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The Use of Ground Penetrating Radar to Assess the Concrete

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Abstract

Ground Penetration Radar (GPR) is a modern and promising geophysical technique for near-subsurface exploring and observing because of its characteristic working scheme (instantaneous underground radargram displaying and subsurface features preserving during the detection tests). In this technique a very high and/ or ultra-high electromagnetic radiation frequencies were utilized to be transmitted to the targeted underground area, then the reflected ones which occur because of the sudden changes in the medium electric properties or texture would be recorded and processed to achieve the final GPR radargram.

The main goal of this study is to find out the GPR radiation extension which is suitable for concrete or rebar tiling identifying and measuring in addition to discover the cracks in the concrete walls, the minor goal is studying the effect of GPR device parameters changing on produced radar imagery and identifying the most effective parameter settings for concrete buildings cornerstone locating and wall cracks detection. These parameters are (radiation phase velocity m/sec., frequency coding or sampling, time windows in nano sec., and background removal for unwanted layers removing). The study executed using 1000 MHz antenna on 12 paths and clearly showed that the most important filter/ and or parameter in concrete sites locating and mapping is the "background removal" filter, while other parameters were image improvement ones or sometimes had a negative role in detection procedure.

Keywords: Ground Penetrating Radar GPR, Rebar Slab, Void, Concrete.

استخدام رادار الاختراق الأرضي لتقييم الخرسانة

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الخلاصة

رادار الاختراق الأرضي (GPR) هي تقنية التصوير الجيوفيزيائية المستخدمة لاستكشاف باطن الأرض والرصد، ويستخدم على نطاق واسع في الهندسة والجيولوجيا والتعدين والمجتمعات الأثرية. يوفر رادار الاختراق الأرضي تقنية مثالية لتقييم ملموس في التصوير تحت سطح الأرض ويعتبر أكثر أمنا من اي طريقة أخرى مثل تكنولوجيا الأشعة السينية. ساهمت التحسينات الأخيرة في الأجهزة (على وجه الخصوص البرمجيات) في توسيع المعرفة بسرعة وسهولة الاستخدام من هذه التقنية.

الهدف من الدراسة هو معرفة مدى فعالية تقنية رادار الاختراق الارضي في تحديد و تقدير سمك طبقات التبليط الخرساني والشقوق في الكونكريت والفجوات ورسم حديد التسليح والكابلات ، والحزم الصف، قنوات، الفراغات , ودراسة العوامل المؤثرة على عملية المسح الراداري. و تحديد مواقع الاجسام المدفونة المعدنية

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وغير المعدنية. نفذت هذه الدراسة من خلال اثنى عشر مساراً. بعد ضبط اعدادات المعلمات(Parameter Setting) المشغلة لجهاز (GPR) المناسبة لنوعية التربة للحصول على ادق عمق ممكن, العوامل هي السرعة المقاسة متر/ ثانية , زمن المقاسة بالنانوثانية, تردد الترميز (Sampling frequency). باستخدام هوائي (1000 ميكاهرتز). عولجت المقاطع الرادارية من خلال تطبيق عدة انواع من المرشحات لمعالجة الأشارة المستلمة وأزالة الترددات الغير مرغوبة منها. تبين ان مرشح (ازالة الخلفية) هو المرشح الاهم في المعالجه اذ أظهر الشذوذ بشكل واضح, بينما بقية المرشحات كانت اما مساعدة لهذا المرشح أو ذات تأثير سلبي على المقاطع الرادارية.

Introduction

Ground Penetration Radar (GPR) technology represents an advancement in shallow subsurface exploration since it detects changes (even small ones) in electric, magnetic, texture, or moisture properties of the underground containment and provides radargram profile with accurate and high-resolution information[1, 2]. The GPR transmits energy to the earth in short interval pulses in between one to twenty seconds. This energy propagates with phase velocity controlled by the dielectric constant of the subsurface media, when this energy falls on two themes interface, some of it reflects back to the opposite direction. The amplitude of the reflected energy depends on the dielectric constant value [3]. When the radar wave's encounter an interface between two different materials (layers) with different refraction indices, some of the transmitted wave energy is reflected back to the surface. A receiver picks up these reflections as analog signals. The input analog signals are digitized and quantified using an analogue-to-digital converter in order to be ready for processing in the computer to create an image called the radargram (Figure-1) [4].

