

Hydrogeological and geotechnical modeling of the foundation soils of Maredolce Lake in Palermo, aided by geophysical surveys

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Abstract – The cultural heritage of Maredolce (Palermo) includes an Arab-Norman castle that originally stood on the shores of an artificial lake carved out of a basin dug out of the calcarenite and filled with water thanks to the channeling of the springs of San Ciro upstream. Subsequently, the lowering of the water table and the high hydraulic permeability of the outcropping rocks caused the lake to dry up. Recently, a project of enhancement of the cultural heritage required the restoration of the lake. The geophysical study presented here, including the integrated use of different techniques such as electrical and seismic tomography, Multichannel Analysis of the Surface Waves and ambient vibration recording, supported by aerial photogrammetry, is aimed at the reconstruction of the hydrogeological and geotechnical model of the subsoil of the ancient lake.

I. INTRODUCTION

Within the Arab-Norman monuments of the city of Palermo, declared "World Heritage", the Monumental Complex of Maredolce (fig. 1) is perhaps the least known. However, it could become a very important tourist resource if it were properly exploited. The complex consists of a building born as an Arab fortification in the 10th century but modified in palace by Roger II two centuries later. Around the Castle a garden of 25 hectares develops, mainly cultivated with citrus groves. The current morphology of the zone allows the reconstruction of the environment in the Norman age: the citrus grove is located on an island that rises a couple of meters from a depression that was once the site of an artificial lake fed by a spring, water, the Great Favara (from the Arab "al-fawwāra", the spring), coming from the overlying carbonate basin: the waters of the lake lapped three of the fronts of the building, creating a context of incredible beauty [1].

The reconstitution of the original lake, called Maredolce, is part of the current restoration project, such as the recovery of the morphology of the places and the enhancement of the monumental complex including the

Arab-Norman building and the vast surrounding park with citrus groves.



Fig. 1. The Maredolce Castle in the background and in the foreground a moment of geophysical measurements on the dried-up Maredolce lake.

Therefore, the reconstruction of the hydrogeological and geotechnical model of the area in which the Monumental Complex falls is necessary within the project. In fact, following the abandonment of the castle, the old spring was diverted and the water supply to the lake failed. In addition, the outcropping rocks, consisting of the stone facies of the Pleistocene sandy-calcarenic complex of the Palermo Plain, are characterized by high permeability by fissuration and porosity and therefore they do not prevent water from infiltrating into the subsoil.

The purpose of the geophysical studies realized on the site is to research the levels belonging to lithologies that are considered to be impermeable within the succession present in the subsoil, at the same time trying to identify the level of the groundwater. To do this, geoelectric methods and active and passive seismic were performed.

An aero-photogrammetric survey was acquired by means of drones equipped, in order to return a detailed digital surface model, to support the geo-referencing of all the data, and which served as the basis for a digital reconstruction of the hydrogeological and geotechnical model of the lake bottoms and the island.

A research was also made for all the previous

geognostic (Todaro, [2]) and geophysical data available in the area, in order to constrain the inversion and enhance the interpretation of the surveys.

II. GEOPHYSICAL SURVEYS ON THE ANCIENT LAKE DEPRESSION

A. Geophysical Tomography

Two alignments have been considered for the electrical resistivity tomographies (ERT), Induced Polarization Tomography (IPT) and seismic refraction tomographies (SRT), 98 m long each. The line A is located in the depression to the east of the Castle, roughly oriented NE-SW, for a length of 98 meters, Line B it is instead located in the depression to the south-west of the castle, with orientation approximately E-W, and the same length as the line A. In both lines electrodes and geophones have been placed in coincident positions and interdistance equal to two meters, in order to be able to perform a joint interpretation of ERT, IPT and SRT, using cluster analysis techniques [3].

ERT and IPT were carried out simultaneously [4], using a dipole-dipole array sequence, comprising 882 measurements, capable of guaranteeing a high resolution and reaching a depth of investigation of about 14 m in the central area of the section [5]. For each SRT 13 shot points were considered to ensure good lateral coverage, thus obtaining 624 seismograms. Seismic data have been processed and inverted through Rayfract software, using Wavepath Eikonal Traveltime (WET) algorithm [6].

