New Real-Time Landslide Monitoring System in Polish Carpathians

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Abstract

The first in Poland fully automated real-time landslide monitoring and warning system was implemented in Beskid Niski Mountains. Project was financed by EU funds. Investigated region was characterized by the high landslide risk. A public road, a new bridge, private buildings and important infrastructure were located in risk area. Landslides had difficult engineering geology conditions with active mass movements to the depth of 7–20 m below the natural terrain level. Observed ground movements were varied 5–180 mm in 3 years time. Lithology represented mainly soft clayey soils interbeded by stiff sandstones with shallow groundwater level. Partial stabilization of active landslide area were implemented in the end of 2009. However ground movements of 10–15 mm were observed in some parts of the landslides after that time. They have significantly accelerated in May–June 2010, because of record precipitations and a flood in southern Poland. New instrumentation completed in June 2010. It included three landslide monitoring and one meteorological field stations. Monitoring devices included 3D inclinometers, 60 sensors to the depths of 14–16 m, three uniaxial in-place IP sensors, two automatic VW pore pressure as well as groundwater level and temperature transducers. Meteorological monitoring included automatic monitoring of precipitation, air pressure, air humidity, and air temperature values. All data every hour were transferred into the Internet. It should allow recognizing of landslide processes nature and predict alarm warnings for a public road and a new bridge. Special data interpretation software will help to recognize risk conditions. It will sent early warning SMS messages. Continuous monitoring will be conducted till the end of 2012.

Keywords

Landslide monitoring • Early warning system

Landslides Localization and Characterization

The monitoring system include three field monitoring stations and meteorological station. They were installed on active landslides above a public road in Malopolskie District, southern Poland (Fig. 1). In the research area, complex of six connected landslides with active movements towards Bystrzanka River Valley were localized. In this valley over 30 % of area are landslides. Monitoring devices were localized on three landslides no 1, 5, and 6 (Fig. 2). These landslides were characterized by depths 7–20 m, areas 3.7–6 ha, lengths 350–500 m and widths 150–200 m. New monitoring system installation was preceded by the site investigations and standard monitoring measurements which were realized 2006–2010 (Fig. 3). It was detected that some parts of the landslides were active with cumulated displacements 90–180 mm to the depth of 10.8 m.

– *Landslides no 1* large active landslide altitude 300–370 m above the see level, length 355 m, width 116 m, slope

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Fig. 1 Landslide localization map

inclination 9 °, landslide depth 6–11 m. Important public road, two private buildings, power, gas and water supply infrastructure in risk area. Real time monitoring M1 Field Station located in landslide central part including three uniaxial in-place inclinometers to the depth of 12 m, automatic pore pressure VW transducer and automatic piezometer. Fully automatic whether station located near the border of the landslide area.

– *Landslides no 2–4* small landslides, altitude 300–315 m, length/width 38/65 m, 100/154 m, 27/50 m between landslides no 1 and 5, close to the public road.
– *Landslide no 5*, very large active landslide, altitude 310–405 m, length 476 m, width 180 m, slope inclination 9–12 °, landslide depth 3–20 m, in lower parts partly stabilized. Important public road, 7 private buildings, power gas and water supply infrastructure in risk area. Real time 3D monitoring M2 Field Station (16 m depth) located in upper part of the landslide, 250 m above the standard inclinometer (18 m depth) and VW transducer (10 m depth) installed in 2005
– *Landslide no 6*, – large, active, landslide close to new bridge, altitude 315–405 m, length 561 m, width 147 m, slope inclination 6–9 °, landslide depth 6–20 m. New bridge, important public road, 10 private buildings, power, gas and water supply infrastructure in risk area. Real time 3D monitoring M3 Field Station (12 m depth) located in the lower art of the landslide 100 m above new bridge near the standard inclinometer (7.5 m depth) and piezometer installed in 2005.

Some parts of presented landslides were stabilized within the SOPO Landslide Counteraction Framework Project financed by the state budget and European Investment Bank in 2009. Stabilization works included anchors, Geobrugg high tensile wire mesh, gabion retaining walls along the river, internal and surface draining system. Anchors length of 6–15 m were drilled into the bedrock (Fig. 4). It helped to safeguard the road area however full stabilization was not possible due to landslides size and activities. Some parts of the landslides located close to road, bridge and private buildings were still active in June 2010 after the record precipitations. They caused infiltrations of groundwater's in upper parts of the landslides and movements activation (Fig. 5). New cracks, high strains in Geobrugg meshes, some destructions of drainage systems and a new cracks at buildings were observed. Previous movements depended mainly on precipitations and snow melting conditions. They were influenced by creeping processes, clayey flysch deposits strength parameters, slope inclination, infiltration processes (high pore pressure) and undercutting of landslide head during a road construction. It was confirmed by inclinometer measurements. Landslides were investigated by Poltegor-Institute in Bednarczyk (2006–2010) by the network of three standard monitoring points to the depth of 7.5, 15, and 18 m. These measurements showed that full landslide stabilization were not reached. That was caused by not fully effective landslide drainage system and difficulties in stabilization of Bystrzyca landslide lower part. Also some others landslides head parts were not stabilized due to limited financing. Displacements have accelerated mainly in periods after intensive rainfalls as in May-June 2010 (2 June 2010, 100 mm rainfall in 3 h time), when some parts of counteraction works were partly damaged (Figs. 6, 7, 8, 9, and 10). They were also intensive in some central parts of the landslides, where new ground movements and cracks occurred (Figs. 7 and 8).

Instrumentation

Five core diamond impregnated boreholes to the depth of 14–16 m, total lengths of 100 m, were used for instrumentation. At two boreholes, 3D real-time M2 and M3 inclinometer systems to the depth of 14 and 16 m were installed. At the third M1 borehole three uniaxial in-place inclinometer sensors were installed. Piezometer and vented wire transducer were located in the boreholes drilled at the distance of 2 m from the inclinometer sites. List of installed instrumentation is presented in the Table 1.

