INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE

ISSN: 2067-533X Volume 3, Issue 3, July-September 2012: 153-162 www.ijcs.uaic.ro

GROUND PENETRATING RADAR INVESTIGATIONS FOR ARCHITECTURAL HERITAGE PRESERVATION OF THE HABIB SAKAKINI PALACE, CAIRO, EGYPT

Sayed HEMEDA*

Conservation Department, Faculty of Archaeology, Cairo University, Egypt.

Abstract

The modern architectural heritage of Egypt is both varied and vast. It covers all non-ecclesiastical buildings, important monumental structures (mansions, municipal buildings) in the history of architecture, as well as more common buildings. They include houses (from mansions to simple dwellings), public buildings (schools, administrative buildings, hospitals), industrial buildings (factories, warehouses, mills), bridges, monastic dependencies (drinking foundations, gardens) and any other modern structures that fall within the category of monuments and comprise the Egyptian cultural heritage. We present herein a comprehensive Ground Penetration Radar (GPR) investigation and hazard assessment for the rehabilitation and strengthening of Habib Sakakini's Palace, in Cairo, considered one of the most significant architectural heritage sites in Egypt. The palace is located on an ancient water pond at the eastern side of the Egyptian gulf, beside the Sultan Bebris Al-Bondoqdary mosque, a place also called "Prince Qraja al-Turkumany pond". That pond was drained by Habib Sakakini in 1892, to construct his famous palace in 1897. Eight hundred meters of Ground Penetration Radar (GPR) profiling were conducted, to monitor the subsurface conditions. 600 meters were made in the surrounding area of the Palace and 200 m at the basement. The aim was to monitor the soil conditions beneath and around the Palace and to identify potential geological discontinuities, or the presence of faults and cavities. A suitable single and dual antenna were used (500-100 MHZ) to penetrate to the desired depth of 7 meters (ASTM D6432). The GPR was also used to detect the underground water. At the building basement the GPR was used to identify the foundation thickness and the soil - basement interface, as well as for the inspection of cracks in some supporting columns, piers and masonry walls. All the results, together with the seismic hazard analysis, will be used for a complete analysis of the palace in the framework of the rehabilitation and strengthening works planned for a second stage.

Keywords: *Ground Penetration Radar (GPR); architectural heritage; geophysics; restoration*

Introduction

The archaeological subsurface represents a potentially difficult problem when imaging targets with ground penetrating radar (GPR) systems. Some structures within the ground may be very deep, or may exhibit large local variations in strike, causing serious migration problems. Furthermore, the target may be located in a medium that is electrically conductive (e.g., clay-rich or waterlogged soil) such that the GPR wavelet rapidly gets attenuated and the signal-to-noise ratio (SNR) in the resulting dataset is diminished. Recently, some techniques used routinely by the seismic industry, for imaging complex, low-SNR targets, have been imported to the field of GPR image acquisition. Specifically, the use of three-dimensional (3-D)

* Corresponding author: hemeda@civil.auth.gr

migration has been shown to significantly improve the resolution of the GPR target in regions of structural complexity [1], while the multi-offset (MO) method has been employed to boost the SNR of otherwise poorly defined targets [2]. When those methods are combined, the potential improvement to the image of an archaeological target may be considerable. An integrated 3-D, MO GPR acquisition was performed over an archaeological target, a Roman-British villa at Ground well Ridge [3] in spring 2006.

Ground penetrating radar (GPR) is extensively used for a variety of applications. Among all the high-resolution geophysical methods, GPR has proven to be the most suitable for the detection of karstic cavities and sinkholes, in a wide range of soil and rock conditions [4-7]. However, one of the main limitations of GPR is the exact determination of the mean velocity of the electromagnetic waves, which is a key data in estimating the depth of penetration into the ground.

Materials and Methods

Ground Penetration Radar Survey

The GPR functions by sending high frequency electromagnetic wave by means of a transmitter antenna. Some of those waves are reflected back to the surface as they encounter changes in the dielectric permittivity of the matrix through which they are travelling and are detected by a receiver antenna. The amplitude and two-way travel time of those reflections are recorded on a portable computer. This information is then used to construct a two-dimensional plot of horizontal distance versus travel time. The data collected in the field are stored on a portable computer for later analysis. A more complete and technical discussion of the method can be found elsewhere [8-10].

