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PERMANENT GNSS MONITORING OF LANDSLIDE UMKA

Abstract:

The Umka landslide is one of the biggest inhabited active landslides in Serbia. The Umka landslide activity has been monitored for a period longer than 85 years, by various geotechnical and geodetic techniques. Since 2010, landslide activity has been continuously monitored by automated permanent Global Navigation Satellite System (GNSS) based monitoring system in real time. Furthermore, since 2018 landslide activity has been monitored by GNSS kinematic positioning of a set of characteristic points as well as by UAV (Unmanned Aerial Vehicle) photogrammetry. The main issue of this paper is the presentation of the results gained with GNSS kinematic positioning of characteristic points of Umka landslide within three observation epochs.

Keywords: landslide, permanent monitoring, GNSS

ПЕРМАНЕНТНО ПРАЋЕЊЕ КЛИЗИШТА УМКА

Сажетак:

Клизиште Умка је једно од највећих насељених активних клизишта у Србији. Активност клизишта Умка се прати већ више од 85 година, различитим геотехничким и геодетским техникама. Од 2010. године, активност клизишта се континуирано прати у реалном времену аутоматизованим перманентним системом за праћење базираним на Глобалним навигационим сателитским системима (ГНСС). Поред тога, од 2018. године активност клизишта се додатно прати кинематичким ГНСС одређивањем положаја скупа карактеристичних тачака као и применом UAV фотограметрије. Главни циљ овог рада је приказ резултата опажања три мерне епохе добијених ГНСС кинематичким позиционирањем карактеристичних тачака клизишта Умка.

Кључне ријечи: клизиште, перманентно праћење, ГНСС

1. INTRODUCTION

Over the past two decades, driven by the development of geodetic instruments for data acquisition and technology for data processing in real time, a wide range of different types of complex monitoring automated systems found its use in various engineering disciplines. The Global Navigation Satellite System (GNSS) based monitoring system is one of the widely used systems, used in order to assess the dynamics of the landslide phenomenon and potentially prevent possible disasters [1-5].

Considering the importance of the Umka urban area permanent monitoring, automated GNSS monitoring system was established in March 2010. This was a part of the technological development project “The application of GNSS and LIDAR technology for infrastructure facilities and terrain stability monitoring“, financed by Ministry of Education, Science and Technological Development of the Republic of Serbia, and the collaboration between University of Belgrade, Faculty of Mining and Geology and Faculty of Civil Engineering, Institute of Transportation CIP, The Highway Institute and company Vekom. The detailed descriptions of the technical part and the main characteristics of the established automated GNSS monitoring system can be find in Erić et al. [6].

Generally, the Umka monitoring system consists of GNSS network and supporting software solutions. The first part of the system, the network, consists of several reference points and one object (monitoring) point on which GNSS stations (sensors) are mounted. The object point is located on the landslide body, mounted on the house roof. Reference points are located outside the landslide area and they are the integral part of the Active Geodetic Reference Network of Serbia (AGROS), which is a permanent GNSS service for accurate satellite positioning over the Republic of Serbia territory. The second part of the system are the two Leica Geosystems software solutions: GNSS Spider and GeoMoS (Geodetic Monitoring System), used in order to monitor the dynamics of landslide in real time, with observation rate of 30 seconds.

The observed GNSS monitoring results, as well as the correlations between precipitation and Sava river level with landslide dynamics were presented in numerous publications [5-9]. Despite the numerous interruptions over the period of almost ten years of permanent monitoring (which are expectable due to the system complexity), the dynamic of Umka landslide is successfully determined and analyzed through time [1].

The main shortcoming of the system is already discussed in previous publications and it concerns only one observed object point. Consequently, in order to further analyze the Umka landslide dynamic, in March 2018, a passive GNSS network consisting of four stable points surrounding landslide area is realized. The landslide area is discretised by 62 properly stabilized characteristic points. Between March 2018 and April 2019, three observation epochs were completed: Epoch 0 - at the end of March 2018, Epoch 1- in late November 2018 and Epoch 3 - in early April 2019. At the same time during the Epoch 1 and Epoch 2, two UAV (Unmanned Aerial Vehicle) photogrammetry epochs were executed as well, but the results are not presented within this paper.

