LANDSLIDE MONITORING IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT

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Abstract: *Environment protection has been, even since ancient times, one of man's major interests, given the obvious negative impact of anthropic activities on natural environment. For ancient cities the need for clean water supply was a necessity and managing waste became necessary whenever people organized a settlement. It is vital for us to know the ecological state of the world, as well as to determine the dangers that might affect the environment, including the irrational exploitation of natural resources, demographical problems, unsustainable development and climate change. A hazard is a very damaging natural or anthropic phenomenon, whose occurrence is due to the overstepping of safety measures each society has to observe. A hazard turns into a disaster if there are at least 10 human lives lost or 50 people injured and material losses of over a million dollars. New technologies such as GPS or laser scanning have significant potential use in the analysis of natural hazards such as landslides. Relying on the recent advances in the mentioned techniques, this paper aims to present the monitoring of a landslide situated in Slănic Prahova, Romania. The present paper takes the opportunity to use GPS and laser scanner data to attempt an analysis for ground displacements induced by landslide hazard, thus showing its high level of topicality. Moreover, the paper's originality is given by the fact that, for the monitoring process which is very important in ensuring sustainable development, state of art technology was used The methods and instruments presented in this paper are characteristic to geodetic and topographic engineering. Although varied and very elaborate, these methods have limits, namely they only help monitoring, anticipating and reconstructing after disasters, but they cannot be used to avoid such hazards from taking place. The importance of this paper also lies in stressing the importance of the surveying profession needed for hazard monitoring, in particular landslide monitoring, thus contributing to achieving sustainable development.*

Key words**:** *sustainable development, landslide monitoring, GPS, laser scanner, hazard.*

INTRODUCTION

Landslide activity is strongly related to environmental changes, such as climate conditions and land cover. Moreover landslides are, among natural hazards, one of the main sources of loss for life and property. These are the reasons why slope instability has been included amongst the 27 Geoindicators in the report by the Cogeoenvironment Working Group on Geoindicators [COGEOENVIRONMENT (IUGS) Working Group on Geoindicators 1995].

However several scientific problems must be solved for a practical use of slope instability as an indicator of rapid environmental changes:

1. Landslide activity undoubtedly reflects environmental variations even on a short time scale, but the relationships between landslide events and climate or vegetation changes are not well defined;

2. To be relevant as a geoindicator, landslide activity should be monitored at different spatial and temporal scales;

3. The use of new technologies for determining displacements induced by landslides and for landslide monitoring is markedly unexploited, whereas these techniques allow a rapid

acquisition of data over wide areas and represent a fundamental tool for a practical use of landslides as geoindicators. [1]

Landslides affect all geological materials and exhibit a large variety of shapes and volumes. The characterisation of these phenomena is not a straightforward problem and may require a large volume of investigation. [2] The data for representing geology are diverse and include boreholes, cross-sections, geological maps, structural geology maps, DEM, etc. Since some geological phenomena bear the characteristics of complexity and uncertainty, the geological data are incomplete and heterogeneous. [3]

The ability to detect and react to potential problems before they develop helps in the reduction of insurance costs and prevention of catastrophic failures that may result in injury, death or significant financial loss. A structural monitoring system will help reduce both your current and long term maintenance cost associated with structural movement. [4]

MATERIAL AND METHODS

- **The location of the area under study**

Slănic Prahova is a balneary – climatic resort, situated approximately at a distance of 105 km from the capital city, Bucureşti, well known for the unique in the world “Salt Mountain” and the biggest salt mine in Europe.

In the last years, several landslides have affected the territory of Prahova County, including Slănic Prahova resort leading to material losses and destroyed infrastructure.

Figure 1. Panoramic view captured with the laser scanner of Slănic Prahova resort

This paper presents surveying measurements that have been conducted in an area (Fig.1) undergoing active processes of land deterioration due to underground mining works aiming at determining the dislocated ground volume and identifying the zones in which significant landslides had occurred.

- **The equipment used for monitoring**

Owing to the advantages of high accuracy, all-weather conditions, no requirements of inter-visibility between measuring points, GPS is playing more and more important role in high precision positioning missions in structure/construction health and land formation movement monitoring. [5] As a consequence, a trigonometric control network was done and the coordinates of the network points were determined using GPS technology.

