Electrical resistivity tomographies for landslide monitoring: a review

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Abstract

This work aims at summing up and presenting both the current state of the art of the electrical resistivity tomography (ERT) technique for the landslide monitoring and its new emerging applications within this framework. In particular, we are overviewing and discussing the most noteworthy results obtained by applying this technique in different geographical areas affected by wide and diffuse hydrogeological instability phenomena. The attention will be focused on the contribution that this technique can give to the different phases (pre-vent, emergency and post-event) of a landslide disaster cycle. The analysis of the results points out the main advantages of this technique and the efforts to be made in order to improve and expand its application fields. Great attention is paid to the use of the time-lapse ERT as a promising monitoring tool to be used during the emergency phase.

Introduction

Landslides are complex phenomena whose study necessarily requires a multidisciplinary approach based on a wide range of observations including geological and geomorphological mapping, geotechnical and geophysical investigations, geodetic surveys, satellite observations and meteorological data analysis (PERRONE et al., 2006; CASTELLANOS ABELLA and VAN WESTEN, 2008; KAWABATA and BANDIBAS, 2009; DE BARI et al., 2011). The integration of different techniques should allow us to obtain useful information for all the phases of the landslide disaster cycle, overcoming the drawbacks of each single method applied.

Different geophysical techniques (seismics, geoelectrics, magnetometry, gravimetry, thermometry, GPS, etc.), which have led to significant results and provided useful information concerning both the landslide geometry reconstruction and the site hydrological characterisation (JONGMANS and GARAMBOIS, 2007), can be applied for the investigation of landslides. Among these the geoelectrical (electrical resistivity tomography, self-potential, induced polarization) and seismic methods play the most important role. In particular, the Electrical Resistivity Tomography (ERT) technique, based on the measurement of the electrical resistivity values and their spatial distribution in the subsoil, has been largely applied in order to investigate landslide areas (LAPENNA et al., 2005, MERIC et al., 2005, GODIO et al., 2006). This technique provides useful data to be used during the pre-event and post-event phases, thanks to its capability of giving information both on the lithostratigraphic sequences and the geometry of the landslide body (lateral extension and thickness), identifying the sliding surfaces between the slide material and the underlying bedrock, and individuating high water content areas. Indeed, during the pre-event phase, it is very important to gather information both on the geological setting of the potentially unstable area (electro-stratigraphy, tectonic lineaments, etc) and the presence of water tables that could trigger off the phenomenon. After the event, it is important to know the geometry of the landslide body and estimate the volume of the slide material, in order to plan the mitigation activities and interventions (drainage system installation, stabilization structures, etc). The application of 2D and 3D ERT, even if indirectly, can provide this information.

Recently, novel algorithms for tomographic data inversion, robust models for the description of the hydrogeophysical processes and new sensor networks for the field data acquisition have turned this method into a powerful and cost-effective tool for the geo-hazard monitoring. These technological and methodological improvements are opening the way to a broad spectrum of interesting and challenging applications in geo-hazard monitoring, as well as the use of time-lapse ERT for the mapping of the time-dependent changes of water content in the vadose zone of a landslide area. Although the literature reports only few examples of the application of time-lapse ERT for landslide investigation (LEBOURG et al., 2010; NIESNER, 2010) the preliminary results seem to encourage the possibility to apply this technique during the emergency phase. This is due to its capability of monitoring the dynamic behaviour of a physical parameter indirectly connected to the triggering factors of a landslide so as to provide important information during the emergency phase. The aim of this work is to describe the evolution of the ERT technique application for landslide investigation, from the 2D acquisition to the time-lapse ERT, paying particular attention both to some examples of 2D and 3D ERT carried out in certain Italian landslide areas and the preliminary results coming from the time-lapse 2D ERT application.

2D and 3D ERT in landslide areas

This work reports a review of the results obtained by applying the 2D and 3D ERT technique during the pre and post landslide events with the aim to reconstruct the geometry of landslide bodies, individuate the sliding surface, estimate the thickness of slide material, approximate the volume of the body investigated and highlight the areas with high water content. The interpretation of the ERT was frequently supported by the comparison with stratigraphical data from direct boreholes performed in the same area.

Figure 1 reports an example of comparison between an ERT carried out longitudinally to the accumulation zone of Varco d'Izzo landslide (Basilicata region, Italy) and the stratigraphies from three direct boreholes (PERRONE et al., 2004). The ERT HH' highlights a clear resistivity contrast between a low-resistivity zone ($\rho < 20$ ohm-m), associated with the mobilized body, and a relatively high zone ($\rho > 30$ ohm-m) related to the compact deposits (alluvial and clayey material) not involved in the landslide. These results are in accordance with the stratigraphic and inclinometric data from boreholes B24, B23, and B22, which show a sliding surface at depths of about 21, 30, and 32 m, respectively. The relatively high resistivity nucleus ($\rho > 50$ ohm-m) located at about 110 m from the origin of the profile is due to a railway tunnel involved in the landslide.

