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Original Research Article

MONITORING OF LANDSLIDE AREAS WITH THE USE OF CONTEMPORARY METHODS OF MEASURING AND MAPPING

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Abstract

In recent years, there is an increase of landslide risk observed, which is associated with intensive anthropogenic activities and extreme weather conditions. Appropriate monitoring and proper development of measurements resulting as maps of areas at risk of landslides enables us to estimate the risk in the social and economic aspect. Landslide monitoring in the framework of SOPO project is performed by several methods of measurements: monitoring of surface (GNSS measurement and laser scanning), monitoring in-deepth (inclinometer measurements) and monitoring of the hydrological changes and precipitation (measuring changes in water-table and rainfall).

Keywords: landslide, SOPO system, GNSS measurement, laser scanning

1. INTRODUCTION

The problem of attracting new investment areas and the inability of current locations are associated with the desire to use for development of all hazardous location area. One way of attracting new investment areas is the development of landslide areas. Landslides are natural processes of the soil and rock movement,

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either natural or anthropogenic, the consequences of which threaten property, health and life of people.

In recent years, there is an increase of landslide risk observed, which is associated mostly with the fact that there is a considerable development of areas at risk of landslides. This is the result, on one hand, the inability to recognize by the investors these types of threats, on the other hand, the lack of attractive both economically and tourists areas for land use planning.

The problem of attracting new investment areas and the inability of current zoning areas, allows us to understand why it is impossible to completely rule out building on landslide areas. Therefore, it becomes important issue of monitoring areas at risk of landslides. Only through appropriate monitoring and proper development of measurements resulting as maps of areas at risk of landslides enables us to estimate the risk and the relevant economic calculation for the realization of the anticipated investment in such areas.

2. LANDSLIDES AND LAND USE PLANNING

Landslide is a form created by the gravitational movement, causing relatively rapid movement of rock or soil masses, in the direction of gravitational force on the slopes resulting in rock material being moved from the upper part to the lower part of the slope [4]. In addition to the geological structure of the ground, the main factors influencing the formation of landslides are the slope inclination and occurrence of heavy rainfall over considered area, which is associated with hydrological properties of the subsoil (Fig. 1).

A major factor in the planning and spatial management of landslide areas seems to be the division based on landslide activity, understood as behaviour of the masses of soil and rock defined as a function of time.

A major criterion for the planning and zoning landslide areas seems to be dividing them based on their activity, understood as the behaviour of the masses of rock or soil specified in relation to time.

Due to these characteristics landslides are divided into:

- periodically active (periodic) landslide - a landslide within which active symptoms occur at irregular intervals, over the last 50 years,
- continually active (chronic) landslide - a landslide that are in constant motion, until they reach static equilibrium of the slope,
- inactive (stabilized) landslide - a landslide without observed and documented signs of activity for at least 50 years.

However, it raises the question whether the return period of fifty years is sufficient to consider the area as safe. In the municipality of Strzyżow (Subcarpathian Voivodeship) it came to the demolition of the houses that were built just on former landslide areas considered already as stabilized.

Hence, so important it is the aspect of recognition through proper monitoring areas at risk of landslides.

Fig. 1. Examples of the effects of the damage associated with activation of landslide [5]

Neither landslide phenomena may be predicted, nor we effectively counteract them in many cases. Usually, the main factors causing the movement of earth masses belong to the group of non-anthropogenic factors. So, a very important aspect in the management of landslide areas is the awareness of citizens and local authorities. It allows us to minimize the damage caused by sudden and unpredictable movements of the ground. Preventive steps include the creation of an efficient system of information on landslides. Proper use of areas vulnerable to landslides soil and rock masses, control and monitoring of the negative impact of rainwater and groundwater, as well as mechanical rock and soil improvement may contribute to this as well [1,2,4].

Primary source of information on landslides, which will be used in the planning process is currently developed by the Polish Ministry of Environment order. It results as SOPO project - System Guards Against Landslides [http://geoportal.pgi.gov.pl].

The primary objectives of mentioned above nationwide project are identification, documentation and application on the map in the scale of 1:10000 all landslides and areas potentially at risk of soil and rock movements in Poland. Also the establishment of surface and subsurface monitoring systems on one hundred selected landslides is expected. The end of the project, which has been conducted for four years is foreseen for year 2016.

