UNIVERSITY OF ZAGREB ENGINEERING GEOLOGISTS PERFORM FORECASTING AND PROTECTIVE MONITORING OF THE KOSTANJEK LANDSLIDE USING TRIMBLE MONITORING SOLUTIONS

The real-time transmission of data from each monitoring location within the landslide observation area was critical to the success of the project.

by Christian Breuer

Kostanjek Monitoring Station

Comprehensive landslide monitoring systems using GNSS receivers and geotechnical sensors to continuously monitor landslide movement in real-time to predict landslide behavior and establish values used for the development of an early warning system (EWS).

Overview

Customer Profile: Engineering geologists from the Faculty of Mining, Geology and Petroleum Engineering of the University of Zagreb are the team of scientists who monitor the Kostanjek landslide, located in the City of Zagreb, capital of Croatia. The monitoring equipment was donated in the period from 2009 to 2014 by the Japanese Government through SATREPS (Science and Technology Research Partnership for Sustainable Development) scientific project with the main purpose to enable landslide risk reduction from the threat of the Kostanjek landslide.

Business Challenge: To enable development of risk reduction solutions, it was essential to establish reliable, automated, continuous, real-time monitoring system network customized to specificity of the Kostanjek landslide. It is a reactivated, deep-seated, large translational landslide (landslide area about 1 sq. km) located in the populated hilly area of the City of Zagreb. Development of the

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forecasting models by scientists also required extensive monitoring of causes of landslide movement (precipitation and groundwater level).

Solution

Trimble 4D Control™ monitoring software, Trimble NetR9™ GNSS reference receivers.

Results

- **Precise GNSS monitoring** - Sixteen Trimble NetR9 receivers collect GNSS data and deliver it in real time via routers to Trimble 4D Control software for real-time landslide monitoring.
- **Remote sensor management and visualization** - City authorities, scientists and other project stakeholders can monitor and visualize the landslide movement, remotely from a web portal using Trimble 4D Control software.
- **Building more reliable landslide movement model** - The landslide monitoring system aids in the development of more accurate movement models which enable forecasting of landslide movements. Kostanjek landslide movement predictions are based on empirical models, combining landslide movement parameters with other parameters of landslide causes such as groundwater levels and precipitation.

Mining Activities Caused Slope Instability

The Kostanjek landslide is the largest landslide in the Republic of Croatia. It is activated by mining activities in 1963, i.e., undercutting of the marly slopes and uncontrolled blasting. Excavation of the total volume of 5.1*106 cubic m. in the marl quarry caused slope instability of 32*106 sq. m. volume and superficial movement in the wider residential area placed around abandoned open pit. Scientists report the width of the displaced mass is some 960 meters, and the total length of the landslide is 1.26 kilometers. The depth of the sliding surface is 62.5 meters in the central part of landslide. Today there are still more than 300 homes and associated infrastructure on the moving landslide mass. Since the movement started, it has resulted in significant damage to both residential and commercial buildings and properties.

Martin Krkač, assistant professor at the Faculty of Mining, Geology and Petroleum Engineering of the University of Zagreb, explains that despite extremely slow landslide movements over the past 50 plus years, the risk surrounding the landslide is still high. Since 2011, scientists have been working to estimate these risks by acquiring new knowledge about landslide movements.

Figure 1. Trimble NetR9™ GNSS reference receiver.

"We analyze its displacements, velocities and accelerations depending on influence of precipitation and groundwater level changes," said Dr. Krkač. "The analyses of continuous time series of landslide displacements obtained by GNSS revealed unambiguous sliding of the huge landslide mass in the direction of 60-meter-high cuts in abandoned open pit. Moreover, we identified two movement patterns, slower and faster movements which corresponds to periods of higher precipitation and higher groundwater levels. High quality data enabled quantitative comparison of the relationship between sliding and its causes using advanced statistical models."

With these observations the goal is to better predict the displacement based on meteorological prognosis of precipitation. Dr. Krkač explains that the prediction of landslide displacement 24 hour in advance is necessary for early warning of civil protection that are responsible to activate measures of evacuation in case of threatening sliding.

