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Non-invasive electromagnetic surveys (ERT and GPR tests) for the detection of foundation geometry in historical site: the case of Carmine bell tower, Naples (Italy)

TECHNICAL REPORT

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Picture of the Carmine bell tower, Naples (Italy)

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Introduction

The technical report describes the recent application of Electrical Resistivity (ERT) and Ground Penetrating Radar (GPR), for reconstructing buried structural geometries of a cultural heritage site in the city of Napoli, characterized by complex environmental and logistic conditions. The investigated site is the Carmine bell tower, located in the East seaside area of Naples (Italy), close to the neighboring magnificent church. The electromagnetic surveys were finalized to detect the foundation geometry of the high monumental bell tower resting on loose alluvial and pyroclastic soils. In fact, such non-invasive methods can assist the geotechnical engineers in the detection of 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.

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. Filomena de Silva	PhD	Geotechnical	Acquisition and Interpretation
Prof. Francesco Silvestri	Professor	Geotechnical	Acquisition and Interpretation

Chapter 1 – Site description

The Carmine bell tower is adjacent to the neighboring magnificent church in the Eastern seaside area of Naples (Figure 1), subjected to a considerable seismic hazard. The current structure, in fact, was built during the XVII century on the basement of a former bell tower, destroyed by the Sannio earthquake in 1456. The brickwork structure, 68 m tall, is characterized by a rectangular cross section, made up of Neapolitan yellow tuff, from the ground level up to the height of 41 m. The upper part, completed by a spire, has an octagonal cross section made up of clay bricks. The bell tower rests on a very deformable deposit of man-made ground and alluvial sands, overlying volcanic tuff (de Silva, et al. 2014)

In order to preserve the monument by future earthquakes, significant mitigation countermeasures may be necessary. Thus, the fine tuning of the seismic protection requires analyses on refined models, based on the deep knowledge of the structure, its foundation and the underlying soil, in order to catch the dynamic soil-structure interaction behaviour in a more realistic way (Sica, et al. 2013).

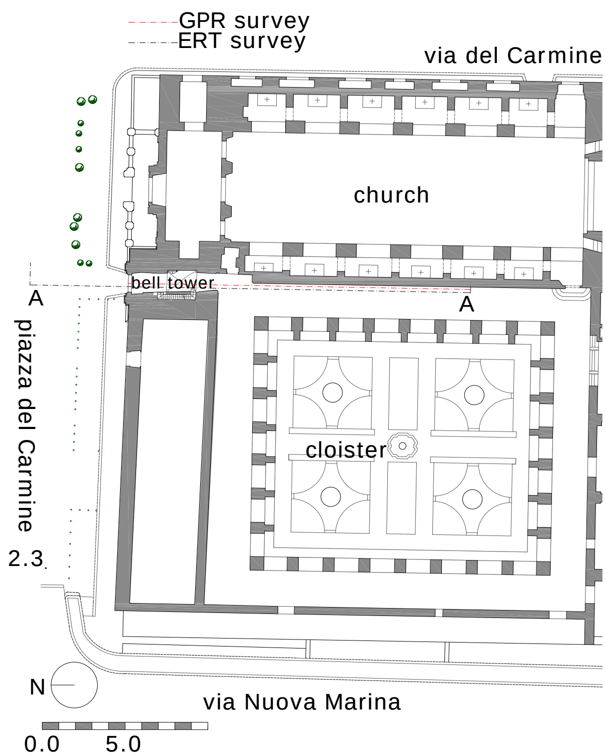

Fig. 1. Plan view of the Carmine bell tower and location ERT and GPR surveys.

Insofar, the geotechnical model was reconstructed on the basis of existing data nearby the site: the subsoil consists of a very deformable deposit of made ground (5m on the average) and alluvial sands (down to about 20m), overlying volcanic tuff. On the other hand, the shape and the depth of the foundations were not yet investigated to date.