The effectiveness of GPR is determined by the local soil conditions. GPR is most effective in locating buried objects in a homogenous soil matrix with a high electrical resistance. GPR is least effective in a heterogeneous environment with high electrical conductivity. A heterogeneous environment contributes to signal scattering and can result in insufficient depth of penetration and a “noisy” reflection (poor signal to noise ratio). A conductive environment can seriously inhibit the depth of penetration, due to conductive losses. Conductive loss is the result of the electromagnetic wave creating a conductive current in the soil medium, causing signal attenuation.

Although a GPR survey can be performed in a number of ways, the method employed in this survey involved dragging the transmitter and receiver antennas together over the ground, which is called the *fixed offset reflection mode*. The transmitter emits pulses at regular intervals along a pattern, which are picked up by the receiver. A laptop computer controls data collection and displays the data as a two dimensional profile.

The GPR is able to detect subsurface features whose electrical properties contrast with those of the surrounding soil. The GPR can detect human burial locations in several ways. It may detect the disturbed soil of the grave shaft, or a break in the natural stratigraphy, or soil profile [11]. It may also detect the coffin, bones, clothes and other articles in the tomb. Reflections may be caused by air voids within the skull [12]. or the coffin. It has also been suggested that the decomposition of bones may leach calcium salts into the surrounding soil for many years, which may change the electrical properties of the soil, making it visible to the radar.

GPR Data Acquisition and Analysis

A Mala X3M Radar System, coupled to a shielded antenna of 500 MHz and 250MHz, central frequencies was used to accomplish the survey. Distances along the surveyed lines were accurately recorded using a measuring tape. The profile spacing was set according to the available space in the Palace and a trace interval of 0.02 meters was set for the 500 MHz antenna profiles. About 100 profiles were conducted at the site. (Fig. 1 and 2).The radar antenna was moved along the lines and the 2D profiles of a large number of periodic reflections were generated, thus producing a profile of the subsurface structure, with a fixed gain. Special care was taken to avoid artificial high-frequency noise that could deteriorate the radar signal. Time windows of 60 ns and 170ns were used during data acquisition in order to receive information from sources located as deep as possible. The layout of the profiles conducted in the basement and on the first floors are shown in figures 1a and 1b.

GPR Data Processing

The analysis of GPR data is carried out by processing the data, using different gain and filtering techniques. Gain is a value, by which raw data are multiplied, to enhance low amplitude reflections. Signal amplitude commonly decreases exponentially with increasing travel times (greater depths below surface). This is compensated by designing a time gain that increases the signal strength at greater travel times. Filtering is the use of mathematical processing algorithms to “clean” noises from the data and/or enhance certain characteristics of the data. This process was specifically customized for each profile. The data processing routine includes background noise removal, time-zero corrections and band-pass filtering applied to the acquired data. Given that, most of the energy is limited to a finite bandwidth, an appropriate use of band limiting filtering may improve signal-to-noise without significantly altering the data (Annan, 1999). Taking into account the information obtained from the amplitude spectra of the raw data, a common band pass filter of 250 MHz to 750 MHz was applied to the whole set of 500 MHz profiles and a 150 MHz -300 MHz band-pass filter was applied to the whole set of 250 MHz profiles to improve the signal quality.

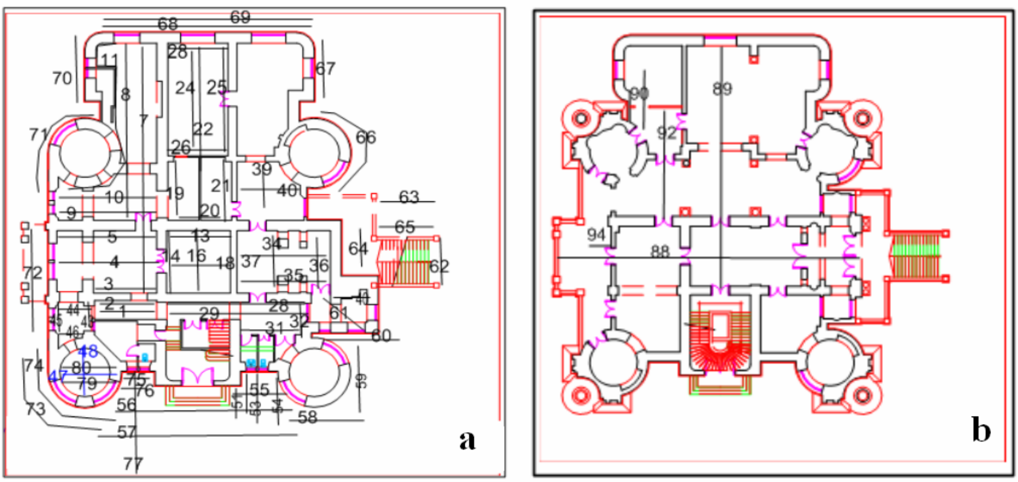

Fig. 1. GPR layout of the basement and area around the Palace (a) and of the first floor of the Palace (b)