The results of the project are to help reduce the damage and destruction caused by landslides. Implementation of the tasks provided for the schedule of the project is to assist local authorities in fulfilling obligations concerning the issue of soil and rock movements under the relevant laws and regulations acts.

3. LEGAL CONDITIONS AND LANDSLIDE AREAS

According to *the Act of April 27, 2001. Environmental Protection Law* [15] - the mass movements of the earth has been defined as naturally occurring or as the result of human activity landslide, downhill creep, or pulls the surface layers of rock and/or weathering and/or soil. This Act has been imposing on local prefects obligation to register areas endangered by mass movements of the earth and the lands on which there are these movements present.

According to *the Act of March 27, 2003 on spatial planning and development* [16] - which imposes on local authorities to take account of landslide areas in the records and show on the maps for urban planning community. The document is obligatory for the entire area of municipality, as well as local spatial plans. Furthermore, the above-mentioned act also obliges the authority performing a study or future plan to request opinions on solutions to the competent authority of a geological survey. At the stage of study of the conditions and directions of spatial development of municipalities it should be taken into account the existence of areas of natural geological hazards and the identification of areas at risk of flooding and landslides. The local spatial development plan obligatory defines the boundaries and ways of developing areas or buildings to be protected. It should be established also on the basis of separate regulations, including structures on the mining areas as well as areas at risk of flooding and risk of landslides. According to t*he Act of February 3, 1995 on the protection of agricultural land and forestry* [17], the protection of agricultural and forest land consists, among other things, of the prevention of degradation processes and devastation of land, as well as the damage to agricultural production and forestry, arising as a result of non-agricultural activities and mass movements of the earth. It is up to the owner of land the prevention of soil degradation, including erosion and mass movements of the earth.

4. MONITORING OF LANDSLIDES

The Regulation of the Minister of Environment of June 20, 2007 on the information regarding the mass movements of the earth imposed on us the necessity of monitoring areas where there were and there are mass movements that may cause or result in a direct threat either to people's lives, or technical or communication infrastructure [8].

That monitoring is based on the measurement of soil surface movement in order to determine the speed and character of displacements and should be implemented in particular using surveying methods. When monitoring of the surface is not sufficient enough to determine the rate and range of the earth masses movement, it is recommended to monitored subsurface layers of the earth downhole measuring the movement of the earth masses in order to identify the number, type and depth of the slip sections of the soil or soft rocks.

In accordance with the *Regulation*, monitoring is carried out at least twice a year (in the periods March-April and September-October) and each time after the occurrence of extreme natural phenomena that may cause mass movements of the earth. The results of the monitoring of prescribed *Regulation* should be introduced to the Register, which is kept as electronic database and includes:

- graphical data in the form of maps of areas at risk, drawn up in spatial information system GIS, made on the backing sheet topographic map scaled of 1: 10,000,
- a registration card of area threatened by the mass movements of land or a landslide.

The system for landslides monitoring, according to *the Instruction to develop Maps of landslides and areas endangered by mass movements on a scale of 1: 10,000*, should include four phases: design, field works associated with the installation of the measuring system, monitoring (measurements) and the documentation [6,18]. The project should include the scope and methods of monitoring of earth surface, as well as the depth inside the landslide. Field works of the surveying maps include the implementation of situational and altitude map, and stabilization of the measurement points, and the installation of instruments to observe the landslide. The surface monitoring is usually performed using the following methods: GPS measurements, classic methods of surveying, terrestrial laser scanning, airborne laser scanning, satellite radar interferometry and photogrammetric methods.

The surface monitoring performed by the classical methods of surveying is carried out on the basis of stabilized grid of measurement points within the landslide. Measurement points should be located in areas with the largest activity of landslides and simultaneously satisfy the condition of durability of the foundation, which allows multiple measurements. The measurement point for surface monitoring should be located so as to enable the measurement of the X, Y, Z coordinates by the methods set out in the project. Additionally, either three reference points, or three 3rd class points located outside the area covered by the motion the landslide, in respect of which, the measurements will be carried out, should be selected.