The laboratory test program included index tests, direct shear tests, IL oedometer tests and triaxial CID and CIU tests on selected soil samples. Obtained results indicated that soils to the depths of 12–15 m were characterized by low strength parameters and very high moisture content. They represented highly saturated clayey loams, clays and claystone gravel with high plasticity ratio located at the steep slopes of Bystrzanka River Valley (Figs. 1 and 2).

Fig. 2 Place of real-time monitoring system installation

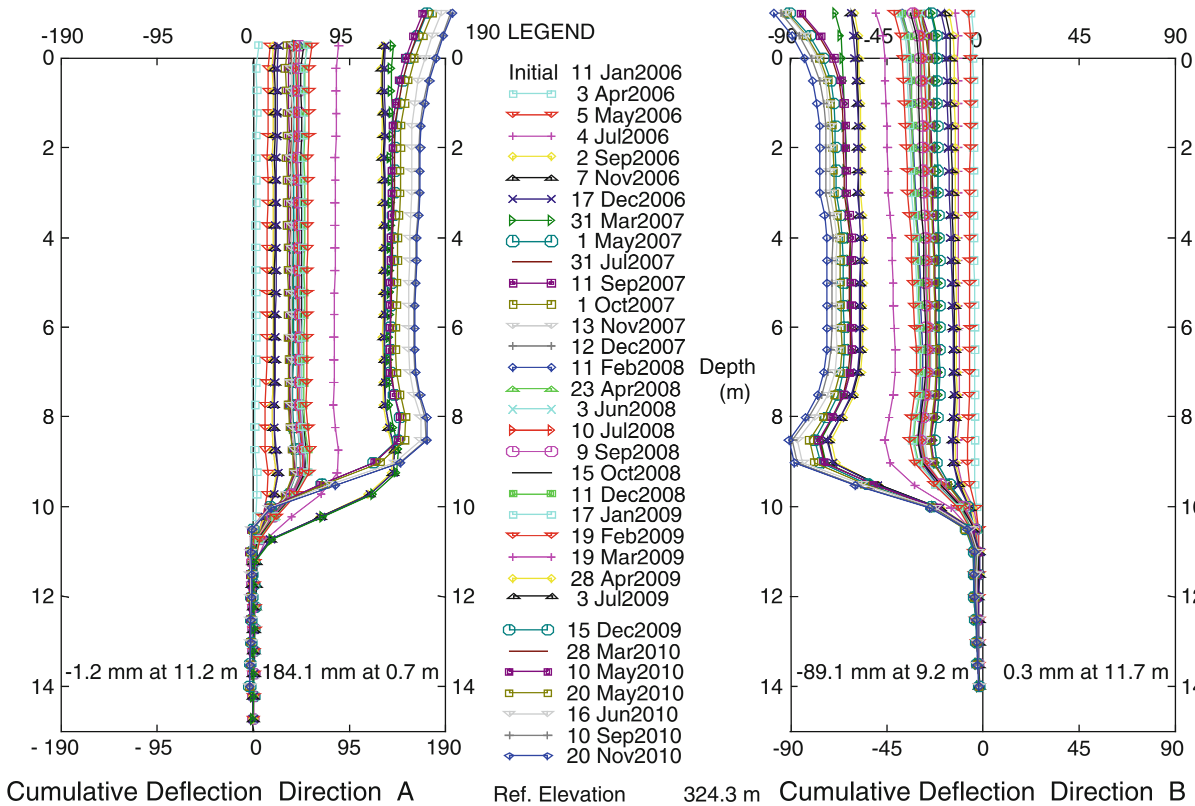

Fig. 3 Cum. displacements in stand. inclinometer at landslide no 1

Fig. 4 Partly stabilized part of the Szymbark-Szalowa public road

Fig. 5 Groundwater reservoirs in *upper part* of landslide no 1

Fig. 6 Damages in partly stabilized *lower part* of landslide no 1

Fig. 7 New cracks (May 2010) – *central part* of landslide no 5

Fig. 8 Destructions of a public road (erosion) landslide no 6

Colluviums depths recognized by boreholes varied from 10.20 at borehole M1 to 11.50 m at borehole M3. Preliminary results of 3D monitoring showed that at M2 earth station ground movements were active to the depth of 15 m, however deeper movements had lower rate than in higher, shallow parts of the colluvium profile.

Fig. 9 New cracks – land no 5

Fig. 10 Damages of drainage system – landslide no 6

Table 1 List of installed instrumentation

Earth station	Measurement type	Instrument depth [m]	Altitude [m] above see level	Landslide
M1	In-place 2D inclinometer	7–10	328.0	No 1
M1/P1	Water pore pressure temperature	11	328.3	No 1
M1/P2	Groundwater level	10	328.5	No 1
M2	3D inclinometers	0–16	359.6	No 5
M3	3D inclinometers	0–12	338.1	No 6
W	Precipitations, atmospheric pressure, air temperature and humidity	1 m above natural terrain level	320.0	No 1 PAS Research Station

