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Real Time Ground-Base Monitoring System for Earthquakes & Associated

Natural Hazards Assessment & Risk Mitigation

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REAL TIME GROUND-BASE MONITORING SYSTEM FOR EARTHQUAKES AND ASSOCIATED NATURAL HAZARDS ASSESSMENT AND RISK MITIGATION

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SUMMARY
The paper is centered on the establishing of a specific methodology useful for the natural hazard assessment due to both the active faults and seismic events associated, which are considered to be sources of the significant landslides in the Subcarpathian area (Romania). Thus, in the Provita de Sus zone cross-cut by active faults orientated NE-SW, the Provita Fault has been reactivated by the intermediate depth earthquakes (M=6) occurred in the Vrancea zone, on 27-th November 2004. This landslide deforms the sliced blocks considerably and produces a complex array of reverse micro-faults, strike-slip micro-faults and folds. Owing to an increasing threat of the landslides, it was necessary to choose an adequate monitoring system taking into account the specific geological conditions. In this context, an adapted electromagnetic (EM) methodology conveying to models concerning the evolution in time of the landslide phenomena was imposed, so that a disaster forecasting become possible. On this way, by using a specific ground-base monitoring system, the following activities have been accomplished: (i) optimization of the specific sensors structure in laboratory and field conditions; (ii) experiment and continuous improvement of the specific ground-base monitoring system at the peculiar conditions of the Provita de Sus (test site) for pattern recognition; (iii) getting of the specific data to produce two-dimensional tomographic images as a first step for the risk assessment; (iv) assessment of the electromagnetic parameters related to both the earthquakes characteristic to the seismic-active Vrancea zone and the landslides associated to the active fault. The final results highlight the possibility of merging electromagnetic parameters with tomographic images and with low frequency electric signals occurred prior the stress to reach a critical value. Subsequently, in the Provita de Sus locality, after implementing this complex monitoring system, it is possible to provide early-warning against the risk arising from landslide triggered by the earthquakes occurred in the Vrancea zone.

Keywords: landslide, active fault, electromagnetic parameters, two-dimensional images, Provita de Sus-test site.

INTRODUCTION
Landslides commonly occur with other natural disasters (earthquakes or floods) and leave the landscape prone to sedimentation, erosion and further mass wasting. The rapid development of various techniques, such as GPS (Malet et al.,2002;), GPS and digital photogrammetry (Mora et.al., 2003), high-resolution satellite imagery (Haeberlin et al., 2004) and light detection and ranging (McKean and Roering, 2004), were successfully applied for continuous observation under real field conditions. Since each landslide is different, it was necessary to choose an adequate monitoring system on the basis of the preliminary analysis of a phenomenon and geological conditions (Stanica and Zugravescu, 2004; Stanica et al., 2004; Stanica et al., 2005). The goal of the paper is to present a specific ground-base monitoring system (SGMS), to better understand its efficiency for broad application in landslide studies and hazard mitigation. Additionally, by combining different data types and analysis techniques, and also by merging electromagnetic parameters with tomographic images and with low frequency electric signals occurred prior the stress to reach a critical value, a compelling dynamical paradigm, in which is emphasized a correlation between electromagnetic parameters and the frequency and the magnitude of the occurred earthquakes, was carried out. In consequence, by analyzing the data from the Provita de Sus (test site), it was possible to assign the

increase of the landslide activity to the local fault which has been reactivated by the earthquakes (EQ) occurred in the Vrancea zone. In the end, this paper ilustrate the stage of the SGMS implementation and to what extent the results carried out in the Provita de Sus test site, Prahova District, may contribute on understanding such kind of landslide.

PROVITA DE SUS LANDSLIDE

Geological characteristics

The test area is located in the upper part of the Provita Valley (Prahova district) in which the landslides are developed in the flyschoid domain of the Carpathians. This landslide affects the Oligocene deposits of the Tarcău Nappe (Moldavides domain), which are characterised by the flyschoid deposits containing slate, sandstone (Fusaru sandstone) and marl. In the studied area the Upper Oligocene deposits occur. They are characterised by the presence of Slon beds a wildflysch formation which is discordant to the Vinetisu beds which is consist mainly by argilaceous marls an thin sandstone beds. This zone is tectonically very complicated by the presence of mesocretaceous and Miocene thrusts and Miocene and post-Miocene faults. In the Provita de Sus landslide area cross-cut by active faults orientated NE-SW, the Provita Fault (PF) has been reactivated by the intermediate depth earthquakes (M=6) occurred in the Vrancea seismic-active zone, on 27-th November 2004. Provita de Sus's landslide (Fig.1) has the following characteristics:

- altitude of the rear boundary of landslide deposits is at average 670 m
- altitude of the front boundary is at 410 m;
- relative height of landslide deposits is 260 m;
- average surface gradient of landslide deposits is 18°;
- average thickness of landslide deposits 35 – 40 m;
- angle of rupture surface 30° (rear average) – 10° (front);
- area of landslide deposits 1.25 km^2;
- average volume of landslide deposits 40 million m^3.

