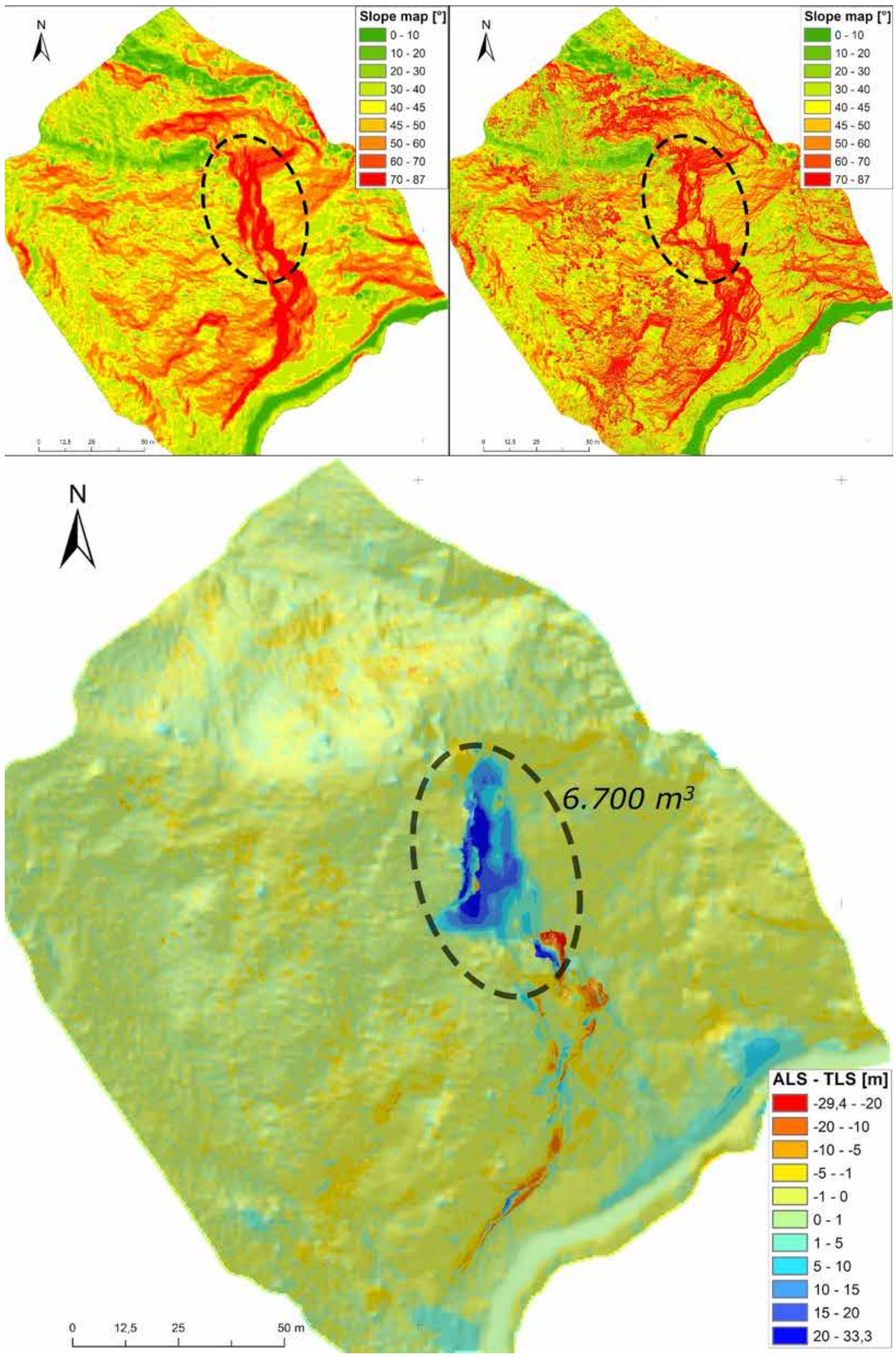

Figure 9. Top left: a relief of the surface, made based on ALS data (summer 2014); Top right: a relief of the surface, made based on TLS data (summer 2015); Bottom: The volume differences.

4 DISCUSSION

4.1 A visualisation of the events and projections into the future

Based on the field survey, measurements and detailed reviews of the measured results, we can conclude that the rock block above the forest road in Belca is still moving. Based on the measurements so far, we can also conclude that the values in the upper block are within 10–20 cm per year.

Often, a graph of the reverse velocity and time values is used to estimate the launching time of a landslide. The launch time is the time when the value of the speed-1 is approaching 0. In the case of all the points from T1 to T6, the values do not asymptotically fall towards the value 0 (Figure 10). However, we must warn of the fact that the upper block is made up of pieces of dolomite, which are clearly separated between themselves with open cracks. Therefore, the falling of free blocks can still occur. Moreover, the conclusions are derived from three series of measurements, which can be a too small number of repetitions for a credible assessment.