Since the radar velocities and the dielectric properties of the studied materials were unknown, two different techniques were used to estimate the mean velocities of the electromagnetic waves: a) the determination of the velocity that produces the best fit between the measured GPR reflections and the dips and depths of the geological structures identified with seismic surveys (e.g. a lithological boundary resulting in contrasting physical properties); b) the determination of the mean velocity of the material directly related to the geometry of the hyperbolic reflections originated by point sources [13].

Fig. 2. Investigations of the Sakakini palace in Cairo

The second method used in the present study was a test carried out on a known depth for objects at the site. All the data were processed, modeled and interpreted using the software Reflex_W.4 [14]. In all the profiles, the position of antenna is represented in the horizontal axis, whereas depth is depicted in the vertical one. An example of data processing results is shown in figure 3.

Results and discussions

The interpretation of the geophysical survey results

The results of geophysical surveys of archaeological sites are generally presented graphically. This is done because anomalies of cultural origin are generally recognized by their pattern, rather than by their numeric values alone. When rendered graphically, we can better recognize cultural and natural patterns and visualize the physical phenomena causing the detected anomalies.

The interpretation of survey data must be a cooperative process, involving both archaeological geophysicists and archaeologists that are familiar with the specific cultural context of the site being studied. An understanding of the geological context of the survey area is also very important.

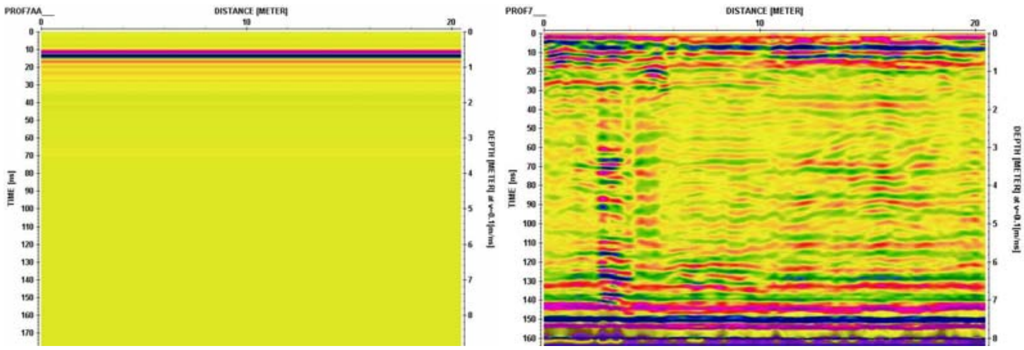

Fig. 3. Effect of the processing sequence on the raw GPR data

Results of GPR Probing at the Basement Floor of the Palace

About 50 GPR profiles were conducted at the basement floor. The target of these profiles was to depict the subsurface condition concerning the layering, disturbed and collapsed soils and foundation locations. Figures 4 to 7, show the radar profile No.7, 8, 22 and 29 and indicate a disturbed soil and the expected locations of the foundation at a depth of about 3 meters.

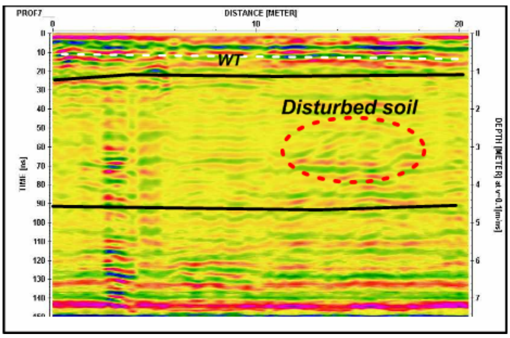

Fig. 4. Interpreted GPR profile No.7 at the basement area showing the disturbed soil at a depth of about 3m.

