The Use of Ground Penetrating Radar for the Detection and Study of a Buried Marble and in Situ Location of Possible Cracks

Ahmed Faize*, Abdellah Driouach*
*Department of Electromagnetism, University of Tetouan Morocco

ABSTRACT

This work described the use of two methods to detect possible abnormalities, debris and cracks inside block of marble. The first method was based on the direct detection of block of marble buried at depth of 0.2 m using Ground Penetrating Radar (GPR). The second method was based on the use of simulation software named GprMax2D for the same block but at depth of 0.5 m. Our results showed that GPR technology combined with adequate simulation software may be used in the field of exploitation of marble in specialized careers. Indeed, they allow in situ distinguishing between usable blocks of marble with higher quality and blocks with fractures or leftover debris in their interior.

Keywords - **Ground Penetrating Radar; Simulation; Marble**

I. INTRODUCTION

Ground penetrating radar (GPR) is a similar technique to the seismic imagery reflection [1]. It uses electromagnetic waves that propagate and refract in heterogeneous medium in order to scan, to localize and to identify quantitative variations within electric and magnetic proprieties of the soil. GPR frequencies usually range from 10 MHz to 2.6 GHz. When using lower frequency antenna (between 10 and 100 MHz) investigated depth will be higher (more than 10 m), however resolution remains lower [2].

The treatment of geophysical data is based on numeric modeling of signals captured by the radar. Within electromagnetic field numeric modeling appeared at the beginning of the seventies [3] and coincided with the introduction of powerful and accessible microprocessors that allow realization of personal calculation within a short time [4]. It is possible to model the physical proprieties implicated in any geophysical technique by using either forward modeling or inverse modeling. Forward modeling takes as model subsoil that includes all of its appropriate physical proprieties and uses theoretical equations in order to simulate the response of the receiver. This, in turn, will determine a given technique to measure through the model. However, reverse modeling uses data collected from the field in order to create a model of subsoil that will fit better with the original data. To obtain reliable data, a number of measures and data processing must be performed. Forward modeling allows us to experiment with and predict the way in which variations in subsurface material properties (and the related variation in dielectric properties) are captured in GPR data.

GPR is used for the exploration of the subsoil in several research fields such as the detection of landmines [5], geology [6], civil engineering [7], glaciology [8, 9] and archeology [10]. It was also successfully applied to 2D imaging of cracks and fractures in resistive soils such as gneiss [11].

Elsewhere, the use of GPR has been suggested for the exploration of some careers of granite [12]. GPR has been previously used to map fractures in non buried marble quarry [13, 14]. However, to our knowledge, such work has never been done on buried marble.

In this work we extend the use of GPR for the detection a buried blocks of marble. In fact, the marble may present some defects such as cracks and non desired internal breaks, resulting in debris of marble or plaque of lower quality.

The objective of this work is i) to try to detect a bloc of marble that was buried by extrapolating structural data obtained from the surface of bloc of marble, and ii) to detect the depth and the continuity of cracks within this bloc. To do so, we, first, carried out a GPR survey on buried real bloc of marble, followed by a simulation of GPR signals on the some bloc buried inside a dielectric medium, which is a simulated soil ($\varepsilon_r = 3, \sigma = 0.0001\, S/m$). The simulation is performed using GprMax software, whose calculations are based on the finite difference time domain (FDTD) [15].

II. OPERATING PRINCIPLE OF THE GPR

GPR is a nondestructive method that has been proved for internal imaging of several types of geological materials such as granite and engineered materials such as concrete construction and other buried structures (pipes, cables ...). The signal can penetrate into the soil and into material buried within the soil, allowing its detection as well as its depth below the ground surface.

The operating principles of various existing GPR radar are based on the same principle: a transmitting antenna is placed in contact with the ground, emitting short pulses towards the ground (Figure 1 (b) Tx). The electromagnetic wave generated propagates inside the ground that is considered as a dielectric medium. If an obstacle (Marble in our case) is encountered, a part of the signal emitted by the antenna of GPR returns to the soil surface (reflected wave) and then detected by the receiving antenna (Figure 1 (b) Rx). This recovered wave reflects a trace of subsoil at a specific point and at given time. As the user moves the GPR radar above the studied field, new signals are transmitted and reflected signals are again recovered at the receiving antenna. This process (sending and receiving generated signals) leads to the acquisition of a set of traces of soil, as numerical data, following a straight prospecting direction thereby establishing what it is called a radargram or a B-scan (Figure 1 (c)) of the studied medium. The treatment of the data set is provided by specialized software that allows the obtaining of hyperbola (Figure 1 (c)). Note that the hyperbola observed in this figure, is an extremely important index, since it gives, suitable information about localization of buried objects.