The ERT results (fig. 2) are quite diversified for the two

lines. In fact ERT A shows a heterogeneous near surface layer with resistivity between 20 and 50 ohm*m. This covers a more conductive layer (resistivity of around 15 ohm*m and thickness of 2-2.60 m) which can be interpreted as the saturated portion of calcarenite; finally, a deep zone with resistivity between 25 and 45 ohm*m related to the blue clays. In ERT B the near surface layer shows a higher resistivity (5-120 ohm*m) related to the unsaturated calcarenite, and the conductive layer is clearly visible only in the western part, near a water well in which the water level is at a depth of 2,5 m. Differences of resistivity of the near surface layer can be related to a different supply of lake sediments.

The SRT results (fig. 3) are fairly consistent with the resistivity images. The stratigraphic limit between the calcarenites and the blue clays seems to correspond to the border below which the pressure wave velocity is greater than 2500 m/s.

B. Multichannel Analysis of the Surface Waves

Two Multichannel Analysis of the Surface Waves (MASW) [7] surveys were carried out almost at the ends of the two tomographic lines, A and B, in order to obtain information on the variation of the shear waves velocity with the depth in the two different zones of the bottom of the ancient lake. Both Rayleigh and Love waves were analyzed [8]. Preliminary results show a first layer of very low shear-wave velocity (170 m/s) and 50 cm thick, over a layer of 1.5 m and $V_s = 200$ m/s, a layer about 30 m thick and $V_s = 330$ m/s and finally a seismic bedrock.