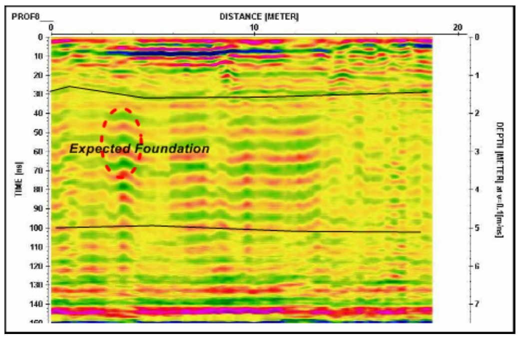

Fig. 5. Interpreted GPR profile No. 8 at the basement area showing the expected foundation at a depth of about 2,5 to 3m.

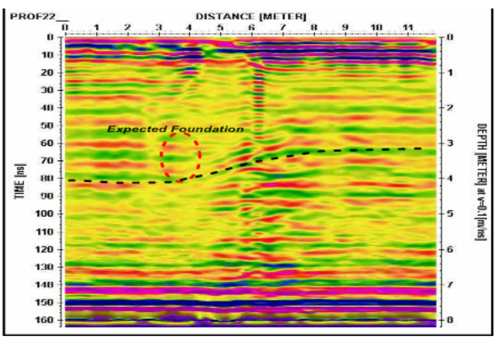

Fig. 6. Interpreted GPR profile No. 22 at the basement area showing the expected disturbed soil due to foundation works at 3m deep

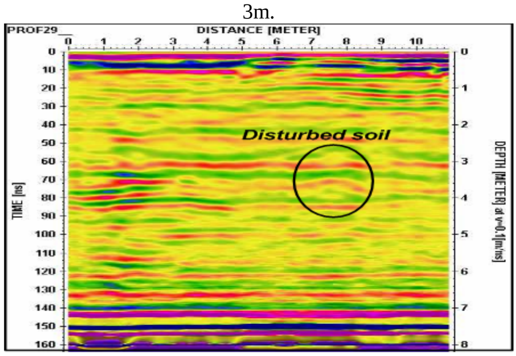

Fig. 7. Interpreted GPR profile No. 29 at the basement area showing the expected foundation at depth about 3m.

The soil succession shows a fill below the floor extended to about 3 to 7 meters. The fill consists of silt, clays and some stone fragments in some places. The silt becomes more clayey below 4 meters, as indicated from the amplitude of the radar reflection. The shallow water presence might be caused by infiltrations or an indication of the past history of the lagoon area at the site of the Palace. The locations of the interpreted profiles in the basement floor are shown in figure 8.

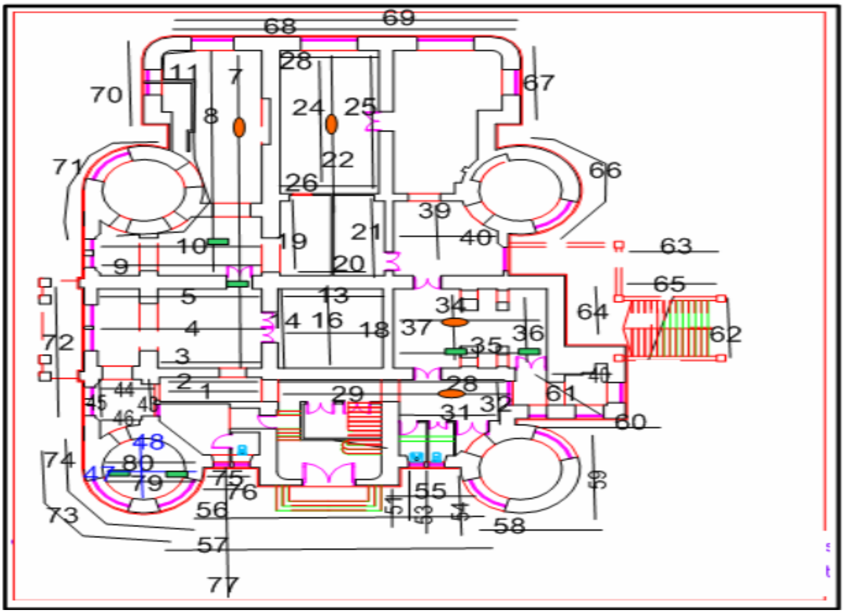

Fig. 8. Interpreted locations of interrupted soils (red circles) and expected foundation works (green box) in the basement area.