Data Interpretation

The velocity value of electromagnetic waves in materials is an essential quantity in the explanation of GPR method. The importance of the velocity value lies in its use for conversion of the profile from two-way time travel scale to depth scale [4].In concrete, for example, change in two-way travel time within this medium suggests the existence of variable concrete thicknesses. If the two-way travel time is short this will indicate a thinner concrete section. But a thicker concrete section would result in longer two-way travel time. In fact, hasty analysis of the two-way travel times is necessary for grade beam detection in slab-on- grade foundation systems[5]. If grade beam location is relevant information in the structural evaluation of slab-on-grade systems, a sharp rise in the two - way travel time would be more appropriate within the radargram. Also, two-way travel time can be used in converting time domain radargram in models to distance domain radargram. In a given medium, the two-way travel time through that model is usually recorded at pre-determined depth location; this can be done by using the coving procedure. In this case, calculation of propagation velocity (v_m), depends on the travel time (t_r) and the medium depth (d_r) at a given location will be dependent on the simple formula (2).

In a given medium, in order to be able to obtain the relative dielectric constant (ε_r) equations (1and 2) may be used. It is a very well-known fact that velocity analysis is the best appropriate method used to convert radargram from the time domain to the distance domain [6]. The knowledge of medium dielectric constant value is essential for accurate target depth identifying according to the following equations [7]:

$$v_m = \frac{c}{\sqrt{\varepsilon_r}} \qquad \text{……......………………….. (1)}$$

Where:
c is the speed of the light in a space, ε_r is a dielectric constant of the medium, v_m is a radar wave speed.

$$d_r = \frac{v_m t_r}{2} \qquad \text{…………………….. (2)}$$

Where ;
d_r is the depth of the body, v_m is a radar wave speed; t_r is the travelling time of the radar wave While the penetrating depth is controlled by two factors; medium dielectric constant and energy wave frequency. By fixing the frequency (utilizing one antenna). The wave penetration depth is determined according to follow relation [5]:

$$D = \frac{35}{\sigma} \qquad \text{.........................} \quad (3)$$

Where
D is a penetration depth (meter); σ is an electric conductivity of the mediums, Table-1 illustrated the materials propagation characteristics.

Table 1-Illustrates Materials propagation characteristics [8]

Material	*Dielectric Constant*(d_r)$^{\varepsilon}$	*Propagation Velocity*(V_m) *m/n.s*
Air	1	0.30
Fresh water	81	0.033
Salt water	80	0.01
Ice	3-4	0.16
Wet clay	33	0.052
Dry sand	4-6	0.15-0.12
Wet sand	30	0.055
Shales and Clays	5-20	0.08
Limestone	4-8	0.12
Granite	9	0.10
Dry salt	5-6	0.13
sandstone	3-4	0.15
Rocks	4-12	0.15-0.078
Dry clay	8	0.11
Asphalt	3-6	0.17-0.12
concrete	9-12	0.10-0.087

The receiver acquire reflected electromagnetic energy in analog format and convert it to digital one after quantization scheme to be ready for signal processing in (data processing unit), then after the profile image is displayed by collecting enhanced radar traces [6]. This can be shown in Figure-1, as follows:

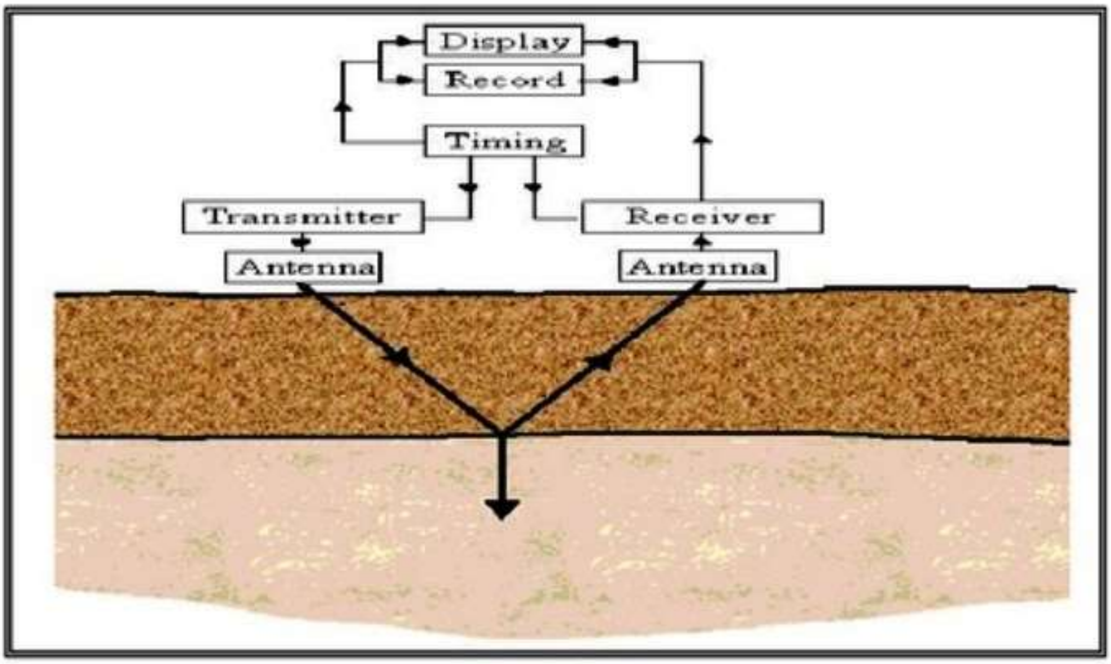

Figure 1-The GPR working mechanism illustration [4]

Dielectric constant or (the relative electric permittivity) of the medium is the most effective parameter on radar signal velocity and reflection amplitude, Figure-2 illustrates the relation between it and signal phase velocity for some principal materials [5].

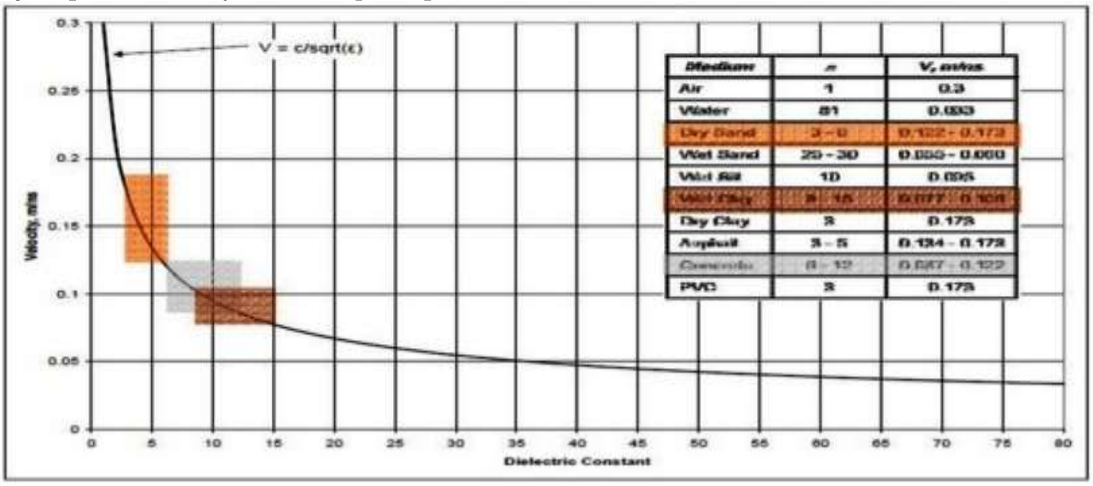

Figure 2-The relation between relative permittivity and GPR wave velocity for some principal materials [5].