In the case of the rock block Belca, we are interested in two things:

- The possibility of more rockfall in the upper block and the consequences of it falling onto the road.
- The possibility of the whole block falling and making its way towards the valley of the river Belca.

4.2 The possibility of rockfall in the upper block and the consequences of rockfall to the road

Smaller rockfall of the slopes and greater filling of the road with the rockfall also occur after repair work. A 10-m road segment is especially at risk. Despite the roadway being wide in this part, the road is also hit with single larger pieces of stones, with dimensions of up to a few decimetres. This area requires constant cleaning of the roadway. Because the area is relatively well shrouded, the potentially dangerous stones can be controlled by a catch fence at the bank above the road.

4.3. Basic and derived measurements

With the basic examination of the terrain, a first picture of the events is made. This picture is then upgraded with new findings and new methods of work: basic recording of data was updated to terrestrial laser scanning, with which we can create a spatial assessment of the fallen block, as well as an assessment of the spatial spreading of the block. The picture of the event was completed by recording with an unmanned aircraft.

5 CONCLUSION

The measurements indicate that the rock block is still in motion, being 10–20 cm/year at the upper part.

We have calculated the volume of the fallen rock (the volume of the rockfall in September 2014) using a 3D deformation analysis of the state of the rock before and after the rockfall.

There is a risk of a rockfall for the whole block of rock in the direction of the river Belca, in the worst case damming the river with the rockfall material. To assess the possibility of the further falling of either parts of the rock block (upper block) or the whole rock block, it is necessary to continue the monitoring process and adapt it per the results.

Figure 10. Projection graph of the reverse speed values.

In the monitoring process, the use of UAV flights is extremely useful in surveying the rock block. The entire block can be reconstructed and hidden details can be clearly visible. Due to a difficult visual surveying approach, which is also very dangerous, the use of UAV can become a standard tool in such operations. The only disadvantage is the low GPS positioning of the device due to the narrow, hilly terrain, which prevents a good signal.

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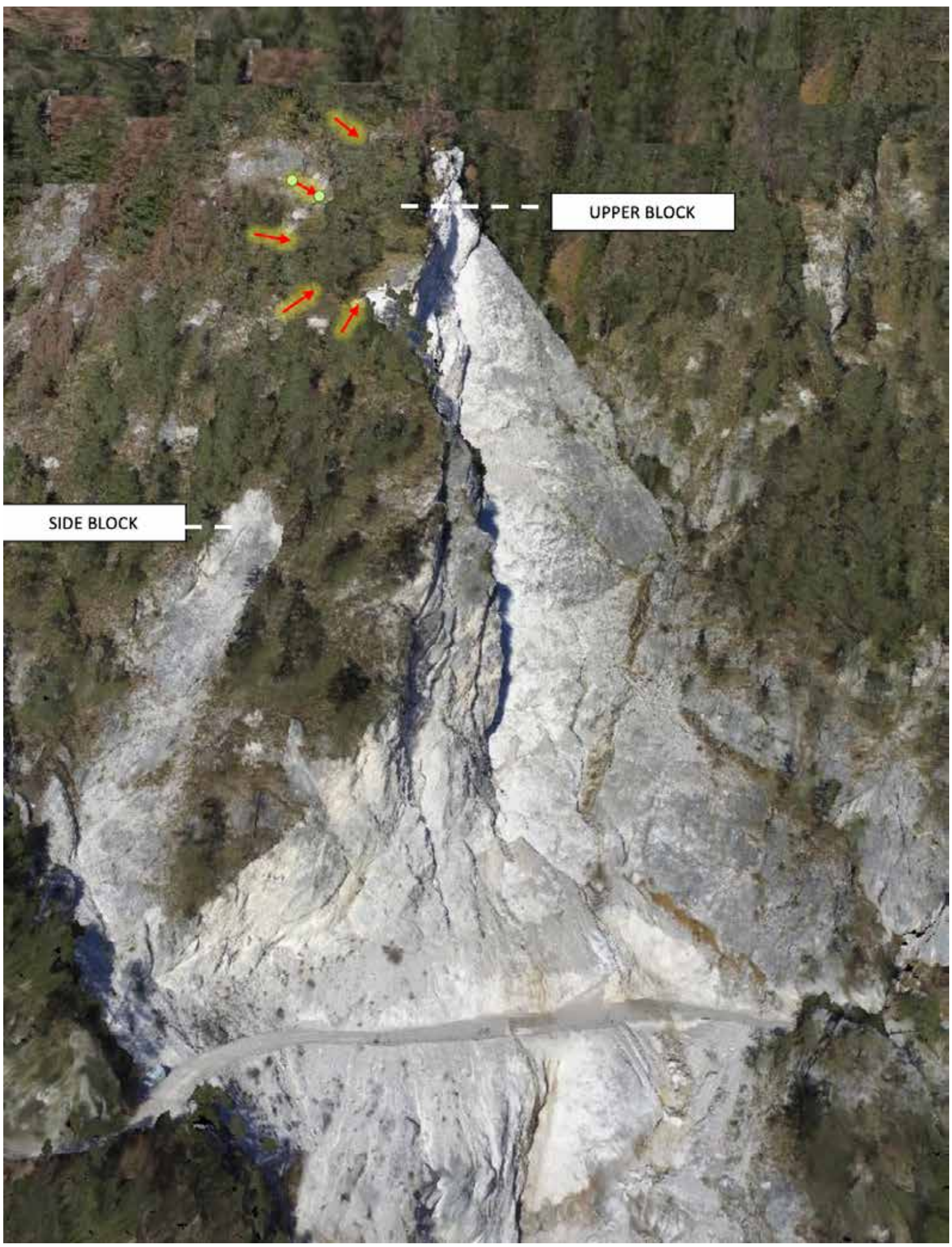