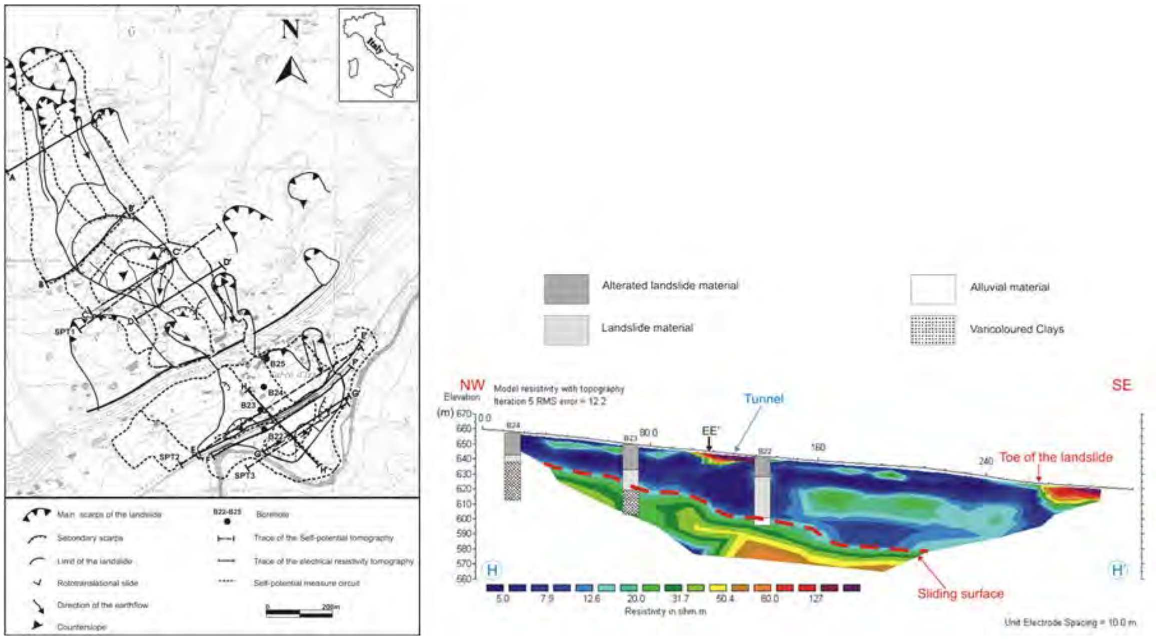

Fig. 1: Comparison between HH’ ERT carried out on Varco d’Izzo landslide (Basilicata region) and stratigraphical data (from PERRONE et al., 2004)

Figure 2 reports the comparison of the electrical resistivity and seismic refraction tomography results obtained along the profile 1 in a landslide area located in the Altındağ district of İzmir (Turkey) (GÖKTÜRKLER et al., 2008).

Both the electrical resistivity and the P-wave velocity images show very similar results and highlight the geometry of failure surface. Low resistivity values (<100 Ωm) and low velocities (400-1600 m/s) characterize the landslide material mainly composed of (by) clay material with high water content. Both the images clearly define the landslide bedrock characterized by consolidated clastic rocks and by high resistivities (100-400 Ωm) and high velocities (2000-3000 m/s).

