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Electrical Resistivity Tomography in Support of Geological Surveys of Landslides Involving Clay Slopes in Asti Reliefs

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SUMMARY

We report on the results of geological, geotechnical and geophysical surveys for the characterization of a landslide, occurred in the Asti Reliefs (NW Italy) during the first ten days of March 2011, just after an exceptional meteoric event. The investigated landslide is located in San Damiano d'Asti (15 km E of Asti) and involved a hilly side, gently sloping. The hazard situation in this area regards a landslide that involved the back of a building. This landslide was caused by excavations made in the time at the toe of the slope with the aim to extend the narrow flat spaces. The contribution given by Electrical Resistivity Tomography (ERT) was essential, in the first phase of the investigation, to recognize deep and localized water seepage, otherwise undetectable. The identification of saturated clays into the slope allowed us to design the correct re-profiling of the scarps and make digging operations in safety. The use of these methods of investigation has a significant economic savings in the choice of interventions for slope stabilization.

Introduction

We report on the results of geological, geotechnical and geophysical surveys for the characterization of a landslide, occurred in the Asti Reliefs (NW Italy), following an heavy rainfall occurred on March 2011. The study area, located in San Damiano d'Asti (15 km E of Asti), involved a building located at the toe of the unstable slope. The slope instability was caused by the excavation cut at the toe of the slope to enlarge the area behind the building coupled with the heavy rain of March 2011. The contribution given by Electrical Resistivity Tomography (ERT) was essential, in the first phase of the investigation, to define the shallow subsurface stratigraphy and, above all, to locate the subsoil water seepage. The identification of saturated clays into the slope (forming the sliding surface) allowed us to optimize both the first emergency action (slope re-profiling) and the final design of the slope stabilization, with a relevant cost saving.

Geological setting

The investigated area is located in the western side of the Asti Reliefs (elevation 130-320 m a.s.l.) in the central Piedmont hilly region (Fig. 1). The sedimentary succession is defined, in the lower bands of the hilly reliefs, by deep marine clay deposits (Argille di Lugagnano) and littoral sandy deposits (Sabbie di Asti) referred to the Pliocene (Zanclean). These sediments are usually covered by the “villafranchian succession” comprising deltaic deposits (Lower Complex) and fluvial deposits (Upper Complex), referred to the Piacenzian and Calabrian respectively, separated by an unconformity (Cascina Viarengo Surface) (Forno *et al*., 2015). Above these sediments a widespread silty and subordinately gravelly fluvial cover of middle and upper Pleistocene occurs. The whole sedimentary sequence is deformed by the Asti Syncline consisting of a wide E-W regional scale fold developed in the central hilly area (Poirino Plateau, Asti Reliefs and Alessandria Plateau) (Fig.1). Recent geological researches (Gattiglio *et al*., 2015), regarding the Plio-Pleistocene evolution of the western edge of the Asti Reliefs, emphasized the presence of a N-S deformation zone, named T. Traversola Deformation Zone (TTDZ). This structure corresponds to a scarp with, a rectilinear trend in map view, an height up to a hundred meters and a length of about 30 km, delimiting the Asti Reliefs from the Poirino Plateau.