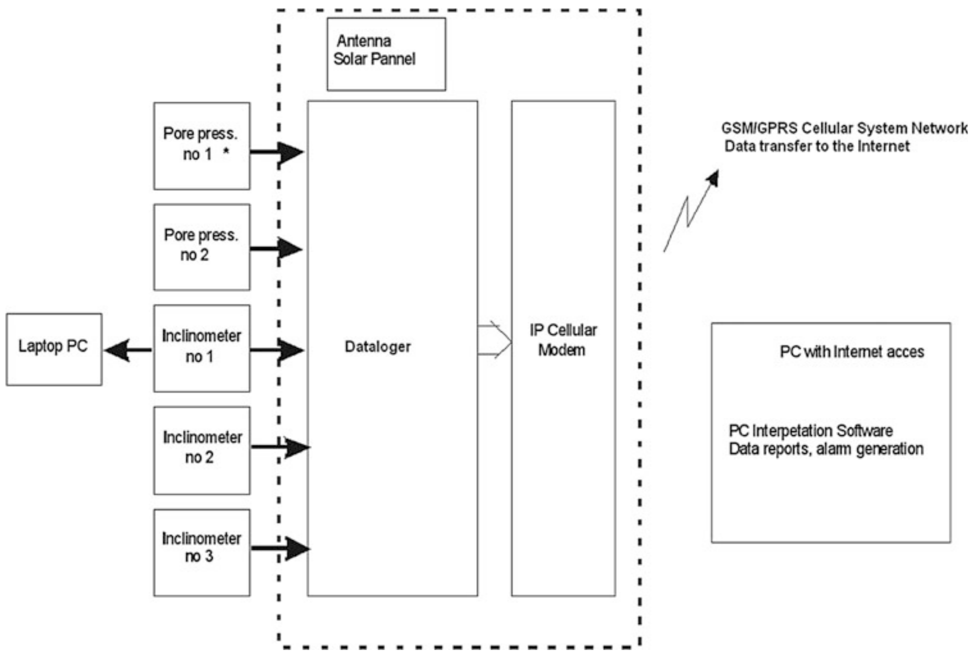

Fig. 11 Real-time landslide monitoring system scheme.* pore pressure semi-automatic transducer installed 2006 – not included in the system

System Scheme

The instrumentation was proceed by study of landslide data and input parameters. Depths of installation were chosen with respect to expected sliding surface depths and groundwater conditions. Standard inclinometer measurements and results of laboratory tests were included in the prediction. System is consisted of four stations. Three fully automated landslide monitoring field stations and the weather station. Data were stored in the loggers and transmitted using cellular GPRS network to the Internet. System was powered by batteries and solar panels (Figs. 11 and 12) (Figs. 13, 15, and 19).

The scheme of ground movement, groundwater temperature and pore pressure monitoring system is presented on Fig. 11. System were activated and calibrated in the end of May 2010. Earth stations worked separately with dataloggers and cellular data transfer to the Internet. Central points of every station were loggers collecting and transferring data by GSM/GPRS network to the Internet and then to the server. Data could be edited for risk levels predictions and exported to others software's in "txt" format. Every device were calibrated for measurement depths, number of transducers and specific calibration values. Data access could be defined for various verified users. Alarms conditions could be generated by SMS messages or emails to defined users. Data stored in the loggers could be uploaded manually to a laptop PC. Earth stations were installed in waterproof enclosures and powered by high capacity battery charged additionally by solar panels in order to ensure maintains-free operation. It allows also to control power supplies (Fig. 19) and GSM signal strength. System contains:

- Two automatic groundwater level, pore pressure and temperature transducers in piezometric boreholes to the depth of 10 and 11 m.

  Device parameters:
  - Measuring rang 1.5 Bar
  - Accuracy: 0.025 %

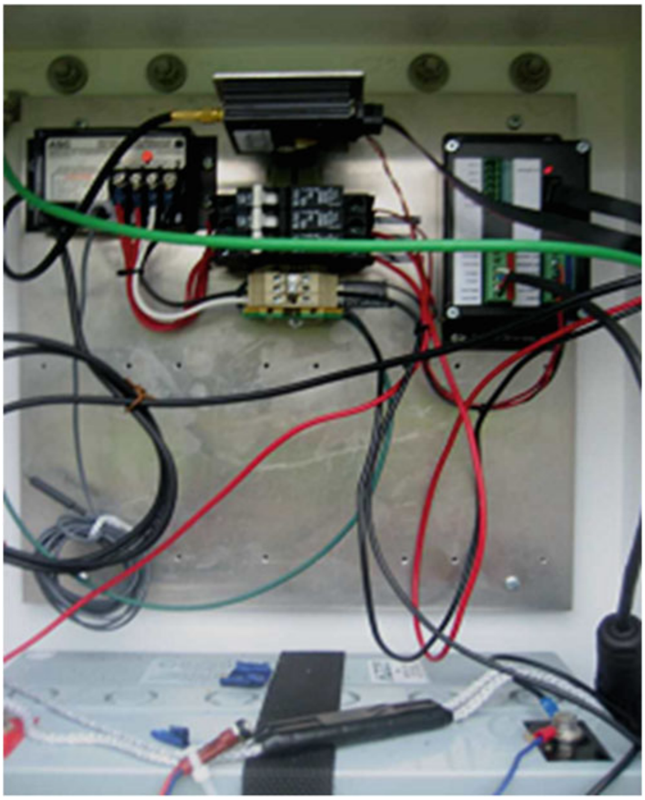

Fig. 12 Interior of M2 Field Station

Fig. 13 M2 Field Station on landslide no 5

- Calibration accuracy: ± 0.1 %
- Maximal pressure: 2 × range
- Coefficient of temperature: <0.02 % for 1 °C
- Transducer diameter <29 mm

* Three ground movement inclinometer systems:
* Inclinometer no 1 (M1) consist of three uniaxial IP sensors, every 1 m connected in rows (multiplex), pulled into inclinometer casings diam. of 70 mm to the depth of 7–10 m

