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GPR scan assessment at Mekaad Radwan Ottoman – Cairo, Egypt

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Ground Penetrating Radar (GPR)

Abstract Mekaad Radwan monument is situated in the neighborhood of Bab Zuweila in the historical Cairo, Egypt. It was constructed at the middle XVII century (1635 AD). The building has a rectangle shape plan (13 × 6 m) with the longitudinal sides approximately WNW-ESE. It comprises three storages namely; the ground floor; the opened floor (RADWAN Bench) and the living floor with a total elevation of 15 m above the street level. The building suffers from severe deterioration phenomena with patterns of damage which have occurred over time. These deterioration and damages could be attributed to foundation problems, subsoil water and also to the earthquake that affected the entire Greater Cairo area in October 1992. Ground Penetrating Radar (GPR) scan was accomplished against the walls of the opened floor (**RADWAN Bench**) to evaluate the hazard impact on the walls textures and integrity. The results showed an anomalous feature through the southern wall of RADWAN Bench. A mathematical model has been simulated to confirm the obtained anomaly and the model response exhibited a good matching with the outlined anomaly.

1. Introduction

Mekaad Radwan (Fig. 1) is one of the civil architectural buildings that were founded by the Ottoman Pasha Radwan who was the governor of Al Mansoura governorate in the Ottoman period in Egypt. The Mekaad has been built in the 17th century in old Cairo at the front of Bawabet Elmetwalli and behind Souq El Khayameya. The monument is a part of a complex known as Radwan Palace or Qasabet Radwan which carries number 406 in the Egyptian classification of Islamic and Coptic monuments, while Mekaad Radwan carries number 208 which is a separate number apart from the main monument (NIKER, 2011). Geometric characteristics of the damages and deterioration phenomena affect Mekaad Radwan monument. These phenomena are resulted from different causes including earthquakes and pre-existing October 1992 seismicity activity, and they are represented by extensive

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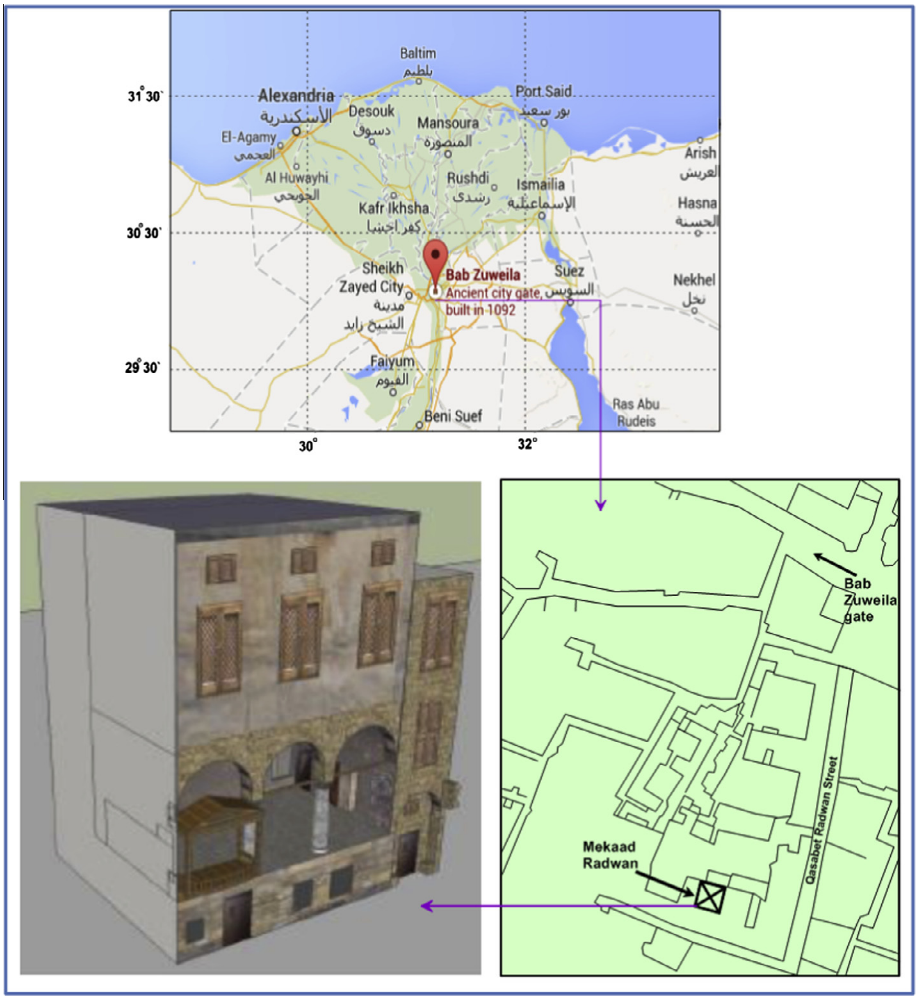

Figure 1 Location and 3D view of Mekaad Radwan.

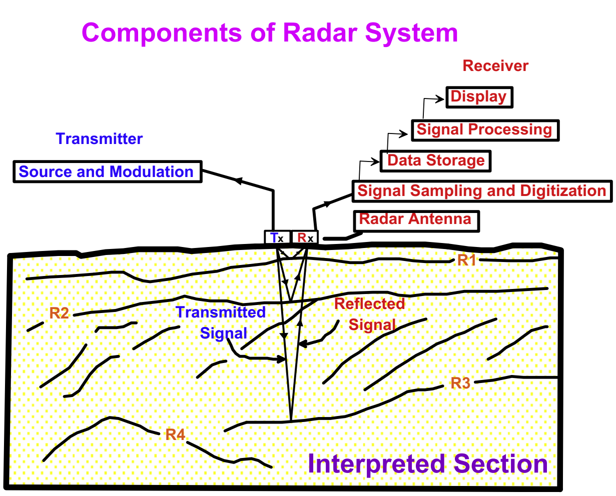

Figure 2 The physical concept of GPR.

