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GEODETIC WORKS IN RESEARCH AND DEVELOPMENT PLAN IN REMEDIATION OF LANDSLIDE KOSTANJEK

SUMMARY: *Modern surveyors play an important role in the field of disaster and risk management. Nowadays in most cases results of their measurements take part in a multidisciplinary study. Projects main idea was realized during 2011 and 2012 within the frame of scientific Japanese-Croatian project and will be continued. According to the previous studies landslide Kostanjek is the largest active landslide in Croatia and since its activation in 1963, it has caused substantial damage to local infrastructure. Different surveying methods were implemented in several phases. In each phase, survey method and required accuracies, were adjusted to the needs of further research. It is significant that the results obtained using different surveying methods has showed important role of geodesy in managing high-risk areas such as landslides.*

KEYWORDS: *City of Zagreb, landslide Kostanjek, surveying methods, high-risk areas*

This year landslide Kostanjek marks 50 years since its first activation. Experts, local authorities and general public are aware of the dangers that natural hazards, such as a landslides, carries. Whole project was realized in three phases. First phase was determination of displacement with relative static method in order to establish integrated monitoring system in real time (February of 2012). Second phase was scrutiny of housing facilities with visible changes (May of 2012). Third phase was measurement of shift and deformation of well with visible changes due to landslide movements (May of 2012).

1. LANDSLIDE KOSTANJEK

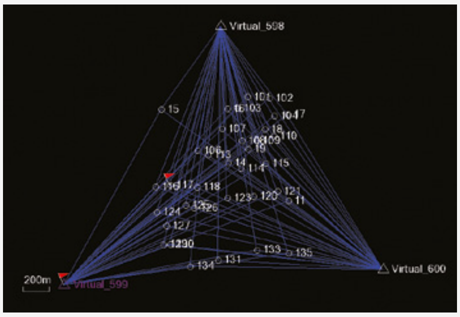
According to the previous studies landslide Kostanjek is the largest active landslide in the Republic of Croatia. It is located at the western part of the City of Zagreb, in residential area at the base of the south western slope of Medvednica (1033 m). Landslide Kostanjek was initially activated in 1963, but its remediation hasn't been done until now. Since its activation the landslide has caused substantial damage to buildings and infrastructure in the residential zone.

Landslide was mainly caused by anthropogenic factors, including mining and excavation from an open pit of marl quarry at the toe part of the landslide. The cement factory was established in 1907 and the production of cement began in 1908. After a longer period of time in 1963 began the excavation of marl from an open mine in the vicinity of the factory using blasting technique. Immediately after blasting, the initial damages occurred on the factory buildings and other structures including settlement and fractures. Conducted geotechnical field investigations revealed that swelling of the unloaded marl layers caused by the excavation is the possible cause of the damage. Several years later, analyzing the occurred movements it was concluded that the displacements could not be caused by swelling. Excavation in the quarry stopped in 1988 after it was realized that mining and excavation of marl are the main triggering factors of the landslide.

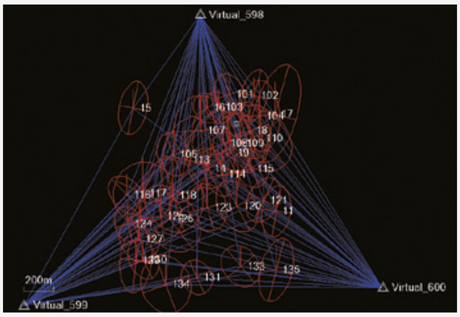
A review of landslide investigations and interpretations of engineering-geological model was given by Ortolan (1996). The conclusions about the landslide model were based and determined upon relatively poor data, including borehole data from 1931, 1972 and 1988 and data from geophysical measurements collected in 1989. Geodetic measurements, including classic geodetic and GPS measurement and the interpretation of aerial photo stereo pairs from different time periods showed the range of the movement in landslide area from 3 m to 5 m since 1988 to 1999.

