Evaluation and Analysis of the Principle of Electromagnetic Wave Dispersion to Define the layers of Soil and Buried Objects

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Abstract

Ground penetrating radar (GPR) is a geophysical technology primarily designed for underground scanning. Provides a 2D and 3D image to identify buried objects. The detection of the soil layer is complicated by the multiple reflections and high attenuation of electromagnetic waves propagating in the soil. This research has been conducted by choosing different sites. Three antennas (250, 500 and1000) MHZ were used to achieve the survey process, many parameters such as (Point Intervals, Sampling Frequency and Electromagnetic Velocity) were used to get the best data. After data acquisition, the recognition and interpretation of each resultant image has been performed using different image processing software such as (RAD Explorer and Ground Vision2). Where the response and the shape of each buried object can be shown by implementing different filters with the most effective ones (Background Removal and Band Pass) as well as the soil and the buried objects layers have been obtained using GPR program.

Keywords: Evaluation, GPR, Electromagnetic Wave and Soil layers.

تقييم وتحليل استخدام مبدأ تشتت الموجات الكهرومغناطيسية لتحديد طبقات التربة والأجسام المدفونة

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بغداد- العراق

الخلاصة

رادار الاختراق الأرضي عبارة عن تقنية جيوفيزيائية مصممة أساسًا للفحص تحت الأرض. يوفر صورة ثنائية وثلاثية الأبعاد لتحديد الأجسام المدفونة. إن اكتشاف طبقات التربة معقد بسبب الانعكاسات المتعددة والتوهين العالي للموجات الكهرومغناطيسية التي تنتشر في التربة. اجري هذا البحث عن طريق اختيار مواقع مختلفة. تم استخدام ثلاث هوائيات بقوة (250، 500 و1000) ميجاهرتز لإنجاز عملية المسح. تم استخدام العديد من المعلمات مثل (تكرار أخذ العينات، فواصل النقاط والسرعة الكهرومغناطيسية) للحصول على أفضل البيانات. بعد الحصول على البيانات، اظهرت نتائج البحث التعرف على كل صورة ناتجة وتفسيرها باستخدام برامج معالجة الصور المختلفة مثل (RAD Explorer و Ground Vision2). اذ يمكن إظهار استجابة وشكل كل كائن مدفون من خلال تنفيذ مرشحات مختلفة مع أكثرها فاعلية (حذف الخلفية وتمرير النطاق). وكذلك تم الحصول على طبقات التربة.

الكلمات المفتاحية: تقييم، رادار الاختراق الارضي، الموجات الكهرومغناطيسية وطبقات التربة.

Introduction

Ground-penetrating radar (GPR) has recently gained widespread acceptance in the community as a method that can quickly and accurately locate buried artifacts and important layers below the near surface, by collecting large amounts of reflectance data from many cross-sections within grids, thus producing massive 3-dimensional databases. (Conyers, 2009). (GPR) is a remote sensing and geophysical method that uses radar pulses to image the subsurface. This nondestructive method uses electromagnetic radiation in the microwave band (UHF/VHF Frequencies) of the radio spectrum based on the emission of a very short electromagnetic pulse (1-20 ns) in the frequency band of 10 MHz -2.5 GHz by moving the antennae over the ground, an image of the shallow subsurface under the displacement line is obtained. These images called radargrams are XZ graphic representations of the reflections detected. Z axis represents the two-way travel time and X axis represents antennae displacement of the pulse emitted (Annan, 1997) and (Annan and Cosways, 1992).

The main objective of this research is to study the effect of changing the parameters of the ground penetrating radar device on the produced radar images and to determine the most effective parameter settings for detecting buried layers and objects. These parameters are radiation speed, time windows, frequency coding or sampling. Also, the effectiveness of a GPR survey is a function of site conditions, staff experience, and equipment used to interpret the results (Basson, 2000).

Materials and Methods

GPR operates by transmitting short pulses (1-20) ns and high frequency (10-1000) MHz of electromagnetic energy into the ground. The reflected images of these pulses are analyzed using one-dimensional electromagnetic wave propagation theory. Figure (1) illustrates this phenomenon clearly (Kazunori, 2012).