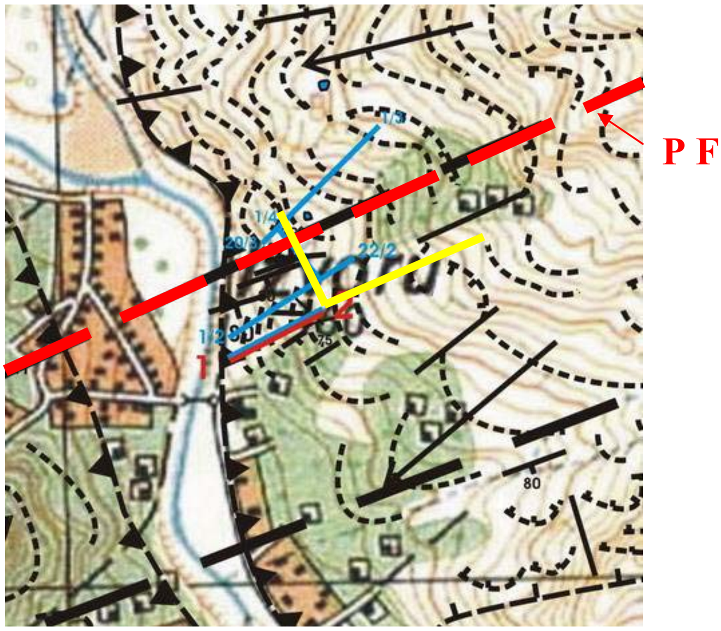

Fig. 1. Provita de Sus landslide map - test site. Dashed red line is PF active fault (reactivated by seismic activity); full blue and yellow lines are geoelectric (VES) and EM profiles, respectivelly;

SPECIFIC GROUND-BASE MONITORING SYSTEM (SGMS)

One of the main objectives of this paper was to implement a complex monitoring system able to provide early-warning against the risk arising from landslide triggered by the EQ occurred in the Vrancea zone, in this particular case concerning the Provita de Sus locality. In this respect, a methodology able to investigate the electromagnetic and electric parameters induced by the crustal and subcrustal geodynamic processes (landslides triggered by earthquakes) will be presented (Stanica et al., 2005). The main activities that have been accomplished consist of: (i) study regarding the optimization of the electric sensors; (ii) experiment and continuous improvement of the monitoring system at the peculiar conditions of the Provita de Sus (test site) for pattern recognition; (iii) getting of specific data to produce 2D tomographic images as a first step for the risk assessment; (iv) assessment of the electromagnetic parameters related to both the earthquakes (EQ) occurred at the intermediate depth, characteristic to the seismic-active Vrancea zone, and the landslides associated to the Provita active fault (PF). The SGMS (Fig. 2) includes three separate equipments able to carry out discrete observation and/or continuous monitoring (Stanica and Zugravescu, 2004, Stanica et al, 2004) of: a) HF and LF electromagnetic field (Geophysical Electromagnetic Measurement System - GMS 06, Metronix-Germany); b) Geomagnetic field (MAG 03 DAM, Bartington-England); c) Geoelectric field (Resistivimeter INTEL V3, INTEL92-Romaia).

All the three measurement equipments have specific sensors, data acquisition modules and adequate software.

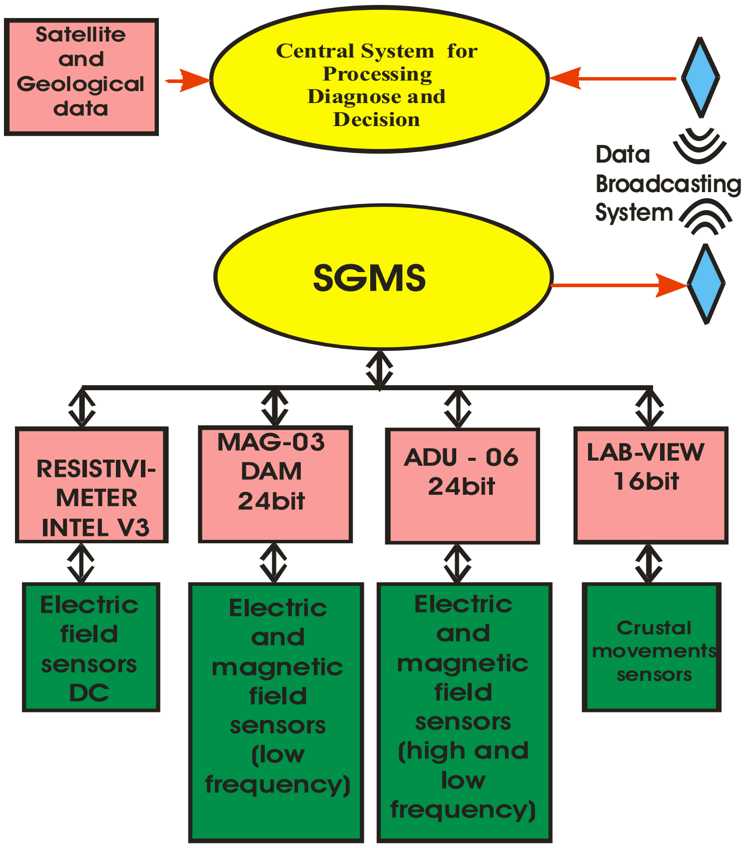

Fig. 2. Specific ground-base monitoring system (only the electric and EM components have been presented in this paper)