Apart from the geodetic survey method, the dynamic of landslide Umka is investigated by various geotechnical techniques [10]. However, the primary focus of this paper is the presentation of the results derived by GNSS kinematic positioning of characteristic points of Umka landslide during three measuring epochs.

2. LANDSLIDE UMKA

Umka is a suburban settlement in the municipality of Čukarica in the city of Belgrade, the capital of Serbia. According to the 2011 census report, there were 5270 inhabitants, 1709 households with the average number of members per household of 3.08 [11]. Landslide Umka is formed on the right Sava river bank It occupies part of Umka settlement and represents one of the largest inhabited active landslides in Serbia (Figure 1.). Despite the fact that the landslide is active and has been threatening people's lives for decades, more than 490 inhabitants are still living on the body of landslide [10]. Furthermore, the state road M26 (from Belgrade to the border with the Federation of Bosnia and Herzegovina) is also affected by Umka landslide. More specifically, 1.7 km of this state road is crossing the landslide body. According to the available data regarding the traffic volume [12] average annual daily traffic across the landslide body for the year 2018 is 13970 vehicles per day and is showing increasing trend. Considering the possible disasters, the Umka landslide is one of the most investigated landslides in Serbia. It is systematically and continuously monitored by different geotechnical and geodetic techniques for decades.

According to geotechnical investigations at 2005 by the Highway Institute, Umka landslide surface is 0.83 km^2, with maximum length of cca. 1.66 km, maximum width of cca. 0.88 km and maximum depth of slip surface of 26 m [1]. The derived results of geotechnical investigations of the Umka landslide were published by many authors and some of them are Vujanić et. al. [13,14], Ćorić et. al. [15], Jelisavac et. al. [16]. In addition to geotechnical investigations, the dynamics of Umka landslide was investigated by various geodetic survey techniques, among which are aero photogrammetry [17], UAV photogrammetry [10] and automated permanent GNSS monitoring [1, 5-9].