Results of the GPR Survey of the Palace Surroundings

About 30 GPR profiles were conducted in the area surrounding the palace. The target of those profiles was to depict the subsurface condition in regard to layering, groundwater, disturbed and collapsed soils and foundation locations. Figures 9 to 15, show the radar profiles No.56, 57, 61, 66, 71, 74, and 75 show a disturbed soil and the expected locations for the foundation at a depth of about 3 meters.

The soil succession shows a fill below the ground surface extended to about 3 meters. The fill consists of silt, clays and some stone fragment in some localities. The silt becomes more clayey below 4 m, as indicated from the amplitude of radar reflection. Shallow water may originate in infiltrations, or the past history of the lagoon area at the site of the Palace. Some profiles show up-arching of the soil layers and lateral unhomogeneity of the soil composition. The locations of the interpreted profiles in the basement floor are shown in figure 16.

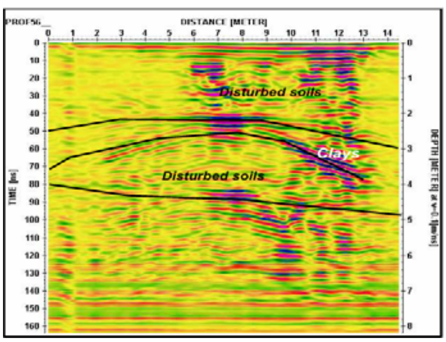

Fig. 9. Interpreted GPR profile No. 56 of the basement area, showing the expected disturbed soils near the tower.

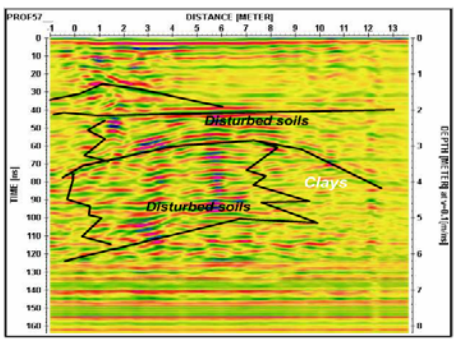

Fig. 10. Interpreted GPR profile No. 57 of the basement area, showing the expected disturbed soils near the tower.

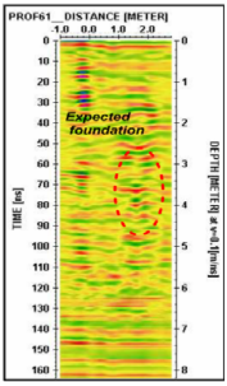

Fig. 11. Interpreted GPR profile No. 61 at the surrounding area showing the expected foundations.

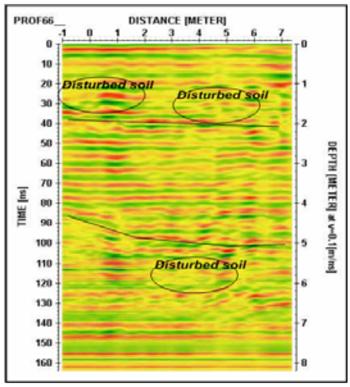

Fig. 12. Interpreted GPR profile No. 66 of the surrounding area, showing the expected disturbed soils near the tower.

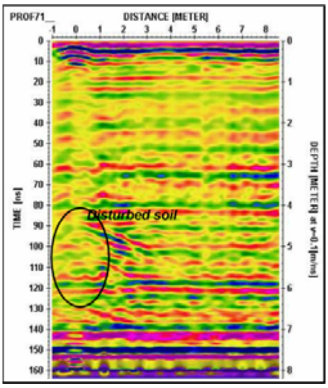

Fig. 13. Interpreted GPR profile No.71 of the surrounding area, showing the expected disturbed soils near the tower.

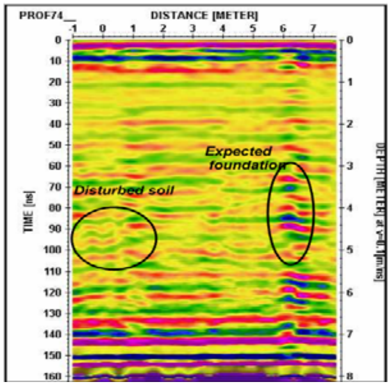

Fig. 14. Interpreted GPR profile No.74 of the surrounding area, showing the expected disturbed soils near the tower**.**