The MAPROS software packages (Metronix-Germany) used for the electromagnetic system runs under Windows 95 or Windows NT operating systems, on a latop connected to a single ADU or an ADU network. The tasks performed by MAPROS are:

- In-field system calibration and automatic offset compensation;
- Real time data acquisition and processing;
- Robust estimation of transfer functions;
- Real time display of time series and all important EM-parameters;

METHODOLOGY AND RESULTS

The objectives of the paper are to be focused on the recognition of the electromagnetic parameters which could be correlated with landslide and seismic activity. The studies had to be involved in a multi-parameters context and, therefore in the Provita de Sus - test site we installed the discreet and continuous monitoring systems of the electric, magnetic and EM fields.

The main condition for a specific approach of this problem was to use long time continuous electromagnetic data and appropriate algorithms to extract possible anomalous variations, so that we could make an analysis of the electromagnetic results during the landslides processes. Thus, the MAPROS software packages and specific methodology have been applied for obtaining, in real time, all the important electromagnetic parameters and to point out the anomalous behaviour versus the specific pattern pre-established in non active-tectonic conditions.

As a first stage in getting to this aim, it is important to mention the specific equipment used for real-time monitoring of the electromagnetic field and the methodology applied to calculate the time evolution of the electromagnetic parameters. By using magnetotelluric (MT) tensor impedance decomposition procedure it was possible to separate the local effects from the regional ones, to identify the type of geological structures and to emphasize the strike orientation of the possible new fractured zones occurred at shallow depths interval.

The selection methodology for precursory EM parameters was established according to the geotectonic features of the Provita de Sus landslide zone. It is also necessary to mention that, according to the frequency range taken into consideration - corresponding to the shallow geodynamic processes, the processing and the analysis of the time series were accomplished in such a manner that these enable to highlight the anomalous fluctuations of the electromagnetic parameters. Subsequently, the specific methodology have consisted in extracting of the peculiar changes in time of the resistivity - parallel and perpendicular to the geological strike, electrical anisotropy, skewness and strike, and to reveal the low frequency electric signals, that “arrive” before the time derivative of the magnetic field, emitted prior the stress reached a critical value.

By analyzing EM data carried out at Provita de Sus (test site), it was possible to connect the increased activity of landslide with the PF reactivation generated by the earthquake of M=6 occurred in the Vrancea zone, on November 27-th, 2004. This earthquake has also been remarked by the anomalous behaviour of the electromagnetic parameter Bzn (Stanica et al., 2004; Stanica et al., 2006) recorded at National Geophysical Observatory Surlari (Fig. 3).