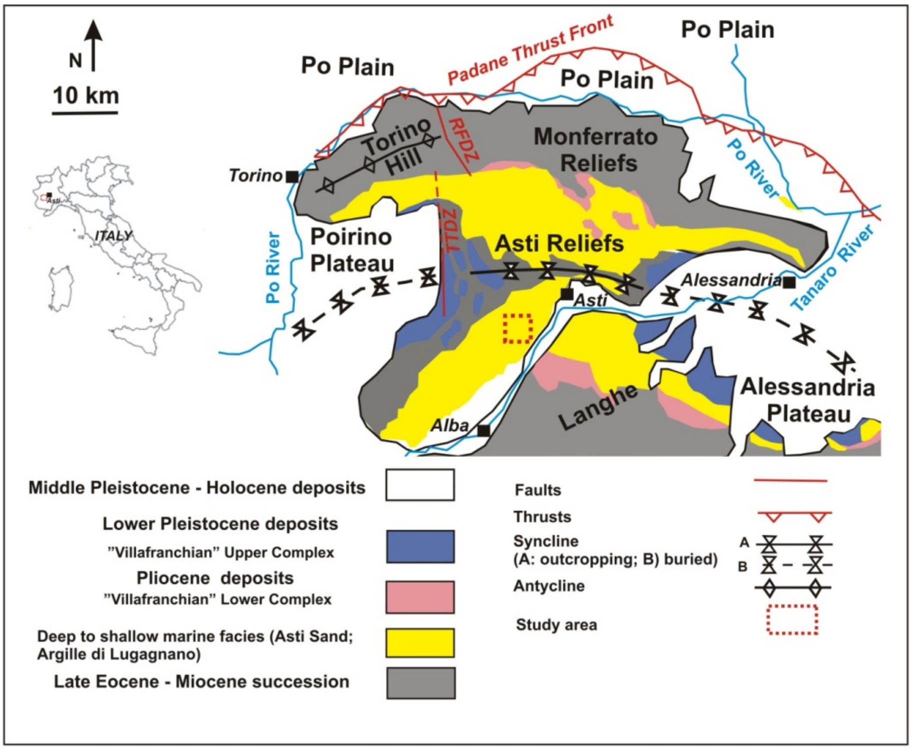

Figure 1 *Schematic geological and structural map of southern Piedmont region. RFDZ: Rio Freddo Deformation Zone; TTDZ: Torrente Traversola Deformation Zone (modified from Forno et al., 2105).*

Geological and morphological surveys

Detailed geological and morphological surveys have been carried out. The investigated side is located in the lower band of a hilly ridge gently sloping towards SSW (**A** in Figure 2). The landslide involves a slope shaped in the marine succession formed by gray-blue clay massive deposits rich in microfossils (Argille di Lugagnano), with horizontal-parallel bedding (strike of 230/20), locally outcropping. The paleontological content allows to refer these sediments to the Zanclean. These sediments show numerous sub-vertical fractures with strike 300/90 and 340/90, some of which are characterized by water circulation.

The landslide body covering the substrate is made of silty-clay deposits with a strong brown color (7.5 YR) with grey mottles and pseudogleys. The landslide sedimentological features suggests that the phenomenon involved the soil developed on the clay substrate and its colluvial cover, that show similar features. The mechanism of the landslide is due to a main rotational slide, that involved the weathered clay substrate, followed by a liquefaction affecting the colluvial cover. It shows a maximum thick of 4 m.

The supposed original topography of the landslide body and its basal surface are reported (**B** and **C** in Figure 2, respectively). The trend of this basal surface is connected to the presence of a terrace, evidenced in the lateral sectors of the slope, not involved in the mass movement, and locally covered by the landslide. A first re-profiling of the side was made in emergency, in order to remove the unstable mass (**D** in Figure 2) which does not reach the basal surface of the landslide (**C**). The proposed re-profiled slope is also reported (**E** in Figure 2), entirely developed in the substrate.