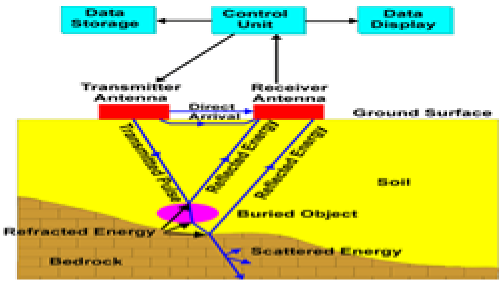

Figure (1) The Block Diagram of a GPR System (Kazunori, 2012).

The pulses are reflected to the antenna with times and amplitudes related to the dielectric constants of the layer's materials. Across the interfaces, so part of the energy is reflected, and part is absorbed, depending on the dielectric contrast of the materials as represented in Table (1) (Faleh, 2018). The difference in media of the underground changes the phase angle and the amplitude of the radar waves which appears as sharp edges on the radar gram, (Daniels, 2000).

Table (1) Dielectric Constants for Typical Pavement Materials.

Material	Dielectric
Air	1
Frozen Soil	4
Dry Sand	4 to 6
Wet Sand	30
Dry Clay	8
Wet Clay	33
Asphalt	3 to 6
Concrete	9 to 12
Water	81
Metal	∞

GPR data consists of a continuous display of the reflected energy in the form of graphics over a specified period of time. This set time interval is the two-way travel time, measured in nanoseconds. The depth of the material the wave penetrates can be determined if the velocity of the electromagnetic energy ( ) through the material is known. Using the dielectric constant of the material, the velocity of the wave can be calculated using the formula. (Hannul, 2008).

$$\upsilon_m = \frac{c}{\mathcal{E}_r} \quad \text{……………………………} (1)$$

Where c is the speed of light in vacuum and $\mathcal{E}_r$ is the dielectric constant of the medium.

Once the speed is known, the depth of a particular object in the image can be calculated by using the formula:

$$d_r = \frac{\upsilon_m t_r}{2} \quad \text{………………………..…… } (2)$$

d_r is the depth, υ_m is the velocity in the medium and t_r is the two-way travel time from the GPR to the object. (Daniels, 2000).

The penetration depths achieved using the GPR depend on the signal frequency and on the nature of the material in which it travels. Higher frequency electromagnetic waves give better resolution but cannot penetrate to deep. Lower frequencies on the other hand penetrate much deeper but provide poorer resolution. The wave will easily penetrate resistive materials and will not heavily penetrate conductive materials. Because of their higher conductivity, dense, moist clays impede the performance of the GPR, and saltwater makes the technique ineffective. Electromagnetic energy, in these frequency ranges, seldom penetrates more that 30m into the surface and, in highly conductive material, may only penetrate a few meters. As shown in the Figure (2) (Salih, 2008).

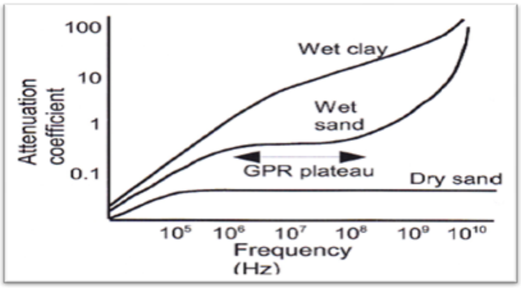

Figure (2) The Attenuation Coefficient of the Radar Wave as a Function to the Frequency into the Wet and Dry Media (Johansson, 2005).

The depth of penetration of the radar wave can be determined in different media by using the relation (Suvarna, 2004):

$$\mathcal{D} = \frac{35}{\sigma} \text{……………………………… } (3)$$

$\mathcal{D}$ is a penetration depth in (Meter); is a penetration depth in (Meter), σ is an electric conductivity of the is an electric conductivity of the mediums.

The Field Work

Ground penetrating radar is a field-testing system that can provide a picture of current road conditions. It uses high-speed data collection, so it requires less traffic control and results in greater security. In order to perform this work properly, the user must have a good understanding to the problem encountered in making subsurface exploration then to get information of soil. Used in radar surveys antennas coated (Shielded) frequency (250, 500, 1000 and 100 MHz) to reveal the layers beneath the ground surface that link to different depths and high accuracy discrimination. Detecting layer separation, determining the depth of the rocks close to the surface, and measuring the thickness of the asphalt. The radar data was processed, and the dimensions of the binary figures were shown by using several filters using the standard Ramac Ground Vision analysis software. The an a carried out field surveys in parallel tracks with the aim of being able to detect changes resulting from the presence of areas (Attenuation) on a frozen lake in Sweden to find the thickness of the frozen layer using an antenna with a frequency of 1000 MHz, as shown in Figure (4). Several surveys were conducted in northern Iraq (Dohuk) using a 500, 250 and 100 MHz antenna. To reveal the layers. As in Figures (5, 6, 7 and 8).

