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Proceedings of the 2nd Regional Symposium on LANDSLIDES in the Adriatic - Balkan Region

14-16th May 2015 Belgrade - Serbia

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Proceedings of the 2nd Regional Symposium on LANDSLIDES in the Adriatic-Balkan Region, ReSyLAB, Belgrade 14-16 May 2015

University of Belgrade, Faculty of Mining and Geology
May 2017

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PUBLISHER:
University of Belgrade, Faculty of Mining and Geology

FOR PUBLISHER:
Prof. Dušan Polomčić, Dean

COVER DESIGN:
Srđan Krstić

PRINTED BY:
Sapient Graphics

ISSUED:
250 Copies

FRONT COVER PHOTO:
Landslide Leva Reka, Kraljevo, Serbia (by Biljana Abolmasov)

BACK COVER PHOTO:
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CIP - Каталогизација у публикацији
Народна библиотека Србије, Београд

551.4.037(082)
624.131.53(082)
624.138(082)

REGIONAL Symposium on Landslides in the Adriatic-Balkan Region (2 ; 2015 ; Beograd)
Proceedings of the 2nd Regional Symposium on Landslides in the Adriatic-Balkan Region, RESYLAB, Belgrade 14-16 May 2015 [Elektronski izvor] ; editors Biljana Abolmasov, Miloš Marjanović, Uroš Đurić / editors Biljana Abolmasov, Miloš Marjanović, Uroš Đurić. - Belgrade : University of Belgrade, Faculty of Mining and Geology, 2017 (Belgrade : Sapient Graphics). - 1 elektronski optički disk (CD-ROM) ; 12 cm

Sistemski zahtevi: Nisu navedeni. - Tiraž 250. - Invited lecturer: str. 256-261. - Nasl. sa naslovnog ekrana. - Bibliografija uz svaki rad. - Registar.

ISBN 978-86-7352-296-8

a) Клизишта - Зборници b) Косине - Зборници
COBISS.SR-ID 234417420

Permanent Geodetic Monitoring of the Umka Landslide Using GNSS Technology and GeoMoS System

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Abstract Numerous landslides have been activated and reactivated during or after the Cyclone Tamara that affected the Balkans in May 2014. In Serbia, so as in other surrounding countries, there are many landslides that greatly affect people's lives for years now, even decades. Modern monitoring techniques provide highly precise and reliable data, sometimes even in real-time, on deformations caused by mass movements and also increase speed, cost effectiveness and overall quality of monitoring. Nowadays, beside geotechnical methods, various geodetic measurement techniques and systems are applied in the process of landslide monitoring. The case study presented in this paper is currently active landslide Umka, the deepest and biggest one in Serbia. The presented data, based on which the possible movements of landslide Umka are analysed, are acquired by geodetic technique using GNSS receivers. The existent monitoring system is established in March 2010 and consists of GNSS network and supporting software solutions: Leica GNSS Spider and Leica GeoMoS. The results indicate that the reference network points have not moved significantly while the "Umka" point is moving continuously. Displacement vector in 2D coordinate system reaches a value of up to 89 cm, while in vertical plane it is -30 cm.

Keywords Umka, landslide permanent monitoring, GNSS, GeoMoS

Introduction

Landslides are geological phenomenon which represents a major threat to human life, property and constructed facilities, infrastructure and natural environment. According to the European Joint Research Centre's Institute for Environment and Sustainability (JRC-IES) the largest part of the Balkan Peninsula is in the high and very high landslide susceptibility class (Fig. 1). The landslide hazard and risk have become topical in Serbia since the Balkans was affected by the Cyclone Tamara in May 2014. Numerous landslides have been activated or reactivated due to heavy rains and resulting floods.