The Kostanjek landslide is reactivated, translational landslide without a clearly defined main scarp and landslide borders. It extends over an area of approximately 1.2 km2 with a total volume of displaced mass of 32.6 x 106 m3. Displacement differences on the landslide surface (defined at approximately 110 points) were interpreted as movements on three different sliding surfaces, the deepest at 90 m and two sub parallel sliding surfaces at depths of 65 m and 50 m. The positions of the sliding surfaces were defined on the basis of unfavourably oriented bedding planes of sediments and sedimentary rocks of Sarmatian and Pannonian age.

The landslide caused extensive damage, including cracks on numerous buildings and facilities, tilting of buildings, poles and trees, wells cut by sliding, significant subsidence within the slide and uplifting at the foot of the landslide. Significant damage also occurred in an abandoned marl transportation tunnel that extended through the landslide body. Damages on buildings, facilities and residential houses imply that the movement of the landslide has slowed, but different parts of the landslide continue to move (Krkač et al. 2011).



Slika 2.1. Base line processing in TBC



Slika 2.2. Network adjustment in TBC

2. MOVEMENTS OF THE LANDSLIDE KOSTANJEK IN PERIOD FROM 1963 TO 2012

First phase of the project was survey of the GPS network established in 2009 on wider area of landslide. Measurements were conducted in collaboration with geodetic company Geomatics Smolčak Ltd., Faculty of Geodesy University of Zagreb that provided necessary equipment and with scientists from Faculty of Mining, Geology and Petroleum Engineering University of Zagreb that led initial research on GPS network within earlier mentioned Croatian-Japanese project.

First phase included:

- Collecting necessary documentation, drafting conceptual solution in terms of equipment, required accuracy and method of measurement
- Survey of the GPS network using relative static method
- Processing of received data and GPS network adjustment
- Determination of landslide movements between 2009 and 2012

Field work was divided in two parts. Before the survey, reconnaissance of the network was necessary in order to check and record the condition of existing network points. GPS network on landslide Kostanjek initially consisted of 43 points, of which 8 were stabilized before 20 years, while others were stabilized in September 2009. Coordinates of all points were determined in October 2009 and in March 2010. After reconnaissance it was found out that points 105 and 119 were damaged, points 111, 112 and 122 were unstable, points 128 and 132 removed, and point 5 was inaccessible so total of 35 points were finally observed.

The next phase was network survey. Survey was conducted on February 2nd 2012 from 10:00 to 15:00 using relative static method. Equipment that was used consisted of Trimble R8 GNSS receivers and Trimble R5 GPS receivers with corresponding Zephyr Geodetic antennas. These GNSS/GPS receivers were, due to their precision, efficiency, user friendly and resistance to low temperatures, an excellent choice considering that the measurements were carried out at very low temperatures. There were no difficulties during field observations.

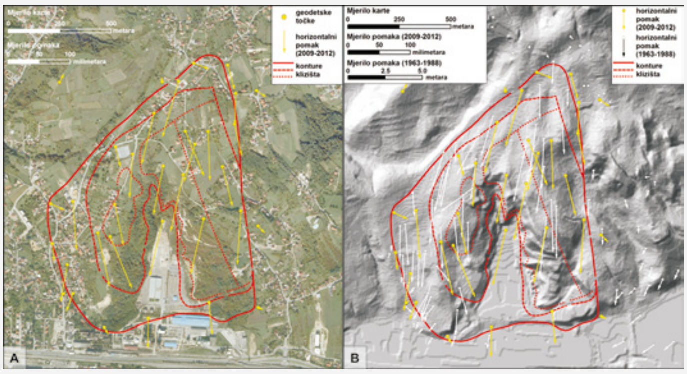
During GPS observations following conditions were fulfilled: points were observed with dual-frequency GPS/GNSS receivers with elevation mask of 10° and registration interval of 5 sec. Duration of measurement on each point was 45 min. Post processing of collected data was done using Trimble Business Centre (TBC) software, and included processing and optimization of vectors and network adjustment. GPS observations were conducted within CROPOS (CROatian POsitioning System) using geodetic precision positioning service (GPPS). Three virtual reference stations (VRS) were downloaded in RINEX format for the period of observation.