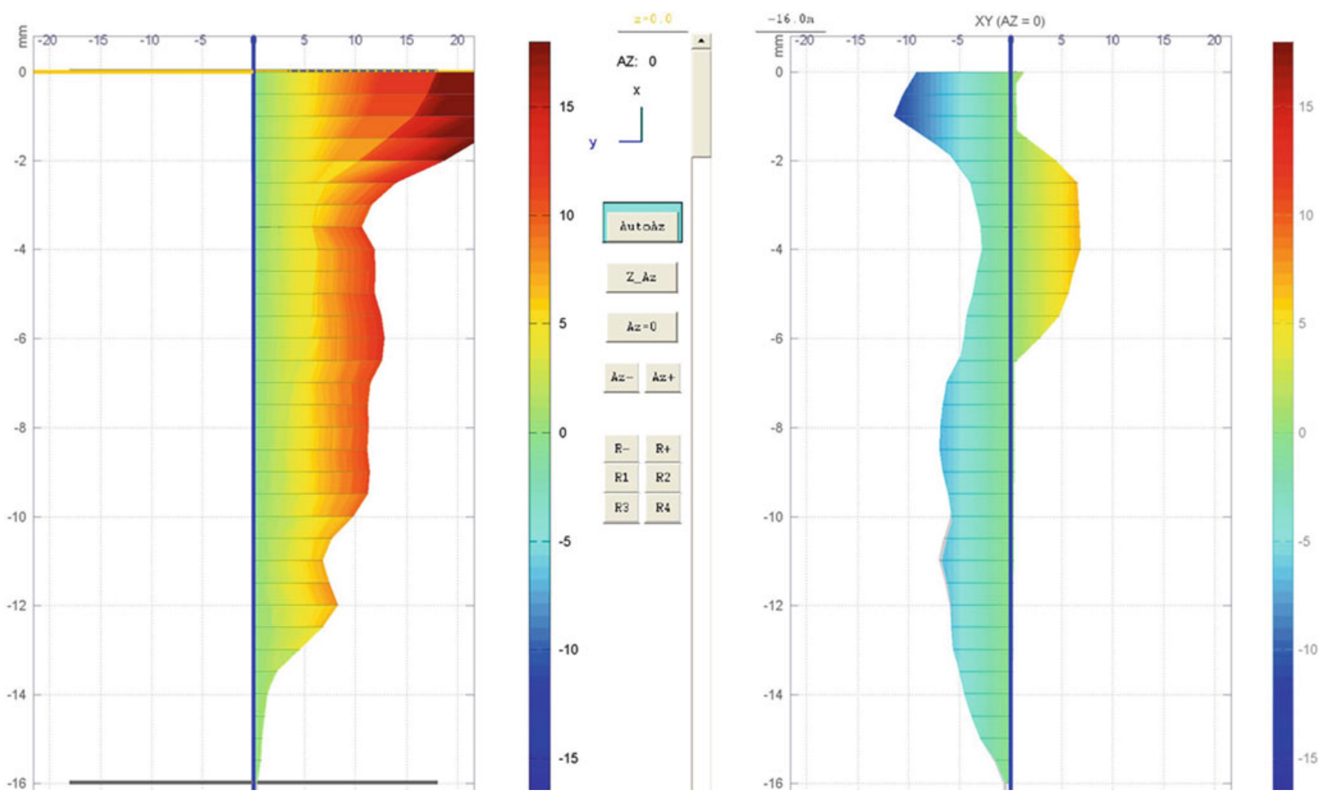

Fig. 14 2D ground movement's preliminary results M2 Field Station in *upper part* of the landslide complex

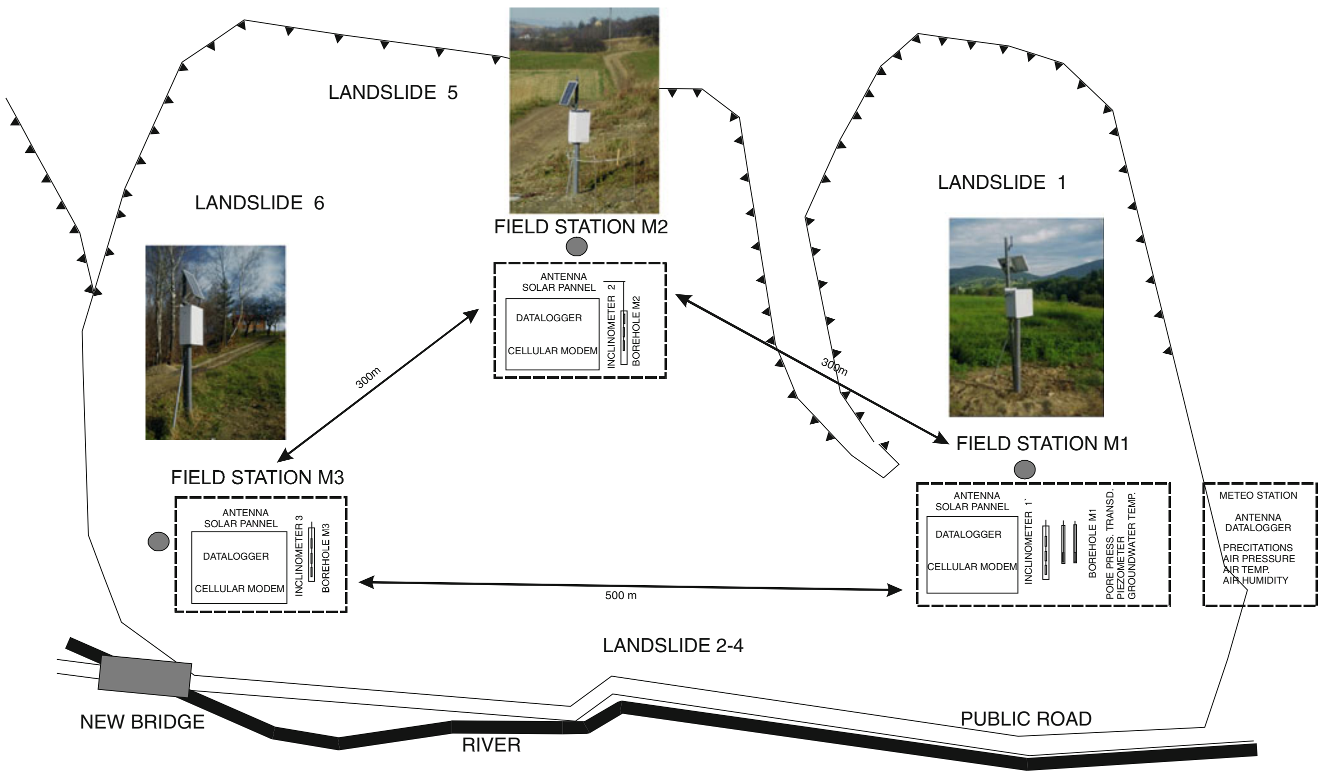

Fig. 15 Scheme of connections between monitoring devices, loggers and data transfer system

