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Advances in Landslide Research

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Automated GNSS monitoring of Umka landslide – review of seven years' experience and results

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Abstract The Umka landslide is the biggest and deepest active landslide in the Republic of Serbia, and has been investigated and monitored using various geotechnical techniques for decades. This paper focuses on the results and experience gained using the automated Global Navigation Satellite System (GNSS) monitoring network of the Umka landslide introduced in March 2010. It remains the longest continuous period of any landslide monitoring in Serbia; however, many operational and maintenance problems were addressed over seven years of monitoring. The main problems were related to the GNSS network's functional operation, such as the replacement of the reference station position and the relocation of the object point station to a different location. The shape of the GNSS network was changed as the result of replacing the reference stations which was implemented by the Republic Geodetic Authority (RGA) in 2011. The GNSS sensor (object point) placed in the landslide body also had to be relocated after December 2013 for technical reasons and was moved to a nearby location after in May 2014. Precipitation data on the Belgrade Main Meteorological Station (MMS) and the level of the Sava River from a Beljin water level station was continuously collected throughout the entire period on a daily basis. The results and experience gained through the automated GNSS monitoring of the Umka landslide over the past seven years will be presented and discussed.

Keywords landslide, GNSS, automated, permanent monitoring

Introduction

The development of geodetic instruments for data acquisition and technology for data processing in real time has encouraged and increased the use of complex automated monitoring systems across an array of engineering disciplines. Consequently, over the past decade a wide range of different types of landslide monitoring systems have been used in an attempt to assess the dynamics of landslides and potentially prevent possible disasters. One widely used system, which has proven to be an effective and reliable tool for landslide monitoring, is the Global Navigation Satellite System (GNSS). In 2000 Gili et al. (2000) provided a general overview of the Global Positioning System (GPS) principles and discussed its applicability to landslide monitoring of the Vallcebre landslide in Spain. Since then, many research papers have presented successful landslide monitoring using GNSS and the integration of such with other observations (gained using other geodetic instruments like totally automated stations and laser scanners) from around the world (Coe et al. 2003, Malet et al. 2002, Zhou et al. 2005, Castagnetti et al. 2013).

According to the European Joint Research Centre's Institute for Environment and Sustainability (JRC-IES) the largest part of the Balkan Peninsula lies in the high to very high class of landslide susceptibility (Erić et al. 2015). Due to climate change and expected increasingly heavy rains, which are one of the main triggers that activate landslides, several countries in the Balkan region have established landslide monitoring systems in order to provide early warning system and prevent possible disasters. The Republic of Croatia, within the Japanese-Croatia five-year (2009–2014) project, designed GNSS- based real time monitoring systems on the two largest landslides in the country – Kostanjek (Krkač et al. 2014, Krkač et al. 2017) and Grohovo (Arbanas et al. 2012, Arbanas et al. 2014).

The first automated GNSS monitoring project in Serbia was established in March 2010, on the Umka landslide (near Belgrade), the biggest active landslide in Serbia (Abolmasov et al. 2013). This seven-year project represents the longest continuous monitoring of any landslide in Serbia and probably one of the longest-running in the Balkan region. The objectives of this paper are to present the results and some of the main issues of the automated GNSS monitoring system used at the Umka landslide. In view of the high correlation between the movement of the landslide with precipitation and the proximity of the Sava River, two additional data sets were analysed: precipitation data from Belgrade (MMS) and data on the level of the Sava river from a Beljin station, which were collected throughout the entire period (2010–2017), on a daily basis (Fig. 1).