Figure 3 GPR system, Model SIR 3000 (GSSI, USA).

cracking, subsiding, corrosion and other failure phenomenon (Fitzner et al., 2002a, b).

Ground Probing Radar (GPR) has become an invaluable and almost indispensable means of exploring shallow structures for geoscientific, engineering environmental and archaeological investigations (Tzanis, 2013).GPR is a high resolution geophysical method, which is based on the propagation of high frequency electromagnetic waves (Conyers and

Goodman, 1997). The GPR method images structures in the ground that are related to changes in dielectric properties. In particular, GPR is well suited to investigate the foundation geometry of archaeological buildings where it is impossible to apply any destructive technique (Abbas, 2005). Ground Penetrating Radar (GPR) is a powerful non-invasive tool to image the shallow subsurface. In the present study, GPR has been employed to inspect ancient walls to outline their structure, homogeneity, fractures, etc., (Clark, 1990). Penetration depth and resolution of the GPR measurements depend on wavelength and frequency of the electromagnetic (EM) waves. For geological investigations 100 MHz antennas are best suitable, whereas, the optimum results for archaeological assessments will be achieved using 270 MHz or higher frequencies antennas.

The GPR system (Fig. 2) consists of a signal (wave) generator, transmitting, receiving antennas and recording unit. A pulse (wave) is generated and emitted through the transmitting antenna. As the wave travels through the ground, it reflected, deflected and absorbed by varying degrees of the soil material through which it travels. The reflected wave is picked up by the receiving antenna and recorded by the recording unit.

In the present study, GPR scan was accomplished against the walls of the opened floor (**RADWAN Bench**) to evaluate the hazard impact of the walls textures and integrity. Besides, this approach was utilized to comprehend the possible hidden objects within the walls.

2. Data acquisition

The data acquisition was carried out using the compact and integrated GSSI radar system, Model SIR 3000 (Fig. 3). The utilized system was attached to compatible GSSI 270 MHz antenna. The survey had been accomplished in parallel lines across the walls of RADWAN Bench in two directions

Figure 4 Mekaad Radwan building.

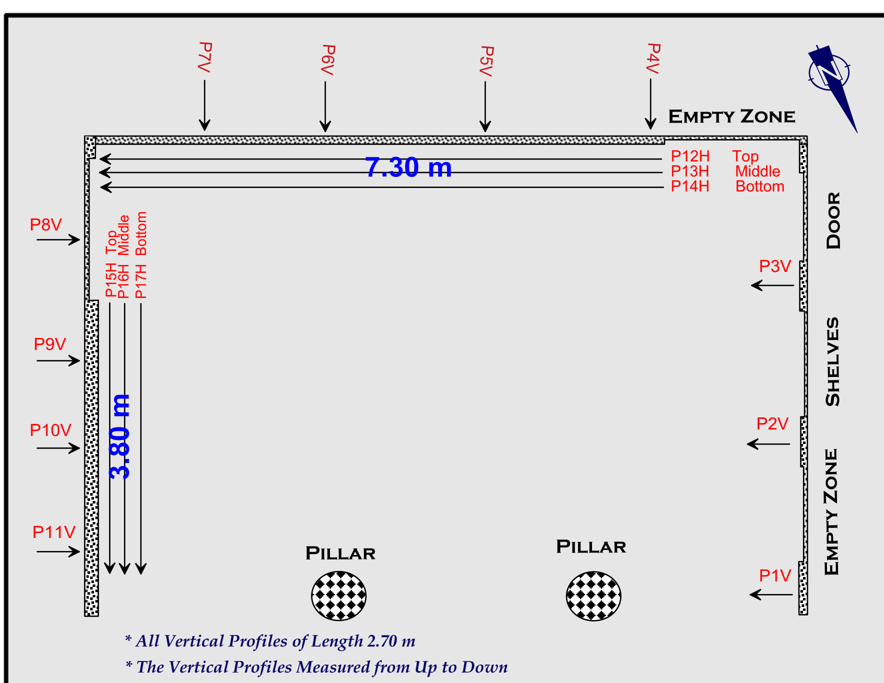

Figure 5 Location of the conducted GPR profiles along RADWAN Bench.