Monitoring of landslide displacements and deformations can provide valuable information about the dynamics of the landslide phenomenon. Based on this information an early warning system could be established that would be very helpful in preventing possible disasters, including human injuries or casualties. Scientists all over the world have developed and tested several different landslide monitoring techniques and systems which proved to be extremely important in predicting the behaviour of landslides. Modern monitoring techniques can provide highly precise and reliable data, sometimes even in real-time, on deformations caused by mass movements and also increase speed, cost effectiveness and overall quality of landslide monitoring. In addition to the classical geotechnical techniques, various geodetic techniques and systems are applied in the process of landslide monitoring: digital photogrammetry (Walstra et al., 2007; Carvajal et al., 2011), Global Navigation Satellite System (GNSS) (Gili et al., 1998; Zeybek et al., 2014), InSAR (Colesanti and Wasowski, 2006; Crosetto et al., 2013) and LiDAR technologies (Derron and Jaboyedoff, 2010), tacheometry, levelling. Each of these techniques can be used independently in the same landslide monitoring study, but very often two or more different techniques are applied.

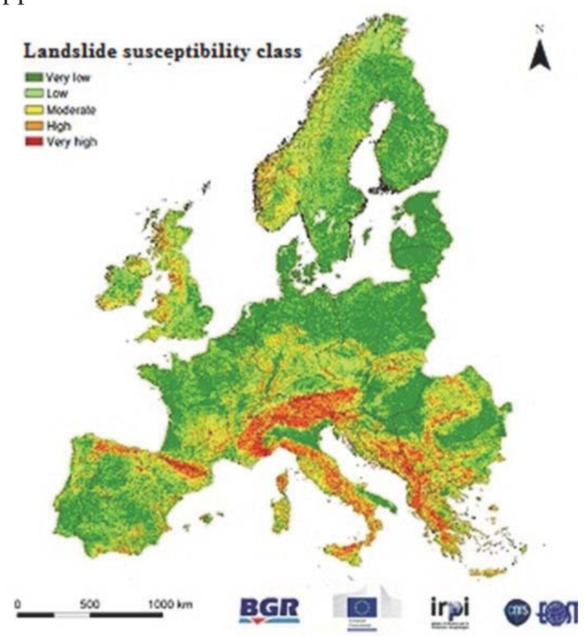

Figure 1 Classified European landslide susceptibility map version 1 (source: European Commission – Joint Research Centre – Institute for Environment and Sustainability, 2013)

Corresponding software solution is also needed as a part of all continuous and real-time monitoring systems.

Nowadays, there are several available commercial software solutions, among which the best known are: Leica GeoMoS, Trimble® 4D Control™ , GRAZIA, etc.

Herein presented case study is currently active landslide Umka (Fig. 2), the deepest and biggest one in Serbia. The Umka landslide has been investigated by different geotechnical techniques for decades but this paper focuses on the automated continuous monitoring system established on Umka in March 2010. The system consists of GNSS network and supporting software solutions: Leica GNSS Spider and Leica GeoMoS. The obtained results indicate that Umka is moving continuously and significantly towards the northwest.

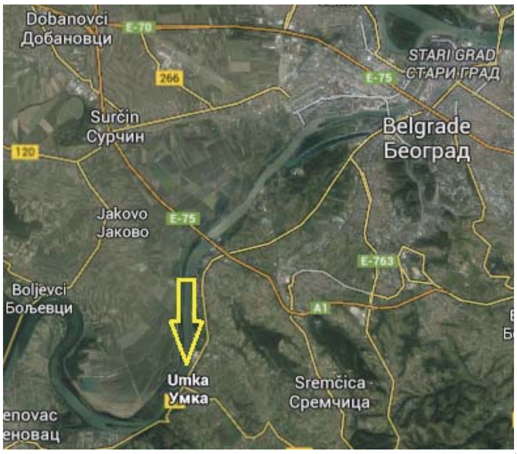

Figure 2 Geographical location of the Umka landslide (source: Google Maps, 2015)

The Umka landslide

The Umka landslide (Fig. 2) is the most famous, biggest and deepest one in the Belgrade city area. This large active and slow moving landslide of the depth of 10-26 m, created in marly clays, takes up the area of 1.8 sq. km. It is fan-shaped, with the length along the slope of 900 m, toe width of 1450 m, area of 100 hectares and average depth of 14 m, volume 14.000.000 m^3 and average gradient of 9°. Upstream landslide part is surrounded by the steep frontal scar with the height from 5 m to 25 m, whereas downstream landslide part does not have pronounced leap. It is also one of the most representative landslides of the right riverbanks of the Sava and Danube Rivers.