Hyperbolic Reflection

The transmitting antenna energy radiation into the subsurface normally takes a conical shape. The con angle around the cone apex at the center of the antenna may vary between 60 o to 90 o. This pattern of energy transmission beam causes reflections of hyperbolic shapes when the antenna crosses linear targets such as steel reinforcements or pipes positioned at right angles to the antenna path. The antenna broad beam transmission pattern creating the hyperbola shapes allows the radar antenna to detect the target directly above it, as well as before and after the target. When the antenna is becoming closer to the target, the left leg of the hyperbola will be formed. The top target is represented by the apex of the hyperbola. When the antenna stars to withdraw from the target the right leg of the hyperbola will be formed. Figures (4and5) show the hyperbolic shapes of a few targets (radar) in the time domain radrgram section. The hyperbola shape is a function of scan spacing. The scan spacing is controlled by the radar system settings and dielectric medium that embeds the target [9]. Higher values of dielectric constant results in lower propagation velocity and more focused,i.e, narrower, energy transmission cone into the ground. This means that a target within a higher relative dielectric constant medium will produce thinner hyperbolas and vice versa. Since the hyperbola shape is a function of the dielectric medium where the target is embedded, the propagation velocity, V, may be determined based on the geometric scaling techniques. The geometric scaling techniques required the conversion of GPR data from a time domain radargram image to a "real world" distance domain radargram image of the subsurface [10].

Structurally Suspended Concrete Floor Slab

Concrete evaluation study of a foundation slab and determine the presence or lack underlying voids require the use of GPR. Figures-(5, 6 and 7) show a time-domain radargram across port of the suspended slab with varying interfaces. The scan for diagnosis of the concrete interfaces. Requires the signal polarity, two-way travel time and reflection strength characteristics to be known the white first third of the scan shows a strong negative reflection and the black strong positive reflection, which indicates of an air-filled void underneath the concrete slab [11].

The Field Work

Many conducted radar surveys had occurred in the interest area in order to indicate the optimum radar signal that penetrates the land of interest. This work passes the following transactions:

1. Antenna mode: 1000 MHz shielded
2. Number of samples: 512
3. Time window: 46 nano seconds
4. Antenna separation: 0.09 meter

5. Sampling frequency: 1189 MHz
6. Trace interval: 0.05
7. Number of stacks: 8

These transactions were suitable for the device operation in an optimal situation. There were 10 conducted tracks perpendicular to the rebar slab and concrete bottom by utilizing the above antenna, this cover a region of (14 × 5) m². (Figure -3)

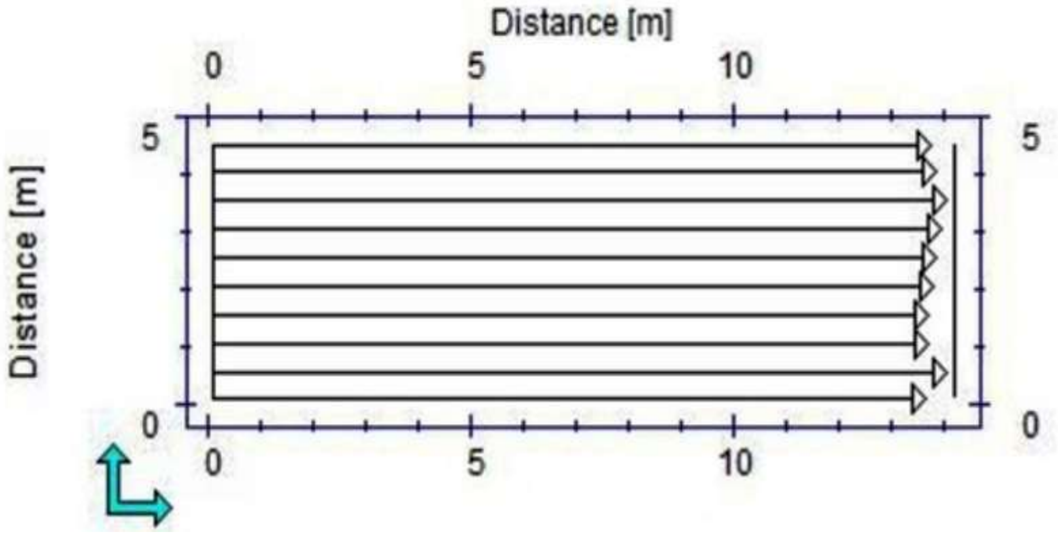

Figure 3-The interest (14 × 5) m² area GPR survey tracks.