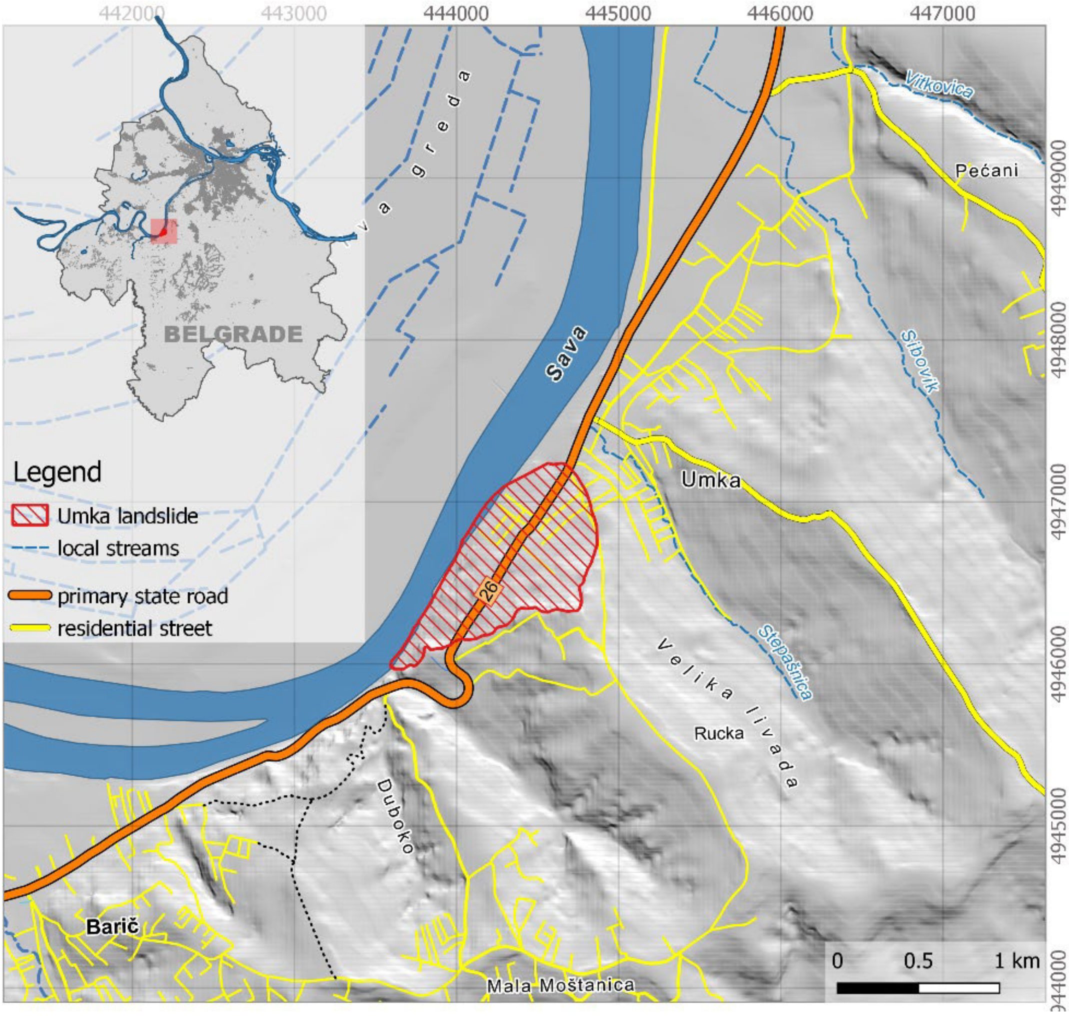

Figure 1. *Location of Umka landslide.*

3. GNSS MONITORING OF UMKA LANDSLIDE

For the purpose of Umka landslide monitoring, different geodetic procedures were applied during last 10 years:

1. Automated permanent monitoring of the position change for a single permanent GNSS station in the landslide area in relation to the three-surrounding stable GNSS permanent stations of the national GNSS service, AGROS;
2. Monitoring of the position change for the set of characteristic points on the landslide area, in relation to the set of stable points surrounding the landslide area, using GNSS kinematic positioning, in the selected time moments (measuring epochs);
3. Comparison of a digital terrain models, created form UAV photogrammetry in the GNSS kinematics positioning epochs.

Considering that the main issue of this paper is the presentation of the results gained with GNSS kinematic positioning of characteristic points of Umka landslide, the second procedure, as well as the obtained results, will be explained in *more detail further* below. In order to compare the displacements obtained from two applied GNSS techniques, for the first procedure (automated GNSS monitoring), only a brief overview will be given *further* below as well. The third procedure will not be discussed within this paper.

3.1. Automated gnss monitoring

As already explained in section Introduction, in March 2010 automated GNSS monitoring system was established on Umka landslide. Despite the numerous interruptions over the period of almost ten years of permanent monitoring, the system was successfully used in order to track the dynamics of Umka landslide in real time. In general, the derived data of automated monitoring are analyzed for two time periods separately, due to the relocation of the object point on December 2013 [1]. The first time period from the beginning of the monitoring, March 2010, to the December 2013; and the second time period from the September 2014 to the date (Figure 2.).