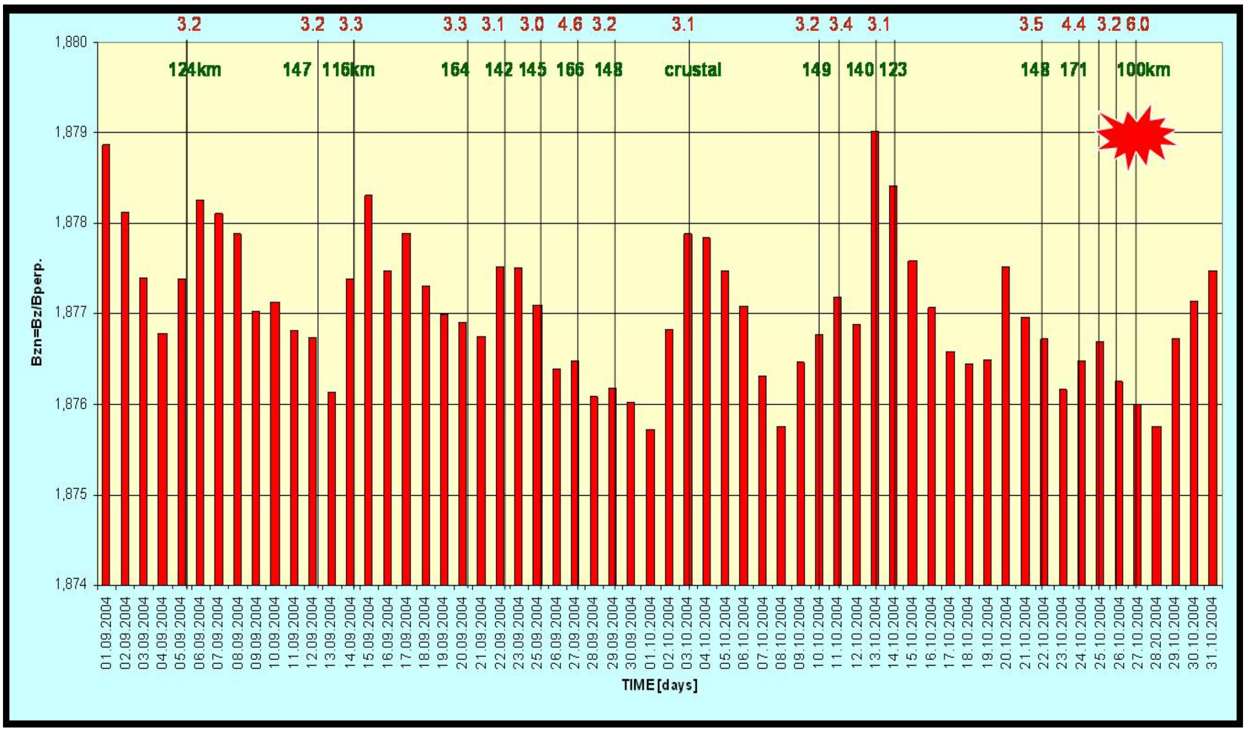

Fig. 3. The earthquake of M=6 occurred in the Vrancea zone, on November 27-th, 2004 has been remarked by the electromagnetic parameter Bzn.

The EM field results, which will be presented, reflect the following two activities:

a. Experimental studies to establish geoelectric/ electromagnetic pattern of the test site in „pre-critical" conditions

All the electromagnetic data, obtained during the experimental studies (Stanica et al., 2006), conveyed to:

- Specific tomographic images carried out by using both the vertical electrical soundings (VES) in Fig. 4 and magnetotelluric soundings (MTS) in Figs. 5 and 6;
- Estimation of the skewness parameter;
- Estimation of the geological strike;
- Assessment of the anisotropy.

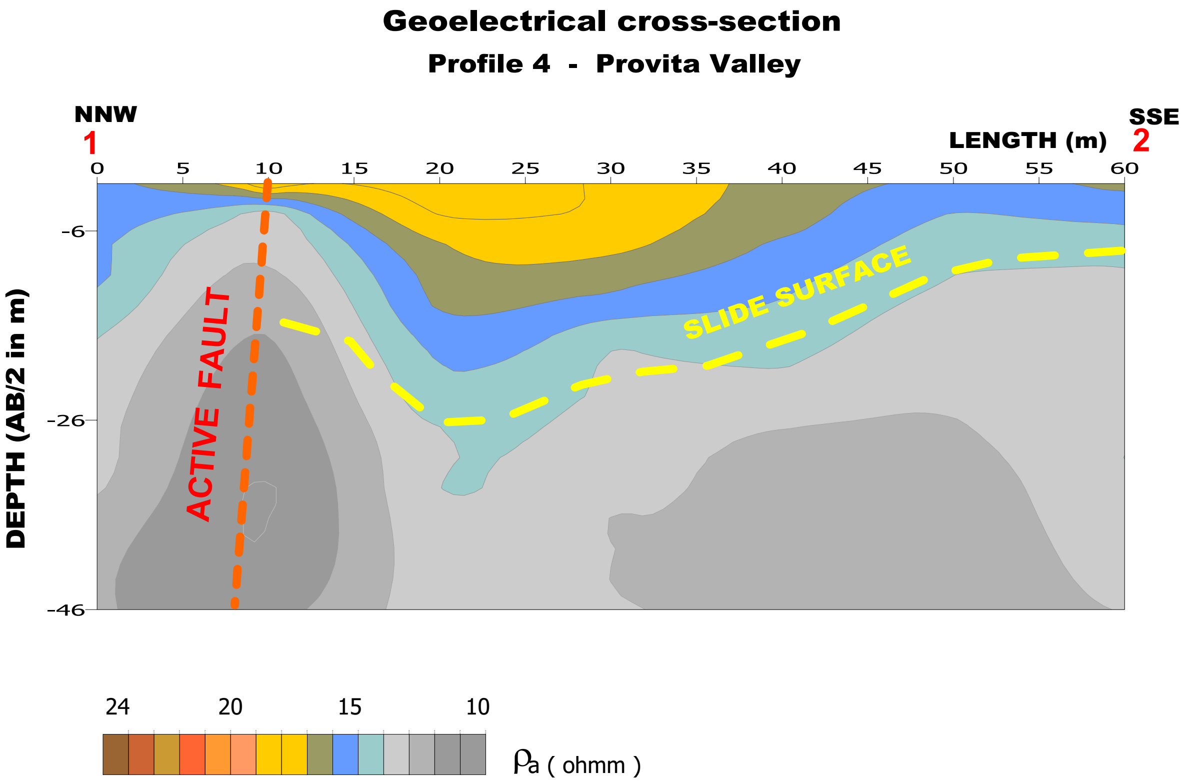

Fig. 4. Geoelectric tomography along the VES profile perpendicular to the active fault (PF)

