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Application of geophysical tests for the detection of buried subsoil geometry in a cultural heritage site in Naples (Italy): the Fontanelle Cemetery

TECHNICAL REPORT

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Picture of the entrance of the Fontanelle Cemetery

Introduction

The technical report describes the application of non-invasive geophysical methods, Electrical Resistivity (ERT) and Ground Penetrating Radar (GPR), for reconstructing the buried subsoil geometries of a cultural heritage site in the city of Napoli, characterized by complex environmental conditions. The investigated site is the Fontanelle Cemetery, a cavity network made by chamber and pillars, 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 electromagnetic surveys were finalized to detect the buried subsoil geometry and the real height of the buried pillars.

The tests were conducted in the period: July-September 2014.

The scientific and technical staff , involved in the experimental activity, was reported in Table1.

Table1 scientific and technical staff

Name	Title	Task	Employment
Dott. Vincenzo di Fiore	Researcher	Geophisical	Acquisition and Processing
Ing. Lorenza Evangelista	Researcher	Geophisical/ Geotechnical	Acquisition and Processing
Dott. Giuseppe Cavuoto	Researcher	Geophisical	Acquisition and Processing
Dott. Daniela Tarallo	Researcher	Geophisical	Acquisition and Processing
Dott. Michele Punzo	Researcher	Geophisical	Acquisition and Processing
Sig. Paolo Scotto di Vettimo	Tecnical	Geophisical	Acquisition
Ing. Anna Scotto di Santolo	Researcher	Geotechnical	Interpretation
Prof. Francesco Silvestri	Professor	Geotechnical	Interpretation

Chapter 1 – Site description

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 shape in plan is rectangular, elongated in the NS direction and consisting of three naves, just like a church (Figura1).

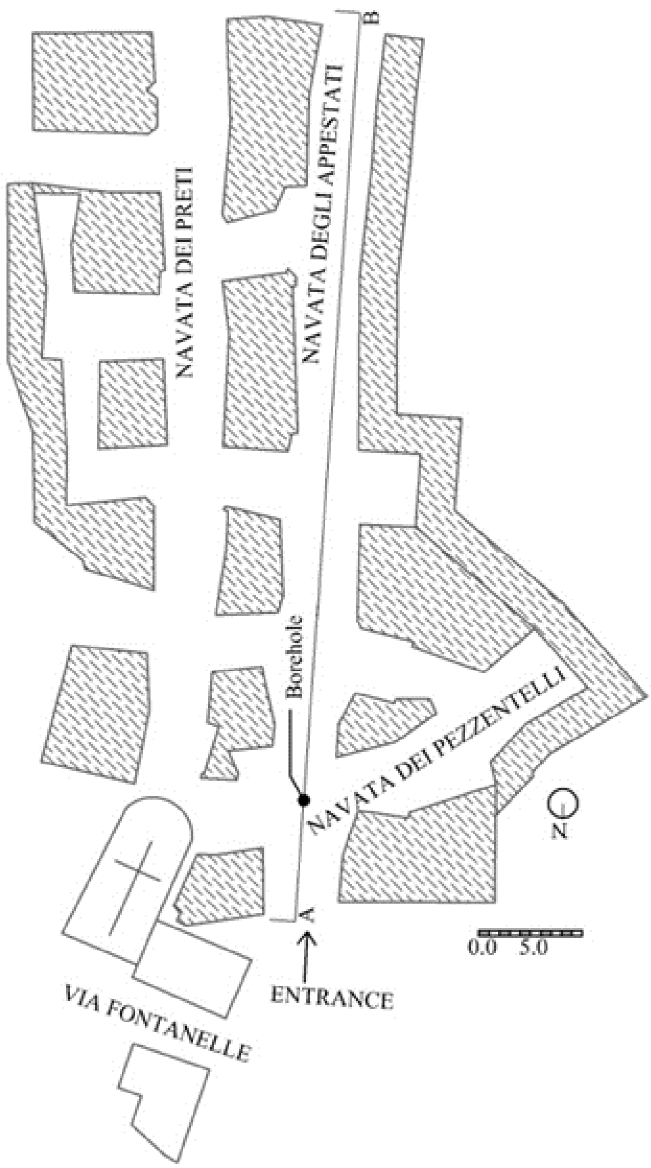

Fig. 1. Plan view of the Cimitero delle Fontanelle and location of borehole, ERT and GPR surveys

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 only borehole available shows that the material below the current floor level (71.50 m a.s.l.) is composed by an inter-bedding 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 9.0m from the current walking level: it is therefore believed that the pillars are buried in the filling material for a significant stretch.