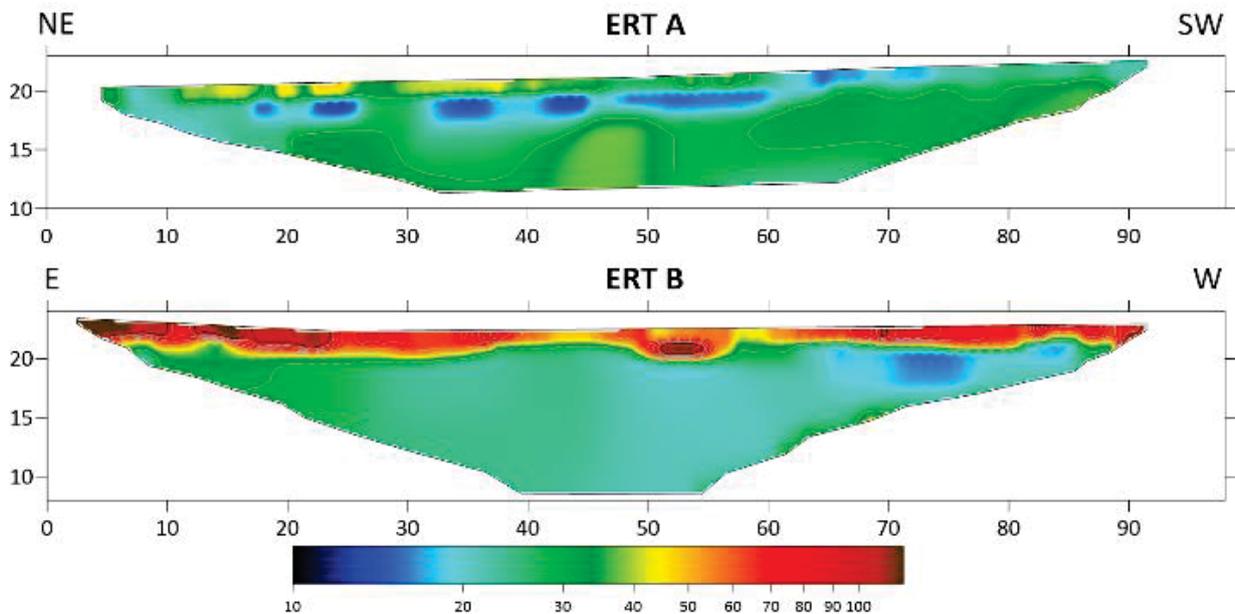


Fig. 2. Electrical Resistivity Tomographies in Mareadolce

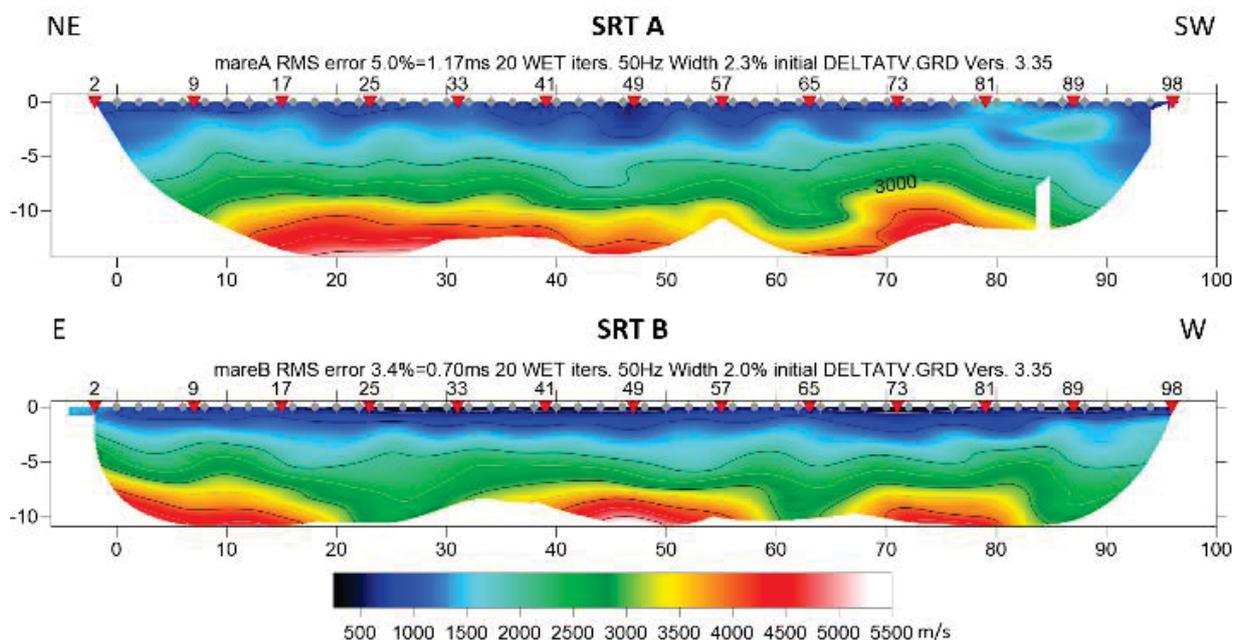


Fig. 3. Seismic Refraction Tomographies in Mareddolce.

C. Ambient vibrations recording

28 HVSR measurements [9] have been performed to detect the fundamental frequency of amplification of the seismic motion and to obtain information on the shear wave velocities of the sedimentary cover and of the depth of the bedrock in the area.

In particular, two linear arrays were realized in the two flat areas facing the castle, coinciding with the above discussed alignments A and B, including eight registration points per line.

Along these arrays the distance between one to the next recording station is about 15 m. Twelve other registration points were acquired to cover the entire surface of the lake.

Noise registrations were made using the Tromino. The acquisition time for each measurement is 20 minutes with a sampling frequency of 256 Hz. The data has been processed with the Grilla software.

From a preliminary analysis of the data (fig. 4) is clear the presence of an amplification peak at low frequencies between 1 and 2.4 Hz in all the HVSR curves. Moreover a velocity inversion is evident from 20Hz down to 3 Hz To overcome in the problem of equivalence between interpretative subsoil models of the HVSR curve the data on the microtremor were constrained through MASW acquisitions. In this way the fundamental peak perhaps can be associated with the stratigraphic limit, at a depth of about 45 m between clays layers and the underlying seismic bedrock [10]. The velocity inversion is probably due to the stratigraphic contact between the calcarenite layer and the underlying blue clays.

