Ground penetrating radar and electrical survey of the roman "Terme Achelliane" in Catania (Sicily): a case history

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Abstract: In the historic centre of Catania, various archaeological sites have been uncovered, as being the result of the various historic settlements established there over time and which were often covered by lava flows, and the topographic necessary levelling.

The aim of this work is to define the existing geometric relationship between the archaeological structures and the surrounding landscape through geophysics and drilling investigations and reconstructing the surrounding area of the *Terme Achelliane* (1C A.D), underneath the Duomo Square in Catania, through geoelectrical prospecting. The studied area is characterized by the co-existence of sedimentary and volcanic rock and by the notable presence of rubble material (1-5 m) originating from destroyed ancient constructions, which collapsed following earthquakes and/or from war damage. The investigation

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was carried out using and integrating the following methodologies: drilling investigations, georadar surveys (GPR) and geo-electrical tomographic prospecting.

The investigation allowed the delimitation of the surrounding area of *Terme Achelliane* which corresponds to a superficial area of high resistivity (> 500 Ω·m) and a clear-defined layer characterized by a resistivity < 100 Ω·m, corresponding to layers of detritus material. At a depth of 6 metres a resistivity value > 200 Ω·m attributable to lithotypes of volcanic nature was found.

Key words: archaeological investigations, ground-penetrating radar, electrical tomography, drilling surveys, urban area

1. Introduction and historic background

The present work contains the results of drilling investigations and of geophysical prospecting carried out in the area of Duomo Square in Catania (Fig. 1) with the aim of defining the geometric relationship between the buried archaeological structures (*Terme Achelliane*) and the surrounding landscape.

Under the lava ground of Catania, there are many buried archaeological structures, dating from the Roman period, and among these is the remains of a vast thermal complex known as *Terme Achelliane* or 'Dionisee', which rose near the Temple of Bacco (Fig. 2). In fact, during the Roman period different thermal buildings were constructed in Sicily (Thermal baths del

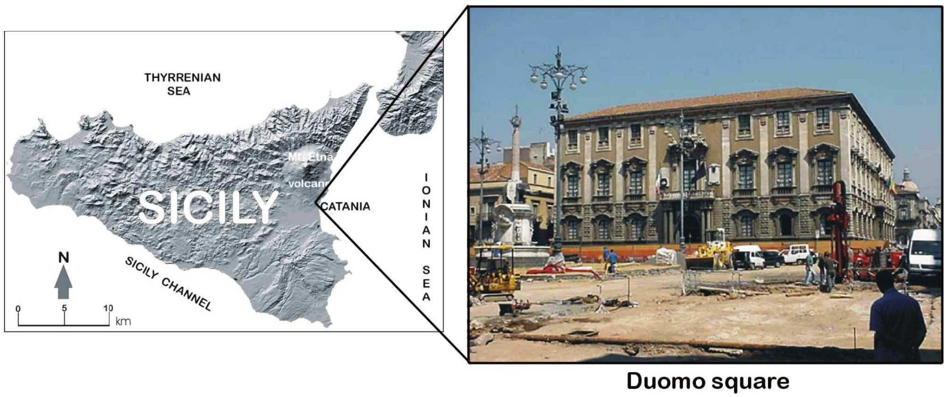

Fig. 1. Location of investigated area and Duomo square.

Fig. 2a. Structure of the arcs of the Thermae is in terra cotta bricks and the vault in blocks of lava stone.

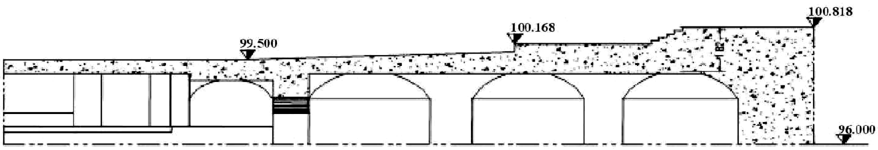

Fig. 2b. Section of the Thermae.

Ninfeo, della Rotonda, dell'Indirizzo) *(Cordaro Clarenza, 1883)* in accordance with the typical building science of that time (*Chiesi, 1980*).

The urban area of Duomo Square in the historic centre of the city has played and still plays a fundamental role for the population living there.

Several are the historic settlements, which were established in the past. The area was more than once dominated by different populations that modified the urban layout. Numerous earthquakes and destructive fires which followed can also be counted as a source of urban modification. Considering the historic type and the drilling surveys carried out in the area under investigation, it can be presumed that the superficial layer of soil is made up of a bland depression filled with rubble from previously collapsed buildings following earthquakes and war damage.