According to the reconstruction of the sequence of events, a mixture of tuff cuttings, debris and mud transported by the floods gradually have been accumulated on the bottom of the excavation, where human remains were buried or simply abandoned by the gravediggers.

Chapter 2 – Equipment and experimental technique

The technical report presents recent examples of application of near-surface geophysical techniques, such as Electrical Resistivity (ERT) and Ground Penetrating Radar (GPR), in order to show their effectiveness in reconstructing buried subsoil and structural geometries in historical centres. In fact, such non-invasive methods can assist the geotechnical engineers in the detection of shallow subsoil conditions and foundation geometry 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

2.1. Electrical Resistivity Tomography (ERT)

The Electrical Resistivity Tomography (ERT) consists of the experimental determination of the apparent resistivity ρ of a given material, through 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, with an investigated depth 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 saturation, taking into account that ρ increases with grain size, cementation and moisture. 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, and monitoring of waste disposals or polluted sites. Few applications, on the other hand, are documented for soil-structure interaction problems.

In the experimental campaigns reported hereafter, the ERT data have been gathered through 48 electrodes, 1 m spacing, partially driven into the ground. The electrodes were then connected through multichannel cables, adopting the Wenner-Schlumberger array configuration (Pazdirek and Blaha, 1996, Figure 2,3). This type of arrangement is hybrid between the Wenner and Schlumberger arrays: 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.

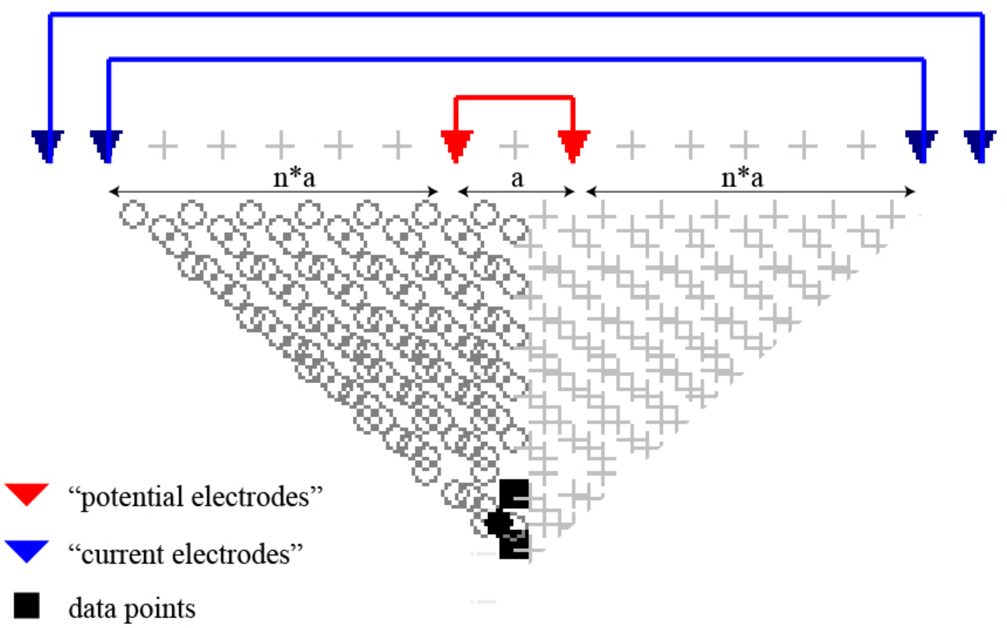

Fig. 2. ERT: Wenner-Schlumberger array configuration

The choice of such an arrangement was due to the need 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 better.

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. The inversion procedure uses a smoothness-constrained least-squares routine implemented into Occam’s optimization algorithm, which permits determining iteratively a 2D resistivity model for the subsoil.

Fig. 3. Experimental array configuration

2.2. Ground Penetrating Radar (GPR)

In order 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), Ground Penetrating Radar (GPR) investigation was carried out. GPR uses a high-frequency electro-magnetic pulse transmitted from a radar antenna to probe the earth. The transmitted radar pulses are reflected from various interfaces within the ground, and this return is detected by the radar receiver (Figure 4). The dielectric properties of materials correlate with many of the mechanical and geologic parameters of materials.

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 will detect smaller targets.