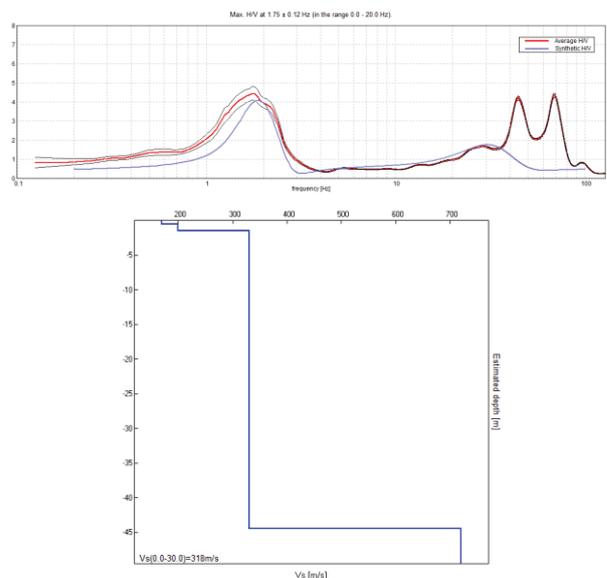


Fig. 4. Example of processing and inversion of ambient noise with HVSR technique: (top) measured and predicted curve; (bottom) theoretical model.

III. DISCUSSIONS OF THE RESULTS

From the geotechnical point of view, based on the results acquired with geophysical surveys and in situ and laboratory tests, it was necessary to consider interventions aimed at reducing the permeability of calcarenites, at least two orders of magnitude. The spatial distribution of the discontinuity surfaces present in them does not allow using localized interventions. Moreover, the high porosity of the material also gives it a primary

permeability that cannot be reduced with classical clogging operations with microcement or similar products of less than 3 m from the ground. The studies in progress are, therefore, addressed to the choice of the most appropriate material, not only from the technical point of view but also on the historical level and compatibility with the ecosystem, to be placed at the bottom of the area to be flooded to prevent the filtration of the lake waters.

REFERENCES

- [1] “Studiare il territorio di Mareddolce/Brancaccio e valorizzarlo come Distretto culturale e turistico” [2014] Quaderni di Mareddolce, 1, Plumelia edizioni, Palermo.
- [2] Todaro P. [2016] “Aspetti geomorfologici, idrologici ed idraulici del lago medievale di Mareddolce a Palermo” *Geologia dell’ambiente* 3, 2016 – Italian Magazine of Environmental Geology.
- [3] Capizzi P., Martorana R., Carollo A., Vattano M. [2017] “Cluster analysis for cavity detection using seismic refraction and electrical resistivity tomography” *Near Surface Geoscience 2017 – 23rd European Meeting of Environmental and Engineering Geophysics*, We 23P2 23, DOI: 10.3997/2214-4609.201702123.
- [4] Griffiths, D.H., Barker, R.D. [1994] “Electrical imaging in archaeology” *Journal of Archaeological Science* 21 (2): 153–158.
- [5] Martorana R., Capizzi P., D’Alessandro A., Luzio D. [2017] “Comparison of different sets of array configurations for multichannel 2D ERT acquisition” *Journal of Applied Geophysics*, 137, 34–48, doi: 10.1016/j.jappgeo.2016.12.012.
- [6] Qin F., Luo Y., Olsen K., Cai W. and Schuster G. T. [1992] “Finite-difference solution of the eikonal equation” *Geophysics*, 57, 478–87.
- [7] Park C B, Miller R D and Xia J [1999] “Multichannel analysis of surface waves (MASW)” *Geophysics* 6 800–8.
- [8] Dal Moro G, Forte E, Pipan M and Sukan M [2006] “Velocity spectra and seismic signal identification for surface wave analysis” *Near Surf. Geophys.* 4 243–51.
- [9] Nakamura Y. [1989] “A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface” *Quarterly report Railway Tech. Res. Inst.*
- [10] Martorana R., Agate M., Capizzi P., Cavera F., D’Alessandro A. [2018] “Seismo-stratigraphic model of “La Bandita” area (Palermo Plain, Sicily) through HVSR inversion constrained by stratigraphic data” *Italian Journal of Geosciences*, 137, 1, 73-86, doi: 10.3301/IJG.2017.18.