Total of 105 base lines were processed (Figure 2.1). Based on the indicators of the quality (Ratio, PDOP, RDOP, RMS) vectors that did not meet the criteria were excluded from further processing. Network adjustment was done using least squares method and virtual reference stations were fixed in the adjustment (Figure 3.2).

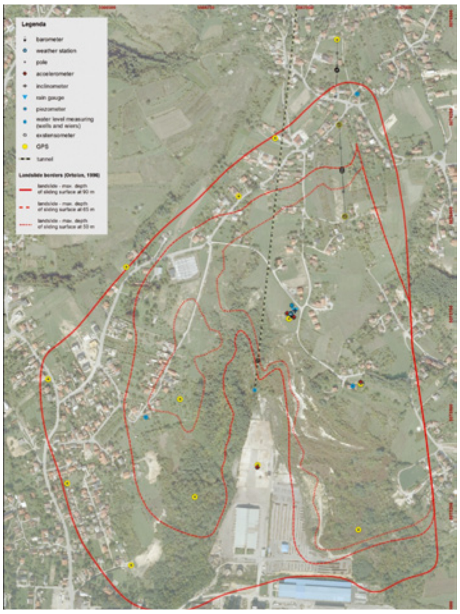
In past surveys coordinates were determined in old Croatian state coordinate system - HDKS. To compare coordinates it was necessary to transform coordinates from global ETRS89 to local state coordinate system HDKS (5th zone), using unique parameters for the City of Zagreb. Ellipsoid heights were transformed to orthometric heights using geoid undulation.

Horizontal and vertical movements of each observed point were determined based on the difference in coordinates and height between two last epochs (2009 and 2012). Limit value of 3 cm was

Slika 2.3. Movement of vectors (mm)



Slika 2.4.a Horizontal movement of landslide Kostanjek in period from 2009. to 2012.; Figure 2.4b Comparison of horizontal movements between epoch 2009.-2012. and epoch 1963.-1988



Slika 3.1. Monitoring plan for landslide Kostanjek

chosen to emphasize bigger movements (Figure 2.3).

Results obtained in 2012 were compared with results from previous studies. Figure 2.4a shows horizontal movements in range from 6 mm to 92 mm in time period of 2 years and 4 months (from 2009 to 2012). Figure 2.4b presents horizontal movements derived from aerofotogrametric data from several epochs in time period from 1963 to 1988 in comparison with movements in period from 2009 to 2012. Movements in period from 1963 to 1988 range from 2 m to 6 m and differ in direction and value in different parts of landscape.

Based on comparisons of landslide displacements from different periods over last 50 years it's clear that the landslide is still active, and that directions of landslide movements, registered in the period from 2009 to 2012, largely coincide with the direction of movement in period from 1963 to 1988. These conclusions as well as the results of measurements are important data for planning of an integrated system for monitoring landslide Kostanjek in real time (Županović et al. 2012).

3. REAL TIME MONITORING AND DEVELOPMENT OF EARLY WARNING SYSTEMS FOR LANDSLIDE KOSTANJEK

Project *"Risk Identification and Land-Use Planning for Disaster Mitigation of Landslides and Floods in Croatia"* started in 2009, as one of the projects in program *"Science and Technology Research Partnership for Sustainable Development"* – SATREPS and is financed by Japan Agency for Science and Technology – JST and Japan International Cooperation Agency – JICA. Within the framework of working group 1 of Japanese-Croatian project, real time monitoring system on Kostanjek landslide will be installed.

The monitoring system will contain 40 geodetic and geotechnical sensors for landslide movement monitoring and determination of sliding triggers (Figure 3.1). Geodetic sensors will measure landslide movements in real time with 15 GNSS receivers installed on landslide surface. Movements within the landslide body will be measured with geotechnical sensors. That includes ten extensometers and inclinometer. Piezometers that measure groundwater level and accelerometer will be installed in boreholes. Few accelerometers will also be installed on landslide surface. Automatic measuring devices will be used to measure meteorological, groundwater and subsurface seismic conditions. Piezometers, inclinometers and extensometers will be installed in the central part of the landslide body while extensometers will be installed at the top and abeam parts of the landside.

