

Multi-disciplinary approaches using non-invasive portable instruments to investigate cultural heritage sites and their surrounding area

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Abstract – The paper describes integrated geophysical investigations for investigating cultural heritage sites. In particular, we focus on data collected at several locations in the Maltese Archipelago (central Mediterranean). The analysis consists in collecting data with non-invasive portable instruments. we were able to locate and determine fracture on cliff area as well as to locate graves and buried structures at the investigate sites. In this paper, some effects of electromagnetic interferences on GPR data have been studied.

I. INTRODUCTION

The opportunities offered by modern technology for the safeguarding and fruition of cultural heritage are virtually boundless, yet their successful implementation requires that all players involved (scientific community, public institutions, private sector, sector operators) adopt new attitudes. Ground Penetrating Radar (GPR) is the main tool that allows the best available resolution within the non-invasive subsurface geophysical techniques. However, integrations with other geophysical techniques can provide information of geological, and structural behavior of cultural heritage sites. On the other hand, several sources of uncertainty can affect the data, among which clutter, several kinds of noises, model errors and interferences from other electromagnetic devices.

This papers aims to serve a proof-of-concept to act as an example for future coordination among conservators, researchers, and developers who share the goals of revealing, researching, preserving, and presenting cultural heritage. In addition, we propose also some results regarding the reconfiguration of the integration time of the harmonic tones radiated and received by a stepped frequency ground penetrating radar (GPR) system in a way programmable vs. the frequency.

II. DATA ACQUISITION PROCESSING AND RESULTS

In this paper we close describe results obtained at several sites (Figure 1) located on the Maltese archipelago. In particular, on two cliff areas (Golden Bay

and La Ferla Cross); a watchtower built by the Knights of St. John in the XVII century and in the hold cemetery of Santa Maria Church (Birkirkara), and the St. John Co-Cathedral (this results will be not showed in the present paper). The data were mainly gathered during a short term scientific mission performed under the COST Action TU1208 “Civil Engineering Applications of Ground Penetrating Radar”. The purpose of the measures has been twofold, namely to test the performances of an innovative GPR system (Persico and Prisco, 2008), recently upgraded, and to perform GPR and passive seismic analyses in several sites of interest in Malta, in order to get an insight about the geological conditions in some sites of interest and about the internal status of some historical monuments.



Fig. 1. Location of investigated sites

The exploited GPR system was a prototypal stepped frequency reconfigurable GPR, implemented by IBAM-CNR together with the University of Florence and the IDS Corporation within the research project AITECH (<http://www.aitech.net.com/ibam.html>). This system contains three equivalent couples of antennas with the same gap, achieved from two series of switches along the

arms. The on and off state of the switches make equivalently longer or shorter the antennas, so to achieve efficient transmission on three bands that cover the comprehensive frequency range from 50 MHz to 1 GHz. Some passive seismic techniques were used in order to gather useful data to be compared and integrated with those obtained with the GPR. Ambient noise was recorded using a three-component Tromino® seismometer in order to obtain H/V curves which can give information about the geological site condition and the passive seismic array measurements were conducted using Micromed SoilSpy Rosina™ seismic digital acquisition system equipped with 4.5 Hz vertical geophones. A total of 42 geophones were used, and placed in an L- or C-shaped configuration with a regular interstation distance of 5 m. Data were processed using standard techniques [1].

We have performed a first set of measurements in the “Golden Bay” area in the vicinity of “Ghajn Tuffieha Tower”. The tower is part of the fortification structures built by the knights of St. John. In particular it belongs to the “Lascari towers” between 1637 and 1652 and commissioned by the Italian knight Giovanni Paolo Lascaris who was Grand Master of the Order. The area is affected by the presence of later spreading and the retreating of the cliff edge due to the fracturing of the Upper Coralline overlaying the Blue Clay typical formations of the Maltese islands [2]. The geology of the Maltese islands is well known [3,4 and references therein] and consists of four main sedimentary layers, but the relief, which is largely controlled by the neotectonic pattern, is rather complex. The Maltese islands are made up of a sedimentary sequence deposited during the Oligocene and Miocene epochs. There are four main strata, reflecting abrupt changes in the depositional environment during this period: Lower Coralline, Globigerina, Blue Clay and Upper Coralline [3,4].

