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Application of ERT and GPR geophysical testing to the subsoil characterization of cultural heritage sites in Napoli (Italy)

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ABSTRACT

The paper describes two recent examples of application of Electrical Resistivity (ERT) and Ground Penetrating Radar (GPR), for reconstructing buried subsoil and structural geometries in two historical sites in the city of Napoli. Both investigation sites were characterized by complex environmental and logistic conditions. The first case study was an ancient hypogean cavity excavated in the tuff, where the integration between ERT and GPR allowed to identify the depth of the soft rock below the natural and anthropic filling. The second investigation was finalized to detect the foundation geometry of a high monumental bell tower resting on loose alluvial and pyroclastic soils. In both cases, the joint interpretation of ERT and GPR tests confirmed the preliminary knowledge on the subsoil and addressed further direct investigation aimed at the stability and safety of the historical sites.

1. Introduction

Near-surface geophysical techniques can be useful for the reconstruction of anthropic and/or natural buried structures in urban context. Although these non-invasive techniques are characterized by some limits in the conventional interpretation [1,2], they are particularly effective in the case of historical sites, when cultural heritage needs to be preserved and penetrating investigation tools (such as boreholes) must be avoided or, at least, their impact reduced to the minimum [3–5].

Among the non-destructive techniques, the Electrical Resistivity (ERT) and Ground Penetrating Radar (GPR) can assist engineers in the detection of shallow subsoil conditions and foundation geometry. The ERT is most frequently used for the characterization of the layering and the lithological properties of soil and rock deposits involved in natural geo-hazards, such as slope stability, seismic response analyses, as well as for the location and definition of buried waste disposals [6], polluted sites [7], coastal erosion and seawater intrusion [8]. Few applications, on the other hand, are documented about its use for the detection of buried foundation structures. Ground Penetrating Radar (GPR) investigation is usually carried out to characterize the stratigraphy of the subsoil and, in particular, to reveal the presence of natural and/or anthropic buried structures (such as crypts or graves), ERT can be more or less effective than GPR survey depending on the local soil conditions.

As an example, the ERT technique provides better results than GPR survey, if the shallow subsoil layers are wet and/or fine grained, or if the targets of interest are particularly deep. For this reason, the combined adoption of these two complementary techniques can be considered as an optimized strategy of investigation [9].

After a brief description of the geophysical technique adopted (Section 2), the main results of the two experimental activities are presented (Sections 3 and 4) comparing the field observations with other mechanical properties measured by geotechnical and geophysical investigations.

2. The experimental techniques

The paper describes the application of ERT and GPR geophysical testing for reconstructing the geometry of subsoil and buried structures in two historical sites in the city of Napoli: the Cimitero delle Fontanelle and the Carmine bell Tower. Hereafter a brief description of devices and procedures used in the two investigated sites is given.

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2.1. Electrical resistivity tomography

The Electrical Resistivity Tomography (ERT) consists of the experimental determination of the apparent resistivity, ρ, of a given material, by means of joint measurements of electric current intensity and voltage introduced into the subsoil through separate couples of electrodes (‘dipoles’), driven in the ground surface. By deploying a linear array of dipoles, and recording the electrical signals for an acquisition time of the order of one hour, it is possible to back-figure a 2D pseudo-section, which can be subsequently turned into an actual resistivity section. The investigated depth is of the order of one fifth of the array length; of course, the longer the array, the higher the depth, but increasing the electrode spacing the resolution decreases.

The resistivity distribution can be interpreted in terms of soil lithology and degree of saturation, taking into account that ρ increases with grain size, cementation and moisture content.

In the experimental campaigns reported hereafter, the ERT data were gathered through electrodes of length equal to 40 cm, partially driven into the ground. The electrodes were then connected through multichannel cables, adopting the Wenner-Schlumberger [10] array configuration (Fig. 1). This arrangement is hybrid between the Wenner and Schlumberger array configurations: during the acquisition, the wiring is continuously changed so that the spacing, a, between the ‘potential electrodes’ remains constant, while that between the ‘current electrodes’ increases as a multiple n of a.

The choice of this arrangement was due to the necessity to study areas in which both lateral and vertical variations of resistivity are present.

The resulting horizontal distribution of the underground data points in the pseudo-section, in fact, is comparable with that typical of the Wenner array, but their vertical resolution is enhanced.

The geoelectric measurements of resistivity were executed with the georesistivimeter “SYSCAL Pro” (Iris Instruments™), and the resistivity data inversions were iteratively carried out through the RES2DINV software [11]. The inversion procedure uses a smoothness-constrained least-squares routine implemented into Occam’s optimization algorithm [12], which permits determining iteratively a 2D resistivity model for the subsoil.