The GPR technique was successful to reveal the layers. However, it has some problems with void detection. Special existing conditions that should be avoided because they may interfere with GPR signal include as shown in the Figure (3).

• High-ground water conditions.

• Standing water.

• Nearby transmission tow.

• Use of cellular phones.

• Metal reinforcement near-surface, or material containing high contents of iron.

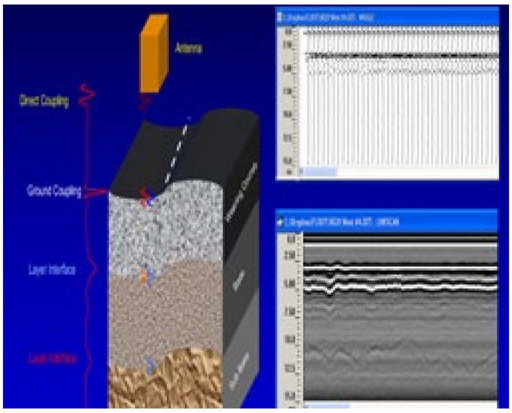

Figure (3) Reflections are Produced when the Pulse Encounters a Material with Different Dielectric Constant (Jorge, 2007).

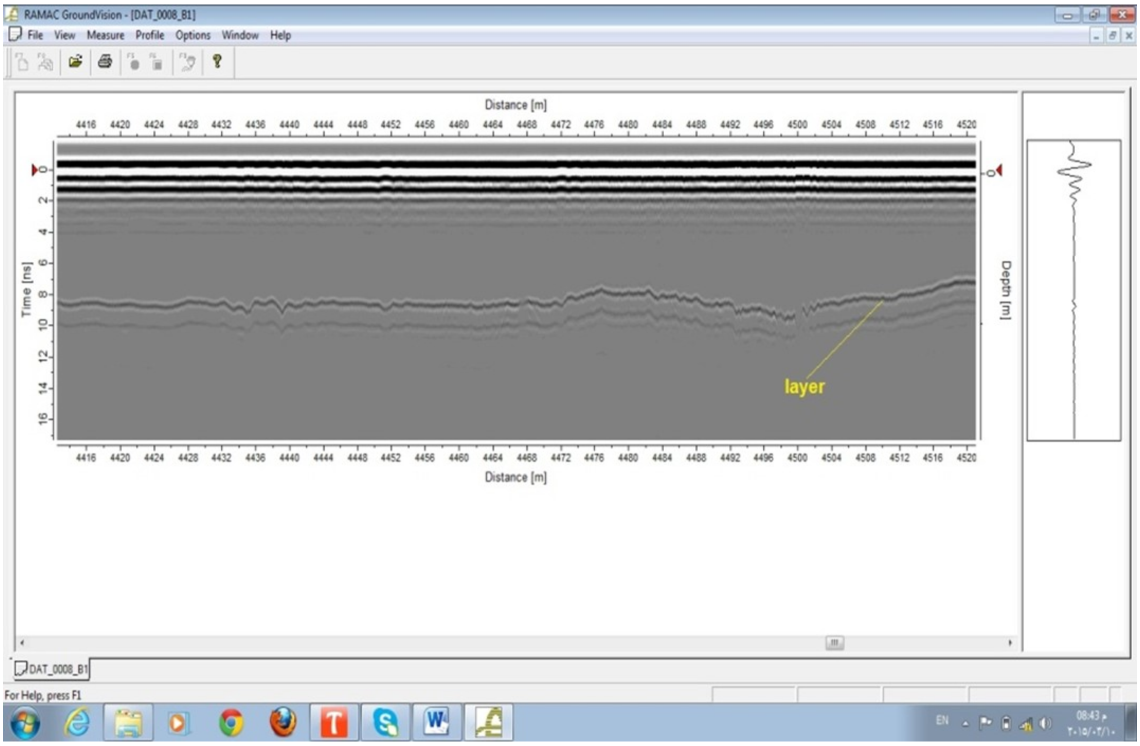

Figure (4) GPR Image was Obtained for 0.6 m Layer Depth Using 1000 MHz Antenna Time Window: 48 Nano Seconds, Sampling Frequency: 1150 MHz and these Parameters were Suitable for Operating the Device in the Optimal Position.