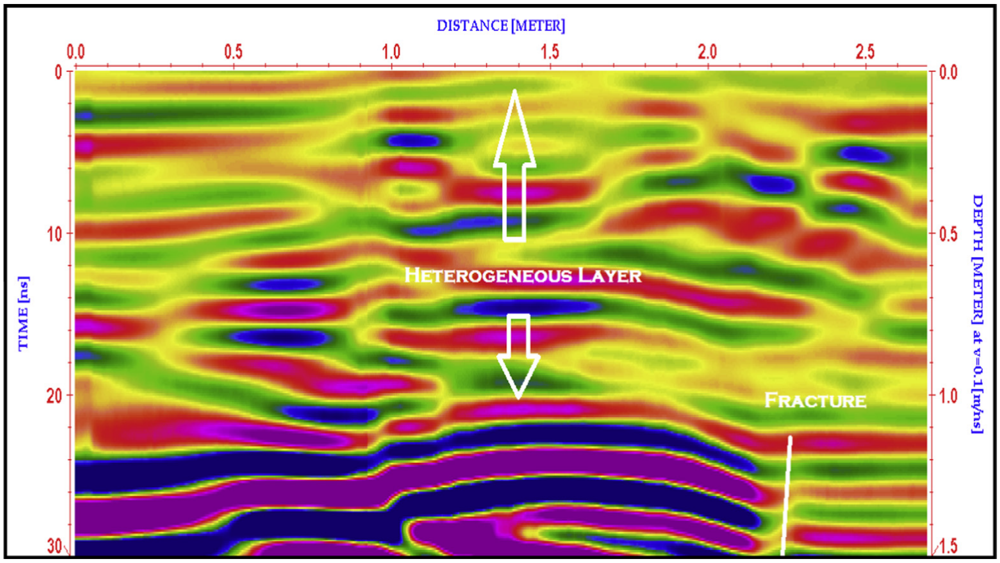

Figure 6 Interpretation of profile P2V.

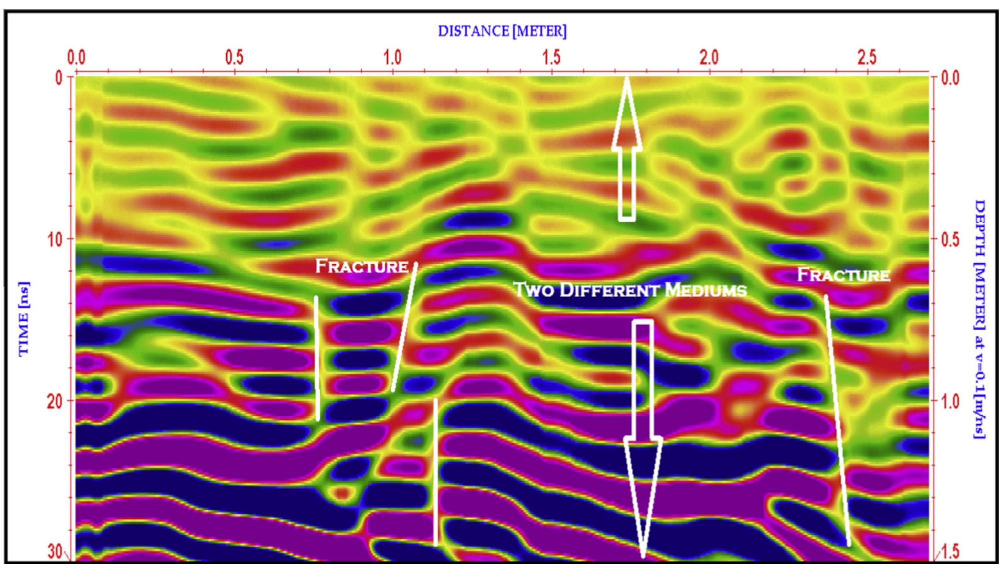

Figure 7 Interpretation of profile P6V.

(Fig. 4). The first set of GPR profiles, including 11 lines, were conducted in vertical direction from up to down and denoted by symbol "V" (e.g. P1V). The second set of profiles, including 6 lines, were conducted horizontally parallel to the floor line and denoted by symbol "H" (e. g. P12H). All of the conducted profiles are shown in Fig. 5. Briefly, RADWAN Bench consists of 3 walls. 3 GPR vertical profiles were measured across the western wall, 7 GPR profiles (4 vertical and 3 horizontal) were measured along the southern wall and the remaining 7 GPR profiles (4 vertical and 3 horizontal) were measured along the eastern wall.

3. Data processing

Although the collected data were generally of good quality, some processing steps were applied using REFLEX software, version 6.0 (Sandmeier, 2001) to increase the S/N ratio. Signal saturation correction (or Dewow) was used in all profiles to remove low frequency components, which are usually present in the GPR signal due to either inductive phenomena or possible instrumentation dynamic range limitations (Annan, 2004). A static correction in time direction has been applied where all traces were shifted and aligned to correctly position the time zero in each section. In addition, band-pass filter was applied where the lower cut-off was 10 MHz, the lower plateau was 120 MHz, the upper plateau was 230 MHz and the upper cut-off was 350 MHz in order to enhance the response from strong reflectors detected at a time range of about 30 ns which correspond to the expected target depth.

4. Data interpretation

Set of GPR profiles measured along the walls of RADWAN Bench have shown a variety of environments such as: fractures, homogeneity and heterogeneity, and anomalous

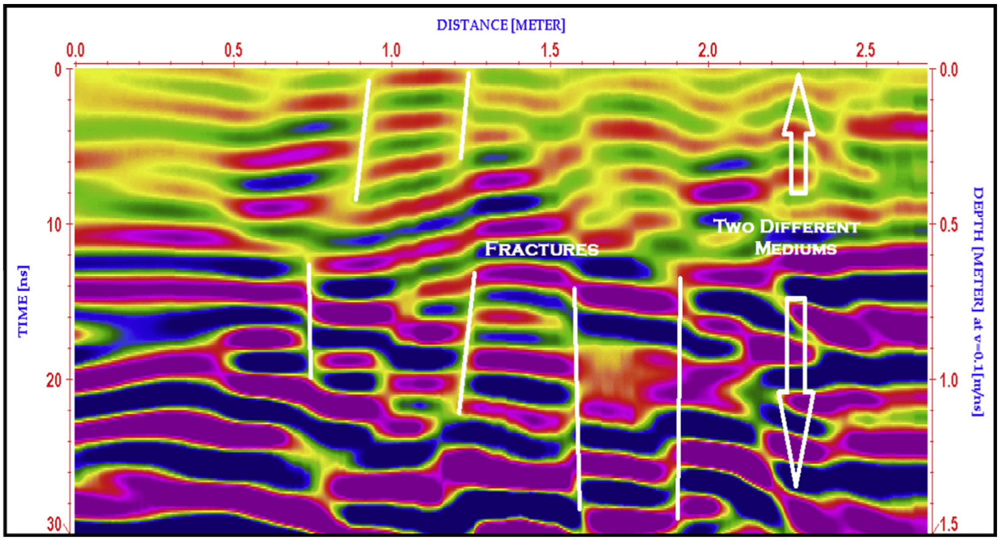

Figure 8 Interpretation of profile P7V.