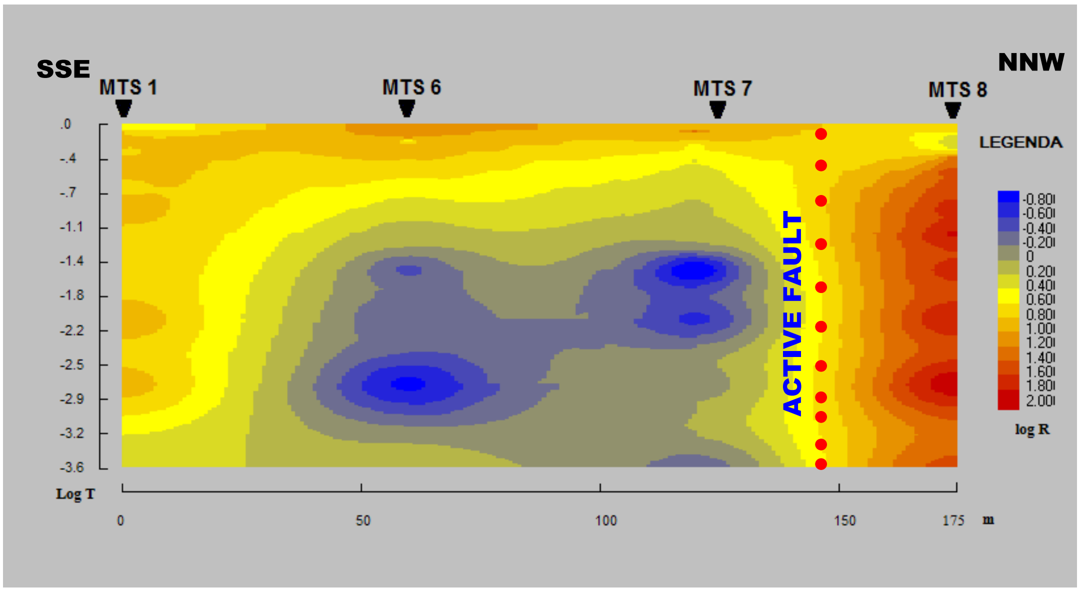

Fig. 5. EM tomographic image along the yelow profile crossing the active fault (dashed red line - Fig. 1)

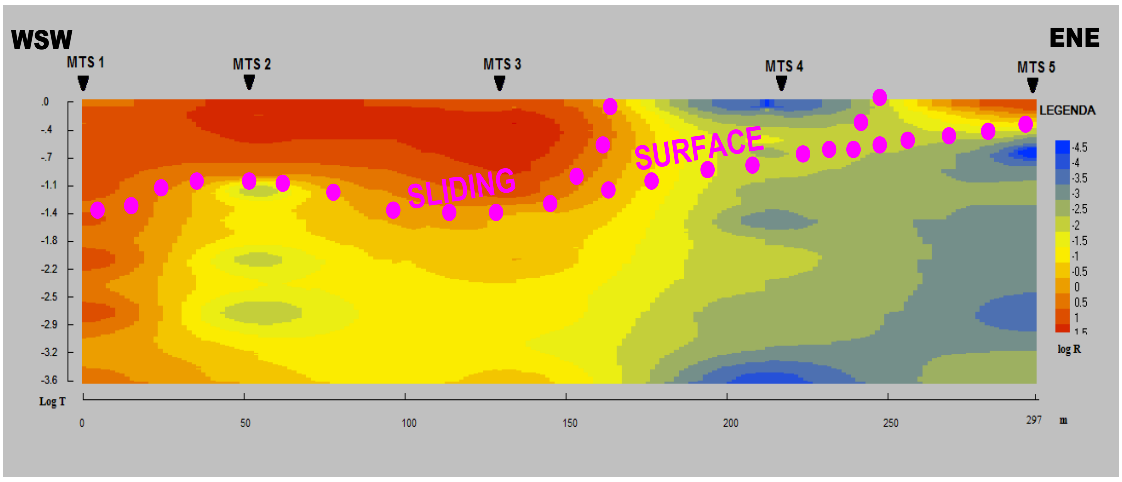

Fig. 6. Magnetotelluric tomography (B-polarized mode) along the MTS profile perpendicular to the landslide.

b. Monitoring of the EM parameters /phenomena related to the landslide activity

In order to determine the time evolution of the slide activity occurred in the Provita de Sus test site, we made the measurements in the same point on landslide (electric and magnetic sensors in unchangeable position), with a sampling rate of 7 days, of both the EM parameters (skewness, strike and anisotropy) and the low frequency electric signals, that "arrive" before the time derivative of the magnetic field, emitted prior the stress reached a critical value.