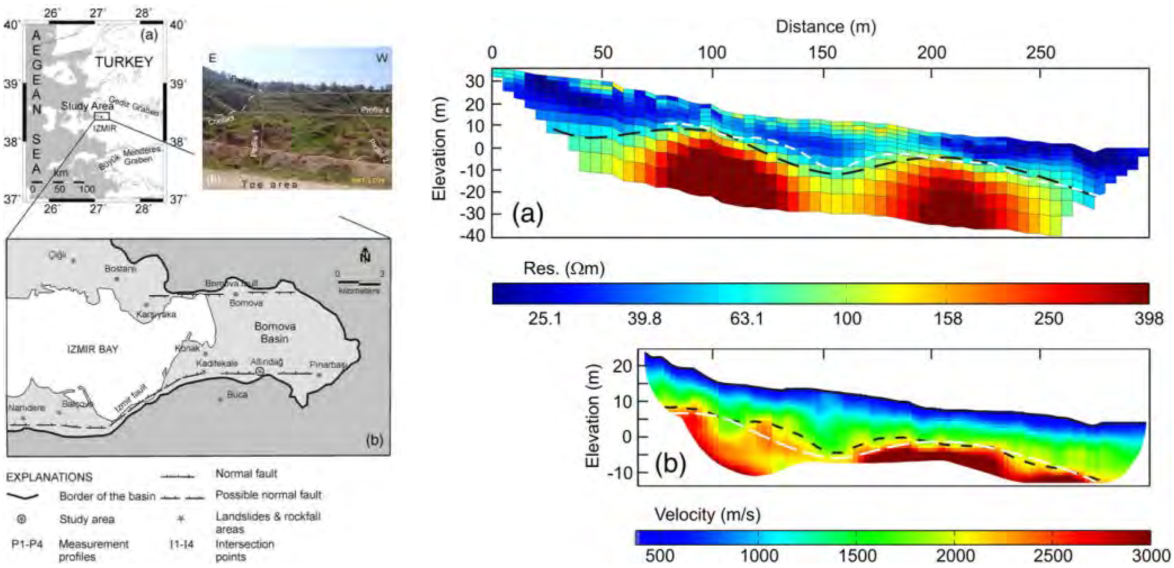

Fig. 2: Left: landslide area located in the Altındağ district of İzmir (Turkey). Right: (a) Resistivity tomogram together with the failure surface interpretations from the resistivity (black dashed line) and seismic data (white dashed line). (b) Velocity tomogram together with the failure surface interpretations from the resistivity (white dashed line) and seismic data (black dashed line) (modified from GÖKTÜRKLER et al., 2008).

Figure 3 reports an example of 3D fence diagram of all resistivity data acquired along parallel profiles in a landslide located on the Quesnel River in British Columbia (Canada), (BICHLER et al., 2004).

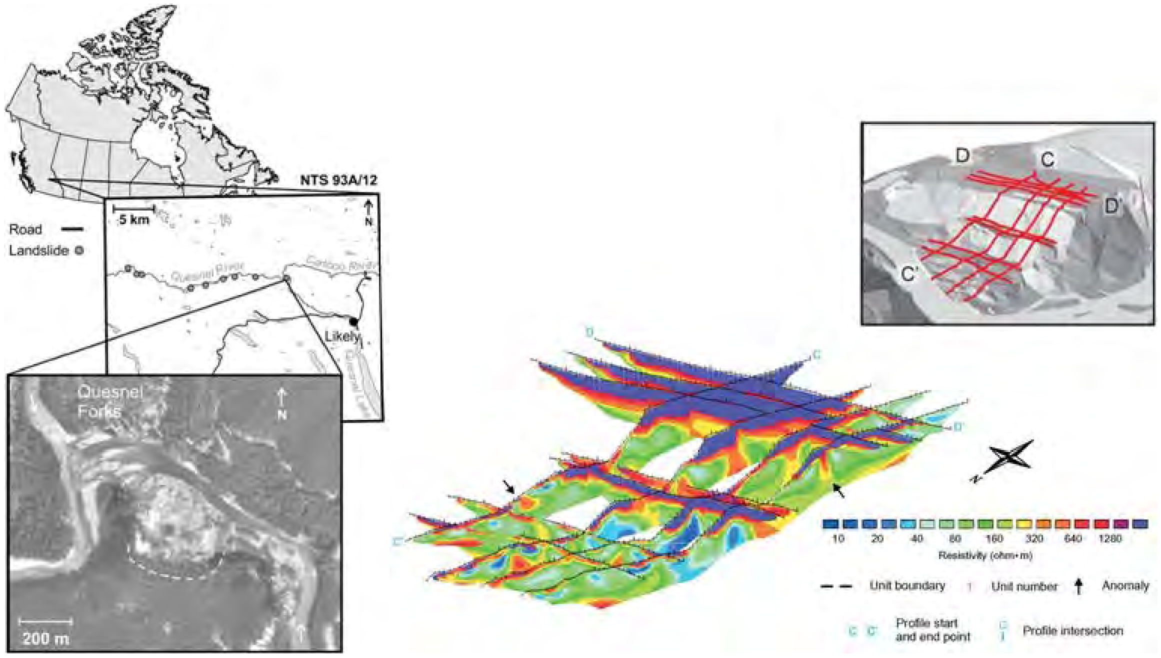

Fig. 3: Left: Landslide on the Quesnel River in British Columbia (Canada); right up: DTMs with DC electrical resistivity survey lines superimposed onto its surface; right bottom: 3D fence diagram of all resistivity data (modified from BICHLER et al., 2004)

Six different lithological units are identified. The 3-dimensional model of the terrace and landslide constructed from the 2D ERT aids in the understanding of landslide processes. The model suggested that increased pore water pressures in the clay unit and artificial loading of terrace due to a perched water table played a role in the instability of the terrace but was not necessarily the trigger. It is much more likely that fluvial erosion of the terrace face was responsible for the loss of shear strength and subsequent collapse of the terrace (BICHLER et al., 2004).