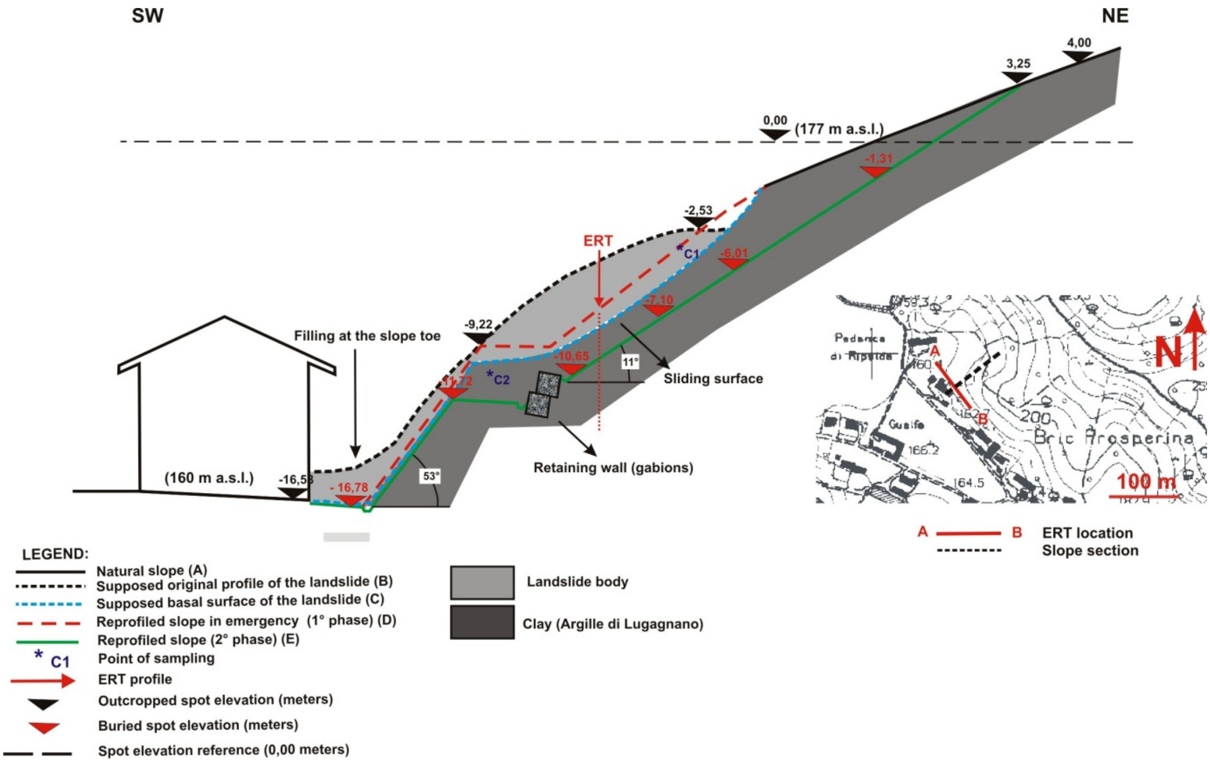

Figure 2 *Landslide section profile and re-profiling design with points of sampling for geotechnical analysis and ERT location.*

Geotechnical laboratory tests

In order to determine the geotechnical proprieties of soil, two undisturbed samples were taken by punches steel type Shelby (∅ = 85 mm) (Figure 2). The sample C1 belongs to the landslide body, the C2 to substrate (“Argille di Lugagnano” Formation). On both samples we proceeded to the execution of geotechnical analysis for soil identification and classification and determination of shear strength characteristics (Table 1). The shear strength was determined with an anular shear apparatus in which the area of the specimen remains constant during the execution of the shear test. For each sample we obtained 3 specimens to examine in the shear test. The geotechnical parameters are listed in Table 1.

Sample	%fraction <0.075mm	Clay %	Silt %	LL (%)	LP (%)	IP (%)	c'_p (kg/cm^2)	c_r (kg/cm^2)	φ'_p (°)	φ'_r (°)
C1	94.43	17.28	77.15	36.86	25.14	11.72	0.05	0.00	27.00	25.20
C2	93.27	22.05	77.22	46.17	27.04	19.13	0.10	0.00	28.70	28.10

Table 1 *LL, LP: Atterberg Limit; IP: Plasticity Index, c'_p: effective cohesion, c_r : residual cohesion φ'_p: peak friction angle or effective angle of internal friction, φ'_r: residual friction angle.*

The sample C1 correspond to a "silty clay of low plasticity, according to Casagrande Plasticity Chart, while the sample C2 correspond to a "medium plastic inorganic clay".

Electrical Resistivity Tomography survey

The purpose of electrical surveys is to determine the subsoil resistivity distribution, which is correlated to variations in mineral and fluid content, porosity and degree of water saturation in the rock. Electrical resistivity method is based on measuring the electrical potentials between one electrode pair while transmitting a direct current between another electrode pair (Reynolds, 1997. According to the landslide morphology, characterized by a stepped slope profile, only one traverse line was conducted approximately in the middle of the landslide, using a combination of Wenner and Schlumberger configuration (Fig. 1). Profile ERT, striking E-W, was performed across slope with 48 electrodes with a spacing of 2 m. Electrical data, including resistivity and induced polarization, were processed with the algorithm developed by Loke and Barker (1996).
The ERT image resistivity profile (Figure 3) shows a layered sequence of low resistivity (wet clay, with resistivity from 10 to 20 ohm.m) and medium resistivity soft sediments (silt and clay, with resistivity values up to 100-120 ohm.m). The colluvial cover (with high porosity) is very thin (less than 1 m of thickness) and shows values of 100-120 ohm.m. The landslide mass has a similar resistivity. The most interesting feature of the section is a globular anomaly of low-resistivity just below the inferred sliding surface. This anomaly is probably related to a channelized groundwater flow along a fractured zone. This groundwater circulation pattern is typical of this kind of sediments. The pore water pressure increases within this fractured zone during heavy rainfall. Consequently, the triggering of shallow movements of the overlying clay can be supported. The determination of size and depth extent of the groundwater channelized flow was, therefore, important to define the boundary conditions to quantify this effect using geotechnical modeling.