The subsurface is characterized by the co-existence of volcanic rock and sedimentary soil. An aquifer is also present (della Cipriana) which covers a very wide area and is located at 0 meters a.s.l. It seems that the underground flow of this aquifer was locally conditioned by the pre-existence of water canals necessary for the Roman Thermae baths, which are today buried. The volcanic soil on which the Thermae are built, favours a rapid circulation of the underground water.

2. Methodology

Drilling investigations and geophysical prospecting (Electrical Tomography and GPR profiles) were carried out to learn about the subsurface of Duomo Square in Catania. In particular, the following investigations were carried out:

- No. 3 drilling investigations with relative stratigraphical reconstruction;
- No. 5 electric tomography with the aim of defining, through electro-resistive images of the subsurface, the geometric relationship between the buried archaeological structure and the surrounding landscape; in particular, the electro-tomographic lines perpendicularly cross over each other. T. 1, T. 2, and T. 3 were carried out in a East-West direction (from Duomo Square towards Via Garibaldi), while T. 4 and T. 5 were in a North-South direction (from Porta Uzeda towards Via Etna);
- No. 28 GPR profiles in a North-South direction and No. 3 GPR profiles are located perpendicularly crossing each other, with the aim of identifying the exact planimetrical development of the archaeology structure

under the square. To complete the measurements some radar sections were taken vertically on a wall of the external corridor of the Thermae in question, in order to reconstruct the constructive typology.

2.1. Drilling investigations

The drilling surveys carried out using the mechanic rotation method and continuous logging were performed at a depth comprised between 2 and 15 metres circa from the ground surface to obtain direct information on the lithostratigraphic succession of the terrain on which the square exists and, in particular, with respect to the load bearing walls of the Thermae. Fig. 3 shows the location of the drillings.

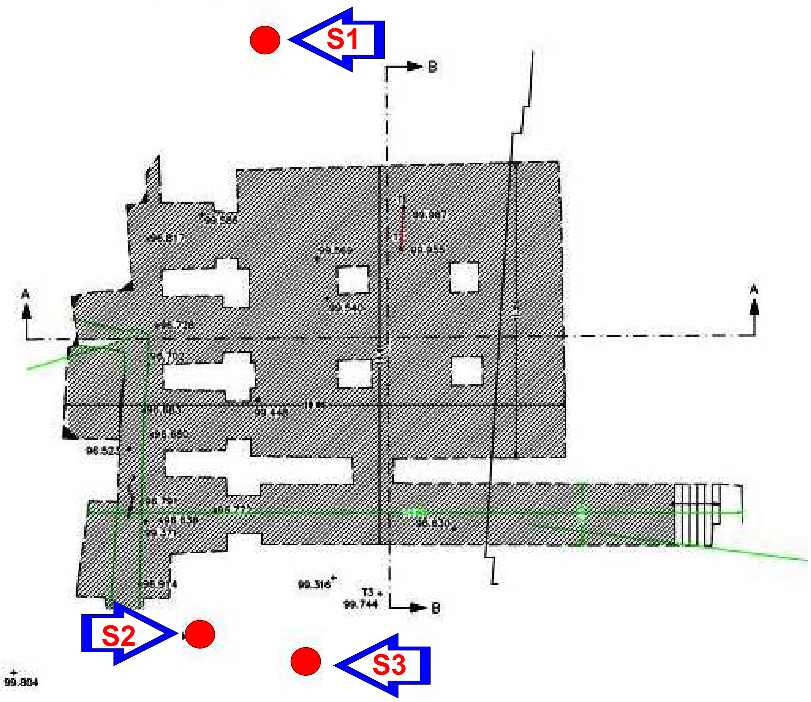

Fig. 3. Location of the drillings and thermal position.

2.2. Electric tomography

The electric tomography consists of defining the resistivity profiles through the placing of an elevated number of electrodes on the surface (*Barker, 1992, 1996*), which were moved progressively along a given direction varying the inter-electrode distance with the aim of carrying out an in-depth investigation. The set of data obtained allowed the construction of a matrix of the resistivity values. When inverted, through mathematical algorithms, a definition of the mean investigated in electro-resistive images was obtained (*Hassaneen et al., 2000*).

The instruments used consisted of a multi-electrode digital geo-resistivimeter (16 BIT) with a resolution of up to 100 micro volts and equipped with an automatic settlement of electrodes which are able to commute the electrodes aligned along the section under investigation in electrodes of emission and in electrodes of measurement giving all possible quadripolar combinations of the electrodes.