Chapter 2 – Electrical Resistivity Test (ERT): equipment and experimental technique

Resistivity method uses, as a parameter geophysicist to investigate the subsoil, the electrical resistivity of the soil. The resistivity is a physical property of rocks and soils, that indicates the resistance encountered by the electric current flows through them. The resistivity parameter is influenced by: texture and porosity, degree of cementation, the temperature of the rock, clay content, permeability, temperature and salinity. Furthermore, under equal conditions lithological, there are some geological processes that cause an immediate variation of resistivity, because they change the porosity. In particular the reduction of the resistivity can be caused by clay alteration, dissolution, billing rock, saltwater intrusion, disconnect and/or weathering. The increase of the resistivity, instead, is due to solidification process, calcium carbonate precipitation or silicification. For this reason, the resistivity of rocks and soils cannot be defined by a single value, but from a range within which it can vary. In addition, the range of resistivity of the various lithologies, often overlap resulting in further problems in the process of data processing and identification of the rock.

2.1. Equipment and array configuration

The equipment used for the measurement of the resistivity consists of two parts: one for the measurement of the intensity of the current I injected into the ground through the electrodes A and B and one for the measurement of the potential difference ΔV between the electrodes MN. The electrodes are constituted by steel pegs (Figure 2a) with a length of 40 cm that are driven into the ground and subsequently connected through terminals multichannel cables. The geo-electric measurements of resistivity and were executed with the Pro SYSCAL of Iris Instrument (Figure 2b). In relation to the position of the electrodes of the current compared to those of potential, it is possible to realize various types of electrode configurations (array). During the acquisition at the Carmine Bell Tower was chosen a Wenner- Schlumberger array configuration (Pazdirek and Blaha, 1996, Figure 3).

(a) (b)

Fig. 2. Equipment: (a) steel peg and (b) Syscal Pro

This type of device appears to be a hybrid between Wenner and Schlumberger array. The spacing between the potential electrodes remains constant and equal to a, while the spacing between the current electrodes increase as multiples of a.

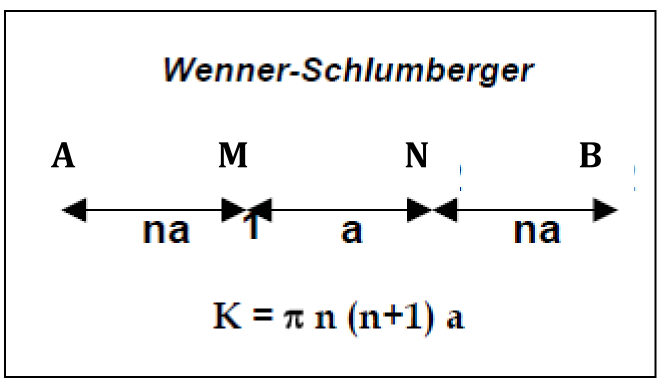

Figura 3. Wenner-Schlumberger array

The value of n, in this case is given by the ratio between the distance of the electrodes A-M (or N-B) and the spacing between the electrodes of potential M-N. For this array the distribution of the measurements is comparable with the Wenner array, but the horizontal coverage is greater.

The choice fell on this type of device, because, in case it is necessary to study areas in which are present both lateral variations of resistivity and vertical, this type of array is a fair compromise between the device Wenner and the dipole-dipole. The intensity of the signal is smaller than the Wenner but is higher than the dipole-dipole axial.

At constant distance between the current electrodes, the depth of investigation that can be achieved with the device Wenner-Schlumberger is 10% higher than the Wenner device.

2.2. Experimental procedure

For the Carmine Bell Tower, an electrical profile with 48 electrodes at 1 m spacing was acquired. The length of profile was 47 meters (Figure 4a-b). The data derived from geo-electric survey provide information on the distribution of apparent resistivity in the subsurface. To get the real resistivity and then to reconstruct the evolution of the real resistivity in the subsurface, it is necessary to carry out an inversion of the data. The inversion results restore profiles of Electrical Resistivity Tomography (ERT).


