Landslides Monitoring on Salt Deposits Using Geophysical Methods, Case study – Slanic Prahova, Romania

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Abstract. Electrometry is most frequently applied geophysical method to examine dynamical phenomena related to the massive salt presence due to resistivity contrasts between salt, salt breccia and geological covering formations. On the vertical resistivity sections obtained with VES devices these three compartments are clearly differentiates by high resistivity for the massive salt, very low for salt breccia and variable for geological covering formations. When the land surface is inclined, shallow formations are moving gravitationally on the salt back, producing a landslide. Landslide monitoring involves repeated periodically measurements of geoelectrical profiles into a grid covering the slippery surface, in the same conditions (climate, electrodes position, instrument and measurement parameters). The purpose of monitoring landslides in Slanic Prahova area, was to detect the changes in resistivity distribution profiles to superior part of subsoil measured in 2014 and 2015. Measurement grid include several representative cross sections in susceptibility to landslides point of view. The results are graphically represented by changing the distribution of topography and resistivity differences between the two sets of geophysical measurements.

1. Introduction

Resistivity imaging method is a modern variant of the resistivity method, developed as a result of improvement of the data acquisition and recording, as well as implementing programs that automatically interpret resistivity data in 2D sections. Physical foundation and principles are the classical resistivity method. The resistivity of the land is registered but, according to a preset program, an automatic device (64 R8/IP SuperSting system), with the help of special cables (multielectrode cables liabilities), then downloaded to a computer, where it is processed through a specialized (EarthImager), and finally it is displayed in the form of 2D vertical geoelectrical sections.

The objectives of this paper are to present the most effective and easiest method, to implement process of monitoring landslides.

The necessary condition is repeated measurements on the same area at different times with identical technical parameters and similar climate conditions. Are obtained several sets of data and images of the underground resistivity distribution that can be compared.

By direct visualization. It is a practical, qualitative but differences can only be estimated.

A good example is the monitoring Slanic Prahova landslide, where between 2014-2015 were repeated measurements both topographical and electrical resistivity surveys.

Intended purpose consisted in detect changes in the distribution of upper subsoil by resistivity measurements executed at intervals of one year, in similar conditions measurements, as follows:

- the same geophysical equipment: Automatic resistivity images generator SuperSting R8 +64 with multi-electrode passive cables and incorporated switchbox for 64 electrodes;
the same measurement device, Schlumberger type, with reception line MN of 2 m and AB emission line between 6 and 38 m;
the same command file, which provides underground investigation to depths of 7-8 m by vertical electrical surveys with a single reception line, that allows interpretation of each VES EarthImager 1D software;
the same period of year;
the same climate weather conditions, consisting of daily showers, alternating with clear weather;
the same way of processing raw data, consisting in pseudo sections inversion of apparent resistivity corresponding for every profile with EarthImager 2D software;
same way of presenting the results in the form of inverted resistivity sections with marking of landslides components studied.

Elevation differences on major axis direction of the landslides showed an irregular terrain rise upstream and descent downstream, evidence that landslide was active in that interval.

These differences, on the landslide axis direction are shown in the table 1 and graphic form. It shows a raising upstream irregular ground caused by the accumulation of material in landslide compartment and lowering the land surface downstream. It is measured proof as the landslide is active, other indications of this are visible changes in morphology of sliding compartment, the appearance of numerous new fissures all over the slope, variation of the lake level and the occurrence of deeper goals about the emergence salt massive.

Table 1. Differences through the profiles.

| Topo pr T | 2014  | 2015  | Difference in (m) |
|-----------|-------|-------|-------------------|
| T30       | 459.5 | 461   | 1.5               |
| T25       | 458.5 | 460.3 | 1.8               |
| T24       | 457.8 | 459   | 1.2               |
| T23       | 456.5 | 457.2 | 0.7               |
| T22       | 455.8 | 456   | 0.2               |
| T21       | 454.3 | 455.6 | 1.3               |
| T20       | 453.8 | 454.7 | 0.9               |
| T15       | 453.1 | 452   | -1.1              |
| T14       | 451.9 | 450   | -1.9              |
| T13       | 449   | 448   | -1                |
| T12       | 447.1 | 447   | -0.1              |
| T11       | 445.8 | 445.8 | 0                 |
| T10       | 444.6 | 445   | 0.4               |

Figure 1. Elevations in profiles
Geoelectrical measurement results of these profiles (2014 and 2015) showed insignificant changes in resistivity distribution at the top of the basement at the same time interval, figure 2 and 3.

2. Methodology
In-situ process monitoring of the basement by using resistivity method has become a recognized technology. The purpose of in-situ monitoring is to investigate changes in the subsoil. In a monitoring application, data are usually collected in the same place at different times. Collected data at the beginning monitoring are basic, initial data, (background data). The initial data are inverted using standard inversion method to reconstruct the basic model, distribution in the subsoil. For further data, sets are inverted using the inversion time lapse method. Percent difference is defined as the difference between ulterior resistivity and initial resistivity divided by the original resistivity. These images of the difference are used to visualize changes in the subsoil. Time lapse inversion method has the advantage that the data of known subsoil incorporates into reverse ulterior datasets.

There are several advantages:
1. Artefacts inversion may be deleted in difference images.
2. It's expected a faster convergence due to a good initial model.
3. Small changes can be detected.
4. It's a new method, modern, with quantifiable results.

The used algorithm can reverse both datasets monitor, and the differences from the initial-original dataset. The result shows that the percentage difference between images of different sections of the resistivity compared to the initial image and the output is obtained and an AVI movie (animation).

3. Results and discussions
Results obtained directly consist in 2D sections of inverted resistivity sections along each profile, starting from the apparently stable area from west to landslide axis. By processing the primary data, will be built more longitudinal sections parallel to the corresponding profile section L, in the western part of the slide.

Profile T10 starts at the intersection of the L longitudinal profile with T1 transversal profile measured in 2014 and continues to the SW on a different route from the latter, hence the difference between their topographic surfaces. There are evident differences between T10 (2014) section and T10 (2015) section. Vertically, inverted resistivity section does not exceed the conductive horizon above the salt massif. In the resistive horizon above the surface landslide, resistivity shows different variations of the structure and composition. Here, the landslide surface continues to depth beyond the western limit of landslide observed on the surface. Finally, near the landslide axis (m 104), the landslide surface dip suddenly. At 2 m depth another shape is the limit of separation between two horizons with different resistivity, which may represent a shallow landslide surface.
4. Conclusions

Presented methodology is a modern method, with quantifiable results. It can be seen as the time evolution of the distribution of resistivity in the subsoil, and in conjunction with the other procedures provided in the project (seismometry, geological mapping, hydrogeological observations, topographic survey, the use of microsensors) can develop scenarios concerning prediction further evolution in time and space at the studied phenomenon.

Using this method of monitoring landslides and other variables in time phenomena will be an absolute innovation for Romania.

Acknowledgment

This work was supported by a grant of the Romanian National Authority for Scientific Research, CCCDI – UEFISCDI, project number 83/2014.

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