2.2. Ground penetrating radar

GPR uses a high-frequency electro-magnetic pulse transmitted from a radar antenna to probe the subsoil. The transmitted radar pulses are reflected from various interfaces within the ground, and the reflection is detected by the radar receiver (Fig. 2). The dielectric properties of soils correlate with its lithology and moisture content [13]. A GPR system is made up of two main components: the control unit and the antenna. The control unit contains the electronics, which triggers the pulse of radar energy that the antenna sends into the ground. The antenna receives the electrical pulse produced by the control unit, amplifies and transmits it into the ground or another medium at a particular frequency. This latter is the major factor affecting the investigation depth: the higher the frequency, the lower the pulse wavelength, hence the shallower the penetration. On the other hand, a higher frequency antenna has a better measurement resolution and detects smaller targets.

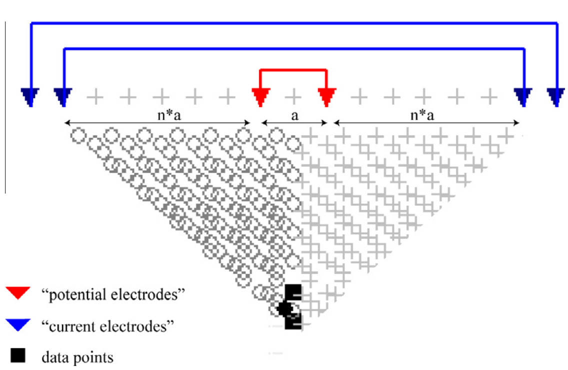

Fig. 1. Wenner-Schlumberger array configuration.

The GPR investigations were performed by using a Subsurface Interface Radar System-3 (SIR-3000) manufactured by Geophysical Survey System (GSSI). A 270 MHz centre frequency antenna was used; this allowed investigating the soil to a depth of about 5 m. The following acquisition parameters were selected: 16-bit data word length, 512 samples per scan, a recording time window of 94 ns; a dielectric constant equal to 5.

The obtained data were analyzed and filtered by using the commercial software “Radan7”, from GSSI, which produces radargrams purged by any anomalous signal caused by the presence of possible interference.

3. The investigated sites

Two historical sites in the city of Napoli were investigated: the Cimitero delle Fontanelle and the Carmine bell Tower (Fig. 3).

The two sites are the expression of the morphologic complexity of the city, whose geologic context (Fig. 3), mainly dominated by the presence of pyroclastic soil, was the result of the volcanic activities of both Campi Flegrei and Somma-Vesuvio districts. The main base formation is the Neapolitan Tuff, originated by the solidification process of loose pyroclastic soil erupted from Campi Flegrei. Tuff is often outcropping within the urban territory as in the case of the Cimitero delle Fontanelle. The tuff is covered by the pyroclastic sequence, which is the result of the primary volcanic deposition in the hilly part of the city, while it appears as alluvial sediments on the costal zone, having continental or marine origin. The volcanic soils are present in all the territory with thickness of some tens of meters, underlying thin layers of a younger formation of pumices and lapilli, covered by volcanic fly ashes and remolded soils, together with man-made grounds, including masonry blocks often used as filling materials.

3.1. Cimitero delle Fontanelle

The “Cimitero delle Fontanelle” is one of the most fascinating hypogean sites excavated for the exploitation of the Neapolitan Yellow Tuff, whose origin may be traced back in the XVI century. The quarry become a charnel house after catastrophic events such as earthquakes and plagues in the XVI century. It is a cavity network made by chamber and pillars (Fig. 4a). The cavity roof, as high as 10 m, is supported by 9 isolated pillars and 4 further vertical elements, defined ‘septums’, protruding from the walls. The overall plan shape is rectangular elongated in the NS direction and consisting of three naves, just like a church (Fig. 4b).

The nave sections have a trapezoidal shape with a flat roof and walls inclined 10–15° with respect to the vertical; the pillars, consequently, have a structural section decreasing with depth. The two boreholes available (Fig. 4b) show that the subsoil below the current floor level (71.50 m a.s.l.) mainly consists of an interbedding of anthropic fill and natural soils of different grain size, with both volcanic and alluvial origin. The tuff formation, covered by cuttings resulting from the excavation, was detected at a depth of 9.0 m from the current walking level: it is therefore believed that the pillars are buried in the filling material for a significant stretch.

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