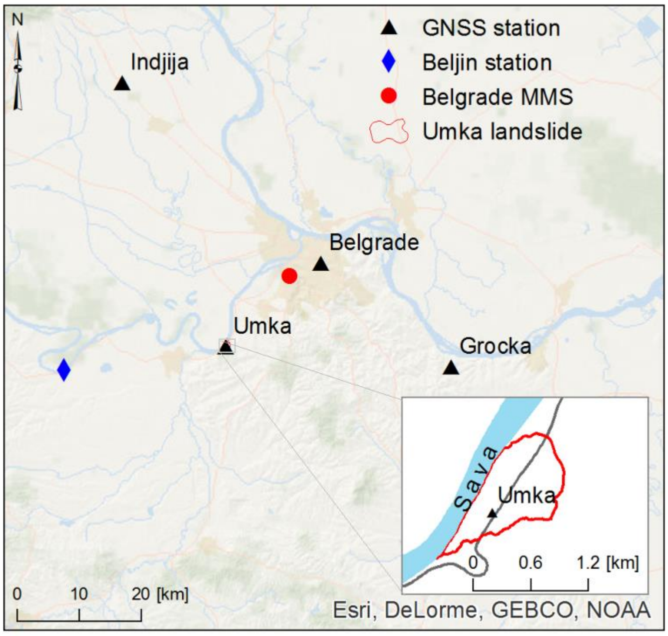

Figure 1 Locations of GNSS stations, Belgrade MMS, Beljin water level station and Umka landslide area.

Study area – Umka landslide

The Umka landslide represents one of the largest inhabited landslides in Serbia. The landslide is formed on the right bank of the Sava river, 22 km southwest of Belgrade, and comprises part of the suburban Belgrade settlement of Umka. Mali Zvornik, part of the important state road IB26, Belgrade crosses the landslide body (1.7 km) (Fig. 1). According to the available data for annual traffic volumes (http://www.putevi-srbije.rs) an average of 13,000 vehicles crossed the landslide body daily in 2016. According to geotechnical investigations performed in 2005 by the Highway Institute – Belgrade (the last phase of investigations for the Preliminary Design of the E-763 motorway) the landslide surface is 0.83 km^2, with a maximum length of cca. 1.66 km, and a maximum width of cca. 0.88 km, with a maximum slip surface depth of 26 m.

The results of these extensive geotechnical investigations of the Umka landslide were published in Vujanić et al. (1981, 1984), Ćorić et al. (1994, 1996). Dangić et al. (1997), Hadžiniković (1988). Results of the conventional geotechnical monitoring of the landslide can be found in Jelisavac (1995), Jelisavac et al. (2006). A recent summary of GNSS monitoring results was published (Abolmasov et al. 2012b and Erić et al. 2015) and overview of landslide geotechnical modeling was presented in Jelisavac et al. 2006, Đurić et al. 2011, Đurić 2011 and Abolmasov et al. 2014a, Abolmasov et al. 2015. Reports on the IPL-ICL project related to the Umka landslide can be found in Abolmasov et al. 2014b, 2017 as a part of IPL 181 Project results.

Automated GNSS monitoring system

The main characteristics of the system

The Umka monitoring system consists of a GNSS network and supporting software solutions. Generally, the network consists of reference and object (monitoring) points on which GNSS stations (sensors) are mounted. Highly precise, multi-channel, multi-frequency systems (receivers and antennas) are used on all network points (Abolmasov et al. 2012b, Abolmasov et al. 2014b). During the seven years of ongoing monitoring the GNSS network has changed twice, but the concept has remained the same. The reference points used comprise an integral part of the Active Geodetic Reference Network of Serbia (AGROS network), which is a permanent GNSS service providing accurate data on satellite positioning over the Republic of Serbia territory. All reference points used are located outside the landslide area, and their movements are not significant over time (Erić et al. 2015). The Umka landslide area is represented by a single object point, which is located in the landslide body on the roof of a house there (Abolmasov et al. 2011, Abolmasov et al. 2012b).

The second essential part of the automated GNSS monitoring system is the supporting software solution. The system used two Leica Geosystems software solutions in order to continuously monitor the dynamics of the Umka landslide, remotely control and communicate with other GNSS stations, store, evaluate and post-process collected data and perform analysis: GNSS Spider and GeoMoS (Geodetic Monitoring System), which was further comprised of two main applications: GeoMoS Monitor and GeoMoS Analyzer. All observed GNSS measurements, with an observation rate of 30 s, are collected by the GNSS Spider and forwarded, in the form of RINEX files, to the GeoMoS Monitor and GeoMoS Analyzer for processing and further analysis, respectively. Detailed descriptions of the system can be found in Erić et al. (2015).