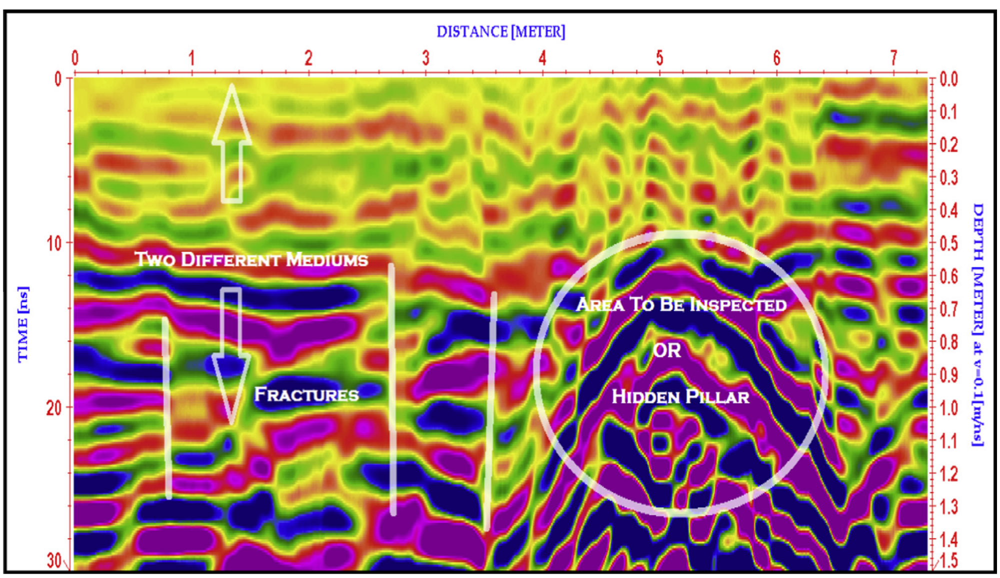

Figure 9 Interpretation of profile P12H.

features. Analysis and interpretation of some GPR profiles (displayed in Fig. 5) are shown through Figs. 6–12.

The results were indicating the presence of anomalous feature through the southern wall of RADWAN Bench (Figs. 9 and 10). As we could not dig a hole to explore the anomalous feature, we have simulated a mathematical model for the possible condition, and the model has shown a good matching with the outlined anomaly.

5. Modeling

All EM phenomena, on a macroscopic scale, are described by the well-known Maxwell's equations. They are first order partial differential equations which express the relations between the fundamental EM field quantities and their dependence on their sources. The nature of the GPR forward problem classifies it as an initial value open boundary problem (GPRMAX, 2005). Many methods can be used to numerically simulate GPR scanning, such as ray-based methods, frequency-domain methods, integral methods, pseudo-spectral methods, and the finite-difference time-domain (FDTD) method. Because the FDTD approach is conceptually simple, accurate for arbitrarily complex models, and capable of accommodating realistic antenna designs and their features such as dispersion in electrical properties, it is the most common approach to be used at the present time (Seyf and Yaldiz, 2012).

Free program MatGPR created as MATLAB code by Tzanis (2013) based on numerical FDTD simulator algorithm of Irvine and Knight (2006) was used to recognize the nature of the hidden object within the southern wall of Radwan Bench. In this program we used the finite-difference time-

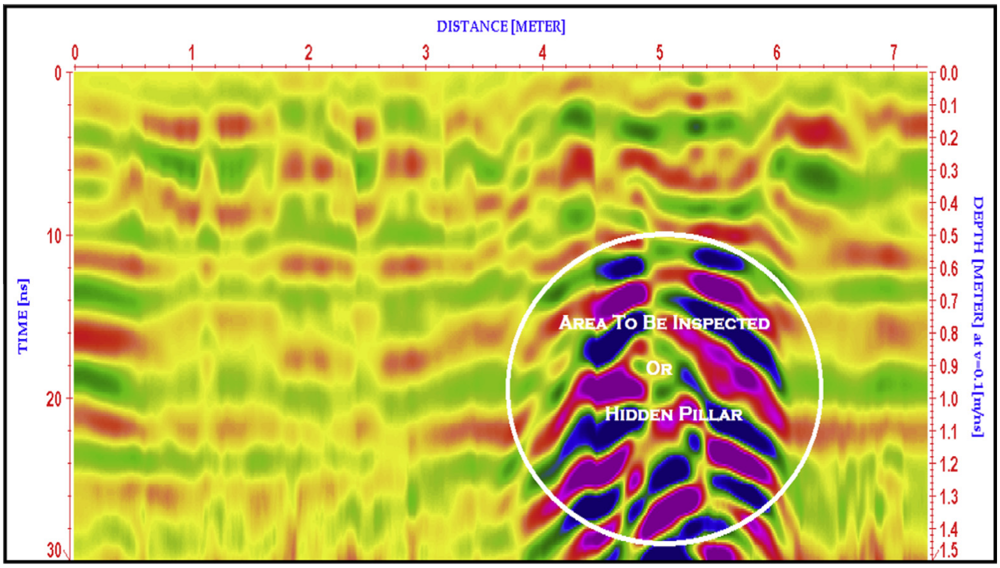

Figure 10 Interpretation of profile P14H.