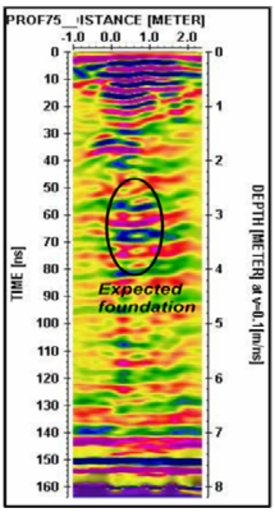

Fig. 15. Interpreted GPR profile No.75 at the surrounding area showing the expected disturbed soils near the tower**.**

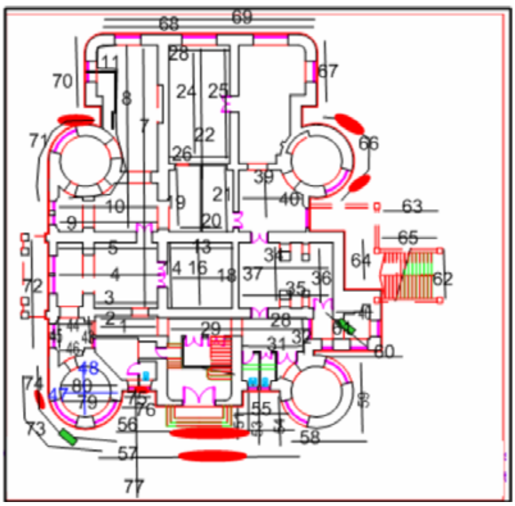

Fig. 16. Interpreted locations of interrupted soils (red circles) and expected foundation (green box) in the surrounding area.

Results of GPR Surveys of the Palace Walls and First Floor

About 20 GPR profiles were conducted on some walls of the palace. The target of those profiles was to depict the subsurface condition regarding the layering, groundwater, disturbed and collapsed soils and foundation locations. Figures 17 to 21, show the radar profiles No.81, 85, 88, 89, and 99. Those profiles indicate fractures and cracks both in walls and in concrete slabs, as well as the variation of the ground of the first floor.

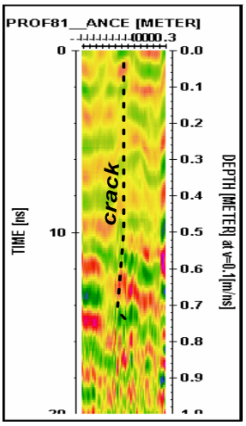

Fig. 17. Interpreted GPR profile No.81 of the outside wall near elevator door.

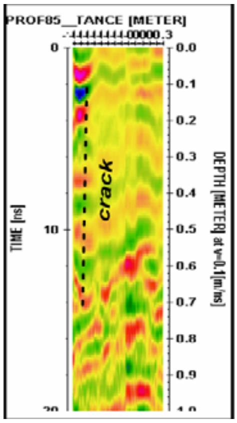

Fig. 18. Interpreted GPR profile No.85 of the outside tower right side of elevator door.

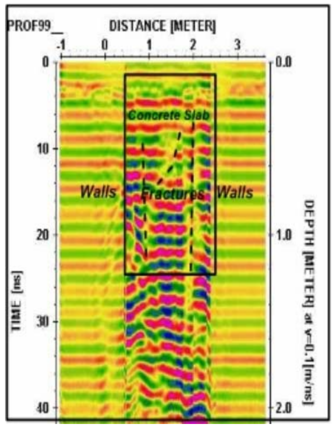

Fig. 19. Interpreted GPR profile No.99 of the slab with fractures on the basement floor.

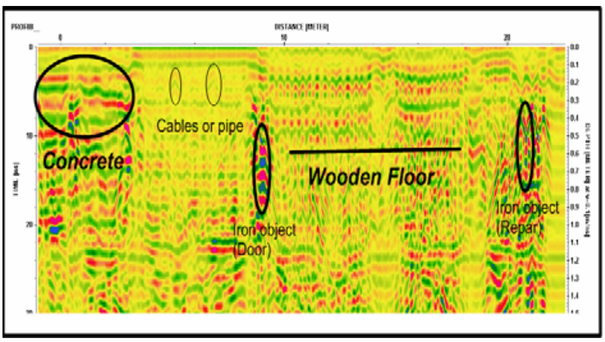

Fig. 20. Interpreted GPR profile No.88 of the ground of the first floor.