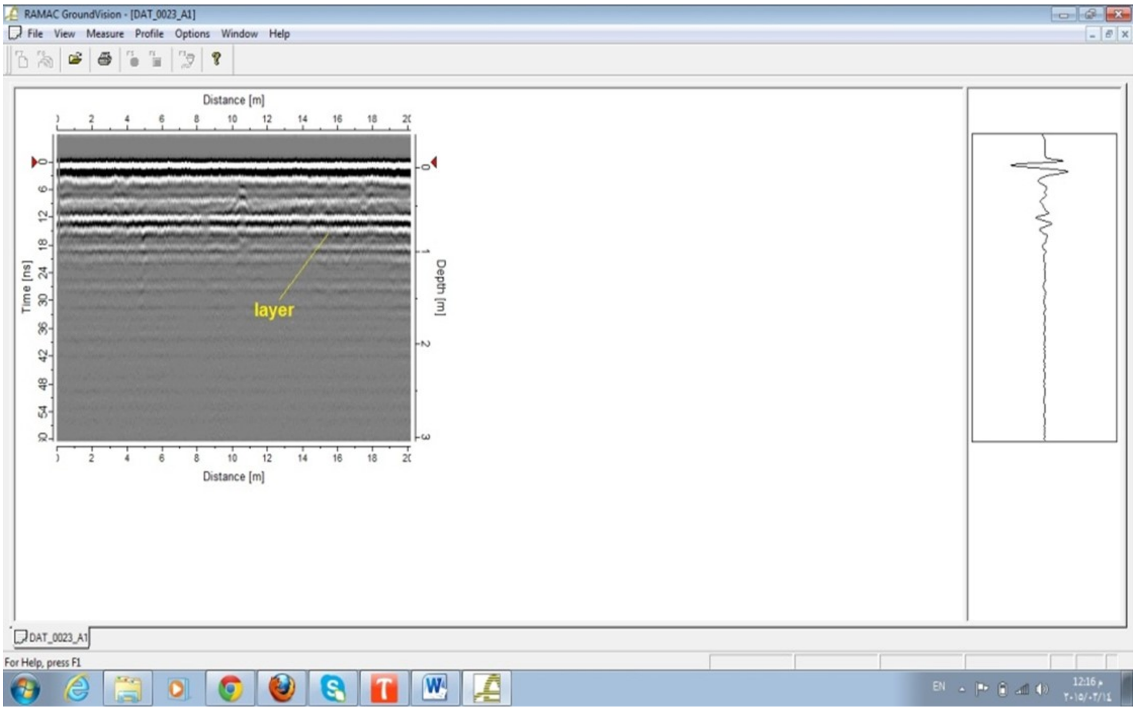

Figure (5) GPR Image was Obtained for 0.8 m Layer Depth Using 500 MHz Antenna. Time Window: 66 Nano Seconds, Sampling Frequency: 5060MHz and these Parameters were Suitable for Operating the Device in the Optimal Position.