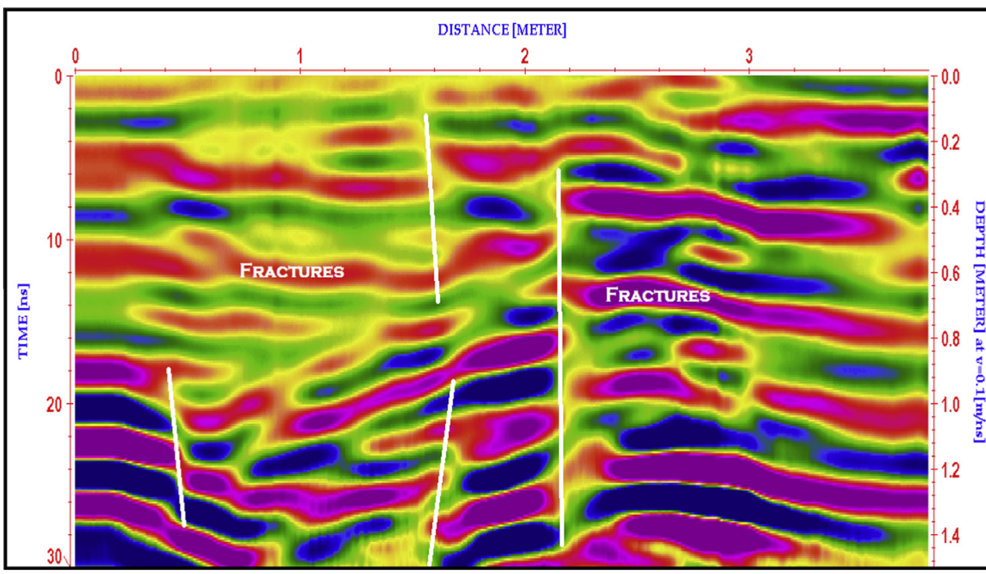

Figure 11 Interpretation of profile P16H.

domain (FDTD) modeling of ground-penetrating radar (GPR) in two dimensions. Two simulations were carried out where we assumed a medium of 4 m surface distance and investigation depth up to 2 m and a circle of 30 cm radius (Fig. 13). The initial model parameters are listed in Table 1, and illustrated in Fig. 14.

The selected parameters were suggested to represent the materials which could form the walls and the immersed mass that causes the anomalous pattern in the measured GPR profiles of the southern wall. As the EM-wave velocity and the dielectric constant were calculated from the GPR data, it was possible to suggest the material constituting the wall. Then, objects of different physical characteristics (lithology) were assumed to be as intrusions in the wall soil. This approach was utilized to comprehend the hidden object within the southern wall. From the obtained results, the wall could be made up of wet/dry sandy materials and the immersed body has been approximated as a circle of concrete or limestone taking into consideration that the electrical resistivity (ρ) and the dielectric permittivity (ε) are independent.

The simulations were implemented through an iterative process. Each iteration represents the travel of electromagnetic waves (E_y) through the assigned media and excitation of a single trace (Fig. 15).

The resulted synthetic radar section due to simulation "1" is illustrated in Fig. 16 and that of simulation "2" is shown in Fig. 17. Comparison between the two simulations outcomes and the interpretation of the measured data are integrated in Fig. 18.

The dissimilarity of the hyperbolas of the two simulation results is attributed to behavior of the EM wave inside the circle whether it is conductive or resistive. When the circle is

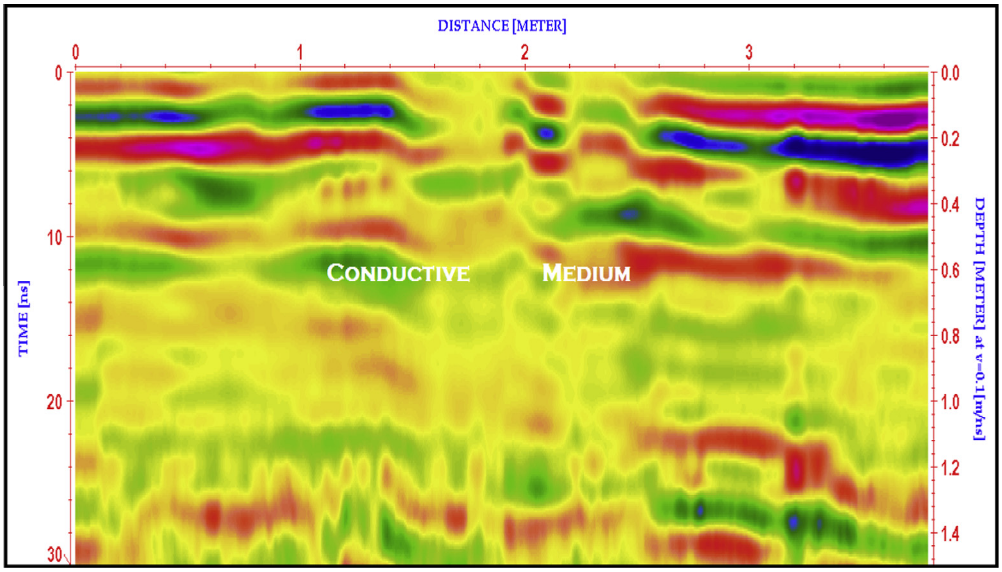

Figure 12 Interpretation of profile P17H.