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 to investigate the soil to a depth of about 5 m. The following acquisition parameters were selected: data word length, 16 bit; samples per scan, 512; recording time window, 94 ns; dielectric constant 8.

The obtained data were analyzed and filtered by using the commercial software ‘‘Radan 7’’, from GSSI, which produces radargrams purged by any anomalous signal caused by the presence of eventual interference.

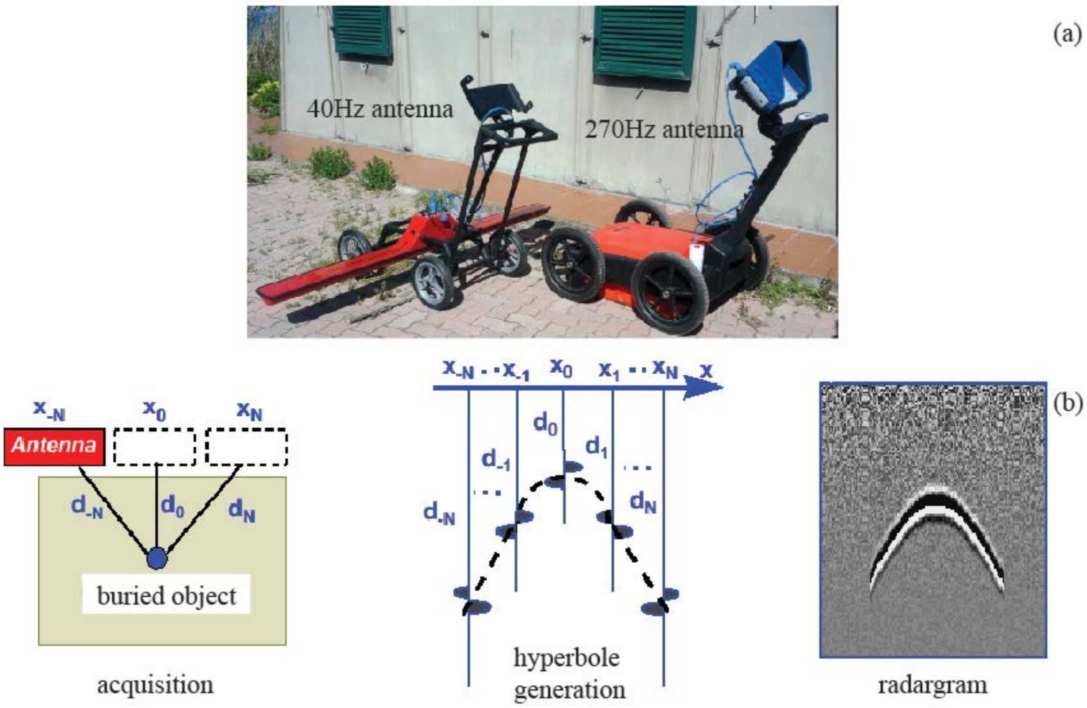

Fig. 4. GPR test: (a) equipment, (b) acquisition and interpretation of experimental data

Chapter 4 – Preliminary results

The 2D image shows apparent resistivity lateral changes (Figure 5b), confirming the complexity of the buried geometry. Overall, it is possible to individuate:

- a shallow layer, about 2 m thick, characterized by a range of resistivity of 100-500 Ωm which can be associated to the anthropic coarse fill (‘acf’);
- an intermediate layer, 2 to 4 m thick, with a lower resistivity (about 10-100 Ωm), corresponding to the volcanic-alluvial sand and silt (‘ss’) formation detected by the borehole down to 4m depth;
- a deeper layer where the resistivity suddenly increases to values between 500 to 1000 Ωm, typical of soft rocks like the Neapolitan Yellow Tuff (‘NYT’).

Note that close to the middle of the gallery, a sharp decrease of resistivity down to about 10-60 Ωm appears also in the shallowest ‘acf’ layer: it can be interpreted as the presence of a moister zone associated to visible water leaks from the cavity roof. Also, while the smooth horizontal variation along the deeper 'ss' layer can be again attributed to changes in the degree of saturation, the sharper discontinuities in the 'NYT' tuff formation can be associated either to its fracturing or to the presence of the cuttings ('NYTc').

Most of the above evidences are confirmed by the radargram recorded along the same alignment (Figure 5c): in fact, the uppermost 2 m (down to the dashed line) are characterized by a clear attenuation and scattering, respectively typical of wet and coarse materials. The intermediate radargram depths, ranging between 2-3m (southern side) and 2-4m (northern side), corresponding to the 'ss' layer, appear quite regular and well stratified. The strong reflector (solid line) in the GPR profile represents the transition from the sand and silt layer to the tuff formation.