For this purpose, the dipole-dipole geometry was used and the data output is in matrix calculus form which allows the immediate elaboration of the data. In the dipole-dipole geoelectrical prospecting, two electrodes of breaking in (couple dipolar A-B) and the two electrodes of measure (couple dipolar M-N) are set on the ground. The distance between each couple of electrodes is equal to a (A $\longleftarrow$ to $\longrightarrow$ B and M $\longleftarrow$ to $\longrightarrow$ N) while the distance between the couples A-B and M-N (dipolar separation n = 1//6) is a multiple a.

Such geometric configuration allows the investigation of a point in the soil resulting from the intersection of two half lines with an inclination of 45°, starting from the centre of the two dipoles of energy and of measure, respectively.

Moreover, to reach an acceptable compromise between an accurate investigation and a lateral - vertical resolution of the section of subsurface under investigation, a space between the electrical couple (a) equal to 1.5 metres and a max dipolar interspaced equal to 6 $\times$ a was used. This allows the subsurface to be investigated to a depth of 8 metres below ground level and to sample 371 measurement points of apparent value resistance. Fig. 4 shows the location of the alignments, where the tomography was carried out.

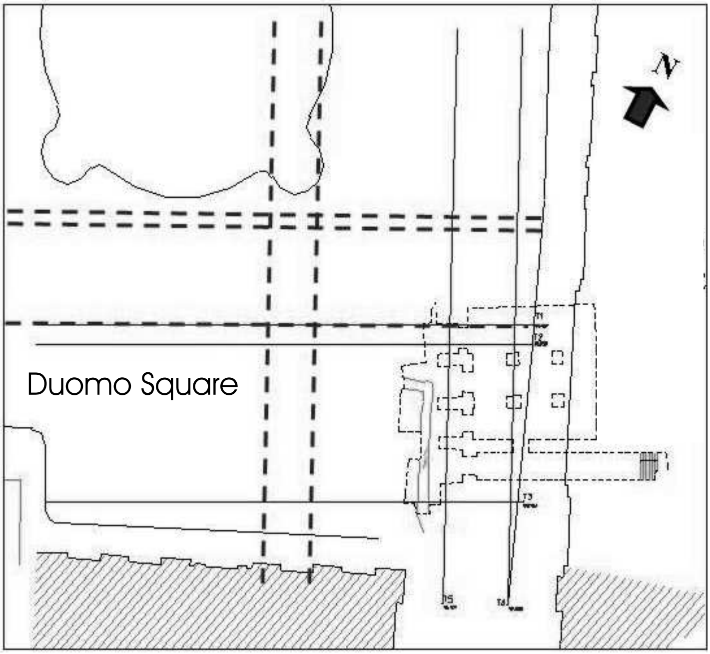

Fig. 4. Location of the tomography surveys.

2.3. GPR survey

Archaeological prospecting using GPR has proven to be successful in a wide variety of applications (*Imai et al., 1987; Sternberg and McGill, 1995; Tohge et al., 1998; Vaughan, 1986*). This study was carried out using grid strips in order to cover the largest surface area possible. The location of the alignments where the survey was carried out is illustrated in Fig. 5. The investigation was carried out with a single array of different aerials. The range limit is equal to 60 n seconds.

The radar investigation was carried out using the unity of field acquisition RIS 2K/MF composed of:

- Multi-frequency array specialized in the research of buried structures and stratigraphical reconstruction;
- MF 600 MHz monostatic and cross polar aerial;
- MF 200 MHz monostatic aerial;

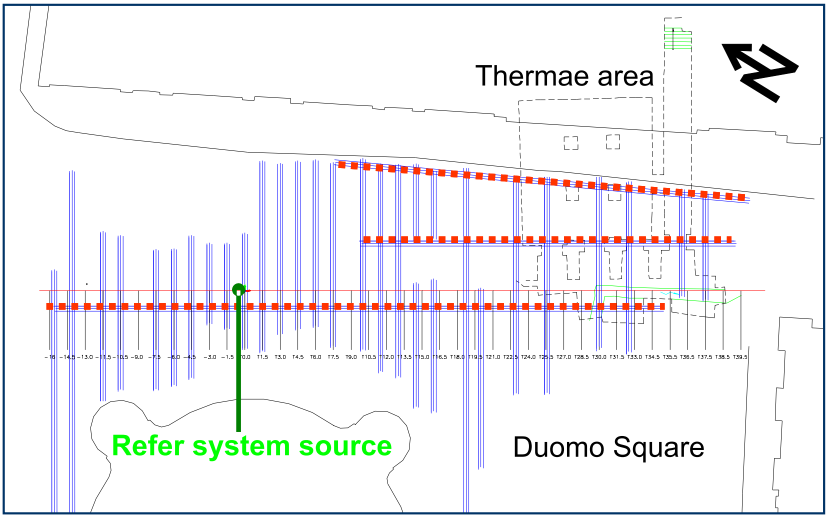

Fig. 5. Location of georadar records.

