

# Geophysical surveys for the restoration of Branciforte Palace in Palermo

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**Abstract** – A multi-methodological and non-invasive geophysical study has been carried out in order to support the restoration project of the historic Branciforte Palace in Palermo. Ground Penetrating Radar profiles and an Electrical Resistivity Tomography ERT, carried out on the floor of the stable of the Palace, allowed to evaluate in detail the state of consolidation of the subsoil, in correspondence of a double row of marble columns, some of which were affected by differential subsidence. These columns have been investigated by means of Ultrasonic Tomography to verify their state of degradation. Moreover Infrared Thermography images of the internal and external walls and of the vaults highlighted differences in the type of masonry and in the state of the plaster. Finally the seismic characterization of the foundation soils was obtained by means of a Vertical Seismic Profile, Multichannel Analysis of Surface Waves (MASW) and Horizontal to Vertical Spectral Ratio microtremor analysis.

## I. INTRODUCTION

The restoration project of the historic Branciforte Palace (XVI-XVII century), was owned by the Banco di Sicilia Foundation, with the aim for it to become a multi-purpose center for the promotion of exhibitions and cultural events. To support this, a geophysical study has been carried out, characterized by a multi-methodological non-invasive approach, including ground penetrating radar (GPR), Infrared Thermography (IR), Electrical Resistivity Tomography (ERT), Ultrasonic Tomography (UT), Vertical Seismic Profiles (VSP), Multichannel Analysis of Surface Waves (MASW) and ambient vibrations measures using Horizontal to Vertical Spectral Ratio (HVSr) analysis. One of the objectives of the investigation was the state of consolidation of the large and picturesque environment of the ancient stable of the Palace, in which the roof, is supported by a double row of marble columns which longitudinally divide it into three naves, covered by cross vaults. and the seismic characterization.

## II. HISTORICAL NOTES

Compared to the historical urban fabric of the city of Palermo, the Branciforte Palace of the Counts of Raccuja

is framed in a position of particular value and interest, belonging to the district formerly known as the "Loggia", in the historic center of Palermo, where since medieval times was the beating heart of commerce and trade with the planting of the merchant lodges of so-called "foreign nations" of the Genoese, the Pisans and Catalans. The most noble and powerful families of the time operated in this extraordinary allocation, including the families of the Branciforte counts of Raccuja.

The original surface of the Palace occupied about half of the current one, expanding from the aforementioned alley to via Lampedusa. The Palace consisted of a basement, a ground floor with warehouses and stables, a first floor reserved for a mansion and a second floor used as a guesthouse, administration and servants' quarters. Subsequently, don Giuseppe Branciforte decided to expand the Palace: the new building doubled the surface by acquiring an almost quadrangular planimetric conformation, the same today present.

The work of expanding and embellishing the Palace continued with the construction of large stables with elegant cross vaults, supported by a double row of Billiemi stone columns. At the beginning of the nineteenth century the Branciforte family gave the Palace to the Senate of Palermo, which after a radical transformation assigned it to the branch of the Pawnshop of Palermo. The transformation works affected the interior, which changed the original configuration.

Subsequently, various events (such as a big fire in 1848, the aerial bombardment of 1943 and the subsequent reconstruction phases) led the building to take on its current appearance. Since 1997, Palazzo Branciforte has been owned by the Banco di Sicilia, which has hosted exhibitions, conferences and other cultural events. Since 2006, the Palazzo has become part of the real estate assets of the Banco di Sicilia Foundation.

## III. RESTORATION PROJECT

The restoration and redevelopment work of the building began in October 2008, following to the restoration project signed by the architect Gae Aulenti, and ended in May 2012, when the building was reopened to the public.

One of the main objectives of the project was to restore those important architectural spaces that had lost their original function: the internal road, the main courtyard and

the horse stable on the ground floor. The internal road was freed from the enclosed spaces that interrupted the perspective cone, so that the main door today leads to a real road, covered only by the central lodge, which divides the Palace into two distinct wings, allowing visitors to reach all the different areas of the building: the new exhibition space (located inside the old stable), the coffee bar, the conference room with about 100 seats, the secondary staircase leading to the ateliers, the internal courtyard that opens up to the offices and all the rooms on the upper floors.