The passive seismic techniques show of a ubiquitous resonance peak at between 1.0 and 2.0 Hz at several locations far away from the cliff. Moving from the inland area towards the cliff edge and rock sliding area, the nature of the peak and it is observed that at higher frequency of the spectrum there are peaks not observed on the plateau area that may be tentatively associated with mechanical vibration modes of the blocks present in the unstable cliff area. This is not surprising because previous ambient noise studies have repeatedly confirmed that all areas of the Maltese islands where UCL outcrops and is underlain by a layer of Blue Clay exhibits a peak in the H/V of this consistent frequency [5,6,7]. Several authors interpret the dip in the H/V ratio in terms of a shallow shear-wave velocity inversion, which in this case corresponds to the interface between the UCL and BC. The interpretation of other features of this peak in terms of Rayleigh wave ellipticity and/or trapping of SH waves in the low-velocity layer is the subject of an ongoing

study using numerical modelling. Moving from the inland area towards the cliff edge and rock sliding area, the nature of the H/V response changes strikingly. On the plateau away from the cliff edge, the site response shows only the simple and consistent peak at around 1.5 Hz as described above, while the rest of the H/V amplitudes remain at a level well below 2.0. Moreover, it is observed that at higher frequency of the spectrum there are frequencies peaks not observed on the plateau area that may be tentatively associated with mechanical vibration modes of the whole blocks.

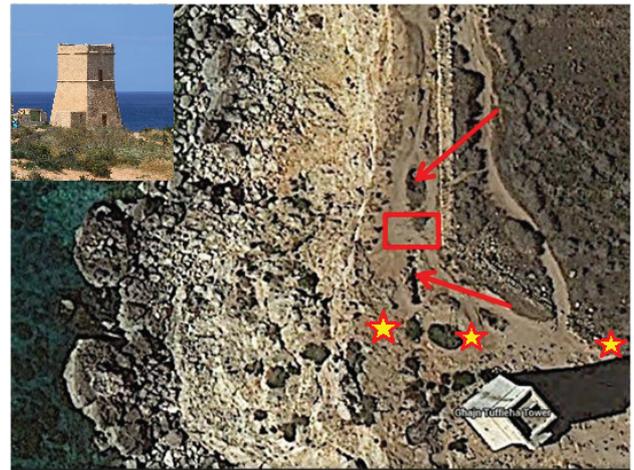


Fig. 2. The golden bay. The prospected area is approximately indicated by the rectangle. The arrows indicate two point where the soil is collapsed. The stars indicate the locations where ambient vibration measurements have been taken

In the area we also performed some GPR measurements which were able to identify a fracture in the proximity of the tower. This area was chosen because the presence of large fractures in the nearby region and being the main one not yet mapped and imaged. The area investigated using the GPR can be approximated to a rectangle of size about 5.2x6.5 square meters (Fig. 2), and has been prospected with Bscans parallel to each other, directed toward the sea and spaced 40 cm from each other. The scan end in proximity of the cliff, about 30 meters high, sharply overhanging the sea. On the top of the cliff, some naturally opened holes witness the possibility of the presence of deep fractures in the cliff, which might one day lead to some collapse. Two of these subsidence points are indicated with the arrows in Fig. 2. As can be seen they are quite aligned to each other. To investigate and locate the fracture the low frequency equivalent antennas have been exploited, because the anomalies of interest are quite extended and it was of interest to increase the penetration depth of the signal. The processing has been minimal, including zero timing, gain vs. the depth, background removal, and slicing. No migration has been performed, being the anomalies quite

large. The processing has been performed with the *reflexw* commercial code. At this site combination of GPR and passive seismic measurements were used to reconstruct the geometry of the fracture.

The Madliena tower (Fig. 3) is a mighty structure, exploited in the past as watchtowers between 1658 and 1659 with very thick walls since it was a military defensive tower. The inner of the tower at the ground floor in just a rectangle of 2.9x3.9 square meters, plus a small corridor toward the door. We have prospected this room, with interline step of 20 cm. We exploited also an option of the instrument, that allows optionally to mount the manhole in a perfectly vertical position. In fact, in general the manhole of a GPR is slightly oblique, because in this way the human strength for pushing the instrument is dynamically better exploited. However, this is useful and in many cases indispensable when the prospecting is performed on the grass. Indoor, the met mechanical resistance is customarily much lower, and a vertical manhole in these cases allows to safe space and prospect a larger share of the room. At Medliena Tower the GPR results suggest the presence of a foundation, with the walls prolonging (and possibly still enlarging toward the inner part) underground at least up to the depth of 1 m.



Fig. 3. The Madliena tower at Pembroke, Malta

The data have been gathered with the medium frequency antennas and the processing was the same as in the previous cases. The GPR results suggest the presence of a kind of foundation. In fact, the main reflections are displaced all around the room toward the walls. This makes us think of foundation excavated directly in the rock also because the soil under the central part of the room is quite homogeneous. For both towers seismic passive techniques were used also to compute the natural frequency of the structures to be used in farther engineering modelling to contribute to studies related to the whole stability of the structures. At this particular site the ambient noise vibrations indicate a flat response of the ground confirming that the tower is located on hard rock.