– MF 600 MHz monostatic aerial and RX 200 MHz;
– MF 600 MHz monostatic aerial and TX 200 MHz.

The unity of 4 channels radar acquisition made up of a: PC Pentium III 266 MHz powered by a 12 volt battery; a radar control card with A/D conversion and radar power and SW of acquisition IDSGRAS. In the complete configuration, the following channel radar has contemporarily been acquired to find buried objects and stratigraphical reconstruction: two monostatic channels to 600 MHz (TX1-RX1; TX3-RX3); two monostatic channel to 200 MHz (TX2-RX2; TX4-RX4).

3. Analysis and discussion of the data

3.1. Drilling survey results

Based on the drilling investigations carried out and relative comparison with the Catania geological map (*Monaco and Tortorici, 1999*) the following stratigraphical succession was obtained (from the lower part upwards):

- grey-blue clays with inter-bedded sands: these constituted the basal formation of all lava covers in Catania, with a thickness of more than 100 mt. These clays show an elevated consistency and low plasticity and often include carbonaceous blackish bands and lenticular sandy interbedding;
- "*Lave Larmisi*" dating 4000 B.C.: these are the predominant lavas found in the city of Catania;
- "*Lave of the Cipriana*": these display a thickness of about 5 - 6 meters; microscopically show an abundance of plagioclase phenocrysts and almost a complete absence of augite and olivine phenocrysts. It is linked to pyroclastic products with a prevalence of black monoclastic sand and is very different from the typical Etnean lavas. This unity is noted in literature as "*Lava dei Fratelli Pii*";
- *Beach deposit*: it has a very modest thickness and passes to a alluvial detritus which becomes downward sandy slime and passes to the clays of the bedrock;
- *Alluvial*;
- *Detritus moved by human activity*: thickness between 1 and 5 meters; in the examined area this deposit shows the characteristics of a morphological depression filling. The mixed heterogeneous, sandy-slimy component prevails, mixed with brick fragments and lava blocks.

3.2. Electric dipole-dipole tomography results

The research reached a maximum depth of 8 meters. Overall, a notable lateral-vertical anisotropy was found and, relative to the T.1, an elevated electric noise. Section T1 (Fig. 6a) shows well defined areas with high resistivity located in the shallow portion of the subsoil with values of resistivity of $103\,\Omega\cdot$m.

Along the final part of the tomographic section, between the abscissa 24 and 36 meters, there is a large portion of subsoil with anomalous values of resistivity, probably referable to the existence of an elevated electric "noise".

Such zones are located in a subsoil characterized by values of resistivity ranging from 145 and $500\,\Omega\cdot$m, and in limited portions of the same areas, $< 20\,\Omega\cdot$m.

Section T2 (Fig. 6b) is characterized by a strong and well located area with high resistivity (> 103 Ω·m) coinciding with the empty spaces of the underlying thermal baths. Even in the superficial part of the ground, a zone with resistivity > 200 Ω·m is to be found. At a depth between 2 and 6 meters, a portion of subsoil, which extends sideways, has a resistivity between 20 and 100 Ω·m. In a portion of this ground there are narrow areas with low resistivity (< 20 Ω·m). In this portion there is an increasing resistivity.

Section T3 (Fig. 6c) introduces characteristics analogous to the T.2. In fact, along this section, in the shallow zone and at the edges, two areas are individualized characterized by a high resistivity (> 103 Ω·m): the first one which is intercepted in the initial part of the section, is located in proximity to the Thermae and deepens to reach more than three meters; the second, intercepted between the abscissa 27.5 and 39.5 meter is rather superficial and has the characteristics of an anomaly due to underground channels. Under this portion of terrain, the values of resistivity gradually fall from 196 Ω·m to 20 Ω·m.

Along section T4 (Fig. 6d) a wide zone is observed between the ordinate 10.5 and 42.5 meter characterized by values of resistivity > 500 Ω·m. Well defined areas are individualized where the resistivity reaches values > 103 Ω·m. At a depth of between 3 and 6 meters, terrain with values of resistivity < 100 Ω·m is intercepted and there are limited areas where the resistivity reaches values < 20 Ω·m. From coordinates (16.5–7) and (29–7), the values of resistivity increase, reaching values of up to > 500 Ω·m.