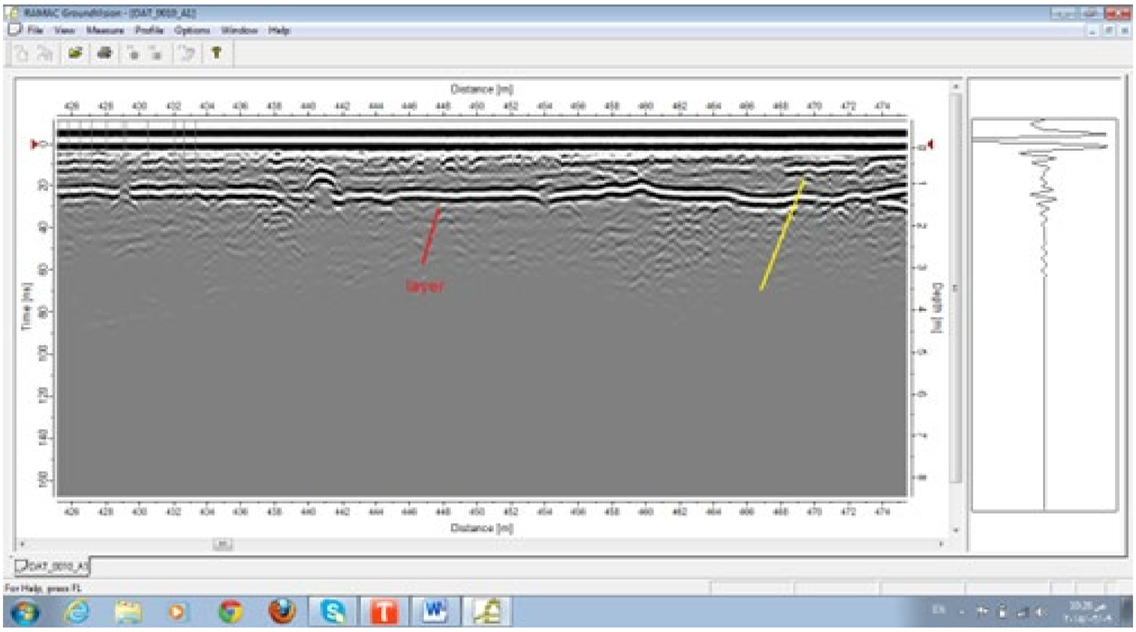

Figure (6) GPR Image was Obtained for 1 m Layer Depth Using 250 MHz Antenna Time Window: 121 Nano Seconds, Sampling Frequency: 2240 MHz and these Parameters were Suitable for Operating the Device in the Optimal Position.

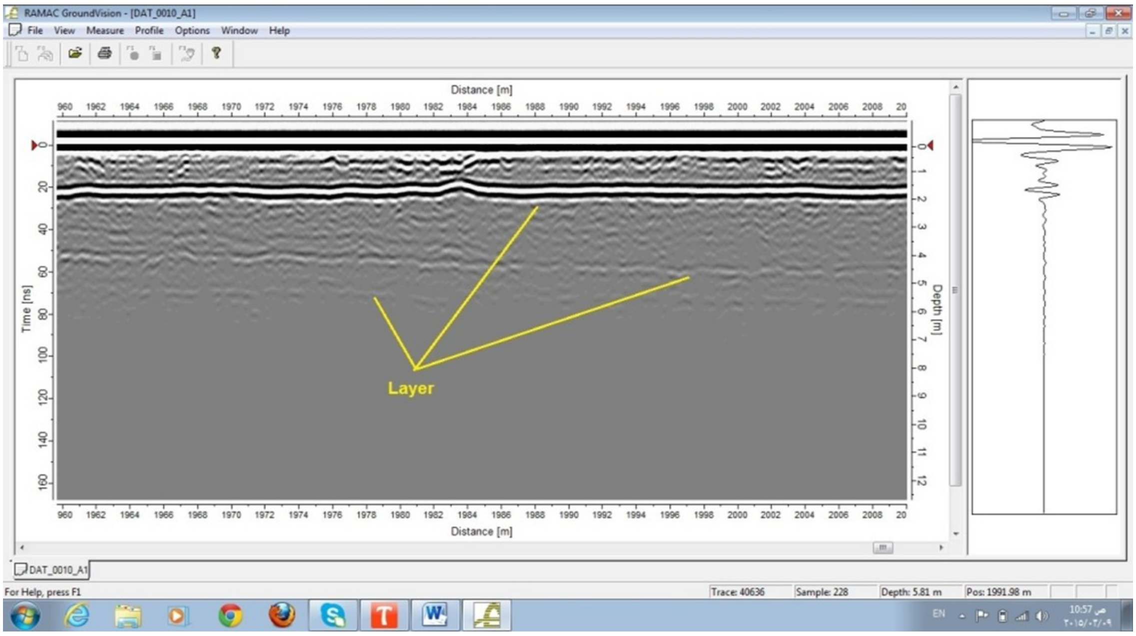

Figure (7) GPR Image was Obtained for 2-5 m Layer Depth Using 250 MHz Antenna. Time Window: 121 Nano Seconds, Sampling Frequency: 2240 MHz and these Parameters were Suitable for Operating the Device in the Optimal Position.