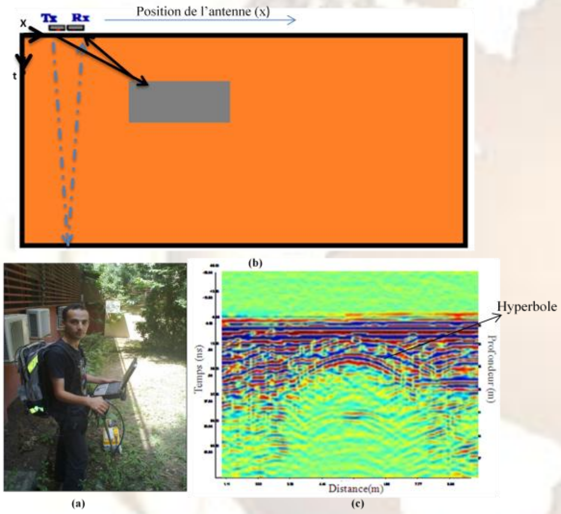

Fig.1: Schematic explanation of the principle of the GPR.

Before interpretation, GPR processing filters were used in order to reduce clutter or any unwanted noise in the raw-data, to enhance extraction of information from received signals and to produce an image of the subsurface with all the features and/or targets of interest, which makes GPR data interpretation easier. Each radargram was filtered using Reflexw V4.5.0 software [16] by applying the processing sequences described below.

1. Dewow filtering (1.2 ns)
2. Bandpass frequency (380/700/4600/5200)
3. Energy decay (0.45)
4. Background removal based on all traces

III. RESULT

A. Experimental part

The blocks of marble used, has for dimension: 1.3 m length and 1 m width (Fig. 2). This block is buried at a depth of 0.2 m. For measurements, 24 profiles of 1 m of length (in the x direction), 30 profiles of 1.4 m of length (y direction) and 0.2 m spacing between two profiles, were taken. Each emission and reflection signal is recorded during a period of 32 ns.

The position of the block of the marble is revealed, with a precision, by the radargram obtained by the GPR (Fig. 3).A radargram (Fig.3 and Fig.4) is typically carried out using the displacement of a 2.3 GHz antenna. Arrows numbered 1, in Figure 2, indicate the position of cracks in the studied marble block. The pseudo-horizontal events seen in figure 3 indicate the positions of upper and lower edges of the block (The arrows number 2). We observed a difference of signal amplitudes, given by the GPR. This difference is due to the variation of relative permittivity values. The hyperbolas indicated by arrow 3 in Figure 4 show the diffraction of the incident waves on the corners of blocks of marble. These waves were diffracted by constructive interference, giving rise to two diffraction hyperbolas (commented on above) in each of the horizontal edges of the rectangular surface. The discontinuity observed in the upper of block, indicates the presence of breaks at this level (Fig. 4, arrow 4).

Fig.2: Photo of block of marble that will be buried and studied by the GPR

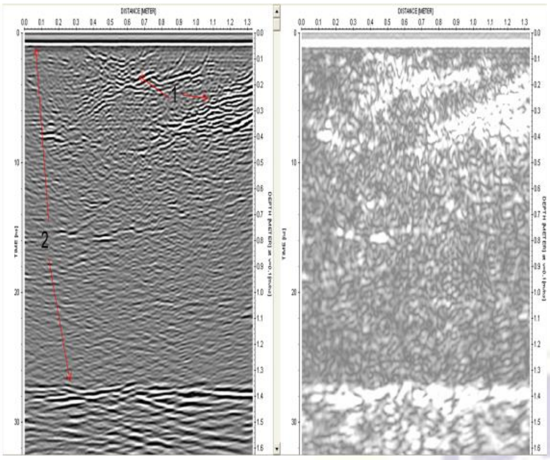

Fig.3: Radargram of block of marble in line 10 along the x axis

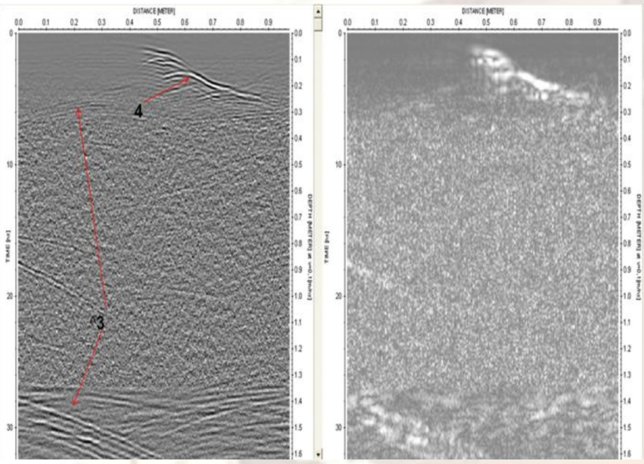

Fig.4: Radargram of block of marble in line 2 along the y axis

A. Treatment by GprMax

Figure 5 (a) shows a geometric model of marble used for simulation of radar signals reflected by a simulator (GprMax). This block, with dielectric characteristic $(\varepsilon_r = 5.5, \sigma = 0.0255\, S/m)$, is buried, this time at 0.5 m depth. The emission and reflection of the simulated signal is recorded for period of time of 35 ns using an excitation source of Ricker type for a central frequency of 2.3 GHz. This frequency corresponds to wave length directed in the simulated medium [15]: $\lambda = \frac{c}{3f\sqrt{\varepsilon_r}} = \frac{3.10^8}{6.9.10^9.\sqrt{3}} = 0.025$ m. The spatial increment: $\Delta x = \Delta y = \Delta l = \frac{\lambda}{10} = 0.0025$ m. The total simulated length is 2.0 m x 1.6 m, which corresponds to 800 x 640 cells ((2.0/Δx) x (1.6/Δx)).