Further on, some examples regarding this activity are set off:

- Skewness parameter recorded on 30-th September, 2005 and 07-th October, 2005 (Fig. 7);

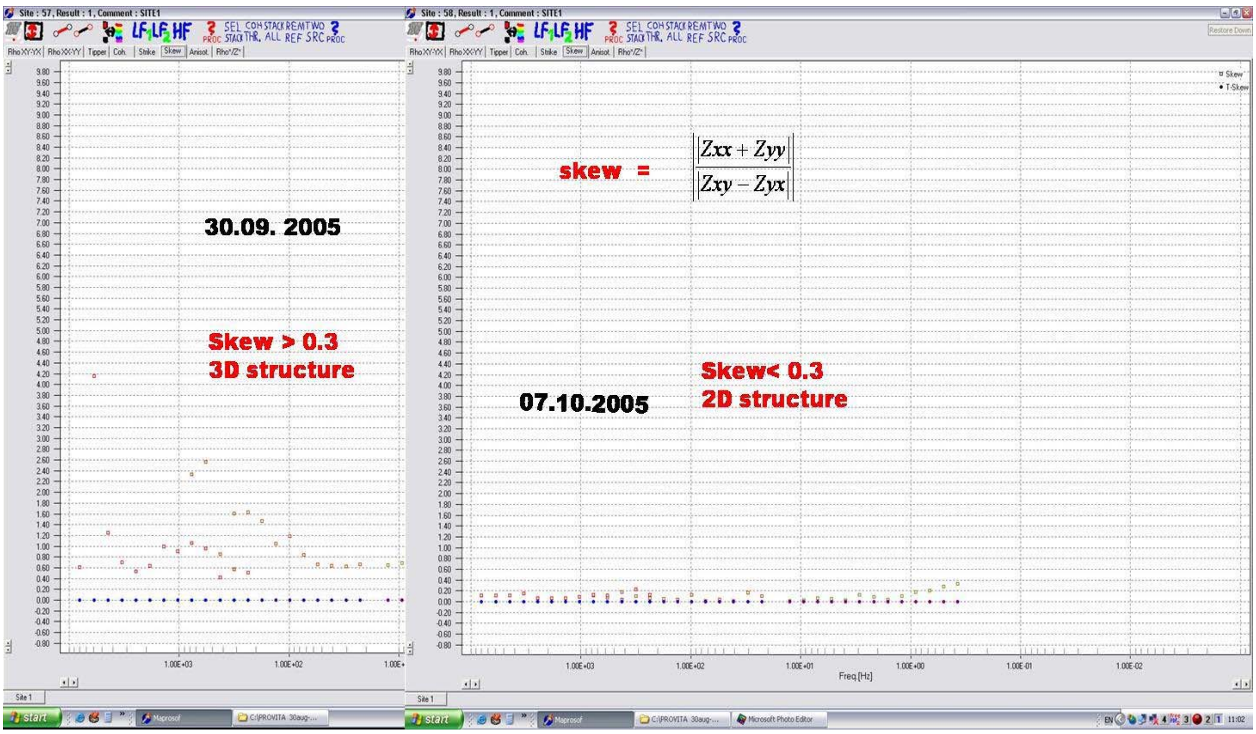

Fig. 7. Skewness parameter

- Strike parameter recorded on 30-th September, 2005 and 07-th October, 2005 (Fig. 8) ;