(a) (b)

Figura 4. (a) and (b) experimental array configuration

In general, the inverse method is an mathematical technique used to analyze the data in order to obtain useful information about the physical reality that has led to the trend of the measured data. An initial resistivity model is iteratively modified until the difference between this and the pseudo-experimental section is minimized. The process continues in an iterative mode, gradually making changes to the model, to minimize Root Mean Squared (RMS) between the measured and calculated pseudo section; when this difference is minimal, it may be assumed that it is also the minimum difference between the calculated and real model. In geo-electric surveys most of the inversion techniques are represented by approximate methods or by iterative methods that require high computational power (Loke and Barker, 1996). In our case, for the inversion of the data was used Occam as the inversion algorithm. The guiding idea is the minimization of a function bound, in which the constraint is represented by the standard deviation, while the function to be minimized is the roughness of the model.

Chapter 3 – Ground Penetrating Radar (GPR): equipment and experimental technique

Ground-Penetrating Radar (GPR) uses a high-frequency EM 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. The dielectric properties of materials correlate with many of the mechanical and geologic parameters of materials (Davis and Annan, 1989).

A GPR system is made up of two main components: 1) Control unit 2) Antenna. The control unit contains the electronics, which triggers the pulse of radar energy that the antenna sends into the ground. It also has a built-in computer and hard disk/solid state memory to store data for examination after fieldwork. The antenna receives the electrical pulse produced by the control unit, amplifies it and transmits it into the ground or other medium at a particular frequency. Antenna frequency is one major factor in depth penetration. The higher the frequency of the antenna, the shallower into the ground it will penetrate. A higher frequency antenna will also ‘see’ 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 us 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 a commercial software ‘‘Radan 7’’, from GSSI, which produces graphic purged by any anomalous signal caused by the presence of eventual interference. Initial data processing was to remove ringing noise applying background removal technique and “dewow” each trace to remove very low frequency components. An automatic time zero shift correction was applied to each radar section to compensate for time zero drift. This correction should bring time zero to the start of each trace and align each trace in the section. Sections were generally plotted using an AGC (Automatic Gain Control) gain; this gain attempts to equalize all signals by applying a gain that is inversely proportional to the signal strength. Deconvolution technique was useful to increase the resolution by making wavelet spiky and removing multiples and/or inter-bedded multiples, which look like ringing. Kirchhoff two-dimensional velocity migration was performed to evaluate the object's correct placement and size.

Chapter 4 – Preliminary results

Both ERT and GPR surveys were performed along the base of the tower and the church, crossing the tower masonry walls through two openings, in order to achieve the maximum investigation depth under the tower itself (Figure 6b).

The ERT clearly highlights an area of high resistivity (more than 600 Ωm) as wide as 10 m, extending from a depth of 4 m until a maximum of about 8 m (Figure 6b). Being this area located just beneath the structure of the bell tower, and since the resistivity values are similar to those measured in the NYT in the other site, the anomaly can be ascribed to the foundation shape. Similar evidences could not be detected in the GPR profile (Figure 6c) due to the low depth reached (maximum 4 m); the presence in the radargram of a well-defined and continuous reflector at a depth of about 0.8 m just outside the bell tower (chainages 0-6 m and 14-18 m) might identify an old floor level. It is also interesting to observe in the ERT the presence under the church wall of a 1-2m layer, characterized by resistivity values between 150-200 Ωm and overlying a formation with higher conductivity, with values of the order of 50 Ωm, comparable to those detected above the tower foundation and in the shallow soil outside the building. The presence of this high resistivity zone can be attributed to the vicinity of the church wall foundation. The effects of changes in soil saturation, expected to result into a sudden decrease of resistivity across the groundwater depth of 2m, are more evident outside the building than inside it: in fact, on this side the groundwater conditions may be influenced by a pumping system operating in the hypogean rooms underneath the church apse; moreover, the monolithic foundation may represent a watershed inducing a damming effect.