Changes and some of the main issues of system

During the more than seven years of continuous monitoring of the Umka landslide two major changes occurred in the system, together with various technical problems that caused operational problems.

Firstly, the system underwent two main changes. Initially, the GNSS monitoring network consisted of three GNSS points: two reference points, Belgrade and Lazarevac, which are included in the AGROS network, and the Umka point that is placed in the Umka landslide area (Fig. 2). In June 2011, the Republic Geodetic Authority (RGA) made changes on the AGROS network and excluded the permanent station Lazarevac (Abolmasov et al. 2014). In response, a new GNSS monitoring network was established in December 2011, consisting of the initial reference point Belgrade and the Umka point, and the two new reference points – Indjija and Grocka – both of which were also included in the AGROS network. Given that the observations from the Indjija and Grocka reference points were not logged prior to the detection of RGA changes, i.e. December 2011, it was not possible to reanalyze the measurements in order to form a continuous data set. It was possible to acquire the data from RGA for post-processing, but there were no funds available at the time. Thus, this change resulted in the loss of almost six months of continuous monitoring.

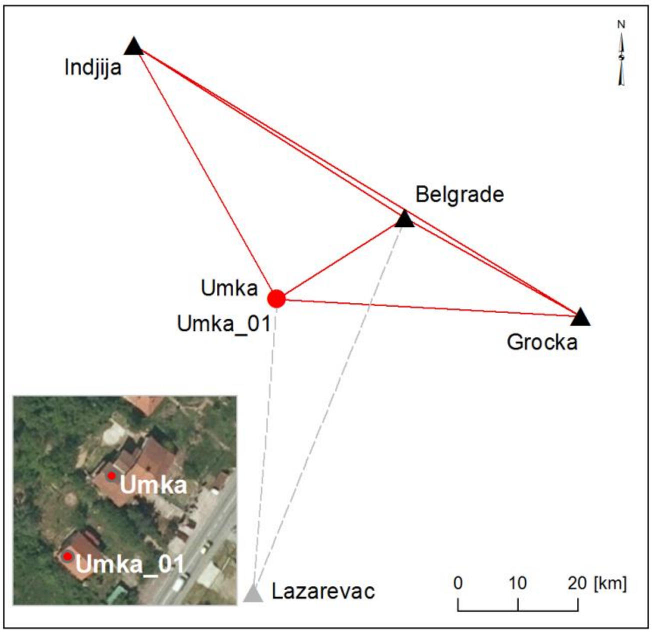

Figure 2 Location of all GNSS network points used from March 2010 to the present.

The second significant change occurred as the result of relocating the Umka point (station) (Fig. 2). This resulted in the loss of more than nine months of continuous monitoring, from the end-December 2013 through September 2014 and the establishing of a new monitoring point. Namely, the house on which roof the Umka monitoring station receiver was placed changed owners, resulting in the relocation of the receiver to the roof of a neighboring house (Fig. 2).

All told, the system did not record data for some 31 months over the seven-year monitoring period: more than 15 months owing to the changes outlined above, and an additional 16 months of interruptions caused by various technical problems. Those additional gaps in monitoring occurred at different time intervals, lasting several days to a full one-and-a-half months, depending on the problem. Generally, the main problem lay in the interrupted communication with the sensors (especially with the sensor on Umka) caused by difficulties with the Internet connection, loss of power (technical problems and human error), replacement of the modem due to malfunction and similar. Due to the complexity of the monitoring system, which requires the parallel (synchronized) operation of all system components, the gaps in monitoring caused by these kinds of technical problems are to be expected and are practically unavoidable. Despite the numerous interruptions during the seven years of continuous monitoring the dynamics of the Umka landslide can be determined and analyzed through time.

