Research Article

Geoelectrical Tomography as an Operative Tool for Emergency Management of Landslide: An Application in Basilicata Region, Italy

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During the landslide emergency many kinds of data, even if preliminary, can help to better understand the complexity of the investigated phenomenon and to give a valid contribution to the successive damage valuation. The electrical resistivity tomography (ERT) method was applied for investigating the deep characteristics of a landslide body that occurred in March 2006 close to Potenza town in Basilicata region (southern Italy): the landslide slid on a road near some farmers' houses which had to be evacuated. The information obtained by the application of this indirect technique appeared to be particularly useful for end users involved in the risk management. The high resolution of the 2D ERT technique allowed the detection of possible sliding surfaces and the characterization of high water content areas in which the increase of the saturation degree and of pore pressures could cause a weakening of the slopes and a reactivation of the movement. Due to the comparison between ERT results and stratigraphical data from boreholes carried out in the area it was possible to decide on the adoption of other evacuation decrees.

1. Introduction

The investigated area is located in Basilicata region, one of the southern Italian areas more involved in heavy meteorological conditions [1]. On March 2006, the intense precipitations have increased the saturation degree and the pore pressures of the terrains. The snow blanket has made heavy the slope changing the equilibrium of the strengths involved in the stability of a slope. These climatic conditions have deteriorated the physical and mechanic characteristics of the terrains outcropping in the region. As consequence of all these alterations, the reactivation of many dormant landslides, which affected the slopes of the region in the past, occurred. The main typologies of reactivation have been earth-flow, translational, or rotational slides.

The new slides have involved buildings and infrastructures on the slopes. The risk for people and assets needed the intervention of the end users involved in the risk management and, in particular, the inspection of Regional Department of Infrastructure and Civil Protection (RDICP).

In many involved areas and for many families evacuation decrees have been issued in order to ensure the safety of the people and allow the damage valuation. The study of such complex phenomena required a multidisciplinary approach based on the integration of all the direct and indirect data acquired in the area. An important contribution has been provided by the geophysical data and, in particular, by the 2D ERT that have been carried out in the areas affected by the reactivations some days after the landslide event.

The use of 2D ERT method for investigating landslides is now well tested. Many examples of the ERT application are reported in literature. In many cases the results of its application allowed to reconstruct the geometry of landslide body, to outline the sliding surface, and to locate areas characterized by high water content [2–7].

By using the Mobile Laboratory for chemical-physical and geophysical measurements of the Institute of Methodologies for Environmental Analysis (IMAA) of CNR, some ERTs have been performed in the more damaged areas of the Basilicata region (southern Italy). In particular, the present

FIGURE 1: Location of the study area in Basilicata region.

paper describes the test case of a complex rototranslational slide occurred close to Potenza town in the Picerno village territory during the winter of 2006.

Immediately after the event occurred two ERT, one with transversal direction and the other one with longitudinal direction to the landslide body, were performed in order to try to give an answer to some important questions for the RDICP like what are the geometrical characteristics of the landslide? How many houses and infrastructures could be involved in the evolution of the phenomena? Is it necessary to issue an evacuation decree for others families?

2. Geological Setting of the Landslide Area

The investigated area is characterized by the presence of a diffuse slope instability. On March 2006, due to the meteorological conditions, many reactivations occurred in the area like the one considered in this paper. In order to define the geological and geomorphological features of the area, aerial photogrammetric analysis and in-field observations have been performed.

From a geological point of view, Basilicata region is located along the axial zone of the southern Apennine chain that is mainly composed of sedimentary cover of platform and deep water environments, scraped off from the former Mesozoic Ligurian ocean, the western passive margin of the Adriatic plate, and the Neogene-Pleistocene foredeep deposits of the active margin. From west to east, the main Mesozoic domains are as follows: (1) the internal oceanic to transitional Liguride-Sicilide basinal domains (internal nappes), (2) the Apennine carbonate platform, (3) the Lagonegro-Molise basins, and (4) the Apulian carbonate platform [8].