All monitoring equipment will be connected in one system with continuous monitoring and export of the data to a central computer unit. This real time transmission enables an early warning system for landslide hazard establishment, when measured values exceed defined limits. An early warning system for possible landslide occurrence and assessment of landslide risk will be established based on the monitoring results.

4. SHIFT AND DEFORMATION OF LOCAL INFRASTRUCTURE

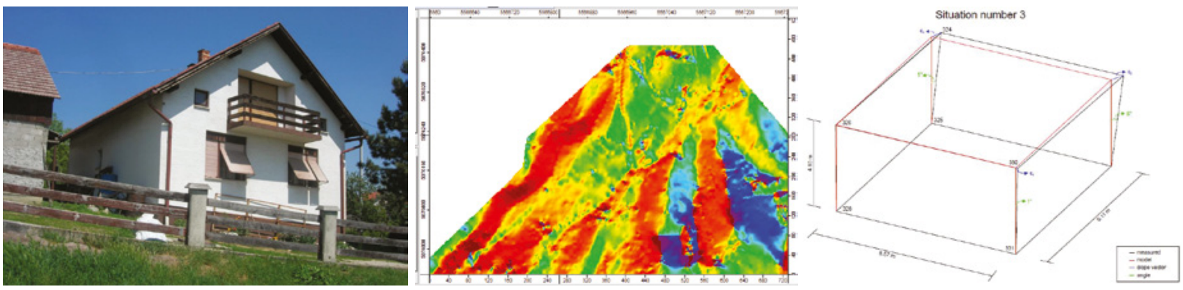
According to the current described situation on Kostanjek, land sliding has caused severe damage of local infrastructure. Whereas area of Kostanjek landslide is highly populated deformations are visible on household facilities and they cause major problems and financial outlays for its residents.

Within this project five houses with evident deformations, cracks and tilt caused by land sliding were measured (figure 4.1).

For more precisely analysis we measured the objects which are located at different parts of landslide. On the basis of the obtained coordinates of the top and the bottom of the house, it was possible to calculate the angle of the slope relative to the direction of the north. Simple 3D models of houses were made in order to compare their tilt with landslide slope and movement. (figure 4.2).

Calculated values of the slope of the house were compared with SAGA digital terrain model and it showed that slope of houses coincides with the slope of terrain.

Slika 4.1. Monitoring plan for landslide Kostanjek



Slika 4.2. Facility No. 3
a) house
b) DTM
c) simple 3D model


Slika 5.1. Analysed well


Slika 5.2. Cross sections on the upper side of the well


Slika 5.3. Measurement of cross sections

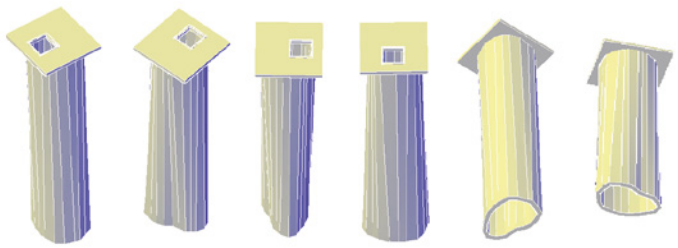
5. SHIFT AND DEFORMATION OF THE WELL

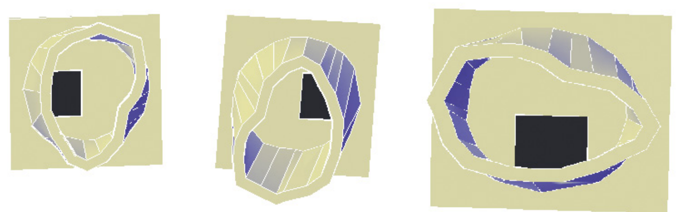
Due to the lack of boreholes and piezometers, geologists have been using private wells for hydrological researches, such as measurement of water level, geochemical analysis etc. There are more than hundred wells located around and in the landslide area, varying in depth from 4 to 33 meters. Water in wells is mainly derived from the shallowest aquifer related to superficial deposits and top zone of weathered marl sediments. Inspections of the opened wells have shown shifts and deformations due to landslide movements.