Section T5 (Fig. 6e) is characterized by two separate superficial areas (9–24 mt and 36–42 mt), where the resistivity varies from 433 Ω·m to over 3000 Ω·m. At a depth of between 3 and 6 meters, a stratum extends characterized by values of resistivity of about 100 Ω·m of local zones of resistivity < 20 Ω·m s. In Fig. 6f the emptiness of the Thermae rooms detectioned are shown.

3.3. Results of the GPR survey

The area under investigation was divided, using a grid model in order to identify eventual anomalies and their planimetrical distribution. In particular, No. 29 GPR profiles oriented in a North-South direction (indicated

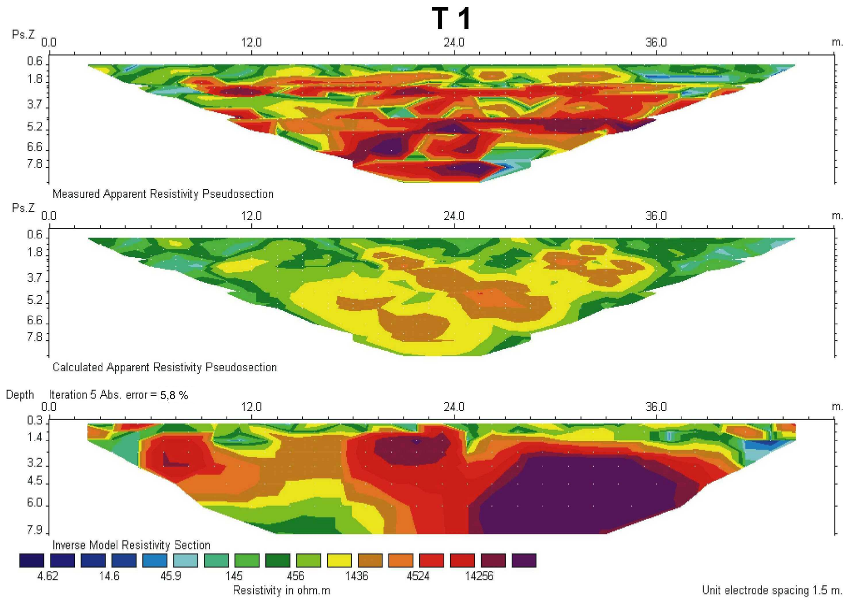

Fig. 6a. Electric tomography section results.

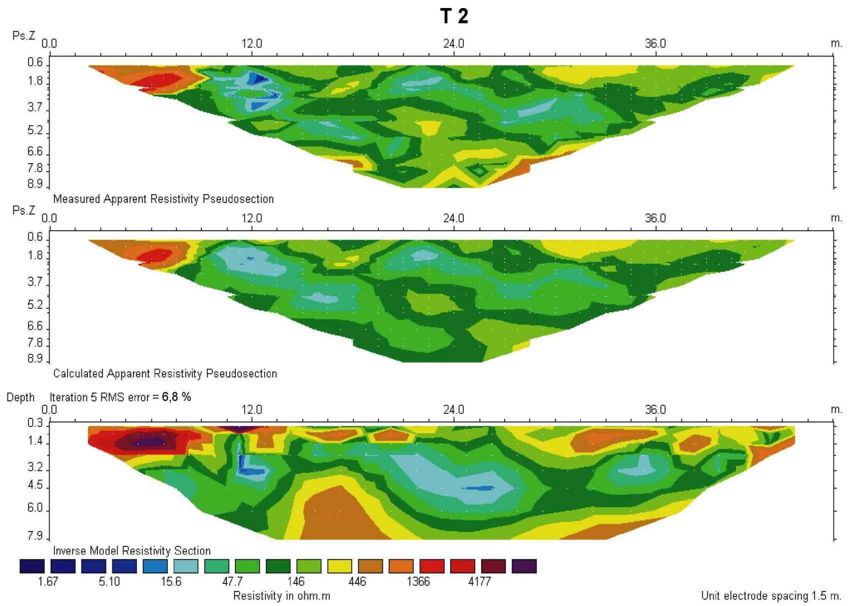

Fig. 6b. Electric tomography section results.