The study area (Figure 1) is located in the west of the Basilicata region and on the southeastern slope of Li Foi Mountain (1355 m a.s.l.) near the S. Loja Basin along the axial zone of the Lucanian Apennine. The area is characterized by the outcropping of terrains belonging to the Pignola-Abriola facies (calcareous-silica-marly series) of the Lagonegro Unit II [9]. This facies is composed of the Siliceous Schist (Upper Triassic-Jurassic), the Galestrino Flysch (Lower Cretaceous), the Red Flysch (Upper Cretaceous-Lower Miocene), and the Corleto Perticara Formation

FIGURE 2: Geomorphological map of the area (aerial photo by Google Earth) with location of geophysical and geotechnical soundings.

(Upper Eocene-Lower Miocene) [10, 11]. The landslide occurred in 2006 involved the terrains belonging to the Corleto Perticara Formation mainly constituted by calcarenites, calcilutites, and whitish marly limestone.

From a geomorphological point of view the area is characterized by a moderate slope angle of 13–16% with an altimetry range varying between 1072 m a.s.l. at the main crown and 970 m a.s.l. at the toe. The landslide can be classified as a complex retrogressive rototranslational slide and is 600 m long and 230 m wide (Figure 2). Due to the movement, counter slope terraces filled with stagnant water formed. Transversal and radial cracks are still evident in the accumulation zone of the landslide that involved infrastructures and buildings some of whose had to be evacuated [12].

3. ERT and Analysis of the Results

ERT is a geoelectrical method widely applied to obtain 2D and 3D high-resolution images of the resistivity subsurface patterns in areas of complex geology [13]. During the field survey, ERT can be carried out by using different electrode configurations (dipole-dipole, Wenner, etc.) placed at the surface to send the electric currents into the ground and to measure the generated voltage signals. Technically, during an electrical resistivity measurement, the electric current is injected into the ground via two electrodes and the potential drop is measured between two other electrodes in line with current ones. The values of the apparent resistivity acquired along a horizontal axis are assigned at a defined depth and position. In a second step, it is necessary to transform

FIGURE 3: (a) Comparison between AA' ERT, carried out with longitudinal direction to the landslide body, and S1 and S2 stratigraphical data; (b) comparison between BB' ERT and S1 stratigraphical data. The horizontal resistivity contrast, highlighted with white dashed line in both the ERT, corresponds to the contact between detrital material (slide material) and argillite material.

the apparent resistivity values obtained during the field survey into real resistivities of the subsoil and the pseudodepths into true depths.

In this work, the algorithm proposed by Loke and Barker [14] for the automatic 2D inversion of apparent resistivity data was used. The inversion routine is based on the smoothness constrained least-squares inversion [15] implemented by a quasi-Newton optimisation technique. The subsurface is divided in rectangular blocks, whose number corresponds to the number of measurement points. The optimisation method adjusts the 2D resistivity model trying to reduce iteratively the difference between the calculated and measured apparent resistivity values. The root mean squared (RMS) error gives a measure of this difference.

The knowledge of local geology associated with the high spatial resolution of the measurements gives us an interpretative tool to explain the ERT obtained for the case study of this work.

ERTs have been carried out with direction longitudinal (AA') and transversal (BB') to the axis of the landslide (Figure 2) by using a multielectrode system with 32 electrodes and the dipole-dipole array. Both the ERTs were topographically correct in order to reduce possible mistakes and improve the interpretation of the model.

The longitudinal profile (length 780 m) was carried out by using an electrode spacing of 20 m, reaching an investigation depth of about 55–60 m. The AA' ERT (Figure 3(a)), obtained along this profile, is characterized

by a semivertical discontinuity, located at 280 m from the origin of the profile, which separates relatively high resistivity material ($20\text{--}80\ \Omega\cdot\text{m}$) from conductive one ($4\text{--}20\ \Omega\cdot\text{m}$). This discontinuity represents the main scarp of the landslide here investigated. The remainder of the ERT is characterized by a vertical resistivity variation with a first resistivity ($20 < \rho < 50\ \Omega\cdot\text{m}$) layer (about 25 m thick) which covered a more conductivity material ($0 < \rho < 20\ \Omega\cdot\text{m}$). The relatively high resistive layer could be associated with the slide material involved in the reactivation.