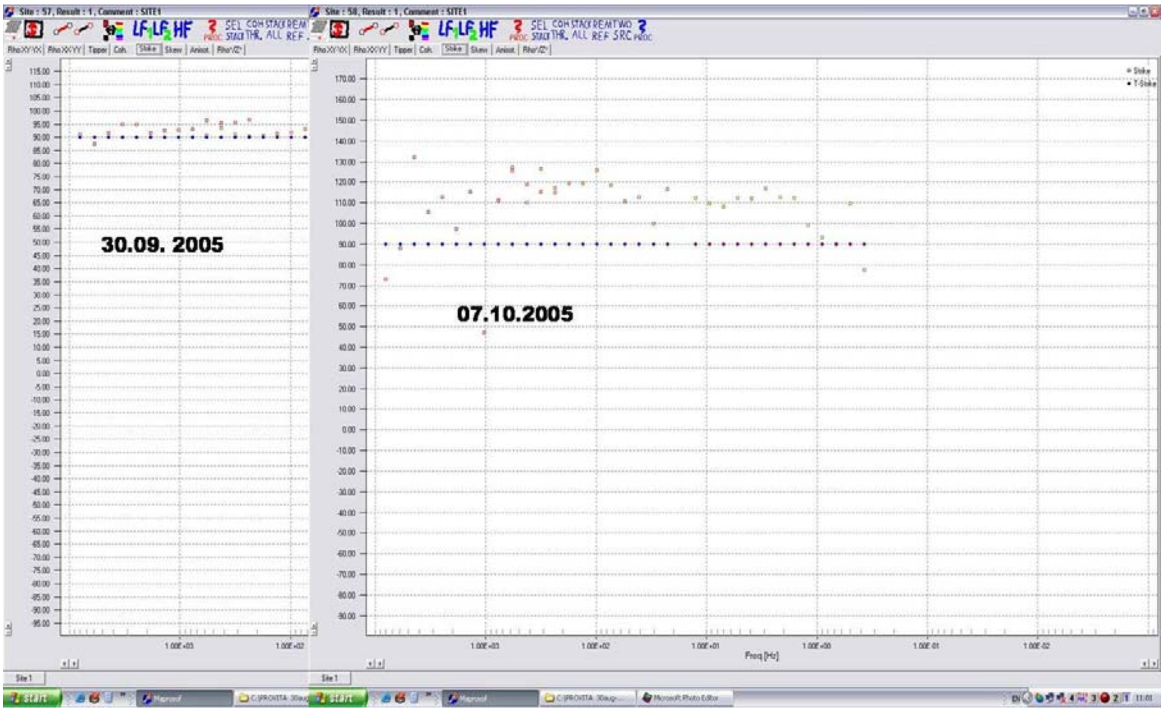

Fig. 8. Strike parameter

- Electrical anisotropy recorded on 30-th September, 2005 and 07-th October, 2005 (Fig. 9);

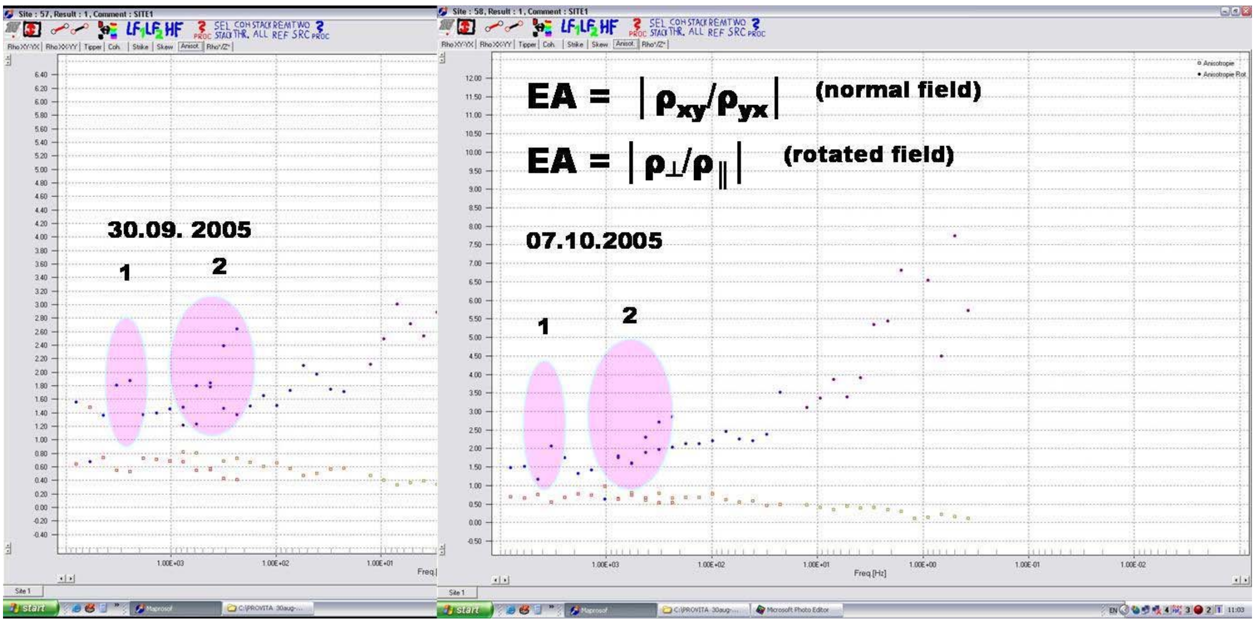

Fig. 9. Electrical anisotropy

The results reveal the significant changes of the EM parameters as follows:

- In the frequency range 2.10^3- 4.10^3 Hz, specific to the sliding activity occurred in the depth interval 0-30m, skewness parameter being higher than 0.3 revealed a 3D structure (for 30-th September), while the same structure becomes 2D on 07-th October (when the skewness is smaller than 0.3);
- For the both records, the strike parameter has deviations of about 12^0 versus its mean value ($92^0 \pm 2^0$), which maybe assigned to the main rupturing process of the landslide that could be associated with the sliced blocks having complex array of micro-faults with different orientation;
- In the same frequency ranges 2.10^3- 4.10^3 Hz, the electrical anisotropy is of about 1.8 on 30-th September and becomes of about 2.0-2.5 on 07-th October.

As regards the low frequency electric signals emitted prior the stress reached a critical value, we used a special array of electrical sensors having the interval (D) between two pairs of 8m (Fig. 10) .