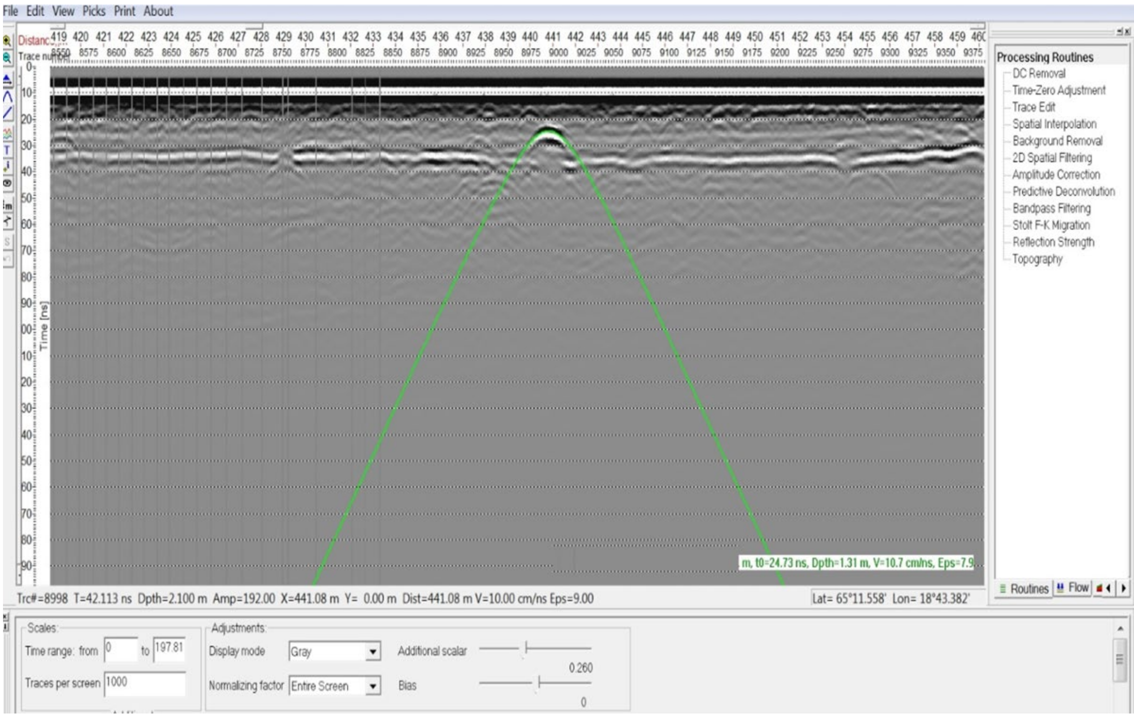

Figure (8) GPR Image was Obtained for 1.31m Layer Depth Using 250 MHz Antenna Time Window: 121Nano Seconds, Sampling Frequency: 2240 MHz and these Parameters were Suitable for Operating the Device in the Optimal Position.

Results and Discussion

The process of detecting layers, where the form of reflected radar waves from the buried material and received by the scanning device can be notice. Each object reflects the wave in different way from other materials, based on the dielectric constant for each object. These received waves have a noise and a distortion due to the overlap between them and the reflected waves from the surrounding soil. So, the data of GPR must be filtered and analysis, the analysis of this data was carried out by software processing such as (Rad Explorer and Ramac Ground Vision) and it uses different filtering techniques and gains to clean noise from the data and enhance certain characteristics of the data. The use of the raw data gain is multiplied to enhance the low amplitude reflections. Signal amplitude usually decreases exponentially with increasing travel. By custom time gain design increases signal strength. The radargrams in this paper are divided into three ranges of the anomalies; the upper part which extends from antenna to surface at depth of ≈ 0.20 m represents the range of the background noise. The range which varies between 0.20 - ≈0.40 m is the range of deformation of the signals. The reasons for that deformation are the soil moistures and the random distribution (Distortion) of the clay bricks on the top roof of the subsurface.

Table (2) Approximate Wave Speed Values for Different Types.