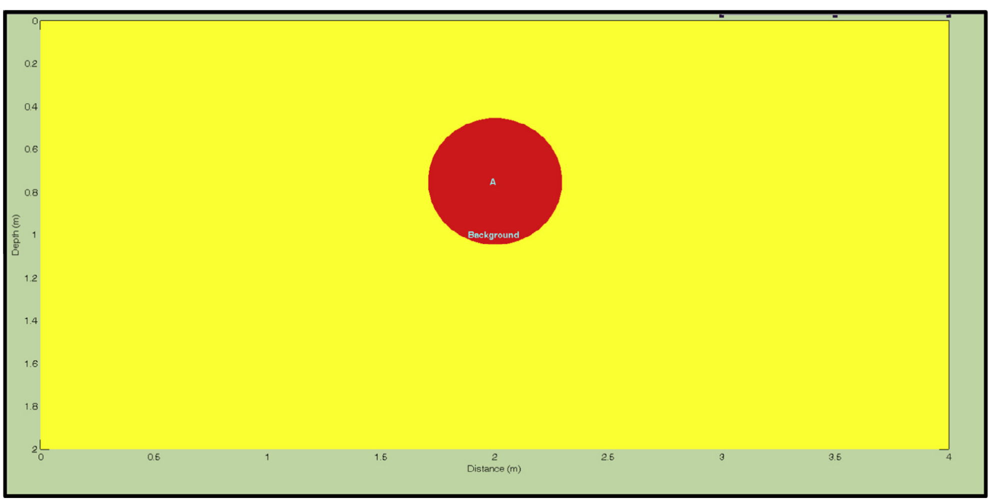

Figure 13 Outline of the modeled media.

Table 1 The initial physical parameters used in the model.

Medium	Parameter	Simulation "1"	Simulation "2"
Background	Resistivity ρ	200	15
	Dielectric permittivity ε	6	35
	Magnetic permeability μ	1	1
Circle	Resistivity ρ	15	200
	Dielectric Permittivity ε	35	6
	Magnetic permeability μ	1	1
Trace spacing dx		0.009 m	
Depth spacing dz		0.004 m	
Source spacing		0.018 m	
Sampling interval		0.025 ns	
Total 2-way travel time		50 ns	

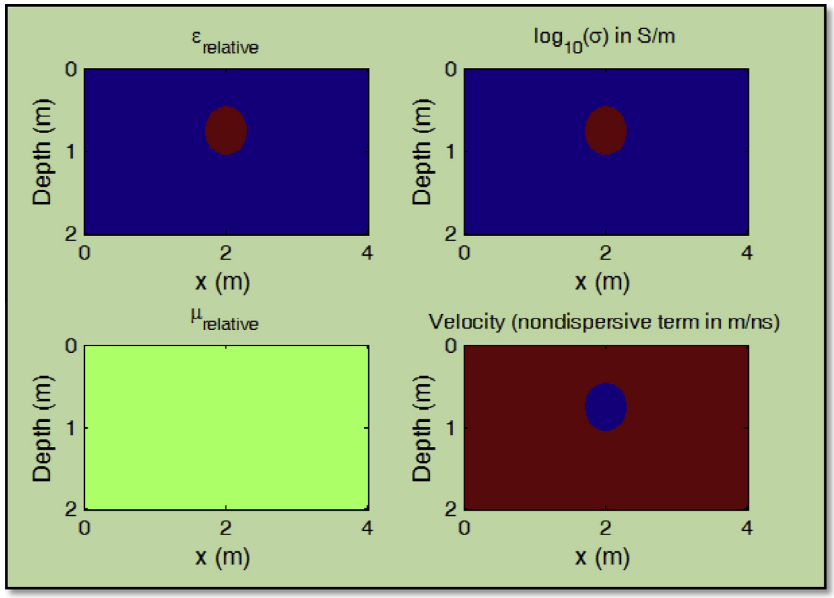

Figure 14 Distribution of the physical parameters used in the model.