Notwithstanding that the Umka landslide has been investigated in detail in several campaigns over the past 30 years, its dynamics is not easy to determine. Such a complex and large landslide, as Umka is, requires a complete or permanent monitoring over a long period of time. Therefore, an automated continuous GNSS monitoring system was established in March 2010. This is the first monitoring system of this kind in Serbia so it represents a huge step forward in monitoring in general and especially in landslide monitoring.

Architecture of the monitoring system

The Umka landslide monitoring system is automated permanent monitoring system consisted of GNSS network and supporting software solutions: Leica GNSS Spider and Leica GeoMoS. The system was established in March 2010 and since then it has undergone certain changes. The shape of GNSS network was changed due to the replacement of reference stations implemented by the Republic Geodetic Authority (RGA). Location of the sensor placed in Umka area also had to be changed.

GNSS monitoring network

Global Navigation Satellite System or GNSS is a satellite navigation system with global coverage which involves four satellite systems: USA's GPS, Russian GLONASS, EU's Galileo and Chinese Beidou. GNSS receivers determine their position in global 3D coordinate system by using timing and positioning data encoded in the signals emitted from four or more GNSS satellites. This measuring technique enables continuous monitoring of landslides by providing 3D coordinates in WGS84 coordinate system. As opposed to classical surveying techniques, GNSS technique does not require visibility among observing points. This important feature of GNSS allows greater flexibility in the selection of point locations which will be observed. GNSS technique is also weather independent and can be applied 24h a day, i.e. even at night. The GNSS positioning accuracy depends on various effects. Among the most important are: the number and position of the observed satellites (DOP factors), the quality of GNSS receivers and observations, etc.

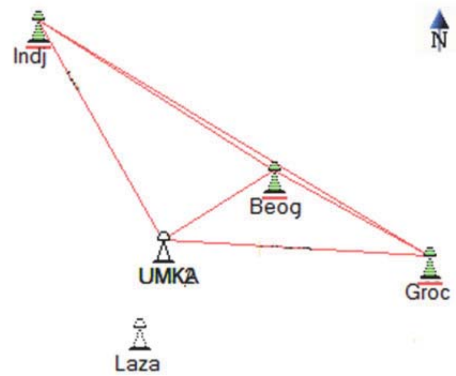

Figure 3 GNSS monitoring network

The GNSS monitoring network, set up to continuously monitor Umka landslide, consists of four GNSS points (Fig. 3). As it is customary in monitoring systems, the network consists of reference and object points. Reference points are always placed outside the landslide area and it is presumed that they are stable, i.e. that their positions do not change significantly over the time. In order to determine if there are any possible movements of the object of interest, first the stability of the positions of reference points should be tested. In this particular case, three network points (Belgrade, Grocka and Indjija) represent reference points. Therefore, unfortunately because of a lack of GPS receivers only one point (Umka) that is placed in the Umka landslide (Fig. 4) area represents the object point. This point is of a major interest as it should indicate if there are any changes in the position of the landslide.

Three reference points of the monitoring network are points included in the Active Geodetic Reference Network of Serbia (AGROS network). AGROS is a network of 30 continuously operating reference stations of Serbia. It covers 80% of the territory of Serbia (i.e. the whole territory without Kosovo and Metohija) and as of December 5, 2005 the network has become operational. Monitoring station installed at the Umka landslide is placed on the roof of the house. Although it would be preferable that the station is placed on the ground (i.e. on pillar) this was done due to the needed electric supply.

Highly precise, multi-channel, multi-frequency systems (receivers and antennas) are used on all network points. Systems on reference points support GNSS measurements (from GPS and GLONASS satellites) but the system placed on the Umka landslide only supports GPS measurements so it means that the monitoring system only uses GPS satellites.