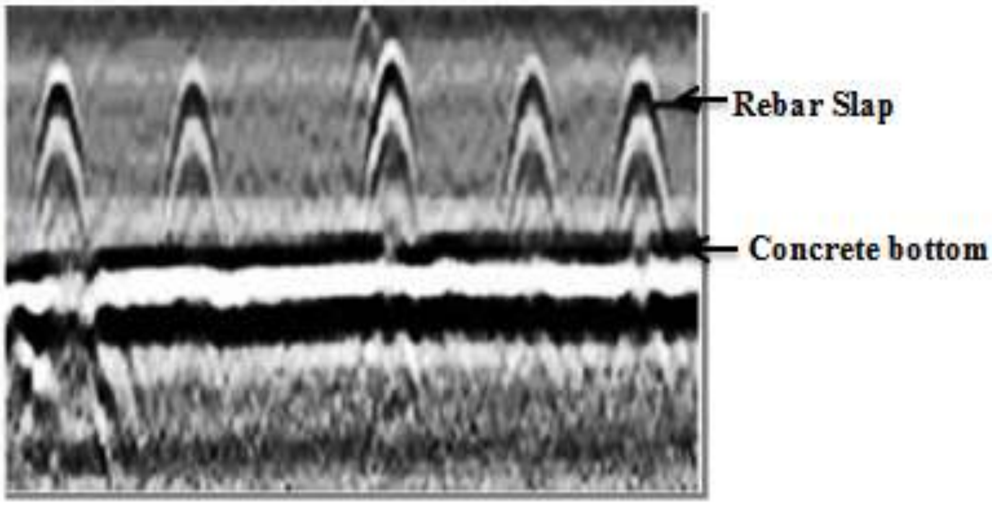

Figure 4-The radargram profile of deeply buried rebar slab and concrete bottom.

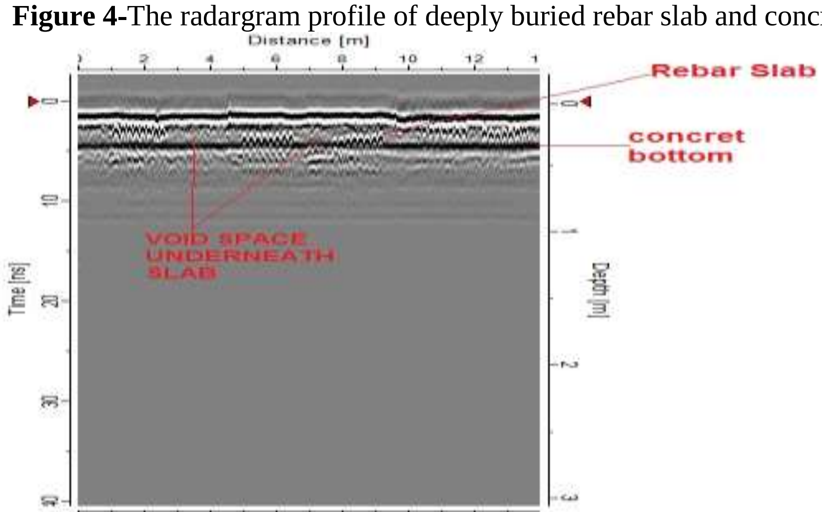

Figure 5-This shows a reflection of the deeply buried void slab.