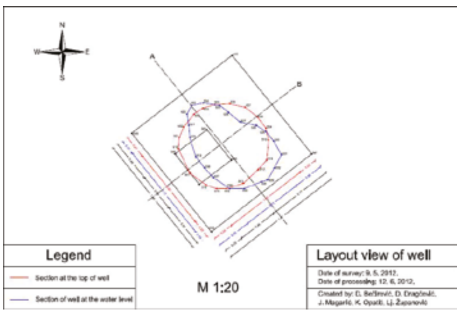
Primary objective of this research was measurement of shift and deformation of particular well (Figure 5.1) near north western border of landslide, while the final goal was to determine the direction and displacement of landslide movement in the vicinity of the well to develop landslide model for the particular well.

Analysed well is located right by the house which also shows visible shifts and deformations due to landslide movements. It is important to note that shift and deformation of this well represent landslide movement probably better than displacement and shifting of the house, because damaged zone in the well is located near the sliding surface, while the house which behaves as one solid body, does not necessarily move as the landslide moves.

It was necessary to determine direction and size of the shift of the well. Water level of analysed well was 5.57 m below the top of the well. First cross section of the well (blue) was determined for the top of the well, beneath the concrete plate (Figure 5.2), using direct method with measuring tape and wooden rod with centimetre scale. Second cross section of the well (red) was measured right above the water level, using plumb on the wooden rod with centimetre scale. However, it was impossible to place the plumb on the very inner side of the well due to the deformation and the outward shift of the well, so an estimation of the shift was made. Due to measurement technique and working conditions accuracy of the estimated shift was 0.10 m. After the cross sections were drawn out on the upper side of the plate, they were measured using total station (Figure 5.3). Cross sections were used for creation of 3D model of the well, which is the best way to present the size of the shift and shape of deformation (Figure 5.4, 5.5).


Slika 5.4. 3D model of analysed well


Slika 5.5. 3D model of analysed well



Slika 5.6. Layout view of the well

CONCLUSION

Kostanjek Landslide is the largest active landslide in Croatia and since it's activation in 1963 it has caused substantial damage including cracks, significant tilting and subsidence of numerous objects. The topic has been extremely important for local administration which has got a plan for recovery of landslides since 2001.

Whereas Kostanjek landslide is highly populated urban area it is important to have integrated sensors in an early warning system.

NOTE

This article is shortened version of student paper which took first place in category Geodesy, Topography on the first CLGE (The council of European Geodetic Surveyors) student contest.

REFERENCES

- Krkač, M., Mihalić, S., Ferić, P., Podolszki, L., Toševski, A., Arbanas, Ž. (2011): Japanese-Croatian Project: Preliminary investigations of the Kostanjek landslide, Proc. 2nd World Landslide Forum, 3-9 October 2011, Rome, Italy.
- Županović, LJ., Opatić, K., Bernat, S. (2012): Određivanje pomaka klizišta Kostanjek relativnom statičkom metodom, Ekscentar no. 15, pp. 46-53.
- Ortolan, Ž. (1996): Development of 3D engineering geological model of deep landslide with multiple sliding surfaces (Example of the Kostanjek Landslide). PhD thesis. Faculty of mining, geology and petroleum engineering, University of Zagreb, Zagreb, Croatia.
- URL-1: Alleninste, [Internet],<raspoloživo na: http://www.alleninst.com/pdfs/r8.pdf> [pristupljeno 1. 7. 2012.]
- URL-2: California Surveying and Drafting Supply Inc, [Internet],<raspoloživo na http://www.csdsinc.com/store/images/TRMHNA313TA_lg.jpg> [pristupljeno 1. 7. 2012.]
- URL-3: Korecgroup, [Internet],<raspoloživo na http://www.korecgroup.com/media/TrimbleM3.pdf> [pristupljeno 1. 7. 2012.]