#### IV. GEOPHYSICAL STUDY

Geophysical surveys have been performed in order to evaluate the structural integrity of the marble columns, the ground floor and the conditions of general degradation of the basement of the building. The investigations were carried out both with classical and unconventional methods [1].

At the time of the investigation, the columns of the ground floor had appeared partly or wholly embedded in the more recent masonry structures. The Ultrasonic tomographies [2] were performed on three of these columns, two flanked by retaining walls, and one free, to determine the velocity of the elastic waves in the material and to identify and locate internal anomalies. All the columns are made from monolithic blocks of “Billiemi” gray stone, a bluish gray limestone breccia, very hard and compact, widely used as a material for the covering of buildings.

Two of these columns (hereinafter referred to column 1 and column 2) were investigated for their entire height (data has been acquired on the basis of the column and on the rings and on the abacus square of the capital), while the third (column 3) has been investigated only in the part of the capital. The ultrasonic tomography (UT) was chosen, among the various technologies to investigate the columns, for its ability to characterize mechanical stress. The source is positioned, one at a time, in each of the receiver positions. In the case of a column a complete 3D UT, however, can be very laborious to be performed. Alternatively, it is possible to carry out a series of parallel 2D UT surveys, by positioning sensors along parallel outer circumferences (2D circular UT) or along vertical opposite directions (2D longitudinal UT). The main advantages provided by UT, as compared to other non-destructive testing techniques, consist of a high sensitivity provided an acceptable penetration power, allowing to locate relatively small discontinuities (nevertheless larger than the used wavelength). The 3D UT surveys of the columns (for a total height of about 3 meters) were reconstructed by carrying out 26 2D circular UT surveys for column 1 and 25 for column 2, vertically separated from each other by 15 cm. 1196 signals for column 1 and 708 signals for column 2 were acquired and processed, for which both the source-receiver distances both traveltimes of p-waves

were measured. A grid of elementary meshes of size 5 cm  $\times$  5 cm was used for the data inversion, performed by the Geotom software. Results showed velocity values quite homogeneous, with an average velocity of about 6250 m/s in column 1 and about 6650 m/s in column 2 (fig. 1).