Velocity m/msec	Material
10	Sea Water
33	Fresh Water
130	Salt
160	Ice

Signaling profiles for final processing extending between 0.30 - ≈ 5 m below the surface is a set of targets. as illustrated in Figure (4) which shown the 0.6 m ice thickness using the 1000 MHz and, in the Figure, (5) the thickness layer depth of 0.8 m using the 500 MHz antenna can be seen in the Figures (6, 7 and 8) the thickness layer depth of 1, 2, 5 and 6 m using the 250 MHz antenna illustrated, knowing in advance the true value of the wave speed of penetration into a medium has a major effect on the accuracy of the GPR measurements as illustrated in Table (2). This wave speed in fact varies as the wave moves down because of usual in homogeneous, multi layered media. So, the actual wave speed is the average of all these variations ss shown in Figure (8).

Conclusion

The most important points that can be inferred by the results are:

1. It is important that the fields are dry during the GPR scanning process because it causes the water distortion effect on the reflected portion of the radio wave transmitted from the antenna that forms the output image.
2. Some obstacles related to land condition may affect the images radargram. This can be overcome by using some filters which give high accuracy after treatment. (DC, Band Pass, Background Removal and Time Gain).
3. The best arrangement for GPR survey is obtained when the transmitter and receiver antenna parallel to the layer under the ground.
4. Potential for the discovery of non-metallic objects such as concrete, ceramics, a brick which gives ample room for the detection of various materials and similar conditions.
5. Spatial to detect voids and gaps where fixed high vacuum isolation appears.
6. When analyzing the results obtained from place, the following has become obvious:

The layers have been identified on the following depth:

• 0.6 m depth with antennas frequency 1000 MHz.
• 0.8 m depth with antennas frequency 500 MHz.
• 2, 5 and 6 m depth with antennas frequency 250 MHz

References

Annan A. P. and Davis, J. L, (1997). Ground Penetrating Radar Coming of Age at last, Electrical and Electromagnetic Methods, 66, 515–522.

Annan A. P., and COSWAY S. W. (1992). Simplified GPR Beam Model for Survey Design, Society of Exploration Geophysicists, New Orleans, USA.

Basson, G., (2000). Ground Penetrating Radar (GPR), a Research Published in Internet, http://www.geosense.com/index.htm.

Conyers L. B. (2009). Ground-Penetrating Radar for Landscape Archaeology: Method and Applications, Department of Anthropology, University of Denver, Colorado, USA.

Daniels D. J. (1996). Surface Penetrating Radar, the Institute of Electrical Engineers, London, UK.

Daniels J. J. (2000). Ground Penetrating Radar Fundamentals, Report to the U.S.EPA, Region V. 1-21.

Faleh, H. (2018). Utilizing Ground Penetration Radar to Detect Buried Human Remains at two Different Depths, Indian Journal of Natural Sciences, 9(50), 14859- 14868.

HannuL Uodes, (2008). Natural Stone Assessment with Ground Penetrating Radar, Estonian Journal of Earth Sciences, 57(3), 149-155.

Johansson, B. and Friborg J., (2005). Applied GPR Technology, Theory and Practice, Mala Geoscience USA Lectures, in Cairo, September.

Jorge, L. P. and William A. Sauck (2007). Ground penetrating Radar Profiles over Multiple Steel Tanks: Artifact Removal through Effective Data Processing Geophysics, November-December 72(6), 77.

Kazunori Takahashi; Jan Igel; Holger Preetz and Seiichiro Kuroda, (2012). Basics and Application of Ground-Penetrating Radar as a Tool for Monitoring Irrigation Process, Leibniz Institute for Applied Geophysics National Institute for Rural Engineering, Germany, Japa.

Salih, A. S. (2008). Applications of Ground Penetrating Radar (GPR) in Detection of Groundwater Table, Department of Applied Geology, College of Science, University of Tikrit, Tikrit, Iraq, this Research Achieved in Division of Environmental and Resources Survey Center of Northeast Asian Studies, Tohoku University, Sendai, Japan, (1-3).

Suvarna, S. S. (2004). Reconstruction of Ground Penetrating Radar Images Using Techniques Based on Optimization, MSC. Thesis submitted to the Graduate Faculty of North Carolina State University in Partial Fulfillment of the Requirements for the Degree of Master of Science, (1-4).