Leica GNSS Spider and Leica GeoMoS

An automated continuously monitoring system necessarily requires appropriate software support. Deformation monitoring software solutions enable 24 hours a day, 7 days a week real-time monitoring, remote control of applied sensors, reduction of safety risks, establishment of an early warning system, etc.

Leica Geosystems manufactures a wide range of high-precision instruments and supporting software for structural monitoring. In the case study of the Umka landslide monitoring presented in this paper two Leica Geosystems software solutions were needed so that the established monitoring system could operate. These two solutions include GNSS Spider and GeoMoS which are installed on a central computer located in Belgrade and where all the raw data obtained from receivers are stored and processed.

Leica GNSS Spider is an integrated software suite for centrally controlling and operating GNSS reference stations and networks. GNSS Spider is modular and scalable and can be tailored to suit various GNSS surveying, seismic and structural monitoring applications. In the established Umka landslide monitoring system this software is required to enable remote control of the measurements at the GNSS stations. GNSS Spider enables communication with GNSS receivers and through its possibilities a user is able to define: type of the applied receiver and antenna, approximate coordinates of the points, observation rate, type of the connection with receiver, data format of the observations, type of products that will be created based on the acquired observations, etc.

Leica GeoMoS is a system used to permanently observe movements of objects such as buildings, dams and slopes. GeoMoS checks measurements and results against user defined limits so if the limit has been exceeded a message can be sent. It supports connection, control and run of different sensors (GNSS, total stations, meteo, geotechnical). GeoMoS system is also intended for collection, storage and presentation of measurement data, so as for computation, evaluation and post-processing of data. The user can filter the data and plot graphs of displacements and displacement vectors of only one or several points. There are three types of displacement plots: longitudinal (northing displacement), transverse (easting displacement) and height. Leica GeoMoS consists of two main components: Monitor and Analyzer. The network adjustment and deformation analysis software GeoMoS Adjustment complements the Analyzer component.

In the Umka system GeoMoS Monitor receives GNSS product files from GNSS Spider and transforms them into the State Coordinate System of Serbia (Gauss-Krüger projection) based on the given transformation parameters. It also provides graphical preview of the acquired transformed raw observations, i.e. of the chosen file products in GNSS Spider. These data can be transmitted to Analyzer or Adjustment where an improved analysis can be performed.

Results of the monitoring system

Description of the observation setup

As it was mentioned earlier, the permanent monitoring system on the Umka landslide was established in March 2010. At that time GNSS network (Fig. 3), i.e. the reference part of the GNSS network, included two AGROS points: Belgrade and Lazarevac. But in June 2011 AGROS network underwent some changes, in the scope of which Lazarevac station (shown on Fig. 3 as inactive and not part of the network) was replaced with Grocka station. This inevitably affected already established monitoring system on the Umka landslide. From that moment the reference network has been consisted of three points: Belgrade, Grocka and Indjija. Later, at the end of 2013 the receiver on Umka had to be moved to a nearby location due to the change of the owner of the property where receiver had been located before. Both of these changes represent a new beginning in permanent monitoring of the Umka point. It is important to mention that there have also been other difficulties that impeded the proper functioning of the system. Communication with sensors, especially with the sensor on Umka, was often interrupted which resulted in the loss of data and interruption of time series. In the future the objective is to predict those missing values in time series as accurate as possible.

Through GNSS Spider approximate coordinates of the network points were specified. The approximate coordinates are in ETRF2000 coordinate system so the whole network is in ETRF2000 coordinate system. In August 2014, together with the change of the location of the Umka receiver, the approximate coordinates of the reference points were also changed. Because of this only the results obtained before this change are presented and analysed within this paper.