The advent of 3D laser scanners brought about new methods of measuring volumes and examining physical features of the Earth. It has been possible to map and measure the Earth for hundreds of years, but due to 3D laser scanners, the speed and accuracy of mapping has advanced exponentially. [6] Laser scanning technology represents a first reference for GEO-3D modeling and data analysis, being able to be used for studies on many important directions and in various fields, such as: geophysics, mining, hydrology, environmental engineering, constructions, archaeology, meteorology etc. [7] Having in mind these advantages, the laser scanning survey was performed with Leica C10 scan station, collecting the exact position of almost 23 million points with a density of 600 points/m^2. The scan resolution used in the scanning process (Fig.2) was smaller than 1 centimetre and the scanning phase performed lasted 13 hours.

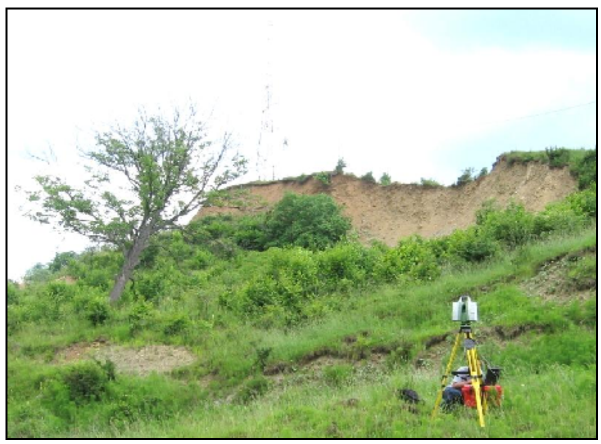

Figure 2. Collecting the data using Leica C10

Practice has demonstrated that by using 3D modeling and the analysis of the movements in mining areas, the experts in the field have better tools to perform a good prognosis on time and a good monitoring of the techniques used for land preservation and for the protection of existing constructions in the affected areas. [8]

The reference digital terrain model (Fig.4) was obtained through the vectorization of the level curves (Fig.3) contained by the most recent topographical plan of the area.

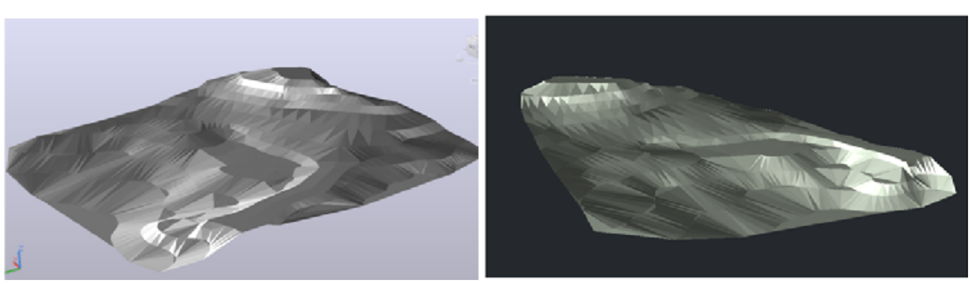

Figure 3. Vectorizing the level curves in order to obtain the reference digital model

