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Electrical resistivity tomography technique for landslide investigation: A review

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ABSTRACT

In the context of in-situ geophysical methods the Electrical Resistivity Tomography (ERT) is widely used for the near-surface exploration of landslide areas characterized by a complex geological setting. Over the last decade the technological improvements in field-data acquisition systems and the development of novel algorithms for tomographic inversion have made this technique more suitable for studying landslide areas, with a particular attention to the rotational, translational and earth-flow slides. This paper aims to present a review of the main results obtained by applying ERT for the investigation of a wide spectrum of landslide phenomena which affected various geological formations and occurred in different geographic areas. In particular, significant and representative results obtained by applying 2D and 3D ERT are analyzed highlighting the advantages and drawbacks of this geophysical technique. Finally, recent applications of the time-lapse ERT (tl-ERT) for landslide investigation and the future scientific challenges to be faced are presented and discussed.

Contents

1. Introduction

Landslides are complex geological phenomena with a high socio-economical impact also in terms of loss of lives and damage. Their investigation usually requires a multidisciplinary approach, based on the integration of satellite, airborne and ground-based sensing technologies. Each technique allows the study of specific triggering factors and/or particular physical features, characterizing the landslide body compared with the material not affected by the movement.

Airborne and satellite methods (i.e. digital aerophotogrammetry, GPS, differential interferometric SAR, etc.) can provide information on the surface characteristics of the investigated slope, such as geomorphological features, the areal extension of the landslide body, superficial displacement and velocity (Catani et al., 2005; Squarzoni et al., 2005; Glenn et al., 2006; Lanari et al., 2007; Baldi et al., 2008; Roering et al., 2009; Cascini et al., 2010; Strozzi et al., 2010; Ventura et al., 2011; Guzzetti et al., 2012), without giving any information on subsoil characteristics.

Direct ground-based techniques (i.e. piezometer, inclinometer, laboratory tests, etc.) give true information on the mechanical and hydraulic characteristics of the terrains affected by the landslide but in a specific point of the subsoil (Petley et al., 2005; Marcato et al., 2012).

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In-situ geophysical techniques are able to measure physical parameters directly or indirectly linked with the lithological, hydrological and geotechnical characteristics of the terrains related to the movement (McCann and Foster, 1990; Hack, 2000; Jongmans and Garambois, 2007). These techniques, less invasive than the previous ones, provide information integrated on a greater volume of the soil thus overcoming the point-scale feature of classic geotechnical measurements. Among the in-situ geophysical techniques, the Electrical Resistivity Tomography (ERT) has been increasingly applied for landslide investigation (McCann and Foster, 1990; Hack, 2000; Jongmans and Garambois, 2007; references in Table 1, 3 and 5). This technique is based on the measure of the electrical resistivity and can provide 2D and 3D images of its distribution in the subsoil.

The frequent use of this method in the study of landslide areas is mainly due to the factors that can affect resistivity and its extreme variability in space and time domains. Indeed, this parameter is mostly influenced by the mineralogy of the particles, the ground water content, the nature of electrolyte, the porosity and the intrinsic matrix resistivity with weathering and alteration (Archie, 1942; Reynolds, 1997; Park and Kim, 2005; Bievre et al., 2012). Some of these factors, especially the change of water content and the consequent increase in pore water pressures, can play an important role in the triggering mechanisms of a landslide (Bishop, 1960; Morgenstern and Price, 1965).

This paper aims at presenting the current state of-the-art on the application of ERT for landslide investigation, mainly considering the technological and methodological improvements of this technique. The work is focused on the scientific papers published in international journals since 2000 and available online. In particular, this study presents the results of field geophysical surveys based on 2D, 3D and time-lapse ERT carried out for the investigation of different typologies of landslide, also considering the acquisition systems and the inversion algorithms. The main advantages and drawbacks related to the application of the ERT method are identified and discussed. Finally, the future challenges for a better use of the ERT in the landslide investigation and monitoring are presented.

2. The ERT method for landslide investigation

The Electrical Resistivity Tomography is an active geophysical method that can provide 2D or 3D images of the distribution of the electrical resistivity in the subsoil. The analysis and interpretation of these electrical images allow the identification of resistivity contrasts that can be mainly due to the lithological nature of the terrains and the water content variation.