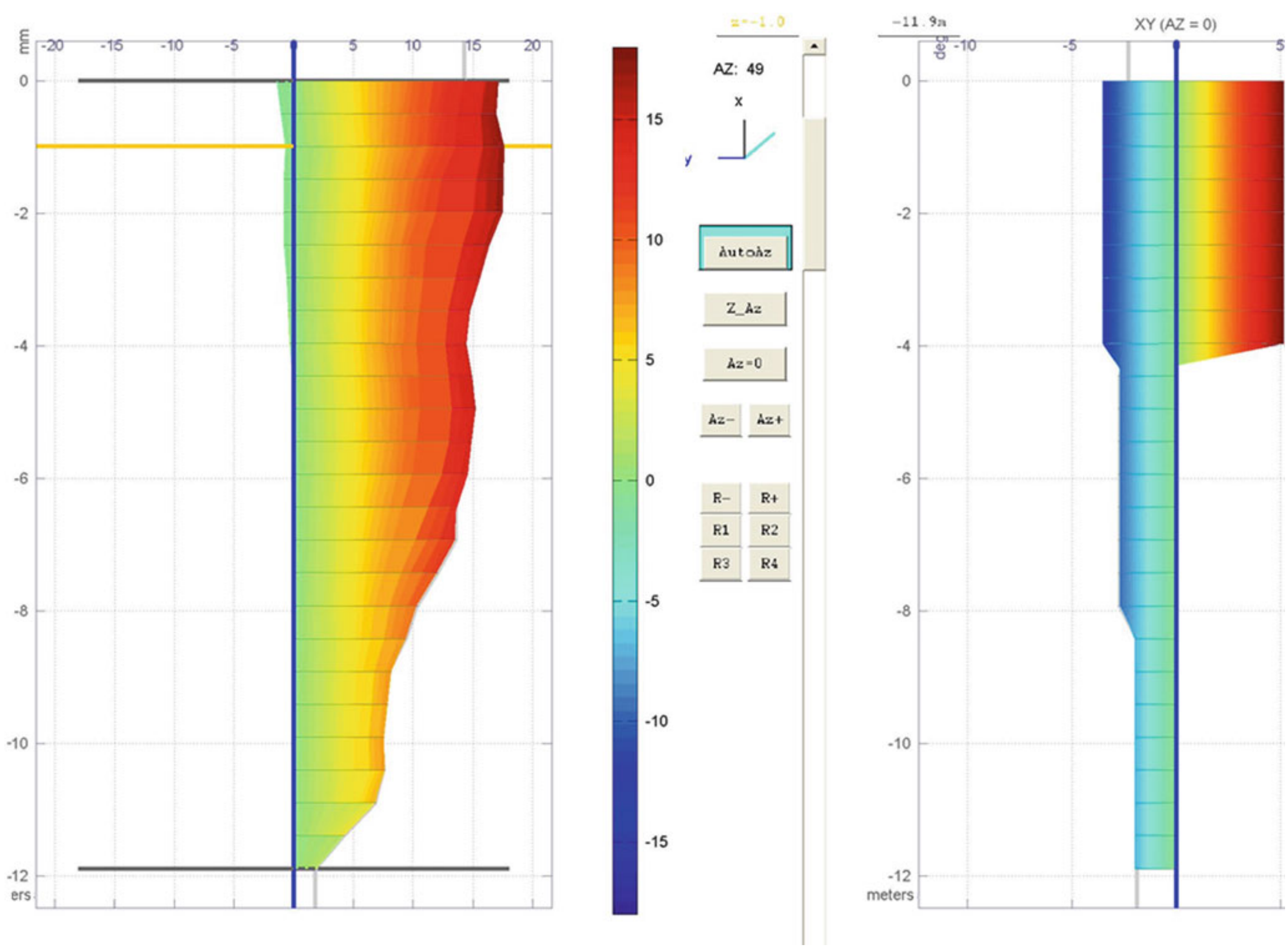

Fig. 16 2D ground movement's preliminary results, M3 Field Station located over the new bridge on Bystrzanka River