As part of the third phase monitoring can be carried out by the methods of classical surveying, or with the use of GPS equipment. Classical surveying (direct measurements) is based on a network of points stabilized on the surface and monitoring points located into the depth. Measurements should be done at least three times a year, and the measurement results should be summarized in tabular form giving the coordinates X, Y, Z. Monitoring of with the use of GPS equipment should be made by the static method with determination of basis points. The interpretation of stereoscopic aerial photographs has been for years a standard method used to initial recognition of landslide range. Recent years have brought new technological solutions that provide additional capabilities in the analysis of digital aerial photographs.

Digital photogrammetric stations offer new tools to generate high-rise photogrammetric models of terrain based on stereo pairs of aerial photographs. The use of archival stereo pairs of aerial photographs allows us to trace the movement of landslides over the years. It also allows to calculate the volume of rock masses displaced at a specified time and to determine the dynamics of movements. Unfortunately, sometimes aerial photographs are of limited use in analysing of the terrain, especially for areas covered with forests.

The technique of Airborne Laser Scanning (ALS) is successfully applied in recent years,. The result of ALS is a cloud of points, which accurately depicts the outline of objects being scanned. By filtering of the cloud one may receive digital terrain model devoid of errors due to masking action of vegetation.

A new quality of landslide monitoring is provided by the data derived from Airborne Laser Scanning and satellite radar interferometry. Both methods allow us observation of large areas with a very high accuracy.

An extremely useful method in the diagnosis of the detailed structure of the landslide is a geophysical method called Electrical Resistivity Tomography (ERT). It allows interpretation of lithology of colluvium of landslide and its substrate. Using this method, one may also recognize the water-bearing zones and to estimate the maximum thickness of colluvium, as well as the depth of occurrence of the slip sections.

According to the manufacturer (IDS) [7] one of the basic directions of use of radar interferometric (IBIS-L and IBIS-M) is the detection, monitoring and prediction of instability of slopes, embankments of settlers and deformation of soil surface and buildings in the areas of mining activity. The instrument of IBIS system allows us for remote, non-contact measurement of unattainable in the current practice precision and frequency. The basis of the device is working in the permitted in European Union Ku-band (17.2 GHz) radar, using previously reserved only for the satellite measurements so called Synthetic Aperture Radar (SAR). Radar emits in the direction of the object a coherent beam of electromagnetic radiation at very low power step-variable frequency and direction by Steeped Frequency Continuous Wave (SFCW), and then receives, registers and analyses signal reflected. A built-in interferometric device performs precise measurement of phase change of the reflected signal relative to the transmitted signal, and allowing for the measurement of displacement of the testing object with a resolution of less than 0.1 mm, while the testing object may be located at a distance up to 5.00 km from the instrument [10,14]. The combination of SAR and SFCW techniques allows the system to resolve the two-dimensional power map [3,13].

5. LANDSLIDE MONITORING IN THE FRAMEWORK OF SOPO

Landslide monitoring in the framework of SOPO is performed by several methods of measurements: monitoring of surface (GNSS measurement and laser scanning), monitoring in-deepth (inclinometer measurements) and monitoring of the hydrological changes and precipitation (measuring changes in water-table and rainfall). In addition, the scope of observation is carried out with supplementary examinations, including the work of mapping, surveying, laboratory tests, the micro-paleontological study and geophysical surveys.

For proper implementation of the surface observation there have been made stabilization points. These works included the establishment of observation network in each of the monitored landslide. These networks done consist on average (depending on the size of the landslide) of twelve permanently stabilized surveying points, measured using precise GPS receivers. A total of 712 points have been stabilized. Some of these points has been completely destroyed or damaged and the network has been complemented or restored during the time of complementary work, but some points, which were destroyed during agricultural work, have not been restored.

In order to achieve geological and monitoring objectives the drillings of boreholes within landslides were performed. Each drilling was performed with the diameter of 132 mm for installation of inclinometers and piezometers and a solid core has been pulled out. During the drilling works, there were performed as well: a description of cores with a special emphasis on follow slip surface, core sampling for laboratory tests (geotechnical analysis) and micro-paleontological, as well as photographic documentation. A total number of 214 boreholes, including 108 inclinometer and 106 and piezometric boreholes have been done. Measurement system for downhole monitoring supplements 15 holes acquired from the local and government units.