All day long observations from all reference network stations are stored in two 12 h long RINEX files and from the Umka station in one 24 h long RINEX file. From the beginning of the monitoring the observation rate of GNSS measurements has always been set to 30 s. Measurement data from sensors on the reference points have been transmitted via raw data streams while measurement data acquired at the Umka sensor have always been downloaded from the sensor. Each of the applied data transmission methods has its advantages and disadvantages. In the case of the loss of connection to the sensor from which the data are transmitted via data streams all the data collected during that period of time will be lost. This will not happen with the data on the sensors which use second method of data transmission. But the second method cannot enable real-time monitoring since the data are transmitted in pre-defined intervals.

Table 1 Length of GNSS network baselines in 3D Cartesian coordinate system

From	To	Length
Belgrade	Grocka	26682.482 m
Belgrade	Indjija	42999.693 m
Indjija	Grocka	69649.237 m
Umka	Belgrade	20429.540 m
Umka	Grocka	36410.389 m
Umka	Indjija	45382.525 m

Several file products are created in GNSS Spider based on the acquired RINEX files. Those are 12 h and 24 h long RINEX files for each station. These file products are further used to create PP Positioning products which are then transmitted to GeoMoS Monitor. The PP Positioning products are in fact processed GNSS vectors (Tab. 1). Vectors are formed between all points and processed using rapid precise IGS ephemeris. Thus processed vectors are transformed in Gaus-Krüger projection in GeoMoS Monitor and further analysed in GeoMoS Analyzer. The GeoMoS Analyzer graphs are plotted automatically whenever new data are received which enables quick and easy identification of landslide movements. The data plotted on graphs can be raw or smoothed for selected time period.

Data interpretation and analysis

The system has been active since March 28, 2010. All the data acquired from that day until the December 25, 2013 are interpreted and analysed within this paper. In 2014 the system parameters and location of the "Umka" sensor were changed so the data acquired in this period are not presented here.

The data shown in the graphs (Fig. 5, 6 ,7) represent absolute longitudinal, transverse and height displacements of the Umka point from the first observation period. These are the graphs provided by GeoMoS Analyzer which under "longitudinal displacement" considers "northing displacement component" and under "transverse displacement" considers "easting displacement component". The horizontal displacements (longitudinal and transverse) are given in Gauss-Krüger projection. Each graph offers three different estimations of displacements of the Umka point: "Umka_B", "Umka_G" and "Umka_I". "Umka_B" displacements represent estimated displacements calculated relative to Belgrade reference point, "Umka_G" are displacements relative to Grocka reference point and "Umka_I" are displacements estimated relative to Indjija reference point. Based on this it can be said that for almost all presented time moments each displacement component of the Umka point is estimated three times.

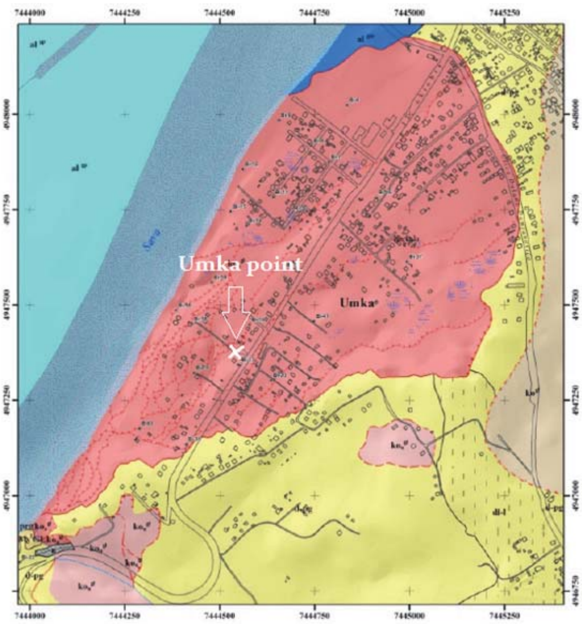

Figure 4 Position of the Umka point in the landslide area.