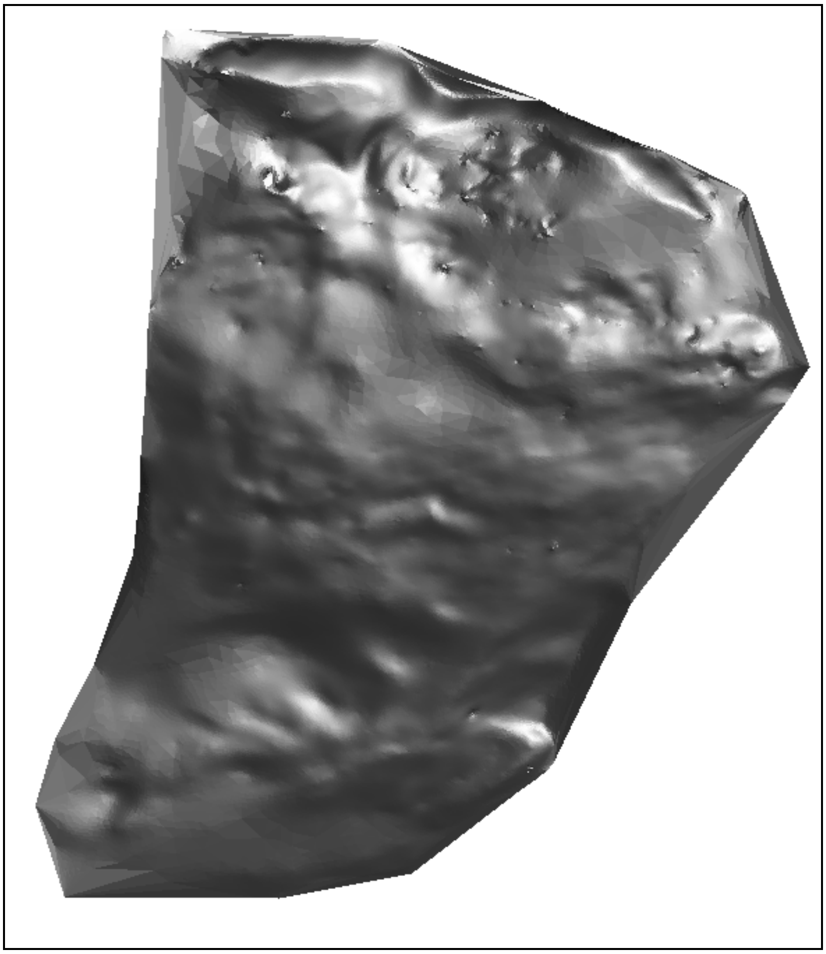

Figure 4. Visualization of the reference digital model

RESULTS AND DISCUSSIONS

The data collected was merged to produce a detailed digital "virtual" terrain model.

The digital terrain model for the scanned area was obtained after using an algorithm for data filtering. This ensures the filtering of the point clouds, meaning that it removes the irrelevant points in creating the final surface. The processes of clearing the noises in the point clouds and removing the unrelated points represent very important stages in creating the digital model because they also determine the precision of the model. If the errors are reduced in the processing phase, the accuracy of the model increases.

In this case, both Leica Cyclone and AutoCAD Civil 3D 2012 software were used for post-processing by reason of their functions which allow filtering on account of points' density. Thus, the most probable points of the terrain surface are determined by calculus and included in the model (Fig.5).

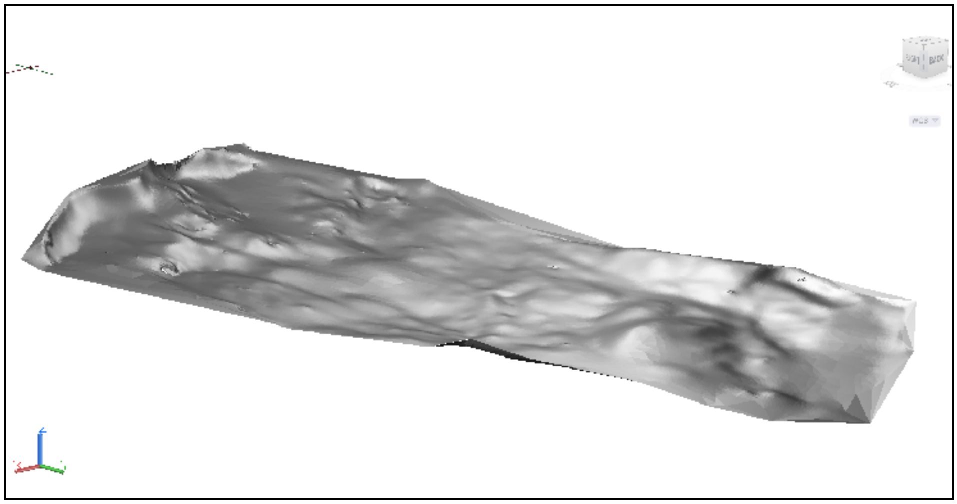

Figure 5. 3D visualization of the digital terrain model for the scanned area

Defining cross-sections is also of great interest in the study and monitoring of landslides and it is possible by means of software used for processing.