Monitoring of hydrogeological and precipitation was based on the measurements of changes in the water table and rainfall. The data collectors Keller's DCX-22 AA and STS BXO-57 measures and registers ground water table levels. As part of phase II of SOPO Project there were prepared in this way 92 measuring boreholes. This measurement system for landslides is complemented with 47 hourly recorded rain gauges (A-ster TPG-036-NH) synchronized with the water table data collectors. Considering the close neighbourhood of monitored objects, some of rain gauges support several landslides. These data are supplemented by the results of measuring from the permanent station belonging to IMiGW [11].

6. CARTOGRAPHIC STUDIES IN FRAME OF SOPO PROJECT

The primary objective of the SOPO program is to develop a procedure for calculating digital elevation models (DEM) as closely depicting the surface morphology of landslides. Calculations are performed for the area scanned using the available software. The various programs have different setting options of input parameters, which define the detection points on the ground and various methods of classification. A list of programs used in the works displayed in Table 1.

Table 1. Software used in the methodology of processing cloud of points [11]

#	Software name
1	ENVI LIDAR
2	Globar Mapper - LIDAR Module
3	Grass
4	InphoDTMaster
5	LasTools
6	LP360
7	Matlab
8	Riscan Pro
9	SCOP

During the study and examination of the data there were requirements and limitations of available software, which contributed to the disqualification, among others, such programs as Grass and Riscan PRO. These version of programs were not enough efficient for data processing from large areas.

The verification stage of digital elevation models was made by the cross-referencing of DEM. In addition to the data calculated using software listed in Table 1, DEM were included based on data provided by ISOK and GUGiK in 'xyz' format at a resolution of 1.0 m, and DEM were calculated from cloud of points classified by ISOK. In addition, the analyses included hybrid solutions. All DEM were calibrated to equal resolution of 0.25 m and interpolated with one method (TIN). The interpolation method was chosen experimentally.

As the result of verification there is the ranking of classification and laser data interpolation methods provided. It determines the most suitable solutions for computing carry out further analyses in defined areas of research, and identifies problems to be solved in future field verification.

Legislation procedures implemented after the "Landslide disaster" in year 2000, required from the local administration in Poland not only the observation of areas at risk of mass movements, but also to collect data on these areas in the form of a database compiled GIS information system. These data, in the form of Map of Landslides and Endangered Areas (MOTZ) in scale of 1:10,000, might be a source of spatial information enabling predictions of mass movements occurrences. Maps of landslides and areas endangered by mass movements are the most important graphical products of SOPO project and the most frequently used by the public. They present spatial range and the degree of activity of landslides along the main elements of the shape and location of the landslide and the areas of potentially at risk of mass movements. The scale of these maps 1:10,000 allows to use them, among others, in the study of local conditions, and spatial development plans at the municipal level, and also in decision-making process for the building conditions (Fig. 2).

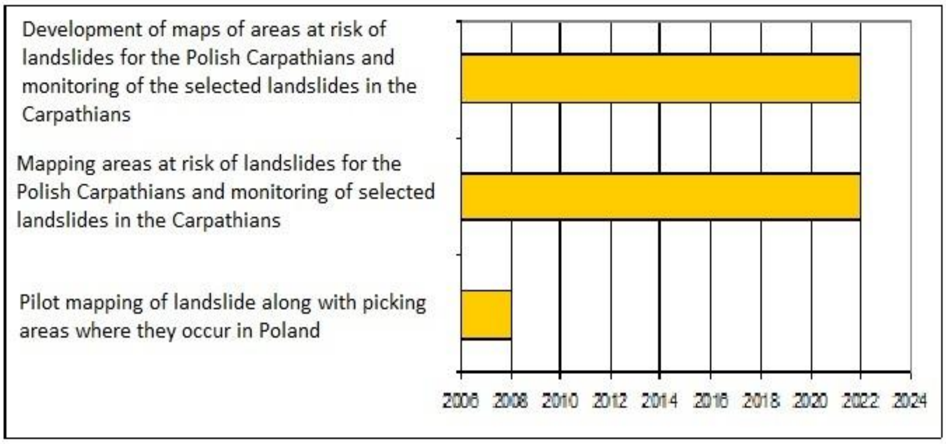

Fig. 2. Cartographic numerical stages of implementation of SOPO project [11]

Since year 2010, during Phase II of SOPO project the maps of landslides have been continuously transmitted to the governors of Subcarpathian districts (then there were transferred to the competent territorial municipalities) in the form of printed paper and electronic CD file (as TIFF or JPEG). In Phase II there have been developed maps of landslides and areas endangered by mass movements of the earth for 198 Subcarpathian municipalities (i.e. representing approximately 75% of the area of the Polish Carpathians). Fig. 3 presents all of 198 Subcarpathian municipalities involved in project, shown by MOTZ on a scale of 1: 10,000.