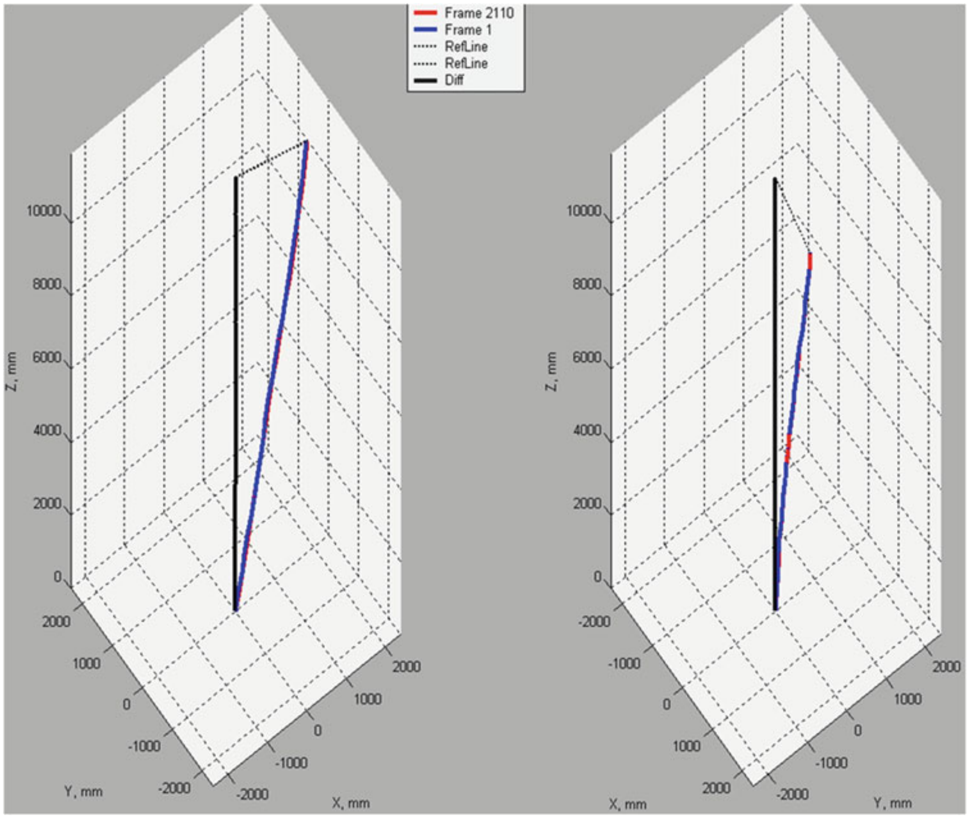

Fig. 17 3D displacements at M3 Field Station

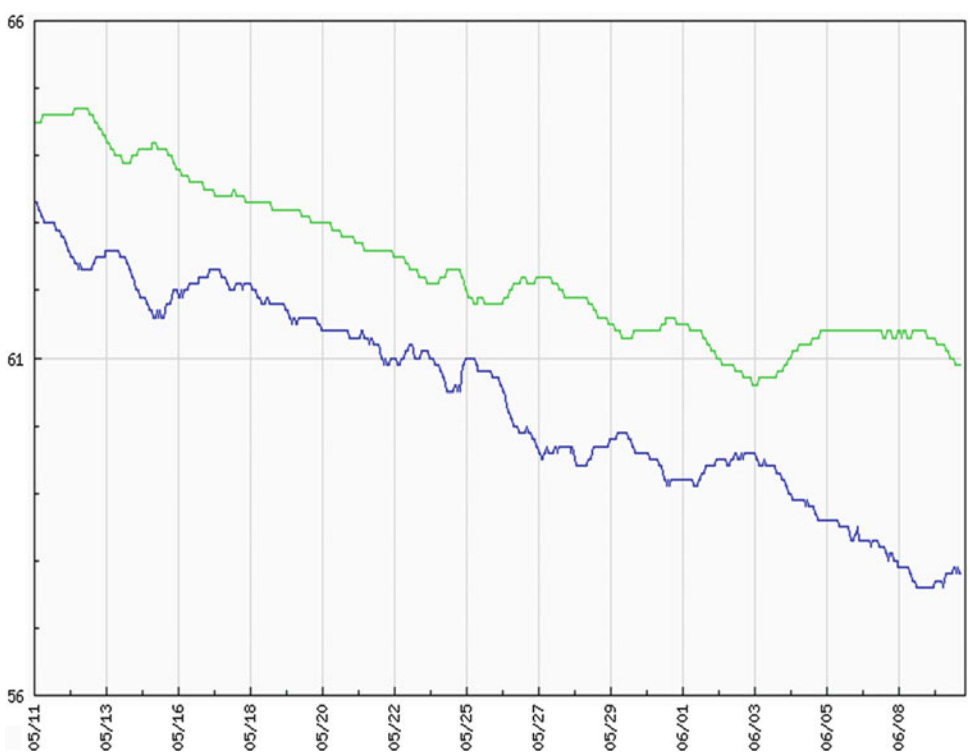

Fig. 18 Pore pressure monitoring M1 Field Station

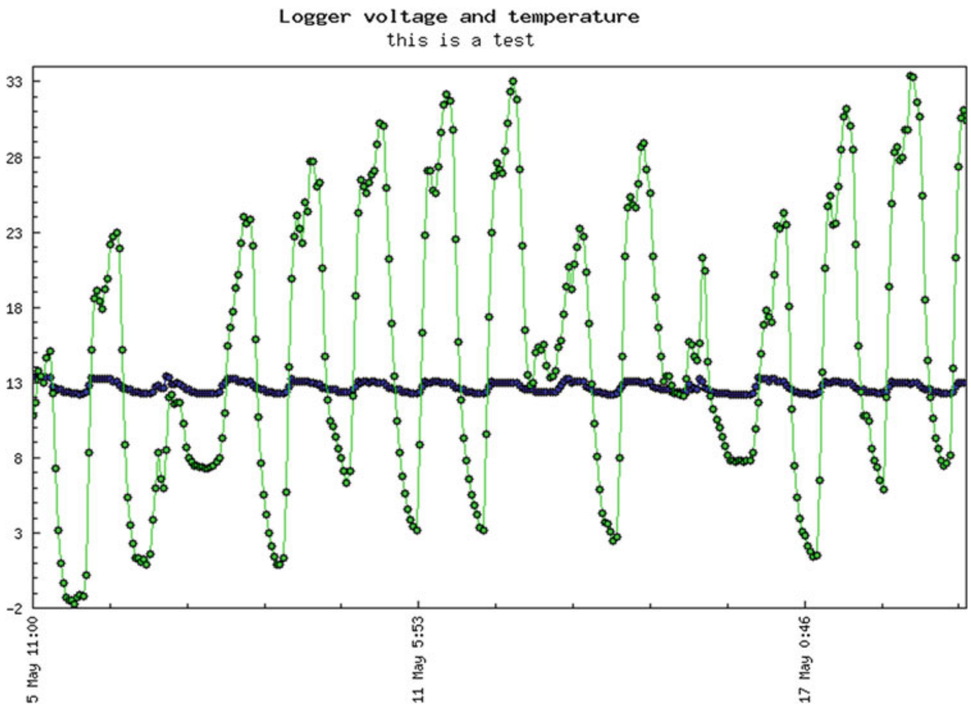

Fig. 19 M1 Field Station battery charge control

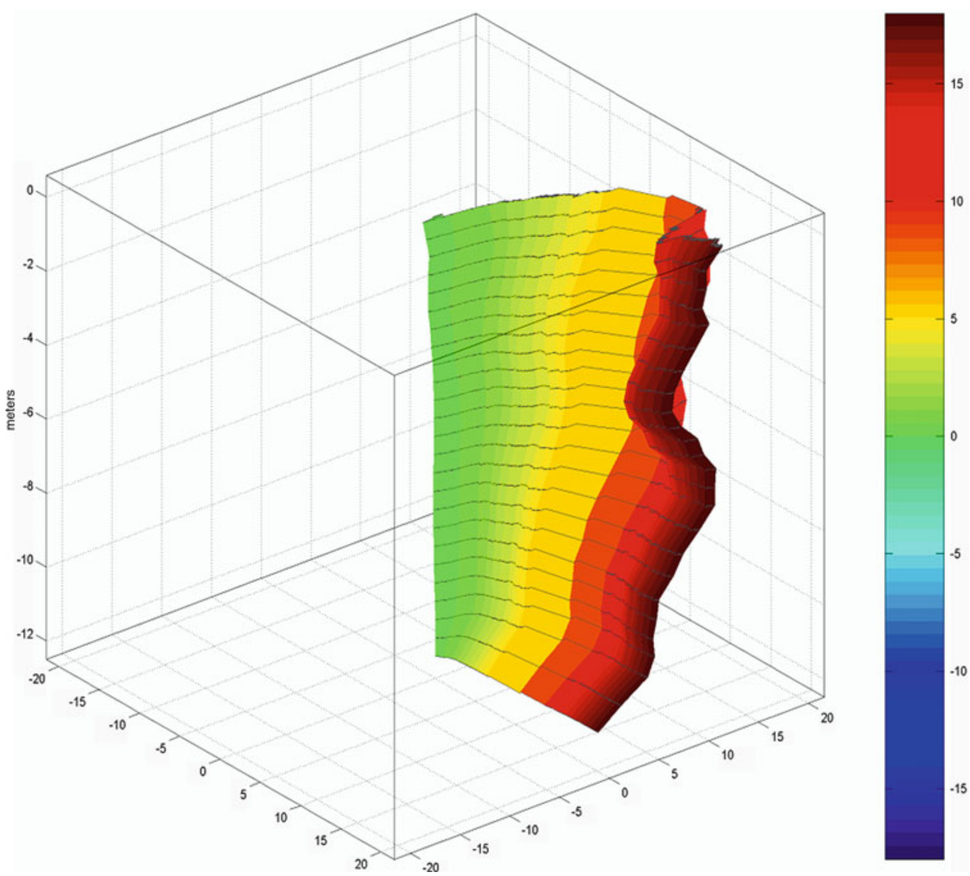

Fig. 20 3D displacement model, M3 monitoring station

Fig. 21 Automatic whether station

Device parameters (inclinometer no 1):

– Measuring range: ± 10 °.
– Accuracy: 9 s or 0.04 mm/m using datalogger,
– Accuracy: 0.04 mm/m
– Calibration: 11 calibration points in three temperatures in range 4–20 °C

• Inclinometer no 2 ÷ 3 – 3D inclinometers consist of :

– Inclinometer 2 (M2) – four segments, eight transducers every 50 cm, total length of 16 m
– Inclinometer 3 (M3) – three segments eight transducers every 50 cm, total length of 14 m

Device parameters (inclinometer no 2–3)

– Measuring range: ± 45 °.
– Accuracy inclination 20° from vertical 0.02 mm/m (0.029 °.).
– Mistake of joints (azimuth) <+/−0.25 °.
– Perpendicularity of segments: +/−0.1 °.

The scheme of the system components and connections is presented on Fig. 11. System consists of three field stations registering landslide data equipped with dataloggers, and multiplexers for inclinometer, groundwater level, temperature and pore pressure measurements. High capacity batteries charged by solar panels providing power supplies. The system powered by lithium batteries allowing at least 3 months of system operation without maintains. Data could be uploaded from the logger at the field manually to a laptop PC. The system is also equipped with special USB converter allowing uploading manually data to laptop PC by direct connection to the transducers (not using dataloggers). This function was valuable for zero readings and system calibration.

Real-Time Monitoring Preliminary Results

Automatic monitoring measurements started in May/June 2010 and will be performed continuously till the end of 2012. Displacements will be compared with groundwater level, temperature and pore pressure readings. This measurements will be analyzed using whether station data including precipitations, temperature, air humidity and air pressure. Obtained correlations will be used for designing of early warning system and prediction of alarm stages. Preliminary results of monitoring measurements presented on Figs. 14, 16, 17, 18, 20 showed that variable displacements were registered up to 11–15 m. At M3 field station, between 24 May and 10 June 2010 displacements reached value of 1.3 cm. Sliding zone depth at that point was 12.4 m bellow natural terrain level. At M2 field station between 18 May till 7 September displacements reached 18 mm and were activated to 15 m depth, however, the largest were registered at depth of 2 m. The values of pore pressure at the landslides were very high 57–63.9 kPa. The interpretation software allowed 3D presentation of measured displacements (Figs. 17–20 and 22). It showed that displacements at M3 Field Station were rotated towards a new bridge on Bystrzanka River (Figs. 15–17).