Fig. 10. Array of electrical sensors

Such an experiment has success if the interval between the sensors is chosen so that the electrical spike to be not masked by natural electric variations (for D=16m the electrical spike is partially masked by natural electrical field , Fig. 11).

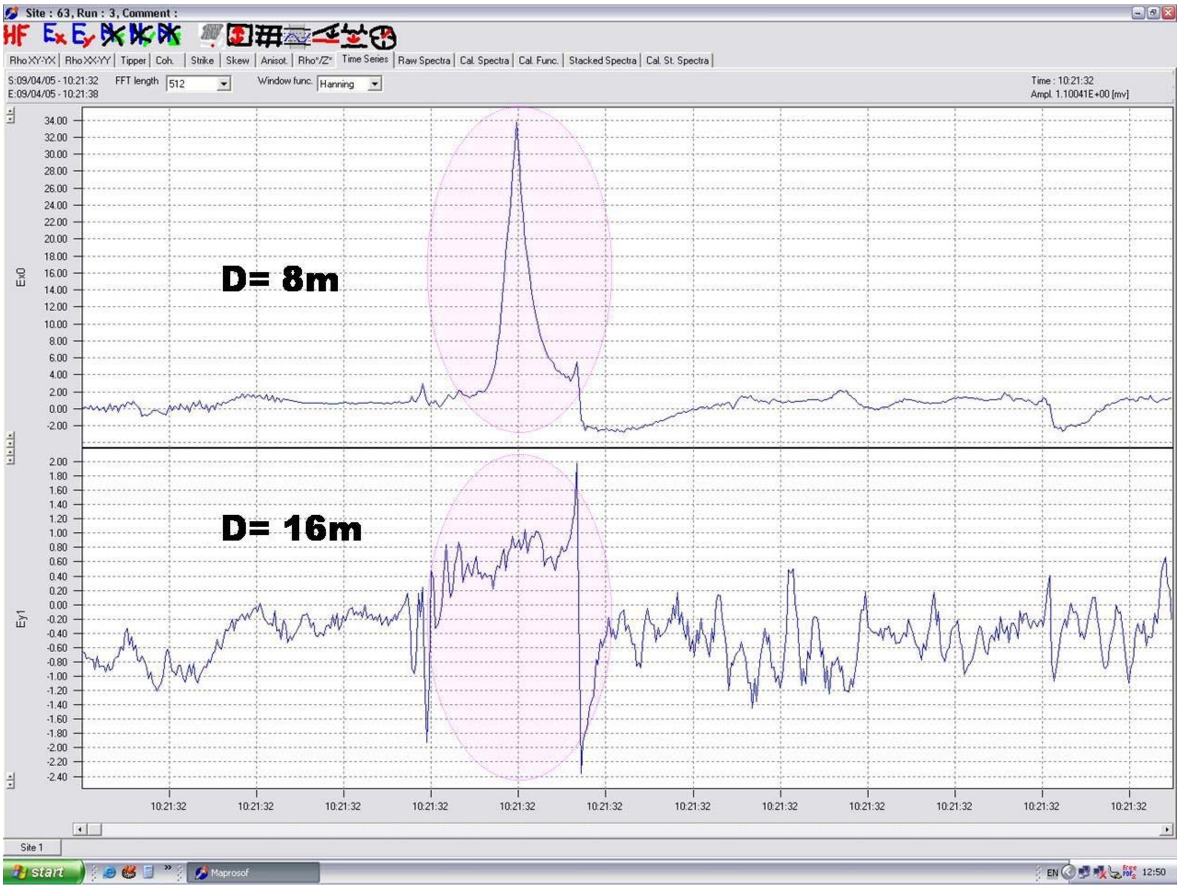

Fig. 11. Frequency electric signals emitted prior the stress reached a critical value

CONCLUSIONS

The described SGMS and methodology proved an effective way of monitoring the EM parameters and phenomena in order to detect their significant changes associated to Provita de Sus landslide. The following general conclusions can be drawn from this test site:

1. In 2005 year, in the Provita de Sus landslide the active fault (PF), reactivated by intermediate depth Vrancea's earthquakes and strong rainfalls were the major forces generating the slide activity. Significant morphological-geoelectrical changes on the landslide surface and its shallow depth (0-20m) had a local character only and were developed mainly between the middle and front part of the landslide. This process deforms the small sliced blocks and produces a complex array of reverse micro-faults, strike-slip micro-faults and folds;
2. The accuracy of the EM parameters' changes versus the geodynamic characteristics of the Provita de Sus landslide allowed us to consider the SGMS as powerful tool to investigate any landslide areas characterized by very complex geology;
3. The related study demonstrates the rich potential of using this new methodology for landslide monitoring. In particular, the SGMS can play an important role in monitoring of landslide-prone

areas and in providing, in near real-time, warnings on the slide motions that can put in danger the life and properties;

4. High-resolution of the EM parameters and tomographic images can lead to an improved understanding of landslide mechanism and hazard assessment due to the seismic activity.

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