Appendix 1. Frontal view

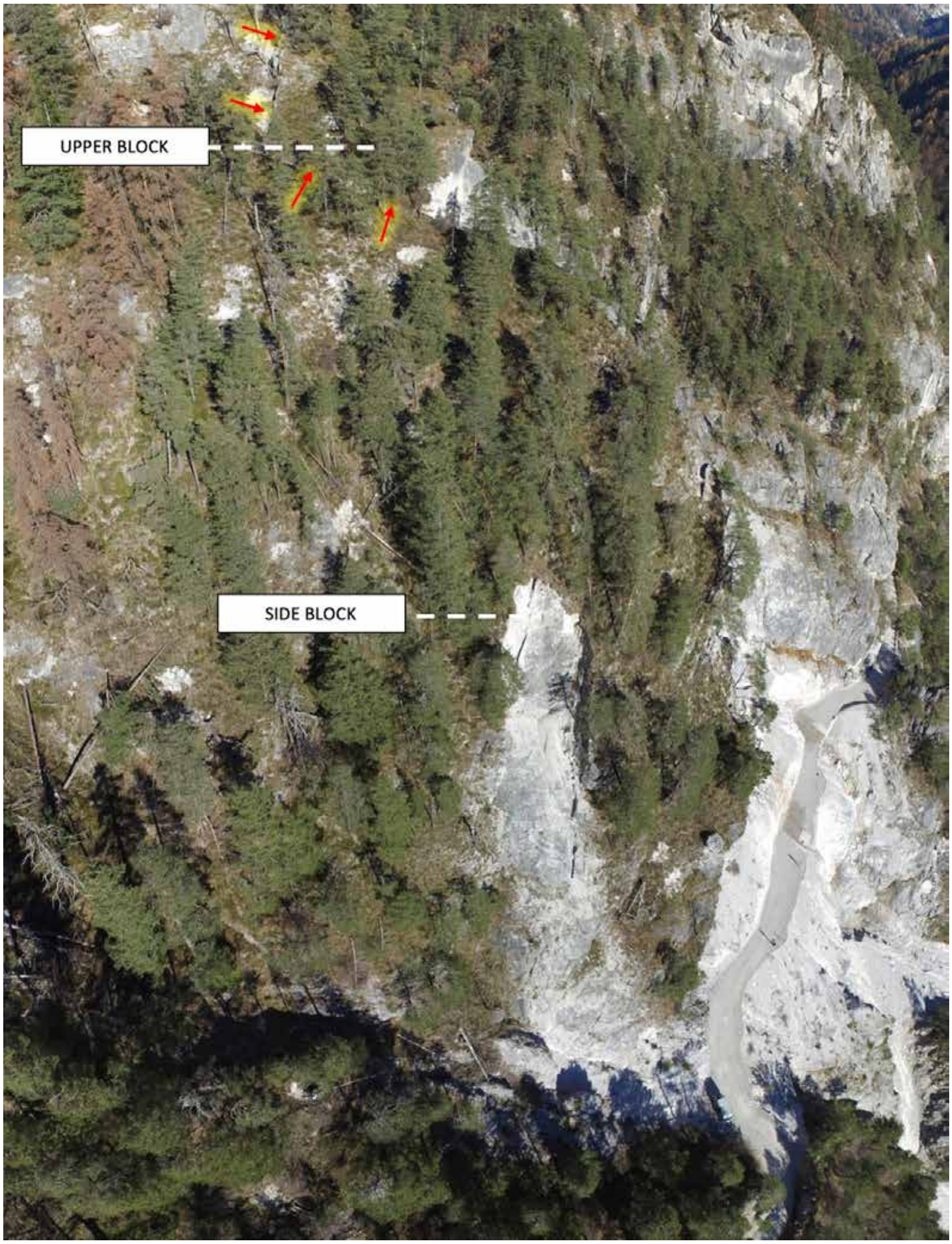
water forecasting system for Republic of Slovenia = Analitičen sistem napovedovanja pretokov površinskih vod v Republiki Sloveniji. RMZ - Materials and geoenvironment 55, 2, 215-224.