Real Time Weather Conditions Monitoring

The weather conditions were investigated using automatic station installed near the border of landslide no 1 (Fig. 21). Measurements were stored in the logger and transmitted every 60 min to the Internet using GPRS network. Station enabled continuous observation of precipitations, air pressure, air temperature and air humidity values. The battery voltage and GSM signal level were also continuously controlled. This allowed prevention of data loosing. Obtained data could be exported as “txt” files or edited as a plots (Fig. 22). Since April 2011 the station is additionally powered by the solar panel.

The meteorological parameters measurements has been started in May 2010 air pressure in August 2010. Exemplar daily values of precipitations are presented on Fig. 22. It allowed registration of record monthly precipitations in

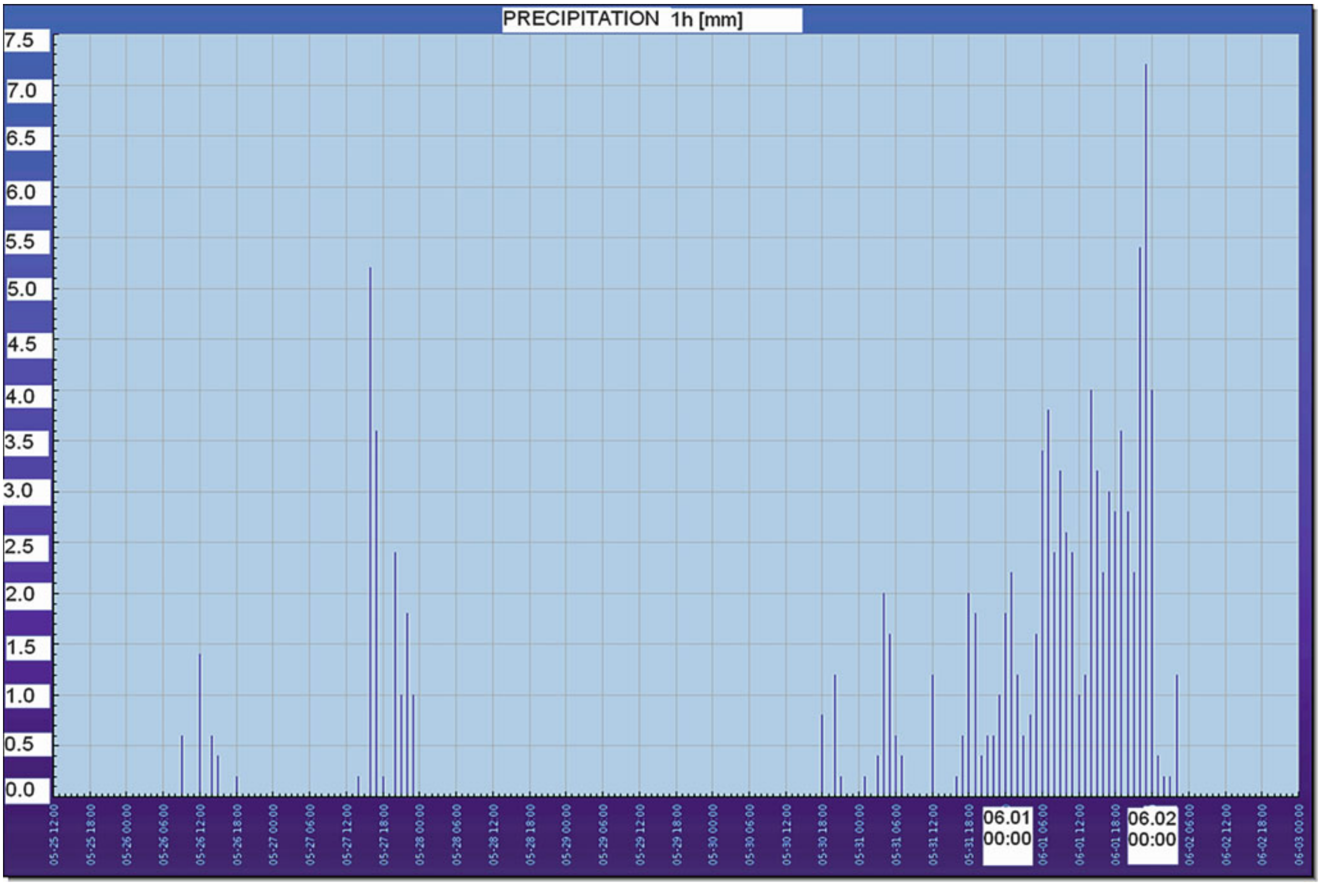

Fig. 22 Precipitation values May/June2010

May–June 2010. Detected record precipitations between June the 1 and June the 2 reached 100 mm (Fig. 22). Meteorlogical parameters will correlated with displacements and pore pressure data.

Conclusions

Implementation of new real-time monitoring system in the Polish Carpathians was presented in the paper. Preliminary monitoring results has been shortly described. On three active and dangerous landslides modern field monitoring stations were installed. They included 3 inclinometers, total length of 50 m and 3 groundwater level, pore pressure and temperature transducers. New geological and geotechnical engineering data were obtained. Detailed recognition of landslides depths and activities will be possible after a longer period of time but preliminary results indicated that ground movements occurred to the depth of 0–15 m. Colluviums were characterized by variable mechanical parameters to the depths of 11–15 m bellow the natural terrain level. The highly saturated (20–40 %) mixtures of weathered, disintegrated claystones and clays with very high plasticity index were recognized to the depths of 3–7 m. Landslides located above Szymbark-Bystra public road were still active despite of partly stabilization works. They had influence road area what was seen on tightening of Geobrugg meshes and new cracks in head landslides parts. It was also visible near the new bridge over the Bystrzanka River. Record precipitations in May and June 2010 indicated that some parts of counteraction works were not fully effective in extreme whether conditions. New system allowed monitoring these of risk sites. Obtained data should be used for correction of counteraction works and early warning messages.

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