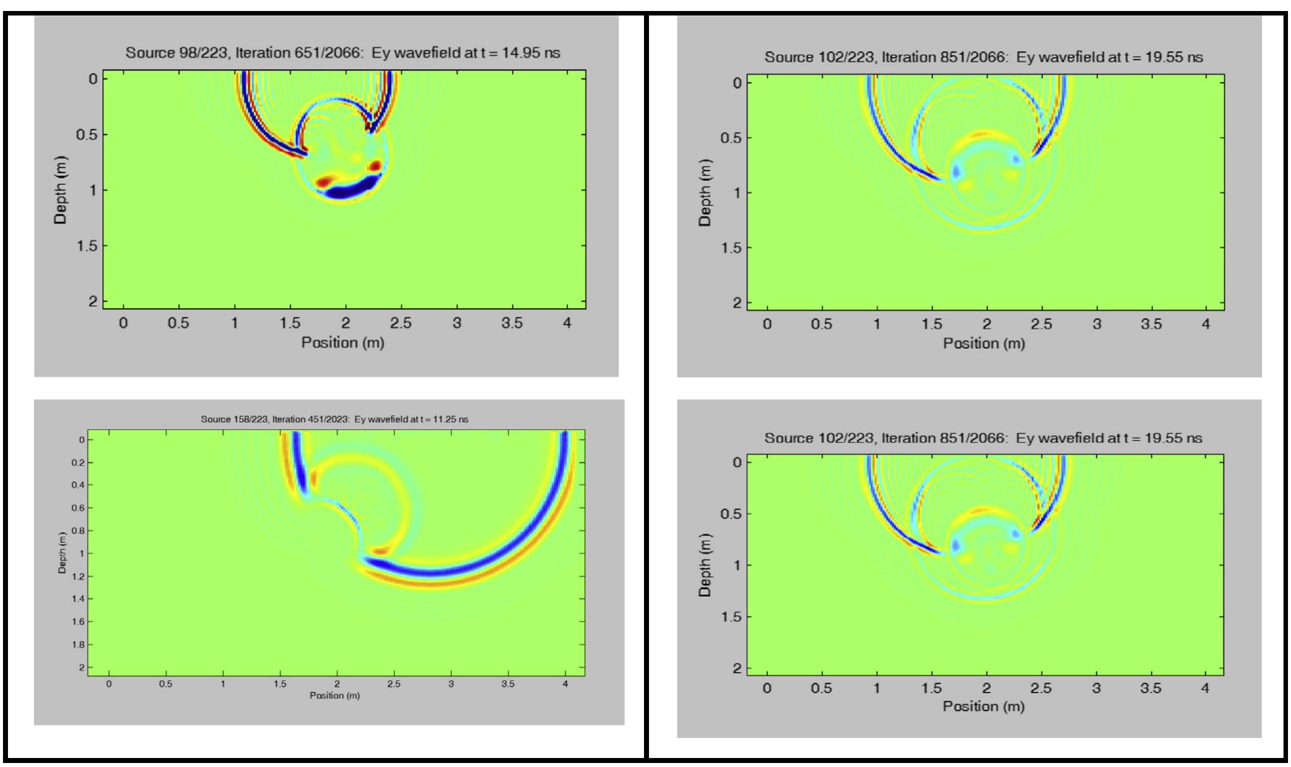

Figure 15 Sample of the wave field excitation progress and the model iterations.

conductive, it absorbs the penetrated EM waves causing a small part of the waves to be reflected back to the surface. Fig. 16 shows two hyperbolas, the first is due to the entry of the EM wave to the circle and the other could be attributed to the EM wave when leaves the circle. On the other side, the resistive circle causes the EM waves to crawl inside the circle and major part of them to reflect back to the surface, and as a result, notable reflections are distinguished inside the hyperbola (Fig. 17). In turn, when the EM wave gets out the resistive circle to the conductive medium, most of the EM waves will be absorbed and so minor part could reach to the surface again.

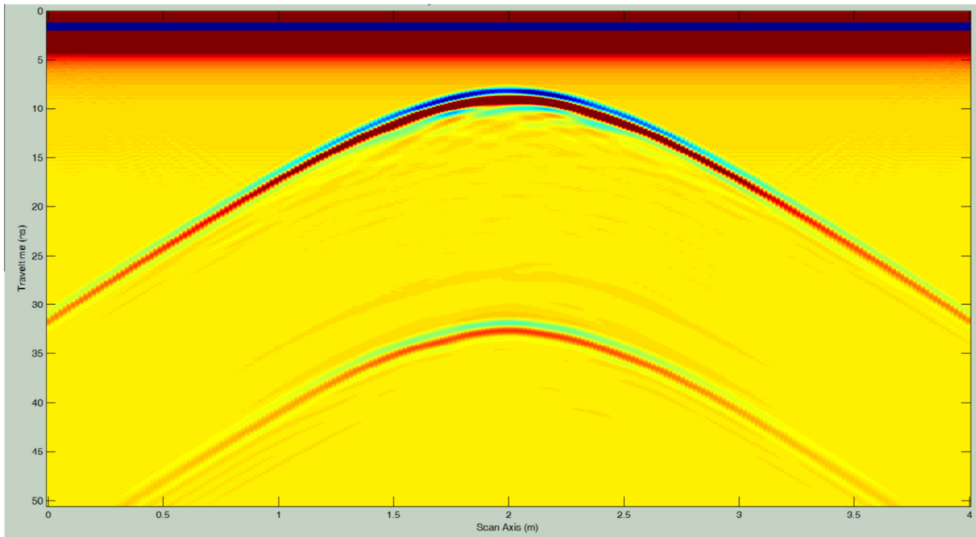

Figure 16 Synthetic of radar section due to conductive circle within resistive background.

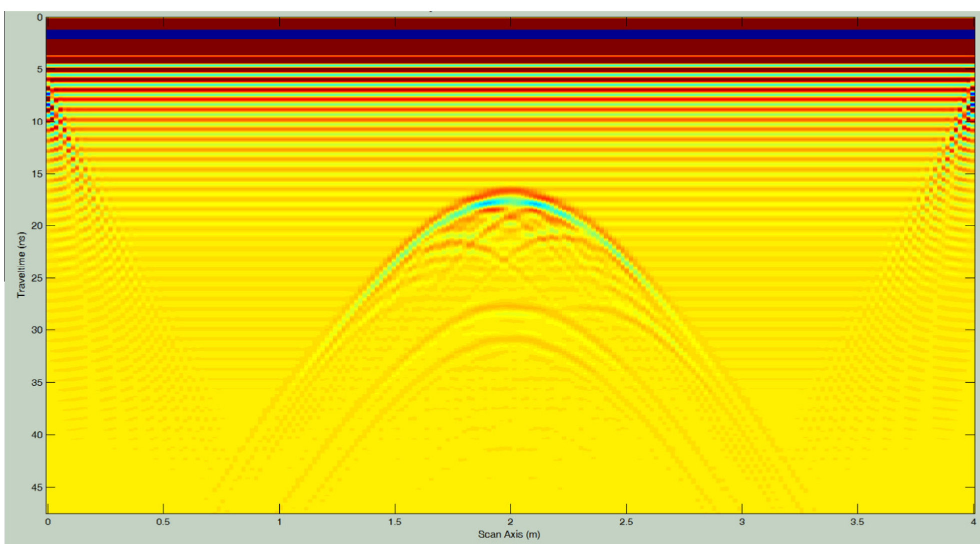

Figure 17 Synthetic of radar section due to resistive circle within conductive background.