Displacements calculated relative to Indjija and Grocka are presented in a shorter time period than to Belgrade due to the problems of obtaining the observation data on these two reference points from the beginning of the observation period until the end of 2011. Gaps in the graphs represent observation period where there were no observations due to the problems in communication with the sensors, especially with the sensor in Umka. It could be noticed that there are several gross errors which significantly deviate from the rest of the data, especially in the Height displacement graph (Fig. 7). This was expected considering the volume of the data and the fact that this is the system for permanent monitoring. It is also no surprise that these gross errors are most frequent in the height displacement data having in mind that vertical position of the points estimated using GNSS technology is less precise than horizontal.

Longitudinal displacements presented in Fig. 5 indicate that Umka is moving towards the north. The trend of movement can be approximated with logarithmic function. Graphs of longitudinal displacements estimated relative to all three reference points almost coincide which contributes to the reliability of the displacement estimation. The largest recorded longitudinal displacement is 0.456 m.

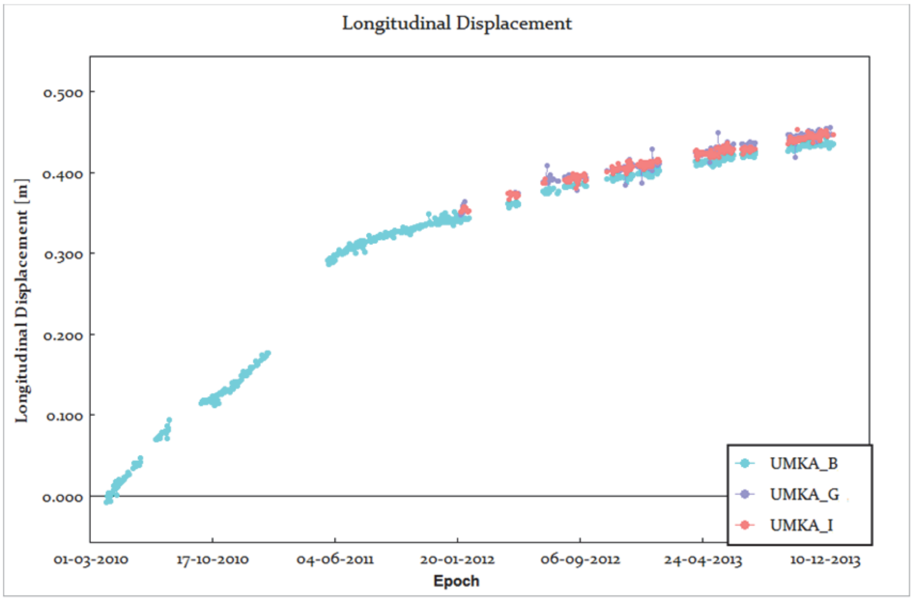

Figure 5 Northing displacement components of the Umka point

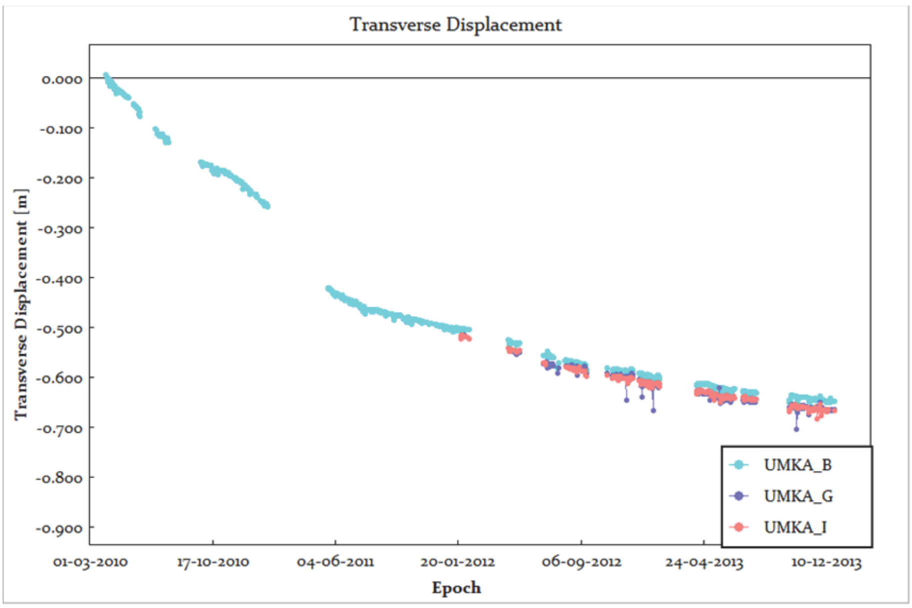

Figure 6 Easting displacement components of the Umka point

Almost the same can be concluded for transverse displacements. Based on the displacements presented in Fig. 6 Umka is moving towards the west. The trend can also be approximated with logarithmic function. It can be noticed that all three different displacement estimates presented in this graph almost coincide. The largest recorded transverse displacement is -0.704 m.