There are several unique characteristics of the Kostanjek landslide that made monitoring challenging including finding adequate positions to monitor within the landslide, providing adequate electrical power supply, gaining permission from local citizens and city authorities to monitor the area. Cheaper solutions, such as total station, were not possible, because landslide morphology disable the line-of-sight visibility between total station and prisms.

Precise GNSS Monitoring Data

Between 2011 and 2014 the landslide scientists from Zagreb, Rijeka and Japan, Geomatika Smolčak Ltd. and Trimble Inc. developed and implemented a real-time monitoring system to monitor and predict the movement of the landslide that got around the problem of line-of-sight. GNSS receivers and various types of geotechnical sensors have been installed. All movement sensors are connected to the core of the monitoring system, the Trimble 4D Control monitoring software. The software processes, visualizes and

analyzes the monitoring data in real-time and issues alarms automatically whenever the system detects movement. Trimble 4D Control is a very versatile monitoring software which is also perfect for the use in other monitoring applications such as mines, dams and construction related monitoring.

In total, 15 Trimble NetR9 TI-2 GNSS reference stations with Zephyr Geodetic 2 GNSS antennas have been installed on site. Dr. Krkač explains that the Kostanjek landslide GNSS receivers are mounted on 4-meter-high poles with 1-meter-deep reinforced foundations. One GNSS reference station, located in a stable area approximately 7 kilometers (4.3 miles) south of the landslide, is used as a base station. In addition to the GNSS receivers the monitoring system also uses various geotechnical sensors such as long- and short-span extensometers, pore pressure gauges in boreholes, water level gauges in wells, and a weather station including a rain gauge.

Trimble 4D Control and GNSS Provide Daily Monitoring

"T4D is an essential tool for monitoring the Kostanjek landslide movement," said Dr. Krkač. "It allows multiple GNSS processing options in parallel. For our project we used 60 minute and 24-hour post-processing intervals as well as 1 Hz RTK results. We also calculated precision of GNSS measurements and proved that they correspond to Trimble specifications which means that measurements at the Kostanjek landslide gives reliable data about antenna positions. Besides, daily monitoring of movement with high precision enable measurements of small displacements which is particularly important for analysis of slowly moving landslides, such as the Kostanjek landslide.

"Among high temporal resolution of GNSS monitoring data, high spatial resolution of movement data is achieved by good coverage of the whole landslide area by 15 GNSS stations. Donation through SATREPS project, financed by Japanese government, make it possible for the Kostanjek landslide to be equipped by densely spaced GNSS stations, comparing to other world-wide known landslide monitoring systems," Dr. Krkač said. "Geomatika Smolčak, together with Trimble Support helped to setup the GNSS monitoring system, and even now, five years after deployment of the solution, they help to solve different kinds of issues that arise related to data measurements and data transmission, which has been a tremendous asset."

Real-time Data Transmission

The Trimble NetR9 receivers collect GNSS data and deliver it in real-time via wireless routers to Trimble 4D Control software, installed on an application server in a data center at the Faculty of Mining, Geology and Petroleum Engineering of the University of Zagreb. GNSS network is stable and average loss of data from particular GNSS station during monitoring period is only 3%, or