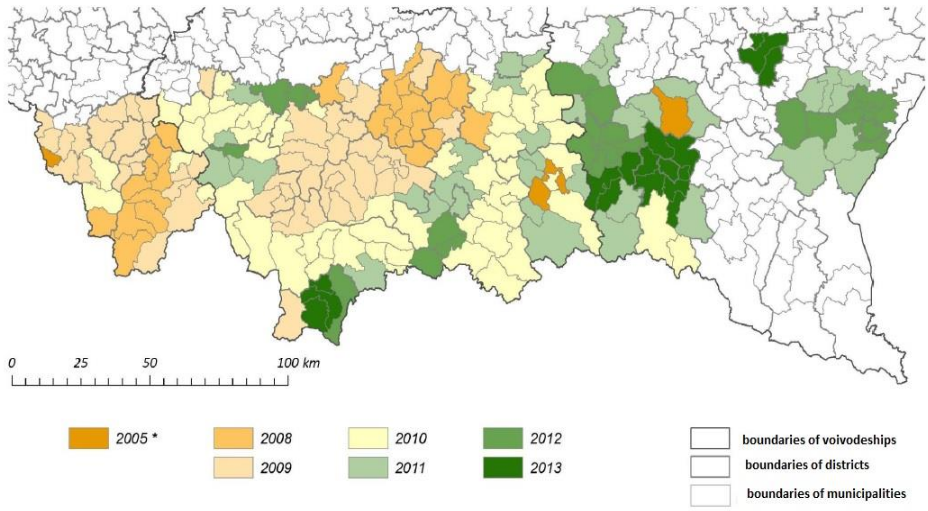

Fig.3. Areas covered by the program - System Guards Against Landslides [11]

Each documented landslide has developed a registration card landslides (KRO), while each risk area for mass movements of the earth - a registration card of area endangered by mass movements (KRTZ). The data compiled in the cards contain the characteristics of landslides or land threatened mass movements of the earth. Data include administrative, geographical, geological, hydrographic, geo-morphological, genetic, morphometric and economic details and the information on the damage caused by the landslide and potential hazards as a result of further development of the landslide. The data collected during the field works and subsequent analysis (i.e. analysis of geological maps, aerial photos and terrain models). The scope and layout of data included in KRO and KRTZ cards comply with the requirements set out in *the Regulation of the Minister of the Environment of 20 June 2007 on the information regarding the mass movements of the earth (Dz. U. 2007 121 840)* [12] already mentioned.

During the implementation of Phase II there were developed about 56 600 of KRO and about 4100 KRTZ in frame of the cartographic and inventory works and several interventions. All KRO and KRTZ are available in SOPO application available on the project website [11].

7. GEOLISP AS A LANDSLIDE VISUALIZATION SOFTWARE

An alternative software, that may be used for data processing of measurements and as a cartographic software is GeoLisp. The package is working in the AutoCAD environment. The GeoLisp system includes a number of programs, which make the most common work on the preparation of cartographic

documentation automatically. All the maps, sketches, charts and geological profiles are quickly and effectively achieved.
One may distinguish the following possibilities of GeoLisp system [9]:

- creating and updating maps on the basis of data obtained from both the direct measurement of terrain detaila and existing maps and aerial photographs,
- obtaining selected thematic map at any scale,
- creating a numerical model of the landslide, aided procedures to facilitate the control and visualization of landslides, earth mass volume calculating, contour interpolation,
- drawing up charts and profiles in longitudinal and transverse direction,
- automatic work when drawing maps (system includes a complete library of convensional signs),
- protection against accidental or deliberate interference in the database content,
- the use of aerial photographs (system includes a program which compensate aerial triangulation),
- transformation between different coordinate systems,
- selection, editing and data report creation for the objects that meet relevant criteria,
- topological cleaning of drawings,
- reading and writing text files in many different data formats.