The in-field procedure includes the use of a multi-electrode cable, laid out on the ground, to which a number of steel electrodes are connected at a fixed distance according to a specific electrode configuration. The electrodes are used both for the injection of the current (I) in the subsoil and the measurement of the voltage (V). Knowing the I and V values and the geometrical coefficient depending on the electrode configuration used, the apparent resistivity values characterizing the subsoil investigated can be calculated. These values are positioned at pseudo-depths according to a geometrical reconstruction (Edwards, 1977), which results in a pseudo-section representing an approximate picture of the true subsurface resistivity distribution (Hack, 2000).

To obtain an electrical resistivity tomography, the apparent resistivity values must be inverted by using inversion routines. The best known and most applied algorithm is Res2Dinv (Loke and Barker, 1996; Loke et al., 2003) based on a smoothness-constrained least-squares method which allows to obtain two-dimensional sections through finite differences or finite elements computations, taking into account the topographic corrections. To evaluate the fit of the resistivity model obtained, the root mean square error (RMS) can be considered. This error provides the percentage difference between the measured values and those calculated; so, the correspondence between the field data and the ones of the model is higher when the error is lower. Although Res2Dinv is the most widely applied software, many other methods are currently available for the electrical resistivity data inversion (see Section 2.1 and Table 1).

The first applications of ERT in the study of landslides (Gallipoli et al., 2000; Lapenna et al., 2003) involved the use of manual systems characterized by separated energization and measurement devices and single cables. Due to the absence of multi-core cables, the operators used four separate insulated cables connected to four metal electrodes, two of steel for the injection of current and the other two non-polarizable for the measurement of the voltage. The use of manual equipment resulted in rather slow data acquisition; moreover, the possibility or the necessity to keep the energization and the measurement systems separate mainly favored the use of dipole–dipole configuration which is more suitable for the investigation of vertical boundaries (landslide lateral boundaries, source area, fault) than for the identification of the horizontal ones (sliding surface, lithological contact).

Technological improvements, which produced more compact and portable equipments and faster acquisition systems, as well as the development of novel software for data processing and the creation of 2D and 3D tomographic images of the resistivity distribution in the subsoil have greatly increased the applicability of this technique for the study of landslide areas.

Over the last 15 years the number of systems for the resistivity imaging survey has considerably grown. Two categories of systems are now available, the static and the dynamic. In the static one many electrodes are connected to a multi-electrode cable and planted into the ground during the survey. The dynamic systems use a small number of nodes but move the entire equipment to obtain a wide coverage (Loke, 2013). The static systems are usually used for the investigation of landslides. In particular, the introduction of static multi-electrode systems (Barker, 1981; Griffiths and Turnbull, 1985; Griffiths et al., 1990; Li and Oldenburg., 1992; Dahlin, 1993, 1996; Dahlin and Bernstone, 1997; Stummer, 2002), mainly using single channel data acquisition, has greatly reduced the acquisition time and also improved some logistic aspects. These systems allow the use of a large number of electrodes with an increase in the profile length and the automatic change of spatial resolution and investigation depth. They have made it easier to carry out 2D ERT on landslides and obtain a 3D geoelectrical model of the subsoil, particularly where the logistic conditions are advantageous (small-sized landslides and slightly steep slopes).

The development of algorithms for the inversion of apparent resistivity data (Dey and Morrison, 1979; Barker, 1992; Oldenburg et al., 1993; Oldenburg and Li, 1994; Tsourlos, 1995; LaBrecque et al., 1996; Loke and Barker, 1996; Dahlin, 2001 and reference therein; Loke et al., 2003) made it easier to analyze the data and generate 2D and 3D images useful for the characterization of the slope investigated so as to obtain information on the geometry of a landslide body (i.e. the slide material thickness, the location of areas characterized by a higher water content, the presence of potentially unstable areas, etc.). From a temporal point of view, the information obtained can be considered static being related only to the day of acquisition. Resistivity data are usually acquired after the occurrence of an event and give an image of that moment, without providing any indications on the dynamic evolution affecting the slope investigated. Very recently, the development of static multi-channel measuring systems, able to simultaneously acquire a number of potential measurements for a single pair of current electrodes, have significantly reduced the acquisition time. These systems can be set up to provide ERT at specific times during the day, and they can also repeat the measurement in order to give ERT images at very close time intervals called time-lapse ERT (tl-ERT). This is extremely important as it allows the exploitation of ERT not only to define the geometrical characteristics of the landslide body or the slope investigated but also to monitor a potentially unstable area. The literature reports some examples of tl-ERT applications in landslide areas with the main aim to obtain information on the water content change (see Section 2.3). Obviously, although some software for the processing of data continuously acquired has already been developed, there