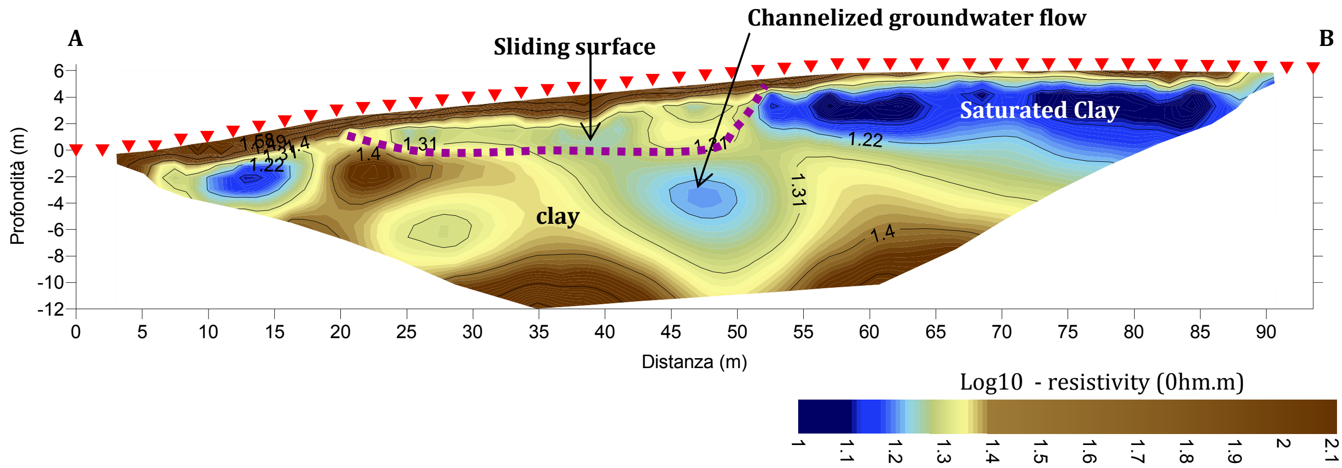

Figure 3 *Geoelectrical tomography section A-B.*

Slope global stability analysis

The slope global stability analysis was made taking into account the results of the ERT surveys in order to assess the optimal slope profile with a proper safety factor. The location of the groundwater seepage surface allowed us to identify the most critical sectors of the slope and to design the stabilization measurmenrts with slopes and terraces. The maximum critical height and inclination of the scarps were calculated using the method proposed by Taylor (1948). The method considers a slope with a simple geometric shape modeled entirely in clays and in homogeneous and saturated undrained conditions. Using the relation c_u/□ = 0.0045LL (Hansbo, 1957), the total stress cohesion value was obtained ($c_u = 0.186$ kg/cm^2). Introducing this value in the Taylor method the critical height of 5.70 m and the maximum inclination of 53° with 5% gradient upwards were returned. The results obtained by Taylor analysis and ERT survey allowed us to elaborate the design the remediation works. It considers the realization of two main terraces, in order to reduce the total slope angle and reduce the energy of surface water runoff (E in Figure 2).
Global stability analyses of the slope was processed according to Sarma method. All tests were carried out on the profile elaborated for the slope mass security (E in Figure 2), using the parameters obtained from the geotechnical laboratory tests with the purpose to consider the more critical failure surface (i.e. F_s minimum). In the slope stability analysis we considered the piezometric level detected by the ERT survey and the introduction of reinforcements at the base of the scarps. According to the results of the stability analysis, we obtained safety factor F_s greater than 1.3.

Conclusions

In this study it was shown that the combination of geophysical methods and of geotechnical test can lead to a better comprehension of the failure mechanisms of unstable slope and to a proper design of the remediation works. The ERT survey has localized the saturated clay along which occurred the sliding. According to this information, a first remediation action (**D**) was the re-profiling of the slope to remove the unstable mass upon the gliding surface (emergency action). Subsequently, the stabilization of the slope has included both drainage interventions (to control the water pressure), a more efficient re-profile of the ground surface (**E**) and the positioning of retaining wall at the toe of the slope.

References

Forno, M.G., Gattiglio, M., Comina, C., Barbero, D., Bertini, A., Doglione, A., Irace, A., Gianotti, F., Martinetto, E., Mottura, A., Sala, B. [2015] Stratigraphic and tectonic notes on the Villafranca d'Asti succession in type-area and Castelnuovo Don Bosco sector (Asti reliefs, Piedmont). *Alpine and Mediterranean Quaternary*, **28**(1), 5-27.

Gattiglio, M., Forno, M.G., Comina, C., Doglione, A., Violanti, D., Barbero, D. [2015] The involving of the Pliocene-Pleistocene succession in the T. Traversola Deformation Zone (NW Italy). *Alpine and Mediterranean Quaternary*, **28**(1), 59-70.

Hansbo, S. [1957] A new approach to the determination of the shear strength of clay by the fall cone test. *Proceedings of the Royal Swedish Geotechnical Institute*, Stockholm, 46.

Loke, M.H., Barker, R.D. [1996] Practical techniques for 3D resistivity surveys and data inversion. *geophysical prospecting*, **44**, 499-523.

Reynolds, J. [1997] *An Introduction to Applied and Environmental Geophysics*. Geo-Sciences Ltd, UK. John Wiley & Sons, New York, 2049.

Taylor D.W. [1948] *Fundamentals of Soil Mechanics*. John Wiley & Sons, New York, 161.