From both tests, still some uncertainties remain on the actual depth of the intact Neapolitan Yellow Tuff formation buried below the cuttings, and on the anomalous zone characterized by an increase of resistivity up to 3000 Ωm and to a chaotic zone in the GPR profile, which can follow from small diffraction hyperbolas, generated by objects smaller than antenna's horizontal resolution.

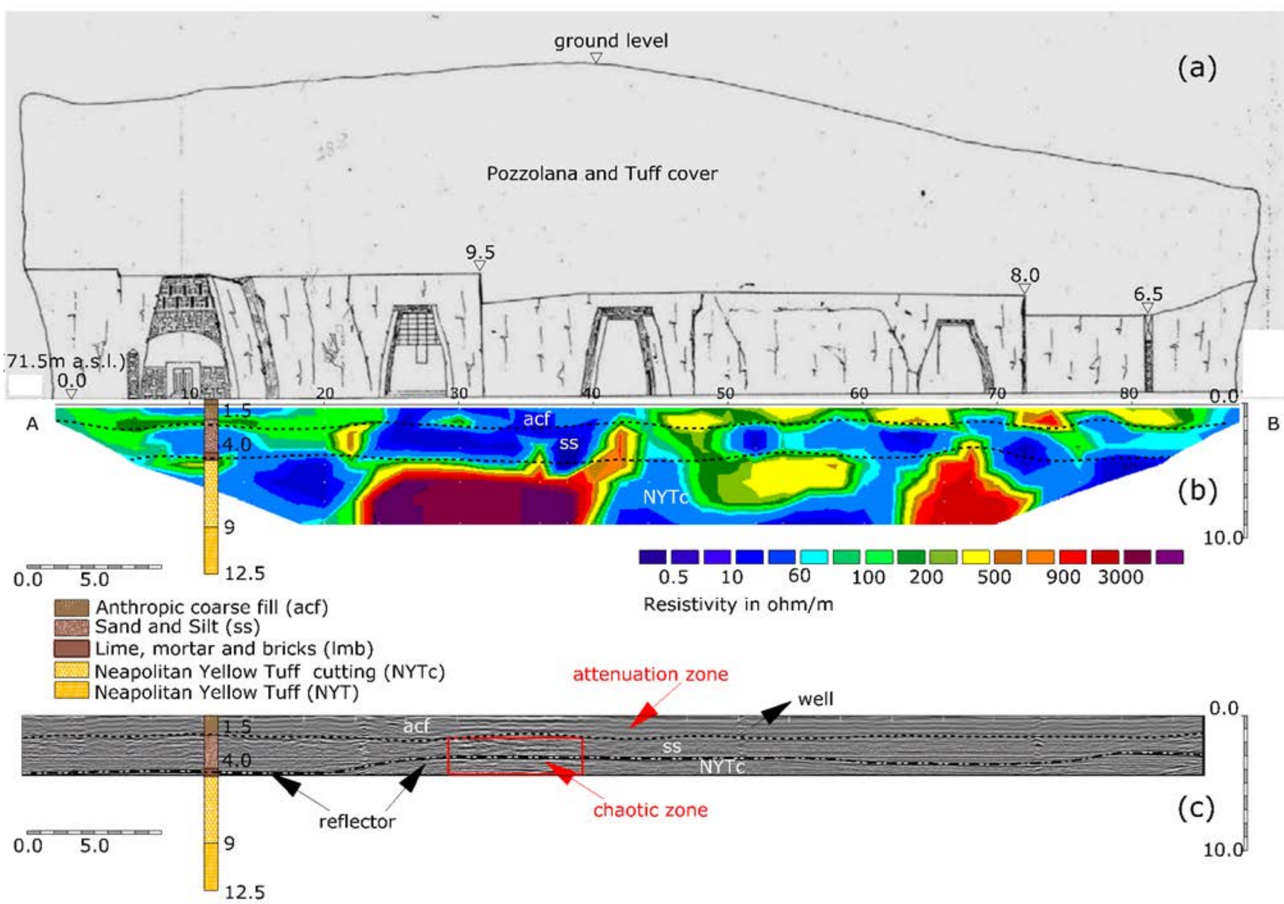

Fig. 5. (a) Cross section of "Navata degli Appestati"; (b) ERT tomography section and (c) GPR radargram.

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