The high resistivity material characterizing the north-western side of the ERT highlights the presence of the bedrock. At a distance of 180 m from the origin of the profile it is also possible to see the presence of another vertical discontinuity that could be associated with the old scarp of a deep ancient landslide now totally eroded and not visible at the surface.

The transversal profile (length 320 m) has been carried out by using an electrode spacing of 10 m, reaching an investigation depth of about 45–50 m.

The BB' ERT (Figure 3(b)), obtained along this profile shows a first resistivity ($20 < \rho < 50\ \Omega\cdot\text{m}$) layer (about 30 thick), which covered a more conductivity material ($0 < \rho < 20\ \Omega\cdot\text{m}$). The contrast between conductive and resistive material could be associated with the presence of a sliding surface. The higher conductive nucleus ($\rho < 10\ \Omega\cdot\text{m}$), located at a distance ranging from 160 to 240 m from the origin of the profile, could be associated with an area characterized by high water content.

The ERTs were compared with stratigraphical data from direct boreholes (S1 and S2) carried out in the area by the RDICP (see Figure 2 for the location). In particular, the first 15–16 m of the S1 borehole (a 27 m deep core drilling) can be considered landslide material composed of detrital clay marl deposits with pebbles, interbedded with marly limestone. Below 16 m more consolidated clay can be found down to the bottom of the borehole. Two water tables are found in the S1 borehole at about 14 and 25 m, respectively [12].

The comparison between direct and indirect data (Figures 3(a) and 3(b)) allowed the better definition of the 2D landslide geometry and the correlation between resistivity values, reported in the ERT, and specific lithological characteristics of the slope. The comparison also made possible the detection of high water content areas for which the technicians of RDICP have planned and realized the first drainage works.

4. Discussion and Conclusion

ERT technique was used for emergency management of a landslide that occurred in Basilicata Region close to Potenza town on March 2006. ERT has been applied with the aim to obtain information about the deep characteristics of the landslide body. In particular, two ERTs were carried out with longitudinal and transversal direction to the landslide body, respectively. The results, also compared with stratigraphical data, highlighted the presence of two layers with different resistivity. The sliding surface has been associated with

FIGURE 4: Aerial photo (modified by Google Earth) reporting the location of evacuated families (circles), temporary accommodation (triangle), warning area (square), and geotechnical instrumentations (stars).

the “layer” corresponding to resistivity contrast and area with high water content has been located. The information obtained by the application of this indirect technique appeared to be particularly useful for the end users involved in the risks management. Indeed, during the first phase of the emergency the main problem was the safety of the people and the relative evacuation of the area. In this case, the houses were principally concentrated on middle and upper part of the slope. RDICP technicians in collaboration with local administration had evacuated only the houses located in the middle part of the slope, in correspondence of the landslide body individuated on longitudinal and transversal ERT. A temporary accommodations for these families was found in a container located in a external part of the landslide (Figure 4).

Thanks to the longitudinal ERT, in which the bedrock was detected, it was possible to exclude the retrogressive evolution of the investigated phenomenon so, thanks to this information, to decide that it was not necessary to issue an evacuation decree for the families living in the upper part of the slope. In any case, geotechnical instrumentations (piezometers and inclinometers) and GPS markers were installed inside and outside of the landslide area in order to obtain additional information about the dynamic evolution of the gravitative movement affected the slope (Figure 4).

Moreover, the thickness of the landslide valuated on both longitudinal and transversal ERTs at a depth of about 20–30 m, helped the RDICP to define the slope stabilization plan to adopt during the second phase of the emergency. Indeed, on landslide body only superficial diffuse drainage systems (Figure 5(a)) for the total length of the landslide and naturalistic engineering works to restore the local route (Figure 5(b)) were carried out and any deep works (networks of micropiles, piles, etc.) were realized.

FIGURE 5: (a) Drainage systems effectuated during the second phase of the emergency with 4.0 m depth, and 1.2 km length; (b) Naturalistic engineering works using light and native material (chestnut tree and broom).

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