Time-lapse ERT in landslide areas

Time-lapse ERT have recently been applied in landslide areas with the aim to test a new powerful tool for mapping the time-dependent changes of water content in vadose zones. This is a very innovative application that could allow us to use the ERT also during the emergency phase of a landslide disaster cycle.
Figure 5 reports the initial results of the ALERT system located on an active landslide in Malton (North Yorkshire, UK). In particular, the subsurface resistivity variations that occurred between static conditions and an active phase of slope failure are highlighted by analyzing time-lapse resistivity results (CHAMBERS et al., 2009). The two times, August 2008 (t_1) and February 2009 (t_2) were chosen as they represent a dry period (t1) and a wet period (t2) during which movement was occurring. The authors (CHAMBERS et al., 2009) concluded that only at depths (i.e. > 5-10m) where the influence of seasonal air temperature variations is minimal, changes in resistivity could be attributed to changes in moisture content.

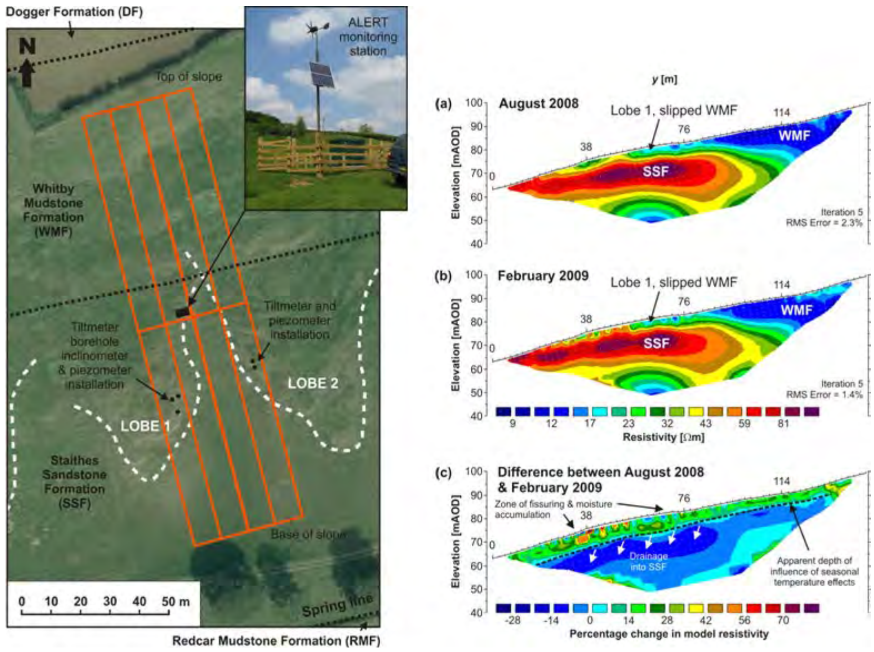

Fig. 4: Left: location of the ALERT station and ERT monitoring arrays (red lines); right: (a) August 2008 and (b) February 2009 ERT models, and (c) resulting differential resistivity image (modified from CHAMBERS et al., 2009).

Conclusions

The results reported in literature and obtained over the last ten years from the application of the 2D and 3D ERT method to study several landslide areas located in different geographical contexts make us consider the ERT method as a very suitable tool for investigating landslides during the pre-event and post-event phases of a disaster cycle.

Indeed, during the pre-event phase the resistivity contrasts which characterize the 2D ERT make it possible to define the subsoil geological setting. They permit to identify high water content areas that could be responsible for events of reactivation. In the post-event phase 2D and 3D ERT allow us to reconstruct the landslide body providing information also about the volume of the material involved in the movement. This information can contribute to better plan future mitigation activities.

The biggest drawback of this method for landslide investigation is the fact that it does not provide time-continuous acquisitions which makes it unsuitable for the study of the landslide dynamic nature. This is also the reason why it cannot be used during the emergency phase of a landslide disaster cycle. Fortunately, the development of systems for the time-continuous acquisition of electrical resistivity and software for data inversion and time-lapse tomographic acquisitions are paving the way for testing this method also during the emergency phase. The possibility to use ERT to monitor the water content changes in the first layers of a landslide area will add important information during the emergency phase. At now, the preliminary results obtained when applying time lapse ERT for this purpose are very encouraging.

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