GeoLisp software contains some typical patterns of charts. It is possible to design and perform simple calculations directly on the chart. One may change the slope of the straight section, perform calculation of the volume between the successive sections, or demonstrating a collision with the local network of technical infrastructure, which increases the value of this software. One may import the results of GeoLisp software with prediction of the deformations to AutoCAD, and then present in the form of contour lines on a background surface map. The software discussed now includes procedures for forecasting and measuring of slopes and landslides. Figure 4 presents the results of data processing and measurements of deformation of landslides and slopes of existing coal mine Bieruń Nowy.

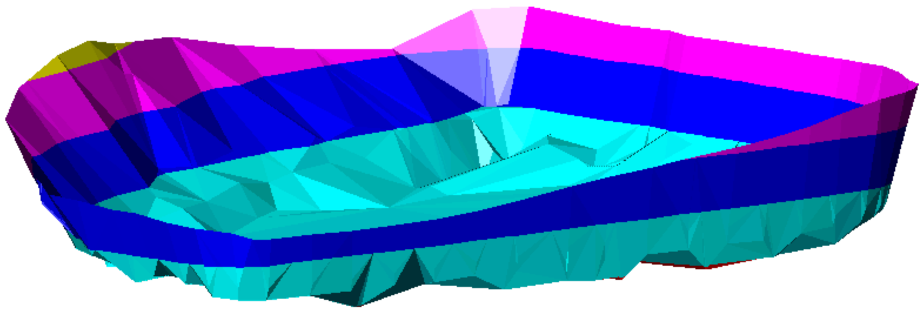

Fig. 4. Numerical model of the terain of the existing coal mine Bieruń Nowy

8. FINAL REMARKS

The results of monitoring of the surface and in-depth of the landslides are supplemented with constant observation of precipitation. The previous analyses and monitoring of landslides show that some of them are continuously active. GPS measurements, especially with laser scanning provide a unique activity data aquired on the surface of each individual landslide. The development of high resolution numerical models of terrain and the creation of differential models based on subsequent measurements, informs us about the size of deformation, both in units of distance (displacements) and volume.
The compatibility of the data with information from in-depth monitoring allows the generation of a very reliable in-depth model of landslide, and as a result proper calculation of the volume of colluvium. GeoLisp software presented here is a very effective tool to generate in-depth model of landslide.
The steps taken under the SOPO project i.e. the monitoring and description of landslides are absolutely necessary for social and economical reasons and they may have a significant impact on the economy and finances of individual municipalities and also a whole country economy.

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MONITORING TERENÓW OSUWISKOWYCH Z WYKORZYSTANIEM WSPÓŁCZESNYCH METOD POMIAROWYCH I KARTOGRAFICZNYCH

S t r e s z c z e n i e

W ostatnich latach obserwowany jest wzrost zagrożeń osuwiskowych, który związany jest głównie z intensywną działalnością człowieka oraz występowaniem ekstremalnych warunków meteorologicznych. Odpowiedni monitoring oraz opracowanie wyników pomiarów w formie map terenów zagrożonych osuwiskowo umożliwia oszacowanie ryzyka w aspekcie społeczno-ekonomicznym. Realizowany obecnie system obserwacyjny projektu SOPO opiera się na następujących formach monitoringu: powierzchniowym (pomiary GNSS i skaning laserowy), głębnym (pomiary inklinometryczne) oraz monitoringu hydrogeologicznym i opadowym (pomiary zmian poziomu zwierciadła wody i wielkości opadów). Pomiary GNSS, a zwłaszcza skaning laserowy dostarczają unikalnych danych o aktywności rejestrowanej na powierzchni poszczególnych osuwisk. Opracowanie numerycznych modeli rzeźby terenu o wysokiej rozdzielczości i tworzenie modeli różnicowych bazujących na kolejnych pomiarach, informuje o wielkościach deformacji zarówno w jednostkach odległościowych jak i objętościowych. Kompatybilność tych danych z informacjami pochodzącymi z monitoringu wgłębnego, umożliwia wygenerowanie bardzo wiarygodnego wgłębnego modelu osuwiska, a w rezultacie obliczenie objętości koluwium.

Słowa kluczowe: osuwisko, system SOPO, pomiary GNNS, skaning laserowy

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