Analysis of the observed data

The Umka object point (sensor) changed location (from one house to another, i.e. from Umka to Umka_01). Given that the sensor was not working for a longer period of nine months, during which the relocation was finalized, the data derived from the continuous monitoring is analyzed for two time periods, separately: the first, from the beginning of the monitoring, from March 2010 to December 2013; and the second, from September 2014 to end-2016. The results of displacements for both time periods as well as the data collected on precipitation, from the Belgrade MMS, and the level of the Sava River from a Beljin station, are presented in Fig. 3. The data shown in the lower graphs (Fig. 3) represents longitudinal (northing displacement component), transverse (easting displacement component) and height displacements of the Umka (bottom right figure) and the Umka_01 (bottom left figure) points from the first and second observation periods, respectively. Data on precipitation and level of the Sava River, from January 2010 to end-December 2016 are presented in the upper graph. Unfortunately, during times of extreme precipitation and very high river levels caused by the Cyclone Tamara that affected the Balkans in May 2014, the automated GNSS monitoring system was not functional.

Generally, both graphics for displacements indicate that the Umka landslide is continuously moving, most significantly towards the northwest, i.e. towards the Sava River (Fig. 1). During the first 45 months (Fig. 3) the object point Umka moves 0.46 m north and 0.70 m west. Based on these results it can be concluded that the total 2D displacement is 84 cm towards the northwest. Furthermore, during the same period, the vertical displacement of the Umka sensor was nearly -0.30 m.

Results from September 2014 to end-2016 indicate that the Umka_01 object point has moved 0.25 m north and 0.46 m west, i.e. the total 2D displacement is 52 cm towards the northwest, while the vertical displacement during those 28 months was approximately -0.15 m.

As already concluded in the previously published results by Abolmasov et al. (2015), the movement of the Umka landslide can be characterized as slow to very slow. Furthermore, it can be concluded that landslide velocity varied during both observed periods (displacement velocity of both monitoring points, Umka and Umka_01). Nevertheless, considering the cumulative displacements velocity of both monitoring points, Umka and Umka_01). Nevertheless, considering the cumulative displacements and the duration of the monitoring for both periods, it can be stated that the velocities for those time periods are in general very similar. The average annual 2D displacement was approximately 22 cm for both presented periods, except for two periods – in early 2011 (January– May).