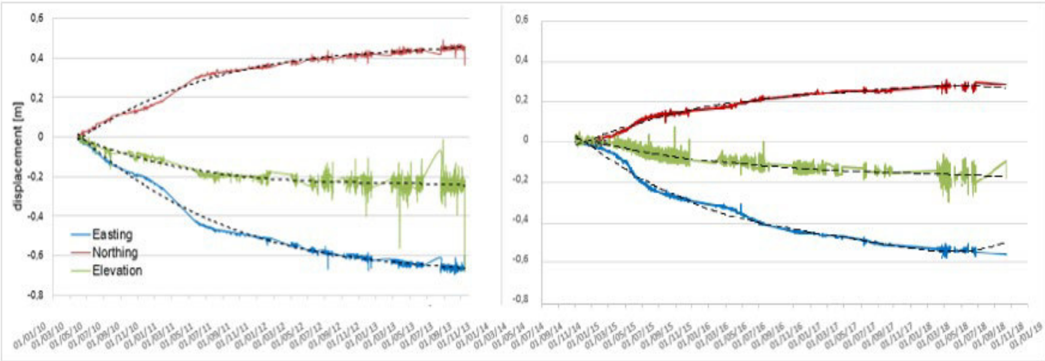

Figure 2. *Displacement of object point from March 2010 to December 2013 (left figure) and from September 2014 to end of December 2018 (right figure), for 12h interval.*

During the first time period (Figure 2. and Table 1.) the total 2D displacement was 84 cm towards the northwest. Furthermore, during the same period, the vertical displacement was nearly -30 cm. During the second time period (Figure 2.) the object point has moved 63 cm towards the northwest and the vertical displacement was nearly -16 cm. Generally, both graphics indicate that the Umka landslide is moving continuously and significantly towards the northwest, i.e. towards the Sava river. The average annual 2D displacement was approximately 22 cm and 15 cm, for first and second time period, respectively, with the same direction of movement. Considering the dynamic of the movement, Umka landslide can be characterized as slow to very slow [9].

Table 1. *Cumulative displacement of object points from March 2010 to December 2013 and from September 2014 to end of December 2018*

Time period	ΔE [m]	ΔN [m]	D [m]	ν (°)	Δh [m]
March 2010-December 2013	-0.67	0.45	0.80	304	-0.22
September 2014 -December 2018	-0.56	0.29	0.63	297	-0.16

3.2. GNSS monitoring by characteristic set of points

As already emphasized, the main shortcoming of the automated GNSS monitoring system used is only one observed object point. Therefore, in order to further analyze the Umka landslide dynamics, a passive GNSS network consisting of four stable points was established at the end of March 2018. Stable points were positioned out of landslide body (Figure 3.). Three stable points (S1, S3 and S4) are located on right bank of the Sava river, and point S2 is located on left bank of the Sava river. Point S1 is stabilized using steel benchmark in asphalt, point S2 is stabilized using massive wooden stake (in loose terrain, embankment), existing stabilization of official state traverse network (P771) was used for point S3, while for point S4 existing trigonometric stone benchmark (1/P16) was used. All stable points were used as a base points for relative kinematic GNSS positioning with post-processing. In addition, the S4 had the additional purpose as a base for real-time kinematic positioning.