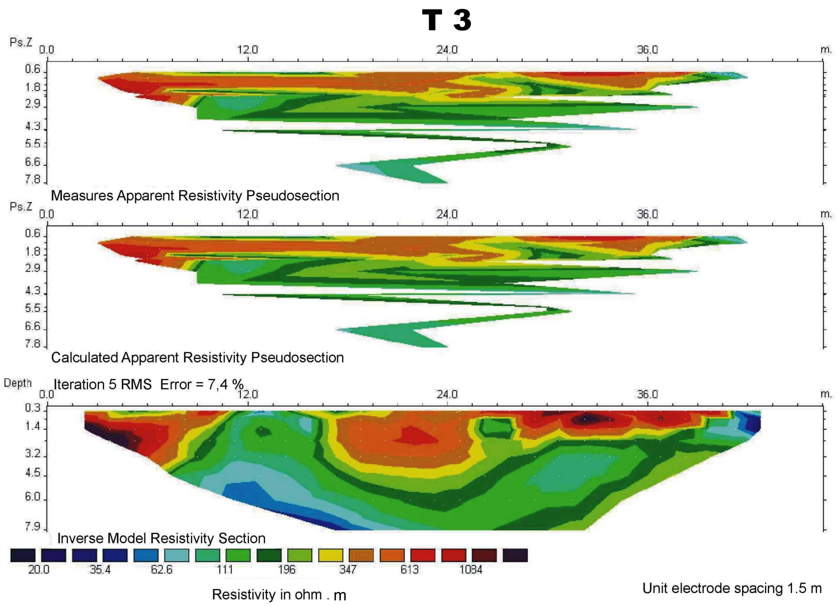

Fig. 6c. Electric tomography section results.

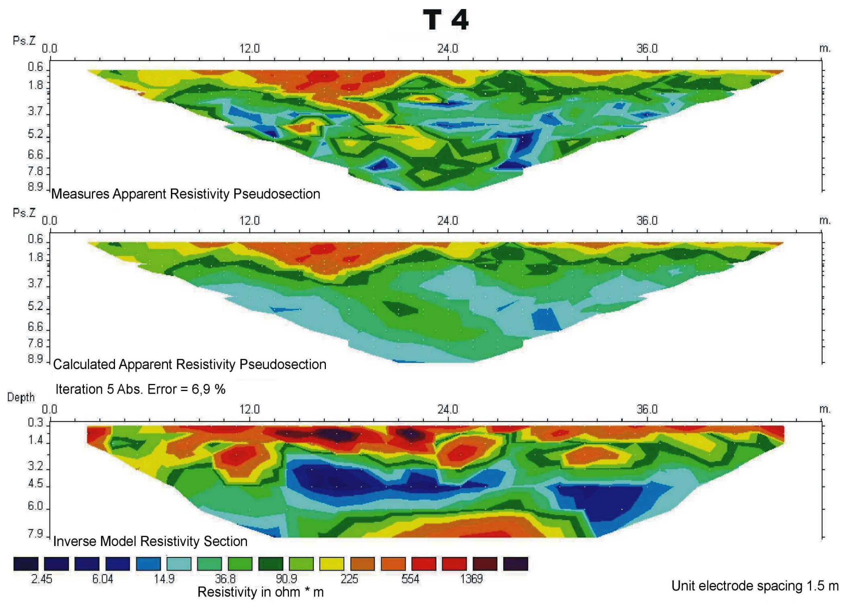

Fig. 6d. Electric tomography section results.

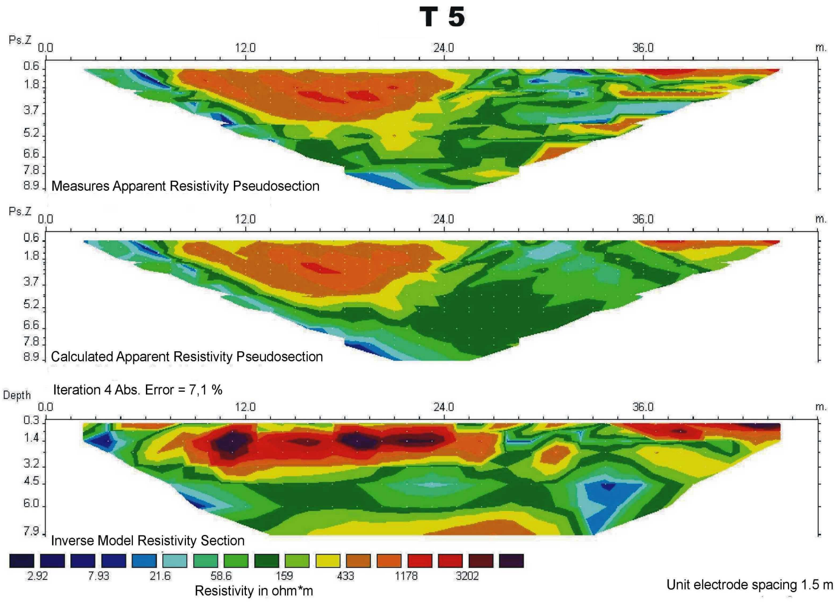

Fig. 6e. Electric tomography section results.