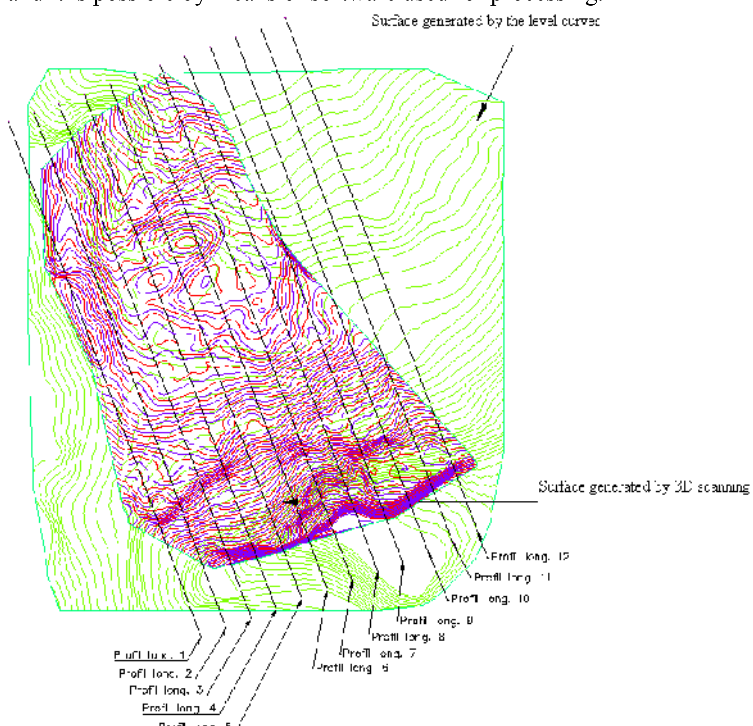

Figure 6. Directions for generating the longitudinal profiles

The longitudinal profiles were realized with the aid of the two surfaces (the reference digital model and the digital terrain model obtained through the scanning process) in order to illustrate the differences emerged after landslides occurred. Directions (Fig.6) were chosen having a gap of 15 meters and, as a result, 12 profiles were created (Fig.7).

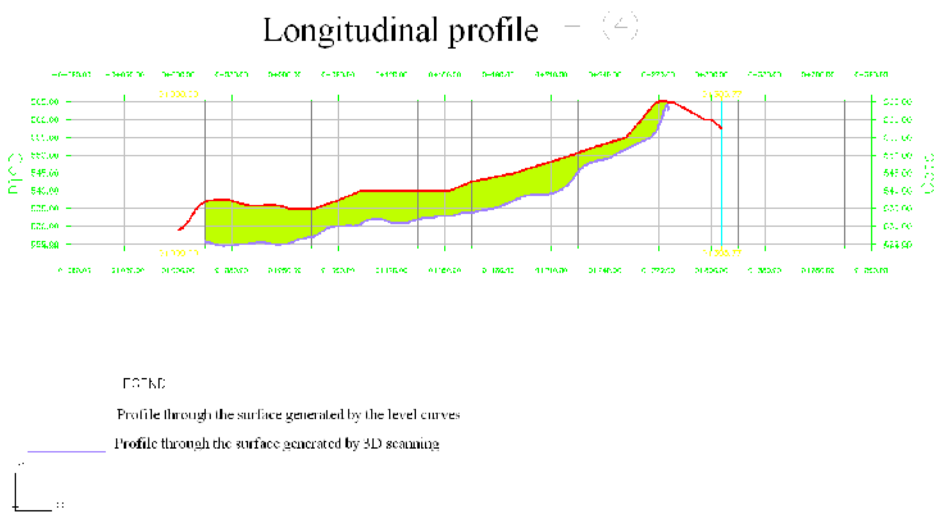

Figure 7. Longitudinal profile through the 2 surfaces

The volumetric calculus was effectuated using AutoCAD Civil 3D 2012 software (Fig.8).