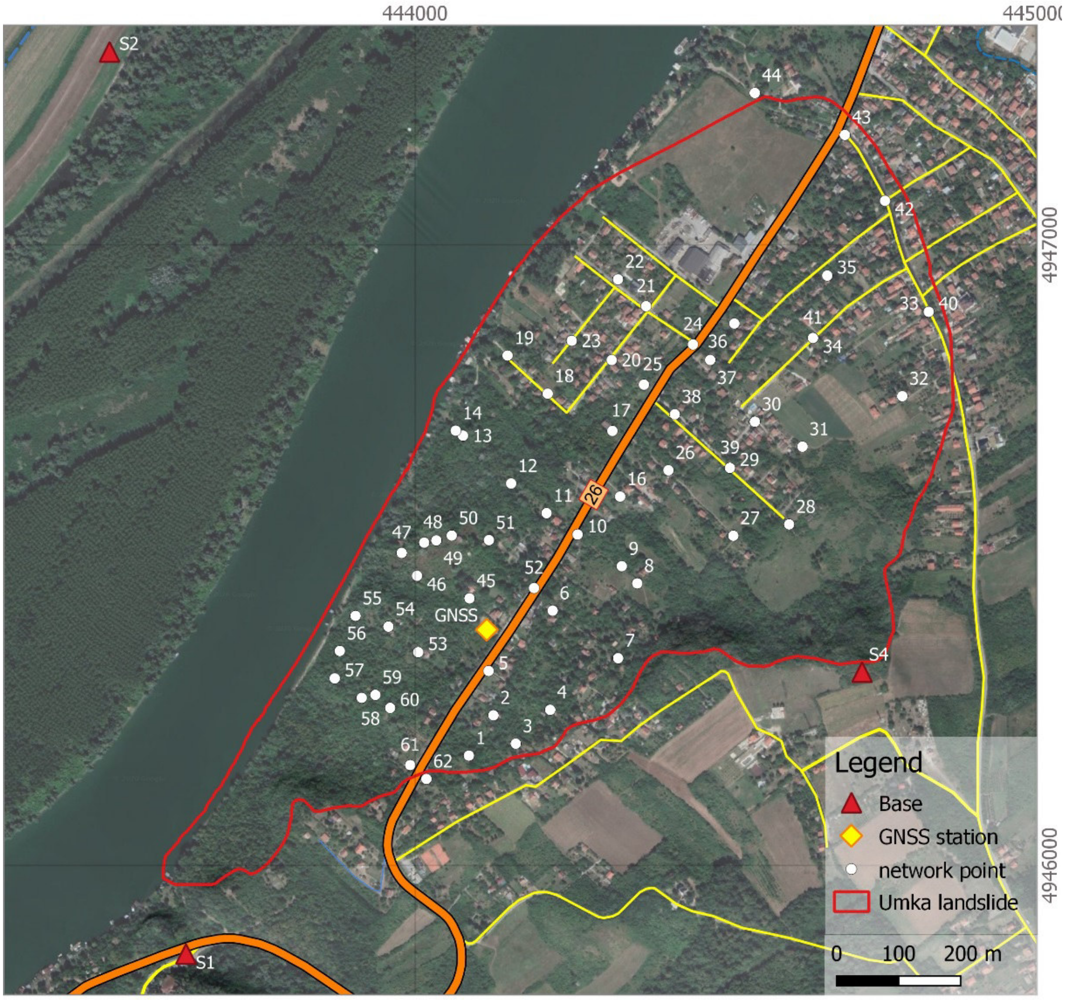

Figure 3. *Position of passive GNSS network points and 62 characteristic points of Umka landslide.*

In order to monitor the Umka landslide using geodetic methods, 62 points were established on the landslide body (Figure 3). Landslide points are stabilized using steel benchmarks in asphalt, wooden stakes in loose terrain or carved crosses in concrete. Point locations were selected ensuring that the points are homogeneously distributed over the area of activity (as much as the field conditions allow), the points are permanently stabilized without the possibility of easily falling out of bed or moving, and there is a good open sky visibility. Together with the stabilization of 62 landslide points, 20 orientation points for UAV photogrammetric imaging were also stabilized in a convenient arrangement, on locations visible from the air and photo-signalized by colored circles, about 20 cm in diameter.

Initial, zero observation epoch was made immediately upon the stabilization of landslide points, at the end of March 2018. After the Epoch 0, two more series of observations were made: Epoch 1 in late November 2018 and Epoch 2 in early April 2019. The months of April and November were chosen because of the reduced vegetation and landslide dynamics, which largely depend on the Sava river level and groundwater levels in the landslide body. For each epoch, after the four base points are proven to be stable since the Epoch 0, landslide point positions were determined by post-processing of kinematic GNSS observations with respect to all four stable (base) points, with each landslide point determined twice (two data collections, each with 30 epochs with a 1 second interval of observation). Comparisons and averaging were made between multiple solutions for a single landslide point position. More specifically, the final landslide points coordinates (E, N, h) were estimated by calculating the arithmetic mean for all four kinematic GPS / GLONASS solutions, with experimental standard deviation $\sigma_E = 3$ mm, $\sigma_N = 4$ mm, $\sigma_h = 11$ mm, for all three epochs. The real-time kinematic solutions from the base station S4 were intended to assure that postprocesed kinematic solution exists. After obtaining the coordinates for each landslide point in an individual epoch, the displacements (ΔE, ΔN, Δh) between Epoch 0 and Epoch 1 and between Epoch 0 and