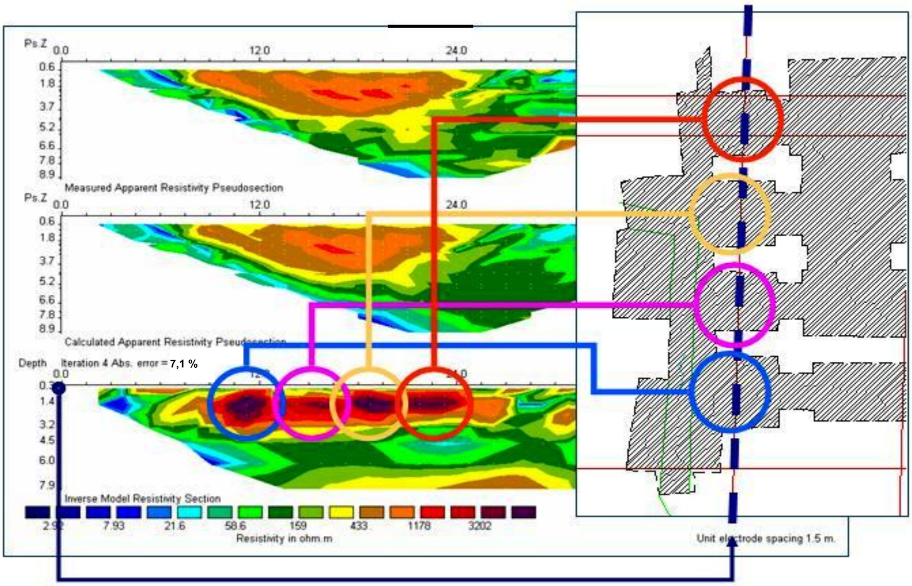

Fig. 6f. Emptiness of the thermal rooms detected through tomographic detection.

as T1, T2,. . . , T29) and No. 3 profiles orthogonal to the former ones (indicated as 1, 2, and 3) were taken with the aim of identifying the exact planimetrical development of the archaeological structure under the square in question. For completeness, some vertical radar profiles were taken of an external corridor wall of the Thermae in question with the aim of reconstructing the construction typology used. From the radar record analysis, the presence of many buried wall structures under the present floor have been found, situated at an average depth of 0.5 metres. Figs 7a, 7b and 7c show the wall frame detected through the study of the anomalies.

The investigation allowed 3 different typology anomalies to be identified.

- **Buried wall structure:** the area in which the observed radar anomalies resulted may be linked, because of its particular form, to referable continuous structures and to the presence of the Thermae consequently obliterated by the subsequent construction of the Cathedral courtyard.
- **Area with diffused presence of humidity:** there were distinct areas in which a strong attenuation of the radar signal was recorded. This was due to the presence of very damp ground which negatively influenced the penetration of the signal.
- **Buried Channels:** there are distinct areas in which very intense radar signals indicated the presence of metallic framework internally inserted in the concrete structures, constituting the covering of ancient canals which conveyed white water flow, restored before the paving of the present square.

For a better localization of the radar anomalies identified, a single point of origin was fixed for all the alignments (co-ordinates 0;0).

4. Conclusion

The aim of this paper was to define the surrounding area of the *Terme Achelliane* and the relative substratum, using the results obtained from tomographic images and radar profiles. The geological model analysis highlights the presence of a superficial area which, in respect to the *Terme Achelliane*, extends up to 4 metres in depth, characterized by elevated values of resistivity ($> 500\,\Omega\cdot$m), mostly due to the alternance of voids with buildings such as channels, wall building etc.