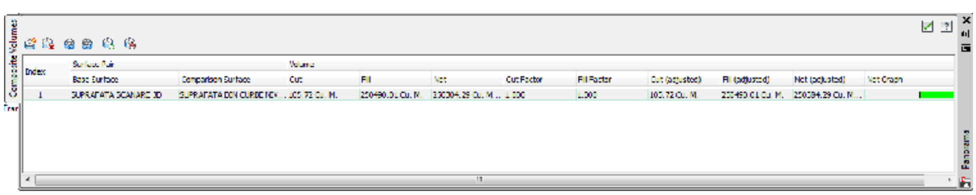

Figure 8. Calculating the volumes

CONCLUSIONS

The surveyor specialist has to interpret the results obtained (Fig.9), for example a visual analysis reveals the fact that the nature and the extent of the displacements were highlighted so one may easily perform a visual inspection in order to identify the landslides. As it arises from Fig.10, the most important displacements appear in the areas symbolised with red and orange colours.

The quality aspect of surveying using laser scanners needs careful consideration throughout the measurement and processing process. Quality starts with a full understanding of project specification. This understanding allows the correct choice of scanner, correct scan resolution, appropriate registration method and so on.

Using new technologies in the field of sustainable development, such as the ones described above, makes possible the storage and easy processing of spatial data gathered on field (GPS measurements, data obtained by means of scanning) that characterize a certain territory. Therefore it is possible to effect a complex monitoring of the areas affected by landslides and adopt the most appropriate environment protection and preservation measures needed, falling into the duty of surveying engineering.

Sustainability is achieved by means of evaluating the present state of environment factors and the development of new technologies that can ensure management of environment reconstruction and facilitate the adopting of optimal decisions to that purpose.

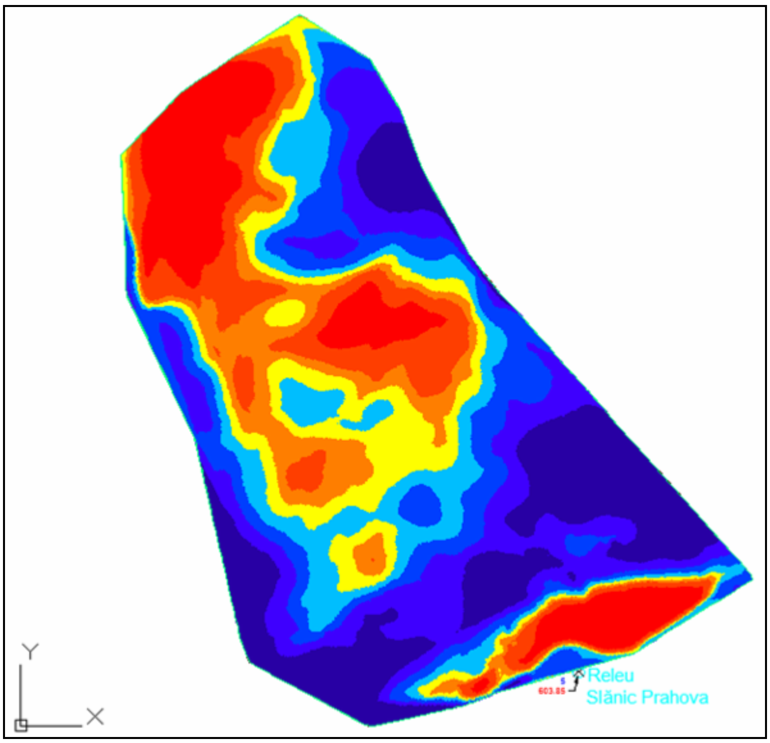

Figure 9. Coloured representation of terrain displacements

Terrain displacements				
No.	Interval (m)	Interval (m)	Surface	Colour
1	-15,51	-10,42	4475.30	red
2	-10,42	-8,96	3710.38	red-orange
3	-8,96	-8,27	3537.57	orange
4	-8,27	-7,46	3960.20	yellow
5	-7,46	-6,50	4494.42	light blue
6	-6,50	-5,33	4839.17	blue
7	-5,33	-3,85	5120.65	violet-blue
8	-3,85	2,04	6278.95	dark blue

Figure 10. Legend associated with the coloured representation in Fig.9

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