[23] Božiček, B., Lojen, S., Dolenec, M., Vižintin, G. 2017. Impacts of deep groundwater monitoring wells on the management of deep geothermal Pre-Neogene aquifers in the Mura-Zala Basin, Northeastern Slovenia. Groundwater for sustainable development 5, 193-205.

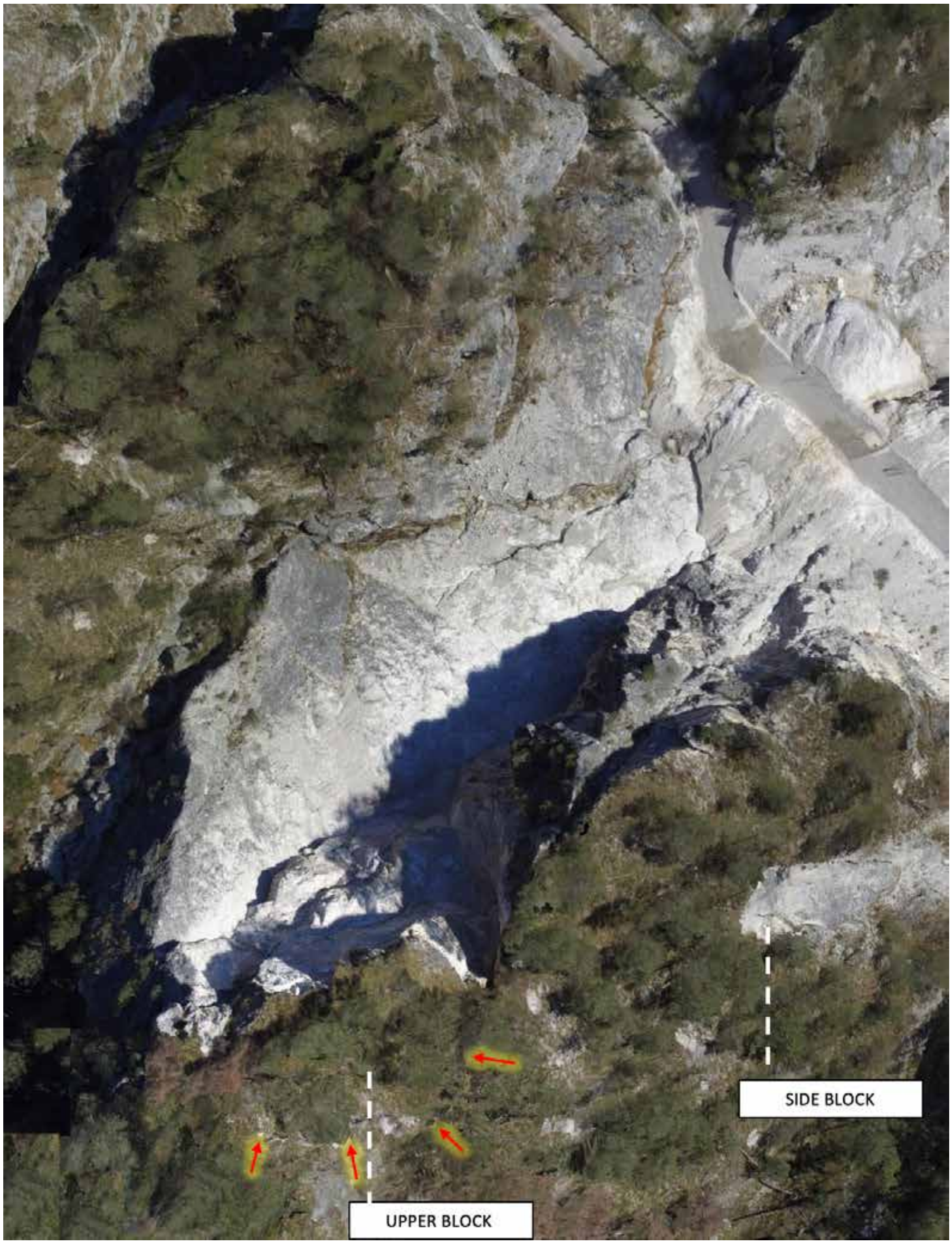
APPENDICES

- Frontal view
- View towards the east
- View towards the west
- Top view

Appendix 2. View towards the east



Appendix 3. View towards the west



Appendix 4. Top view