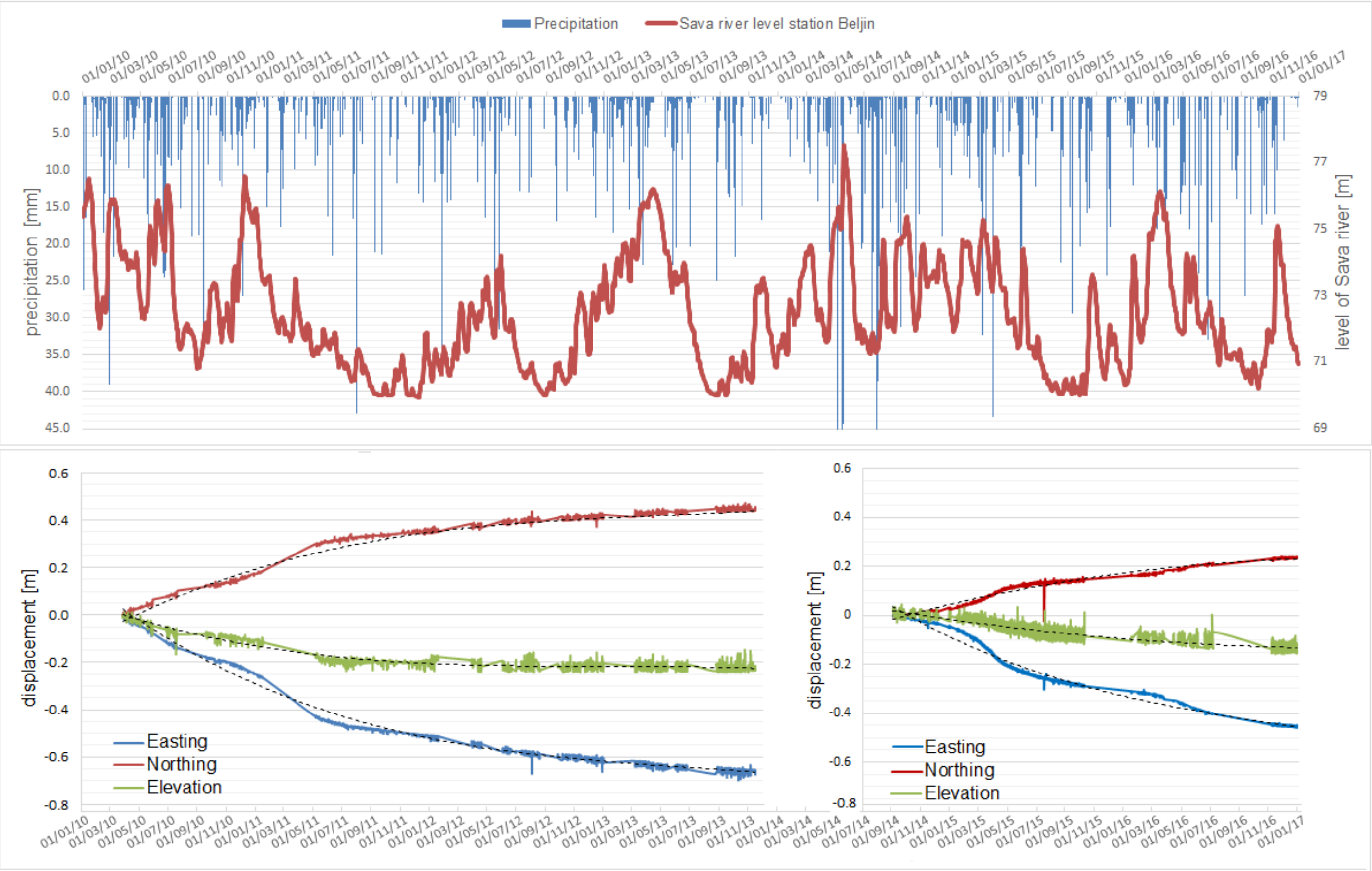

Figure 3 Precipitation and level of the Sava river (upper figure) from January 2010 to end-December 2016, displacement of Umka point from March 2010 to December 2013 (bottom right figure) and displacement of Umka_01 point from September 2014 to end-December 2016 (bottom left figure).

Both periods are characterized by intensive fluctuations in the level of the Sava river level (well-known drop-down effects) and both started with a high river level (76–77.8 m). During 2010 the Sava river twice reached those levels (June 2010 and November 2010), and obvious acceleration began in the early summer of 2010 and continued through May 2015. Said fluctuation in the river level in 2015 was followed by the highest river discharge rates during the floods of May 2014 and after, the drop-down effects caused by the empting of the Djerdap dam accumulation.

Conclusion

The experience gained during the seven years of monitoring and measuring the Umka landslide indicates the advantages of this type of monitoring and monitoring system, with said advantages already highlighted in previous publications (Abolmasov et al. 2012, Abolmasov et al. 2013, Abolmasov et al. 2015, Erić et al. 2015). The consequent analyses and derived results indicate that the points from the permanent GNSS reference systems, which exist in almost all countries (like AGROS in Serbia), can be used as points of reference networks for real time monitoring of slowly moving landslides. They are sufficiently spatially accurate (within several centimeters), and are both economical and reliable for purposes of long-term observation where greater accuracy is not necessary. In other words, using points from such GNSS networks located outside landslide areas as reference points represent an optimal solution – especially in terms of the cost of the system.

The main drawback of such a system is the single observed object point, which drawback is also highlighted and discussed in previous publications. Furthermore, during the seven years of monitoring the Umka landslide the GNSS monitoring network underwent two major changes, together with various technical problems resulting in interruptions in the continual real time monitoring process. However, it can be concluded that the observations collected represent reliable data, and that an established automated system can be used for permanent monitoring. Seven years of monitoring shows that the Umka landslide is moving continuously towards the Sava River, with an average annual displacement of approximately 22 cm.

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