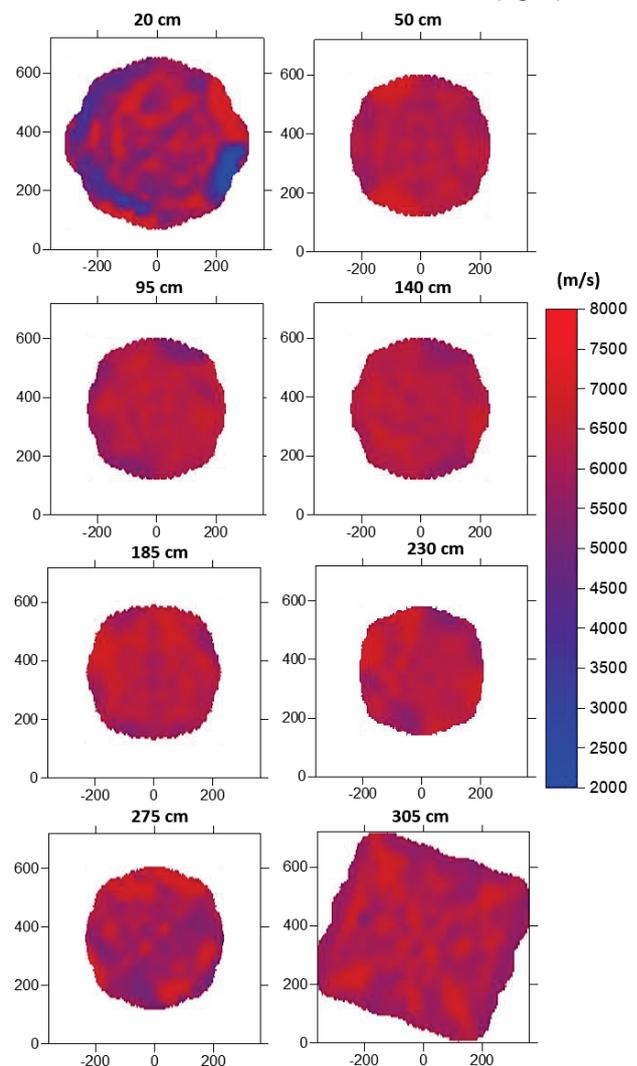


Fig. 1. 2D UT images of a column of the stable of Branciforte Palace at different heights from the floor.

In order to obtain information on the nature and structure of the subsoil of the building, a down-hole VSP was performed, in the area of the inner courtyard of the Palazzo Branciforte, using a drilling already performed as a geognostic survey, whose stratigraphy had been provided. This technique consists in generating elastic waves through a sledgehammer and measuring the first arrival times of p- and s-waves in a three-component geophone placed inside the hole at different depths.

The VSP enabled to assess the seismic velocities and the Poisson ratio of the main geological formations in the subsurface. This allowed to estimate for the weighted average of the shear wave velocity in the first 30 meters of

subsoil ( $V_{s30}$  parameter) a value of 605 m/s, and consequently, to classify the soil type into the category B of the seismic categorization.

Further seismic investigations were performed to better define the vertical velocity profile of shear waves. Two MASW surveys and two seismic microtremor HVSR measurements were carried out for the evaluation of resonance frequencies of the foundation soil. The availability of the information obtained from the geognostic survey and VSP made it possible to perform constrained inversion of the data and to obtain robust interpretative models. MASW data were inverted using the depth and velocity obtained from the VSP as a constraint, while HVSR data were inverted using MASW results, for the most superficial part of the soil. The final interpretative model is therefore characterized by a good surface resolution (within the first 30 meters) obtained thanks to VSP and MASW surveys, and a greater depth of investigation obtained by HVSR.

A detailed characterization of the subsoil of the colonnade environment was necessary to understand the reasons that led to a lowering of the base of the columns. For this purpose, GPR surveys have been planned and carried out [2] using the SIR 3 of the GSSI with 400 and 200 MHz antennas. In order to convert time sections in depth sections, the value of the average dielectric constant  $\epsilon_r = 15$  was estimated, by means of transparency measurements, where possible. The maximum depth of investigation reached is about 3.5 m for profiles acquired with 400 MHz antenna, and about 5 m for profiles acquired with 200 MHz antenna.

GPR profiles were processed for the construction of depth-slices. 3D models of the GPR anomalies were obtained and represented as isosurfaces of normalized amplitude (fig. 2). The results show a large anomalous zone that extends up to about 2.5 meters depth and with a lateral extension of about 7 -8 meters, where the material does not seem to possess the characteristics of good consistency. Some direct investigations (exploratory essays) subsequently showed that the anomaly is related to an area of structural void.

In part of the stable floor a 2D ERT was carried out by using 91 electrodes aligned with a minimum distance of 0.5 m, for a total length of the profile equal to 45 m. Drill holes of about 20 mm in diameter and 10 cm in depth were made for each electrode on the stone floor, so as to place the electrodes in direct contact with the ground under the stone floor. In addition, a conductive gel was injected into each drill hole to minimize the contact impedance between the electrode and the ground. A total of 1475 measurements were performed, using the Linear Grid multielectrode configuration [3].