Epoch 2 were calculated. Subsequently, the magnitude of the displacement vector and the azimuth of its direction were calculated and thus the relevant kinematics data for each point in two epochs were obtained (Figure 4.).

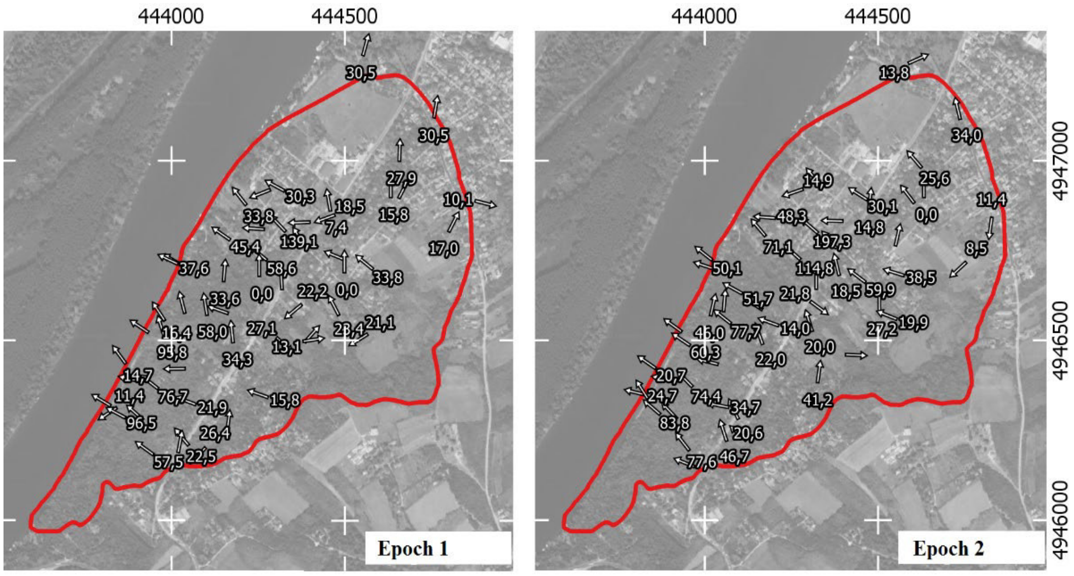

Figure 4. *Vectors of displacement of landslides Umka points from April 2018-November 2018 - Epoch 1 (left figure) and from April 2018 to April 2019 - Epoch 2 (right figure).*

For seven landslide points (6, 15, 19, 34, 40, 43 and 49) presented on Figure 3. there was no solution in any observation epoch, or they have been destroyed. One point (39) had no solution after the first observation epoch, while the three points (29, 41 and 59) had no solution after the second observation epoch. Based on the results presented on Figure 4, it can be concluded that the majority of obtained displacement azimuths are in the expected zone for the Umka landslide (270 °-360 °). As indicated by the results of automated GNSS monitoring system, the landslide body moves toward the Sava river. Due to the large number of characteristic points, only points with horizontal displacements (D) larger than 6 cm, during the time period from April 2018 to April 2019 are presented in Table 2. During the time period from April 2018 to November 2018 the horizontal displacements ranged from 0 cm to 13.9 cm, while the maximum vertical displacement was -23.4 cm. During the time period from April 2018 to April 2019, the horizontal displacements ranged from 0 cm to 19.7 cm, and the maximum vertical displacement was -30.1 cm.