Figure 5 (b) shows the simulation result of this model. In this figure different hyperbolas can be distinguished: those noted 1, denote the depth position of the upper edge of the block, those numbered 2, indicate the position of cracks. Figure 5 (b) shows a sub horizontal crack numbered 3.

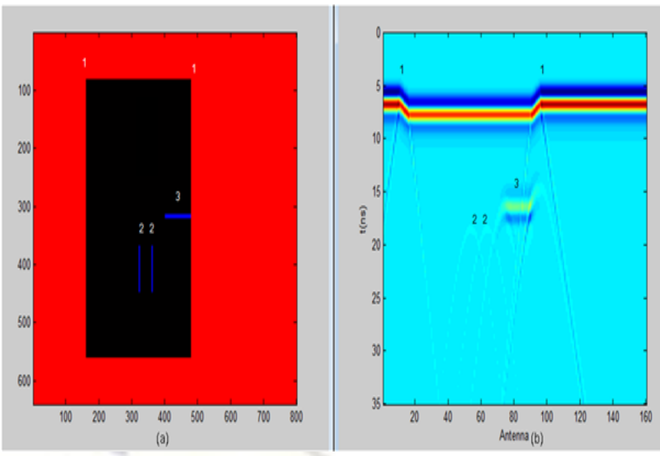

Fig.5: B scan of GPR signals obtained using GprMax2D for model composed of Marble $(\boldsymbol{\varepsilon_r = 5.5, \sigma = 0.0255\, S/m})$

IV. CONCLUSION

Using GPR technology combined with adequate simulation software is very useful in the field of exploitation of marble in specialized careers. Indeed, it allows obtaining a detailed picture of the subsoil, allowing to distinguish, in a quick, cheap and effective manner, the blocks of marble with higher quality and without defects (therefore usable) from blocks which fractures or rests of fragments in their inside.

REFERENCES

[1] Jan C. Francké., 2003. Applications of GPR For Surface Mining. 2nd International Workshop on Advanced GPR, 14-16 May, Dellft, The Netherlands.

[2] Noon, D., A., Stickley G., F., and Longstaff, D., 1998. A frequency-independent characterization of GPR penetration and resolution performance, Journal of Applied Geophysics, 40, 127- 137.

[3] Chen, H.W., and Tai-Min H., 1998. "Finite Difference Time Domain Simulation of GPR Data". Journal of Applied Geophysics, 40, 139-163.

[4] Ceruzzi Paule E., 1998 A History of Modern Computing History of Computing. MIT Press, Cambridge, Massachusetts.

[5] M, Sato, Y, Hamada, X, Feng, F. Kong, Z. Zeng and G. Fang. 2004. GPR using an array antenna for landmine detection. Near Surface Geophysics. 3-9.

[6] Gu, Z.W., 1994. The Application of Ground Penetrating Radar to Geological Investigation on Ground in Cold Regions, Journal of Glaciology and Geocryology, 16, 283-289.

[7] Ulriksen, C.P.F., 1982, Application of impulse radar to civil engineering. PhD Thesis, Lund University of Technology, Lund, Sweden.

[8] Navarro, F. J., Lapazaran, J. J., Machio, F. Martin C., and Otero, J., 2009. On the Use of GPR Energetic Reflection coefficients in Glaciological Applications, Geophysical Research, 11 EGU2009-9804, EGU General Assembly.

[9] Woodward, J., and Burke, M.J. 2007. Applications of Ground-Penetrating Radar to Glacial and Frozen Materials, Journal of environmental and engineering geophysics, 12, 69-85, March 2007.

[10] Leckebusch, J. 2003. Ground-Penetrating Radar: A Modern Three-dimensional Prospection Method. Archaeological Prospection, 10, 213-240.

[11] Grasmueck, M. 1996. 3-D Ground-penetrating radar applied to fracture imaging in gneiss: Geophysics, 61, 1050-1064.

[12] Xiaojian, Y., and Haizhong, Y., 1997. The Applications of GPR to Civil Engineering in China, Shenzhen Dasheng Advanced Science & Technique Engineering Co., Ltd.

[13] Sambuelli, L., and Calzoni, C., 2010. Estimation of thin fracture aperture in a marble block by GPR sounding. Bollettino di Geophysica Teorica e Applicata, 51, 239-252.

[14] Capizzi, P., and Cosentino, P.L., 2011. Electromagnetic and ultrasonic investigations on a roman marble block. Journal of Geophysics and Engineering. 8, S117, doi: 10.1088/1742-2132/8/3S11.

[15] Giannopoulos A, “GprMax2D\3D, User’s Guide” 2005:HYPERLINK http://www.gprmax.org"http://www.gprmax.org

[16] K.J. Sandmeier, Reflexw Version 4.5. Licence number 597 Licenced to centro tecnologico del Marmol y la Piedra Spain.