In this way a maximum depth of investigation of about 6 m was reached. The ERT results show a surface layer of low resistivity almost continuous (values less than 100  $\Omega\text{m}$  and thickness less than one meter) which overlooks a

highly heterogeneous zone, characterized by wide

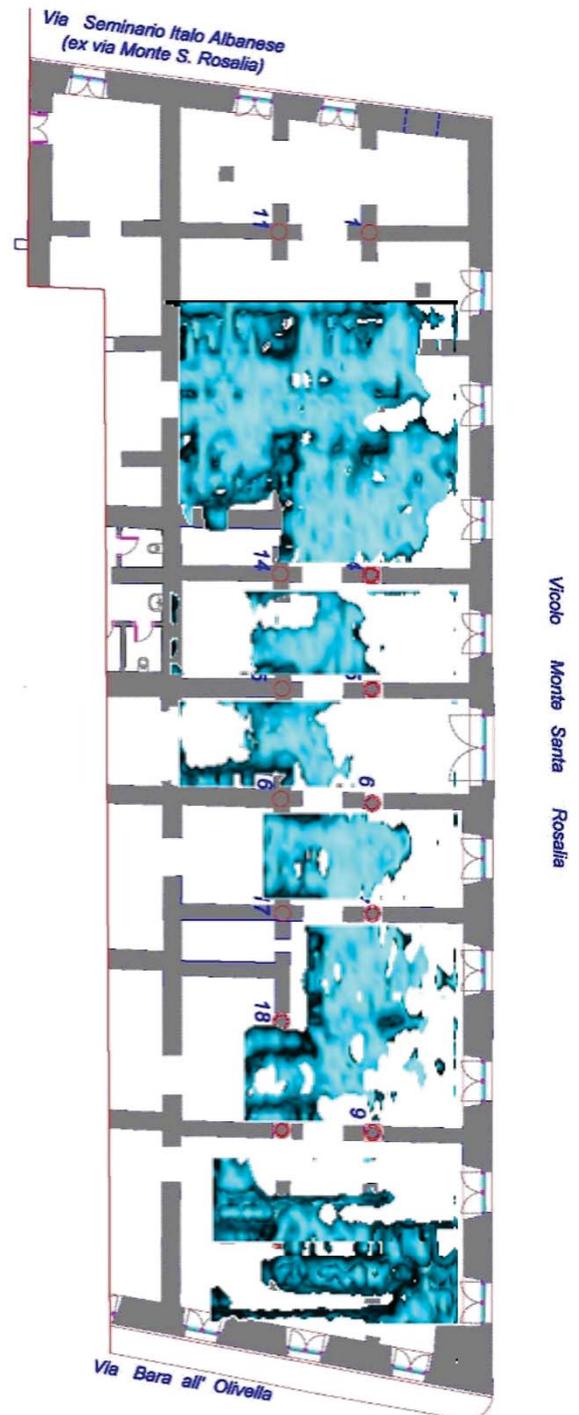


Fig. 2. Plant of the stable of Branciforte Palace with plain view of the isosurface of normalized amplitude of 0.12 referred GPR data with 200 MHz antenna.

anomalies with high resistivity ( $> 1000 \Omega\text{m}$ ), until 2.5-3 m of depth, and finally a bottom zone with a resistivity between 200 and 800  $\Omega\text{m}$ .

The interpretation of GPR and ERT data perfectly agree

in locating the area of voids characterized by very high resistivity values, giving information on their spatial arrangement and on the volumes of the anomalous zones.

Finally, IR thermographic images have been carried out in all the facades of the Palace and some of the walls of the inner courtyard, trying to take advantage of the sunlight as much as possible, in order to take pictures during the cooling of the investigated structures [4]. The perimeter walls of the building, for their azimuthal position and the presence of other neighboring structures, do not enjoy optimum position nor a good and uniform solar radiation, so that the resolving power of the methodology of investigation was rather limited. Positive results were obtained by the thermography of the vaults, that took advantage of the thermal radiation provided by the internal lighting system of the building, thus executing an almost active thermography (fig. 3). IR results have revealed the presence of a different thermal behavior of the masonry on the outer perimeter and on the inner courtyard of the building due to different construction methods. On the outer walls the degradation of the plaster and stone elements is highlighted. In particular, the plaster, which is not uniformly clinging to the wall surface, shows areas of high humidity and consequently localized degradation, probably due to infiltration of water resulting from rain gutter of the roof, especially in the west wall. In some of the thermographic images on the walls of the inner courtyard the masonry texture is visible, formed by regular ashlar.