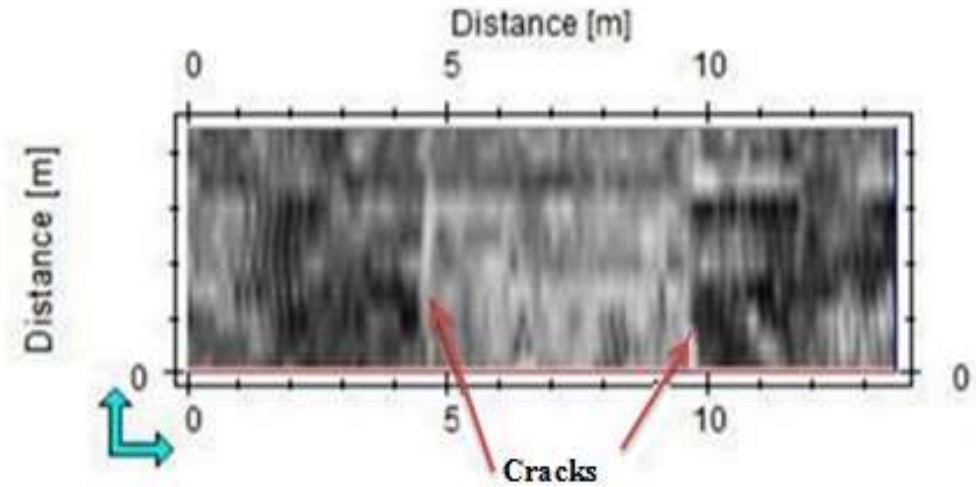

Figure 6-The top view radar imagery of the rebar slab illustrating the cracks detection process in between the slabs.

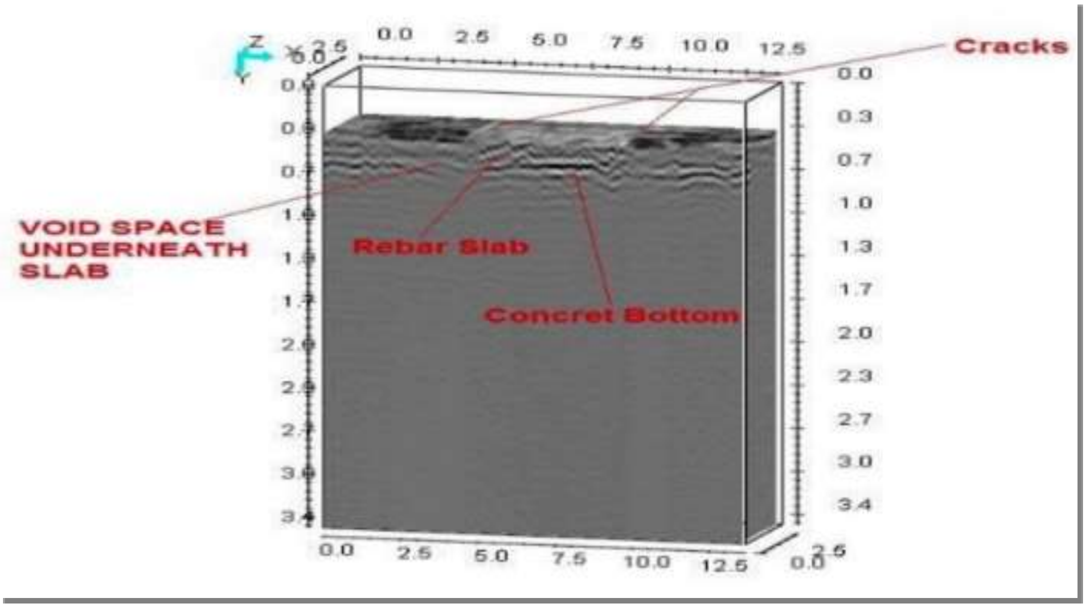

Figure 7-Tomography 3D image of the concrete pouring.

Conclusions

In this study an interest region of 70 m² was selected since it includes a buried concrete pouring covered by some separated rebar slabs, the Ground Penetration Radar (GPR) device with 1000MHz antenna chosen to find optimum radar extensions for this case and similar ones detection, additional technology was used to increase accuracy which was three dimensional tomography. It has been found that 46 nano seconds time window, 0.09 m Antenna separation, 1189 MHz Sampling frequency, 0.05 Trace intervals, and 8 numbers of stacks were the best parameters for cracked concrete detection.

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