Table 2. *Displacement of characteristic landslide points from April 2018 to November 2018 and from April 2018 to April 2019*

Point	April 2018 to November 2018				April 2018 to April 2019			
	ΔE [mm]	ΔN [mm]	D [mm]	Δh [mm]	ΔE [mm]	ΔN [mm]	D [mm]	Δh [mm]
4	-46,3	-46,8	65,8	**-234**	-72,0	-39,3	82,0	**-301**
13	-33,8	18,9	38,7	-65	-57,8	18,1	60,6	-87
17	-46,0	36,3	58,6	-53	-86,7	75,3	114,8	-116
18	-37,8	25,3	45,4	-39	-47,1	53,3	71,1	-98
25	**-97,7**	**99,0**	**139,1**	-83	**-151,3**	**126,6**	**197,3**	-128
38	-33,2	50,2	60,2	-44	-49,2	55,2	73,9	-78
45	-64,4	-0,9	64,4	-66	-74,4	18,1	76,6	-106
46	-30,4	90,8	95,8	-52	-50,7	32,8	60,3	-120
51	-9,7	57,2	58,0	-21	-61,6	47,4	77,7	-86

53	-61,4	45,9	76,7	-85	-53,3	51,9	74,4	-115
58	-85,8	44,2	96,5	-67	-64,5	53,5	83,8	-110
60	-57,5	49,9	76,1	24	-72,3	73,3	103,0	-99
61	-47,3	32,8	57,5	-49	-48,4	60,6	77,6	-130

The horizontal displacements of approximately 21% of all points ranged from 0 to 2 cm, 33% ranged from 2.01 to 4 cm, 23% from 4.01 to 6 cm, and 33% larger than 6 cm. The largest horizontal displacements were noted in the zone along the road M26 and right below it towards the Sava river, for both epochs.

4. CONCLUSION

During last ten years, in order to monitor Umka landslide three different procedures were applied: automated GNSS monitoring system, GNSS monitoring of characteristic landslide points and UAV photogrammetry. Established automated GNSS monitoring system of Umka landslide in March 2010 represents a huge step forward in monitoring landslides in Serbia. Period of almost ten years of continual monitoring is priceless regarding the real-time analysis of dynamics of Umka landslide.

In order to overcome the shortcoming of the established GNSS monitoring system and to analyze the Umka landslide dynamic in more detail, in March 2018, a passive GNSS network of four stable points and of 62 characteristic landslide points were further designed and realized. Up to this time, three observation epochs were completed with the aim of three-dimensional positioning of characteristic landslide points.

The data obtained using this methodology represent very reliable monitoring results with a high density of points from which it is possible to perform more detailed analysis for the entire landslide area. Precision of the observations and the processing results is higher for the horizontal displacements (5 mm) than the vertical (11 mm) and is conditioned by GNSS positioning characteristics, ie the fact that GNSS positioning precision is more than two times lower in height than horizontal position.

Considering the dynamics of the movement, derived from automated permanent GNSS monitoring system, Umka landslide can be characterized as slow to very slow. Therefore, obtained precision of displacement exceeds the required one of 2 cm. The main disadvantage of this methodology is repeatability. An observation epoch requires greater manpower engaged on the field and minimum five geodetic class GNSS receivers, which represents financial, logistical and often technical challenge. After the analysis of the dynamics of the Umka landslide, it is concluded that the third observation epoch should be realized in April 2020.

In general, each of these applied procedures, automated GNSS monitoring, GNSS monitoring of characteristic landslide points and UAV photogrammetry, has an important role in designing of the technology for landslide activity monitoring and results interpretation. The usage of the single permanent GNSS station provides information on landslide activity at any time moment and defines the spacing between the measuring epochs for the other procedures. GNSS kinematic positioning provides precise information about the values of movements in the representative set of discreet landslide points. The role of UAV photogrammetry is to obtain continuous information for the entire landslide territory in order to choose the density and spatial layout of a set of characteristic points.

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