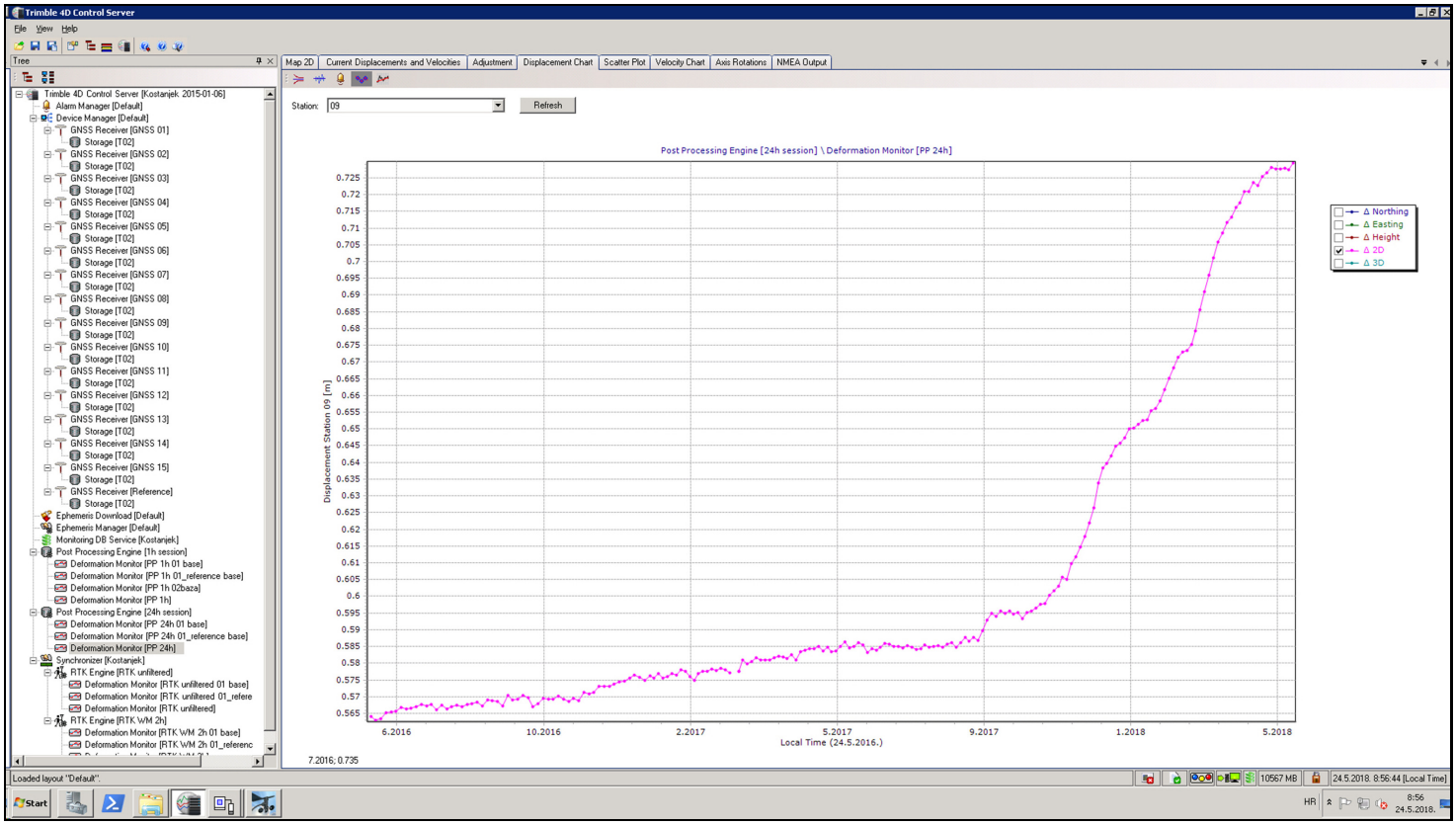

Figure 2. Trimble T4D Displacement Chart

about 20 daily measurements for the period of two years. All losses are caused due to data transmission and human factor.

"The real-time transmission of data from each monitoring location within the landslide observation area was critical to the success of the project," said Dr. Krkač. "Wireless internet at each of the monitoring locations enabled fast and high-quality transmission of large amounts of data being collected continuously, not just from 16 GNSS sensors, but also from weather station and the geotechnical sensors – such as pore pressure gauges. Wireless internet eliminated our need for the line-of-site that is required for traditional monitoring projects."

Looking Ahead - More Automated Data Processing and Analysis Aid in Protective Predictions

The data collected from the GNSS receivers and other equipment is processed by a variety of specialized software for analysis and modeling. Zagreb city officers and other scientists can use the Trimble 4D web user interface as a portal to observe landslide movement behavior remotely.

Dr. Krkač explains that results obtained by the GNSS monitoring system showed multiple reactivations of the Kostanjek landslide during the period between 2013 and 2018. Observations revealed maximum displacements in the central parts of the landslide of approximately 70 centimeters.

Japanese researchers guided by Kyoji Sassa, professor emeritus of the Kyoto University, applied failure predictions based on velocity monitoring, i.e., on the Fokozuno's method of inverse velocities. They also proved high risk of the Kostanjek landslide due to long period of movement, over 50 years, which resulted in large total displacement. Professor Sassa, as technical director of the International Consortium on Landslides (ICL), said that ICL supports applied scientific research of landslide monitoring as one of important risk reduction measure.