6. Results and conclusions

The walls of RADWAN Bench were scanned applying GPR technology. The achieved penetration depth was about 1.5 m (*the word depth implies the distance beyond the wall surface*). From this study, the following remarks could be highlighted:

- The 3 GPR profiles of the western wall show heterogeneous sub-wall materials which penetrated by some fractures as shown in Fig. 6.
- By moving to the southern wall, 7 GPR profiles were conducted. The horizontal profiles have shown a remarkable anomaly which could be attributed to hidden object or material, pillar or deficient earlier restoration (Figs. 9 and 10). Also, existence of heterogeneous medium and fractures was noticed (Figs. 7 and 8).
- Moving to the eastern wall, 7 GPR profiles were carried out and they have shown a transition from heterogeneous medium to homogeneous medium which reflects a change in the materials used in the construction or restoration of this wall. The GPR profile (P17H), shown in Fig. 12, at the bottom of this wall shows a very highly conductive medium which indicates rising in the humidity or wetness.
- Modeling for suggested physical conditions has generated a remarkable similarity between the result of simulation "2" and the real measured GPR data. That implies the presence of resistive object (pillar, deficient of earlier restoration materials, etc.) within the conductive materials of southern wall.

7. Recommendations

The following procedures could be recommended:

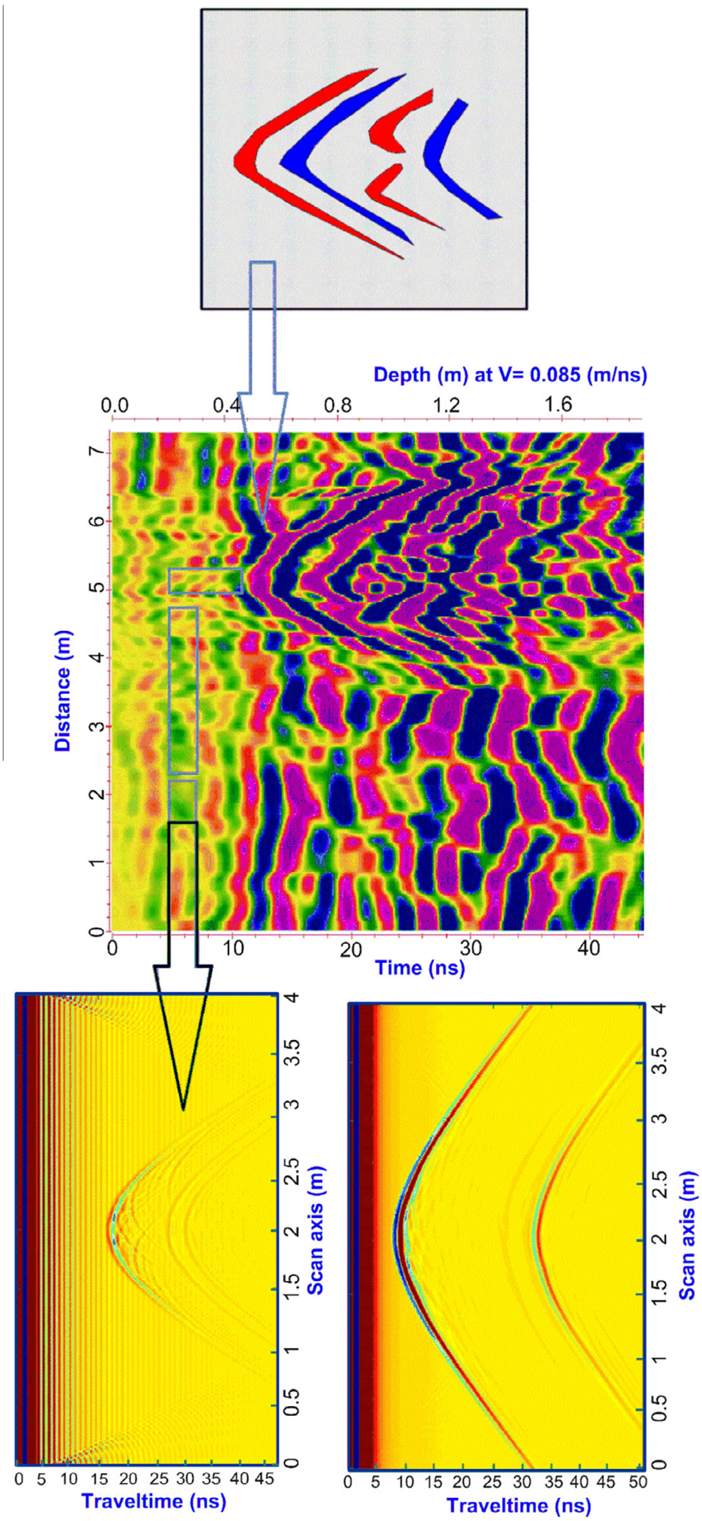

Figure 18 Comparison between the simulation results and the real measured data.

- Inspection of the anomaly which was delineated in the southern wall to find out its actual nature.
- Carrying out a swift restoration for the remnants of the mosaic walls and applying filling processes with proper materials to the delineated fractures.
- Applying a general restoration plan for the whole building.
- Considering the hydrogeological conditions of the sub-soil by applying an appropriate drainage system around the building.

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