## V. CONCLUSIONS

Geophysical surveys have played great importance in the general diagnostic framework of the Branciforte Palace. In particular the ultrasonic tomographies have generally showed a good state of preservation of the columns, highlighting small localized anomalies; the results from the joint analysis of VSP, MASW and HVSR surveys allowed to reconstruct the seismic characteristics of the foundation soil down to depth of 30 m, at least, evaluating with good accuracy the trend of pressure and shear wave velocities; ERT and GPR surveys, carried out in the stable on the ground floor, have jointly detected a large anomalous zone, where the material of the subsoil, at small depth, does not possess characteristics of good consistency, as it has been confirmed by some direct investigations (exploratory excavations). Finally, the IR images showed that the level of plaster degradation was generally wide and widespread, such as the degradation of the visible stone. In conclusion, the integrated approach of several geophysical techniques provided detailed information on the structural characteristics and the conservation status of the heritage, useful during the

restoration phase for the appropriate choices of consolidation and re-architecture of the Palace.

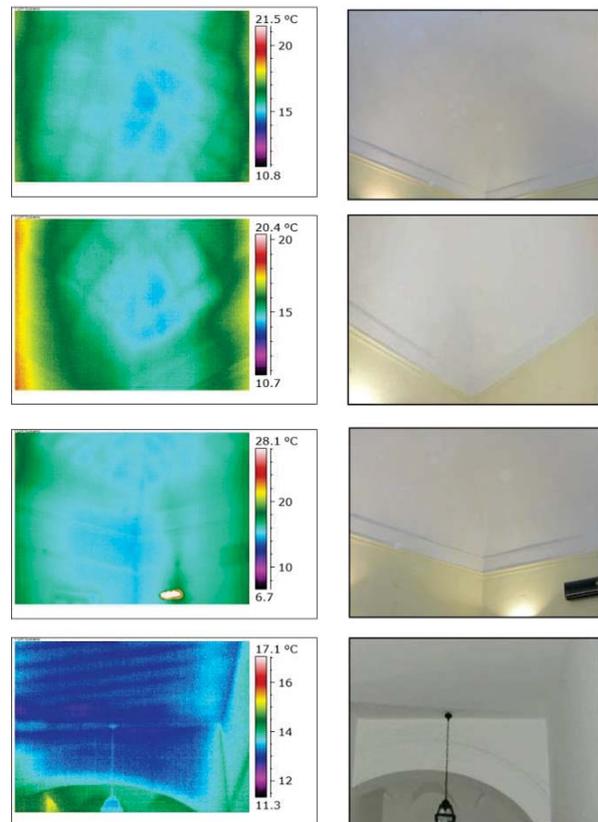


Fig. 3. Some of the IR images obtained in areas inside the building.

## REFERENCES

- [1] P. Cosentino, P. Capizzi, G. Fiandaca, R. Martorana, P. Messina "Advances in Microgeophysics for Engineering and Cultural Heritage" Journal of Earth Science, 2009, 20, 3, 626-639 doi: 10.1007/s12583-009-0052-x.
- [2] J.R. Green, E. Robert "Non-contact ultrasonic techniques" Ultrasonics, 2004, 42, Issue: 1-9, p. 9-16.
- [3] D. Daniels "Surface-penetrating radar" The Institution of Electrical Engineers, 2009, London.
- [4] R. Martorana, G. Fiandaca, A. Casas, P.L. Cosentino "Comparative tests on different multi-electrode arrays using models in near-surface geophysics" Journal of Geophysics and Engineering, 2009, 6, 1, 1-20, doi:10.1088/1742-2132/6/1/001.
- [5] N.P. Avdelidis, A. Moropoulou "Applications of infrared thermography for the investigation of historic structures" Journal of Cultural Heritage, 2004, 5, 1, 119-127.