The church of La Ferla is an abandoned church on the top of a small hill, near to a cross visible at distance. In Fig. 4, La Ferla church is the building on the central low part of the image. Indeed, there is a geological sliding, mainly due to the local geological condition in the area, that has strongly damaged the church. However, since the importance of the old church there are proposals of moving it away from its current position. So, it was of interest to perform a preventive investigation in order to check the situation of an area nearby the church. Indeed, it was not easy to perform a complete series of parallel Bscans, because of the irregular topography of the soil, and so we performed 6 Bscans referenced as in Fig. 4. The processing was the same as that described for the above sites but the data have been also migrated because we were able to evaluate the propagation velocity from the diffraction hyperbolas.

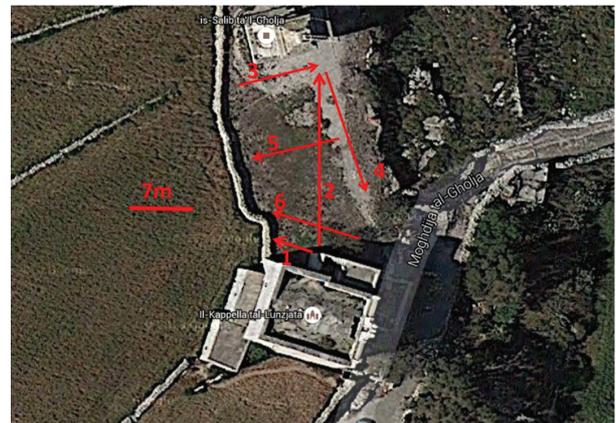


Fig. 4. La Ferla church and the Bscans performed about it.

Due to the purposes of this prospecting, the data mostly of interest are those at medium frequency. At La Ferla Cross the combination of the two techniques described above shows the presence of a soil coverage of about 120 cm. We also located and reconstructed the geometry of a quite large cavity. At this site several scans have been taken.

Measurements have been gathered also outside the church of Santa Maria, an historical building where some structural problem had been previously identified. In particular, some fractures and some movements of part of the walls had been identified. GPR data were gathered with an interline space of 50 cm, the results shown here are relative to the medium frequency antennas. The processing was the same exploited in the other cases. For a geometrical quantification, the notch on the white lines corresponds to the length of 2 meters. The main results are shown in Figure 5, where slices at different time depth levels are shown.

Data indicates a confused situation with respect to the shallowest levels, that have been somehow strongly reshuffled in the 20th century. However, beyond the time

depth level of 10 ns some more isolated anomalies are visible. Those farthest from the wall of the church are at least partially ascribable to tombs, because it is known that there was a cemetery in that area. However, there are some clear anomalies also close to the walls of the church, outlined by the ellipsis superposed to the slice at 10 ns and by the circle superposed to the slice at 15 ns.

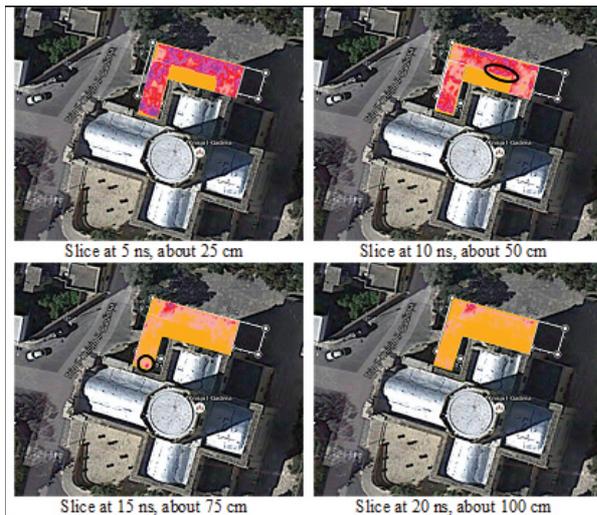


Figure 5. Time slices at different levels outside the church of Santa Maria.

They might be related to the structural problems that the building is having. We identify that under the line of Bscan taken in proximity of the damage wall there is a quite clear discontinuity suggesting a two layered soil. The level of this interface oscillates slowly around 15 ns (about 75 cm). Moreover, several stronger reflections appear within this scenario, indicating maybe past works with heterogeneous materials used for the filling. In any case, the prospecting indicates markedly the most inhomogeneous conformation under this line.

III. CONCLUDING REMARKS

With the combination of several non-invasive geophysical techniques we were able to locate and determine fracture on cliff area as well as to locate graves and buried structures at the investigate sites. In this paper, some effects of electromagnetic interferences on GPR data have been studied, and above all a possible counteraction based on the reconfiguration of the integration times of the harmonic tones of a stepped frequency (reconfigurable) GPR system has been considered. Ultimately this study aims to serve as a platform for sharing knowledge and good practices while stimulating reflections on the role and integration of modern technologies for the preservation and promotion of cultural digital heritage. From this point of view, the present paper will be useful to plan feasibility studies having the main goal of combining several techniques to

study, restore and open to public cultural heritage sites even using virtual reality technology.

IV. ACKNOWLEDGMENTS

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