Integrating Research Results for More Insight into Landslide Movements

By integrating monitoring research results from different sensor types, scientists are more clearly defining landslide models and evaluating critical landslide triggers. Professor Željko Arbanas from the University of Rijeka, head of the Croatian Landslide Group and Vice president of the International Consortium on Landslides, stresses that observing activity of large and deep-seated landslides continuously is of utmost importance for development of an early warning system for extreme conditions for support authorities responsible for emergency preparedness. He also stresses that data and knowledge gathered by monitoring of the Kostanjek landslide will aid in the development of more effective and protective slope stabilization measures.

"High frequency meteorological, hydrogeological and movement data obtained by continuous monitoring enabled us to establish a new, more accurate method to predict landslide movements," said Dr. Krkač.

Professor Snježana Mihalić Arbanas from the University of Zagreb, head of the Kostanjek Landslide Observatory explains: "We have established the Kostanjek Landslide Observatory to focus on the disaster risk factors and scenarios, including emerging risks in the medium and long term changes of precipitation pattern. The main component of the Observatory is precise GNSS monitoring, that is vital and it will continue to have tremendous benefits for scientists, local authorities and residents when it comes to public safety and remediation efforts."

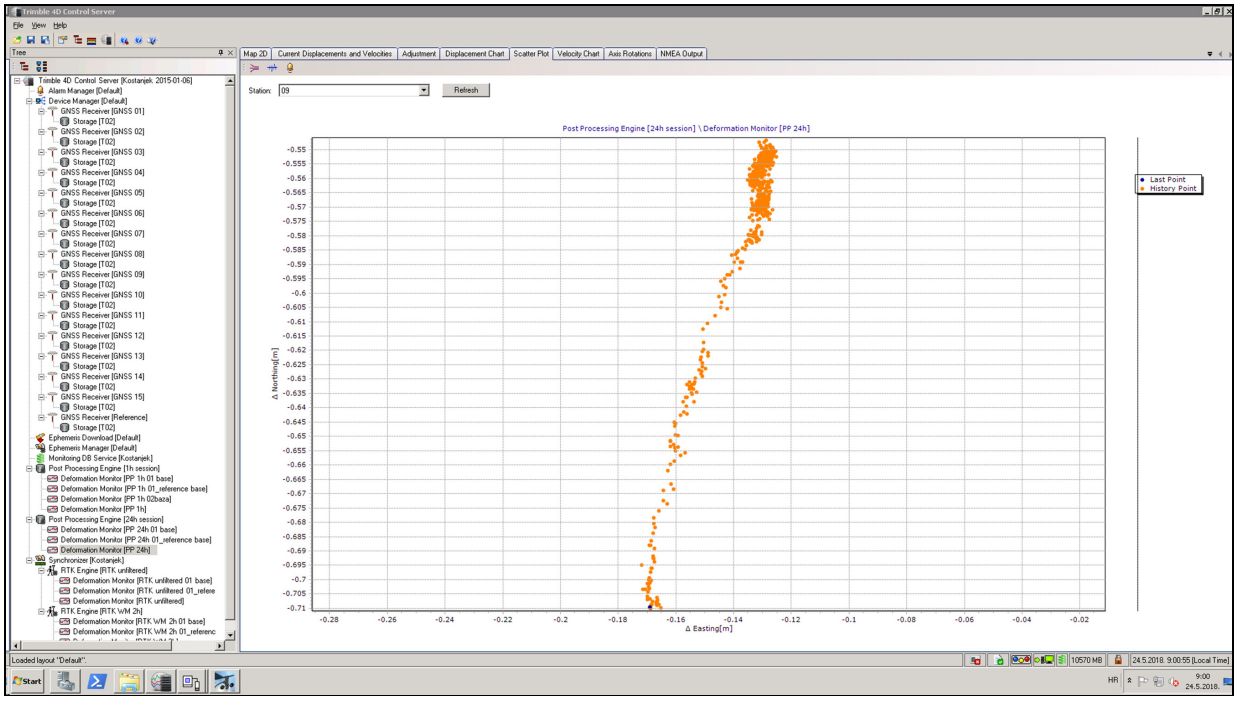

Figure 3. Trimble T4D Scatter Plot