Height displacements presented in Fig. 7 are more scattered than the previous two types of displacements. Based on this graph it can be stated that Umka is sinking. During this 4-year period it has sunk nearly 0.300 m. The trend of sinking follows the same function as for the previous two displacements – logarithmic function.

Total 2D displacement of the Umka point is 89 cm based on the acquired data, i.e. the observed point has moved 89 cm towards the northwest. Looking at Fig. 4 it is obvious that Umka is moving towards the Sava River.

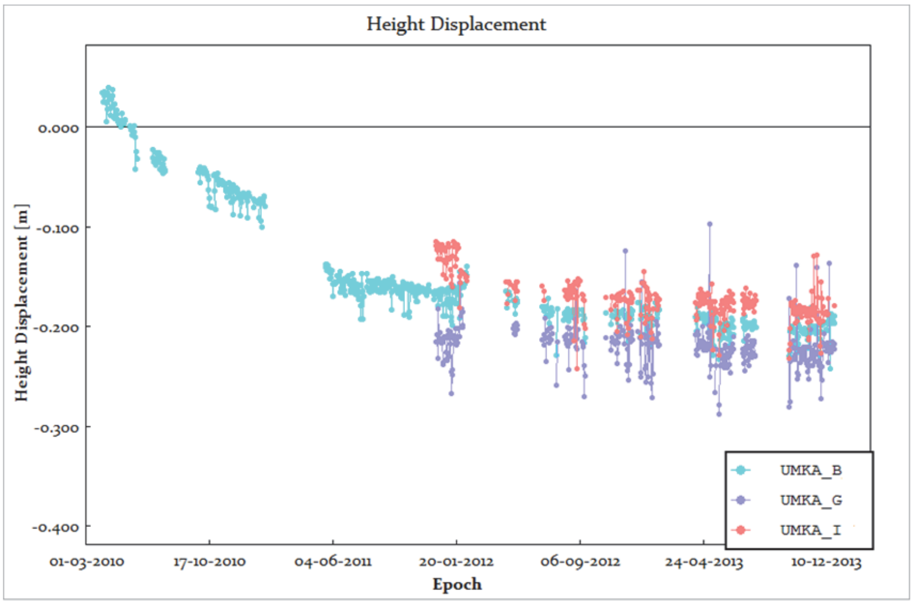

Figure 7 Height displacements of the Umka point

Conclusion

Automated permanent monitoring system established on Umka in March 2010 represents a huge step forward in monitoring landslides in Serbia. Umka is currently the biggest and deepest landslide in Serbia and the data provided by this monitoring system could be extremely important in its rehabilitation. The system is based on GNSS technology and two software solutions: GNSS Spider and GeoMoS. The results provided by the system and presented in Fig. 5 and Fig. 6 indicate that Umka is moving continuously and significantly towards the northwest. During the 4-year period the point that is placed in the Umka area has moved 0.456 m towards the north and 0.704 m towards the west. Height displacements presented in Fig. 7 indicate that Umka is also sinking. During the same period it has sunk nearly 0.300 m.

In the future there are plans to increase the number of GNSS sensors in the Umka area, so as to investigate correlation of the estimated displacements with other parameters (precipitation, temperature, the Sava River water level, etc.).

Acknowledgments

This paper is the result of the authors' activities on the project TR36009, supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

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