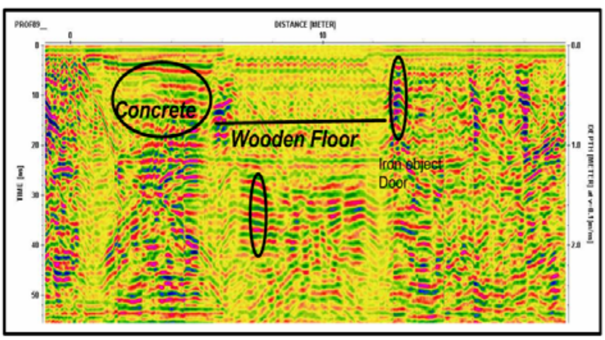

Fig. 21. Interpreted GPR profile No.89 of the ground of the first floor

Conclusions

We concluded the following:

- The soil column of the site comprises heterogeneous materials as a fill for about 5 to 7 meters.
- The shallow groundwater (about 0.5-1 meter deep) has a serious influence on the rigidity of the soils and causes humidity in the foundations and walls of the Palace.
- The composition of silt and clay soil at a low depth might affect the stability of the site.
- Many fractures detected in walls and concrete slabs extended to about 60 cm in the walls and slabs.
- The foundation type is shallow strip and spread stone foundations at a depth of 2,5 to 3 meters on a concrete raft or mat.
- The wall masonry construction system is multiple leaf masonry walls or rubble infill walls
- The added court on the eastern side is a concrete structure.

Acknowledgments

The present paper is part of a project entitled "Risk Assessment and Seismic Response Analysis of the Architectural Heritage in Egypt", funded by Cairo University and under the management of Dr Sayed Hemeda, the author and main investigator of the project. I'd like to thank professor Sharaf el-din Mahmoud, the chairman of the Geophysics Department, Cairo University for his great efforts and help throughout our investigation.

References

[1] M. Grasmueck, R. Weger, H. Horstmeyer, *Full-resolution 3D GPR imaging*, **Geophysics**, **70**(1), 2005, pp. K12-K19.

[2] O. Yilmaz, **Seismic Data Analysis,** Society of Exploration Geophysicists, Tulsa, OK, 2001.

[3] N.L. Linford, P.K. Linford PK, *GPR Survey over a Roman Building at Groundwell Ridge*, **Archaeological Prospection**, **11**, 2004, pp 49-55.

[4] R.C. Benson, L. Yuhr, *A summary of methods for locating and mapping fractures and cavities with emphasis on geophysical methods*, **Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems** (Editor R. S. Bell, editor), Oakbrook, Illinois, April 26-29, 1992, pp. 471-486.

[5] J.S. Mellet, *Ground penetrating radar applications in engineering environmental management and geology*, **Journal of Applied Geophysics**, **33**, 1995, pp. 157-166.

[6] H. Tomita, H. Tada, T. Nanbu, K. Chou, *Nature and detection of void induced pavement Failures,* **Transportation Research Record 1505**, 1995.

[7] A. Batayneh, A. Abueladas, Kh. Moumani, *Use of ground-penetrating radar for assessment of potential sinkhole conditions: an example from Ghor al Haditha area, Jordan*, **Environmental Geology, 41**, 2002, pp. 977-983.

[8] L.B. Conyers, D. Goodman, **Ground Penetrating Radar: An Introduction for Archaeologists**, AltaMira Press, Walnut Creek, London and New Delhi, 1997.

[9] A.P. Annan, S. Cosway, *Ground penetrating radar survey design,* **Proceedings of the Symposium on the Applications of Geophysics to Engineering and Environmental Problems**, Environmental and Engineering Geophysics Society, Englewood, CO., 1992.

[10] A.P. Annan, *Practical Processing of GPR data*, **Sensors and Software**, Ontario, 1999.

[11] B.W. Bevan, *The search for graves,* **Gephysics, 56**, 1991, pp. 1310-1319**.**

[12] J.J. Mellet, *Location of Human Remains with Ground Penetrating Radar,* **Geological Survey of Finland**, Special Paper No. 16, 1992.

[13] C.C. Nascimento da Silva, W.E. de Medeiros, E.F. Jardim de Sa, P.X. Neto, Resistivity and ground-penetrating radar images of fractures in a crystalline aquifer: a case study in Caic¸ara farm—NE Brazil, **Journal of Applied Geophysics, 56,** 2004, pp. 295– 307.
[14] K.J. Sandmeier, **REFLEXW: Version 4.0 Instruction Manual**, Karlsruhe, Germany. (http://www.sandmeier-geo.de), 2006.

Received: April, 04, 2012
Accepted: July, 27, 2012