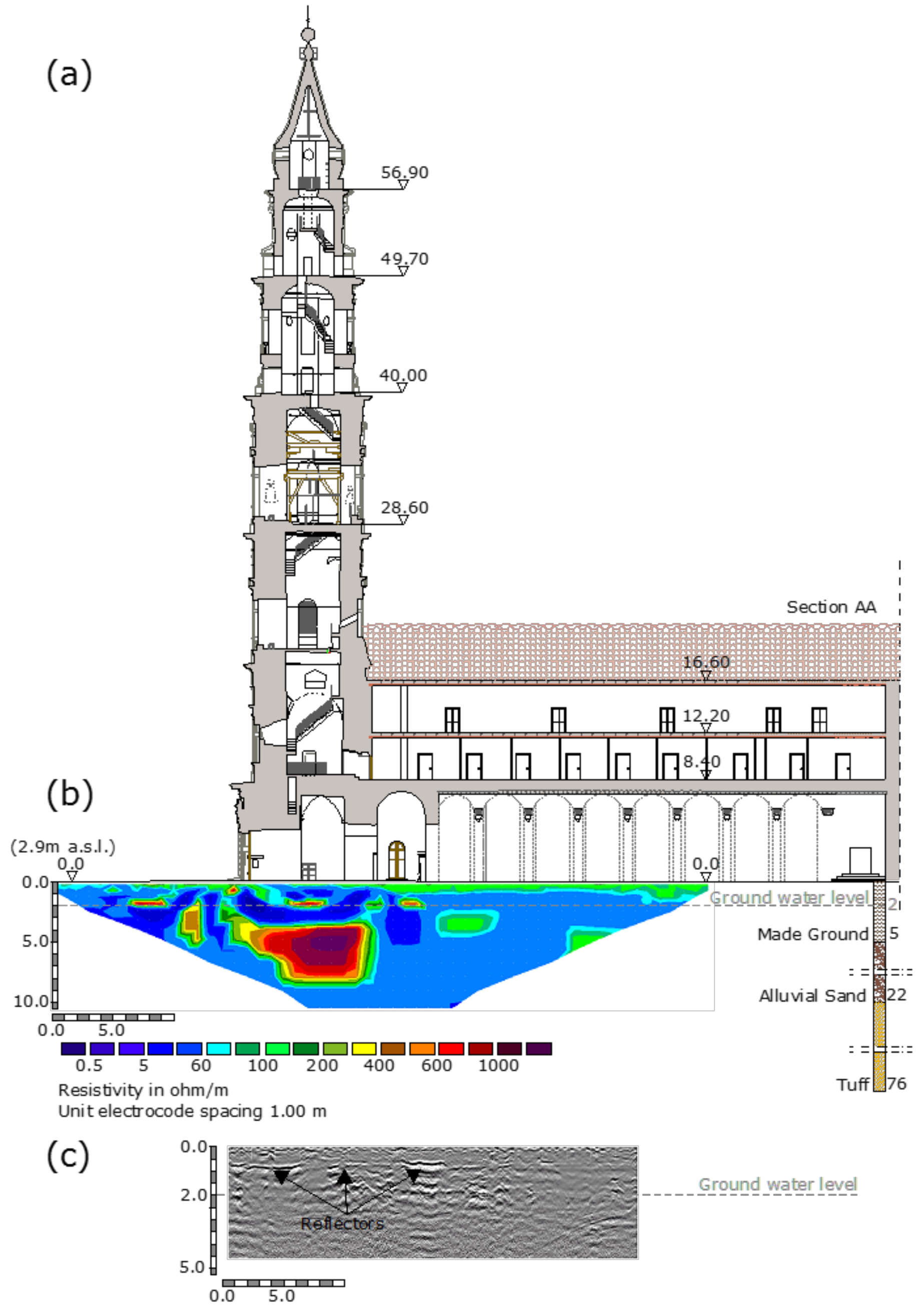

Fig. 6. (a) Cross section of Carmine bell tower; (b) ERT tomography section and (c) GPR radargram.

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