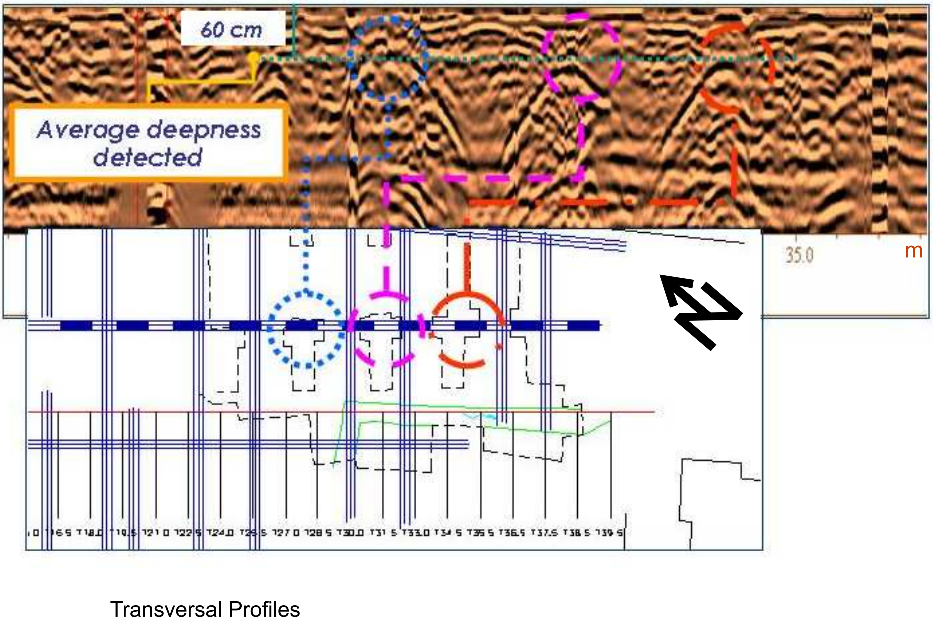

Fig. 7a. Wall frame detection through anomalies study of the radar records.

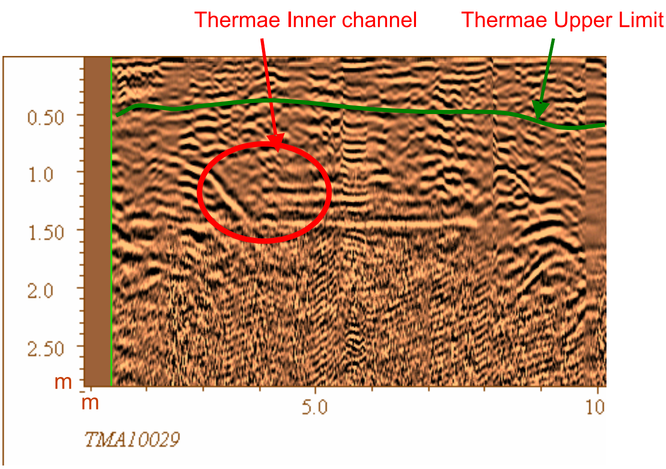

Fig. 7b. Wall frame detection through anomalies study of the radar records.

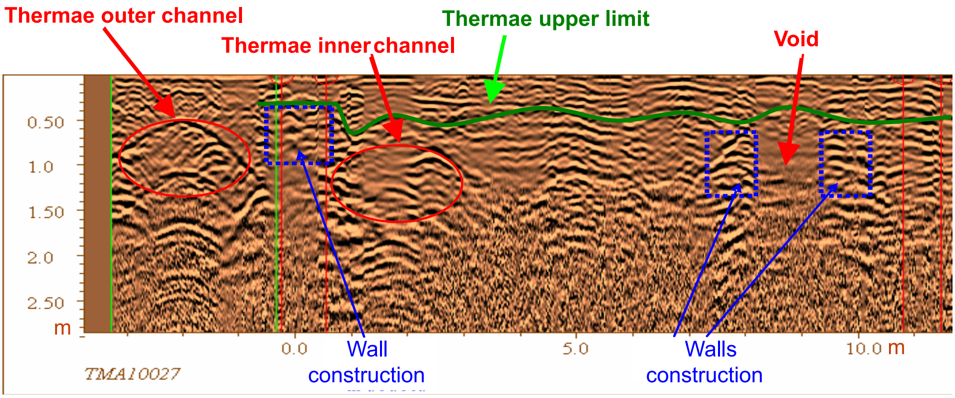

Fig. 7c. Wall frame detection through anomalies study of the radar records.

This type of surface overhangs a well defined layer, characterized by a resistivity value of $< 100\,\Omega{\cdot}$m connected to a predominantly slimy layer and detritus material. Inside this layer are located areas in which the resistivity reaches a value of $< 20\,\Omega{\cdot}$m therefore indicating saturated and/or slimy soils. From a depth of 6 metres the terrain is distinguished by a resistance value of $> 200\,\Omega{\cdot}$m attributable to volcanic material. Lastly, the GPR investigation has allowed the identification of three different typologies of radar anomalies; buried wall structures, buried channels and areas of widespread humidity. There is also a shallow aquifer which covers a large area (to 0 meter a.s.l.).

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