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Evaluation of Road Pavement and Subsurface Defects Mapping Using Ground Penetrating Radar (GPR)

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ABSTRACT

GPR is frequently used for inspection road pavement (thickness estimation, damage detection and diagnosis), so this technique was selected for this purpose. Three types of antennas were used: 250, 500 and 800 MHz. In the field, the survey has been carried out on one lanes paved road about 1250 m long inside University of Technology Campus. The obtained radargrams raw data were analyzed using sophisticated softwares to determine asphalt and concrete layers thicknesses for base and subase. Several inspections have been carried out to study the effect of changing the operating setting parameters of GPR on the data accuracy and interpretation for paved roads damages and the pavement layers thicknesses. The interpretation results, using 250 MHz antenna, showed the possibility of identifying buried plastic pipe and the flexible pavement layer. While the rigid pavement layer is unresolved. With 500 MHz antenna, the plastic pipe, rigid pavement, steel reinforcement bars and joint sheet cork appeared clearly. It was found that the short type of the Max. Time Window using antenna 800 MHz is the most suitable for detecting some radar anomalies (plastic pipe, cork sheet and reinforcement bars and pavement thickness) which were more clearly defined. No change is noticed on radargrams when applying different point intervals. The suitable radar wave velocity for estimating the thicknesses of the surface, binder and rigid pavement layers were 80, 160 and 180 m/ns respectively. While, the surface cracks were undetectable with 800 MHz antenna but the cause of such crack was identified. Correlation GPR thickness data with the asphalt core data, states that the error of the thickness measurements from GPR resulted in average deviation (the percentage error) of about 4%.

Keywords: Ground penetrating radar, Road pavement, Center frequency, Max. time window, EM wave velocity, Point interval

تقييم رصف الطرق والعيوب تحت السطحية باستخدام الرادار الأرضي (GPR)

الخلاصة:

كثيرا ما يستخدم الرادار الأرضي GPR في هندسة الطرق لفحص حالة التبليط (تحديد سماكات طبقات التبليط، تشخيص و كشف الأضرار في طبقات التبليط) لذلك تم اختيار هذه التقنية لهذا الغرض. استخدمت ثلاثة أنواع من الهوائيات (250, 500 and 800 MHz). في العمل الحقلي، تم تنفيذ المسح على مسارين من الطرق المعبدة داخل موقع الجامعة التكنولوجية بطول 1250 متر. تم تحليل البيانات الأولية باستخدام برامج متطورة لتحديد سمك طبقات الأسفلت والخرسانة. أجريت فحوصات عديدة لدراسة تأثير التغيير في اعدادات تشغيل الجهاز وتأثيرها على دقة البيانات وعلى تفسير السماكات والعيوب تحت السطحية لطبقات التبليط. أظهرت نتائج التفسير باستخدام الهوائيMHz 250 امكانية التعرف على الأنبوب البلاستيكي المدفون وطبقة التبليط المرنة دون تحديد طبقة التبليط الصلدة. وباستخدام الهوائي MHz 500 ، ظهر كل من الأنبوب البلاستيكي و طبقة التبليط الصلدة و قضبان حديد التسليح وقطع الفلين المستخدمة في الفواصل بشكل واضح. وجد ان أفضل نافذة للحد الأقصى للوقت هو النوع القصير باستخدام الهوائي MHz 800 وهو الأكثر ملائمة للكشف عن بعض الشواذ الرادارية (الأنابيب البلاستيكية و طبقة الفلين وحديد التسليح وسمك التبليط) التي تم تحديدها بشكل واضح. وجد ان السرعة الموجية للرادار المناسبة لطبقات التبليط السطحية والرابطة والتبليط الجاسيء هي 80 و 160 و180 م/نانوثانية على التوالي. في حين لم يتم التعرف على الشقوق السطحية باستخدام الهوائي 800 MHz ولكن تم التعرف على سبب حدوثها. بمقارنة النتائج المستحصلة من الرادار الأرضي مع بيانات اللب الاسفلتي، وجد ان نسبة الخطأ لسمك طبقات التبليط بحدود 4%.

INTRODUCTION

A GPR unit emits a short pulse of electromagnetic energy and is able to determine the presence or absence of a target by examining the reflected energy from that pulse. Nondestructive pavement testing methods, such as Ground Penetrating Radar GPR has been using in the pavement engineering since almost twenty years (e.g. Maser, 1996 [1]; Saarenketo and Scullion, 2000 [2]; Benedetto et al., 2004 [3]). The traditional and mostly diffused application is the evaluation of the thicknesses of pavement layers (e.g. Scullion et al., 1994 [4]; Benedetto et al., 2006 [5]). GPR has gained increasing popularity in quality control surveys of new road structures. The greatest advantages of GPR methods are that they are not destructive in comparison to the traditional drill core methods, costs are low and GPR surveys can be performed quickly [6].

GPR uses transmitting and receiving antenna. The transmitting antenna radiates short pulses of the high-frequency (usually polarized) radio waves into the ground. When the wave hits a buried object or a boundary with different dielectric constants, the receiving antenna records variations in the reflected return signal. The principles involved are similar to reflection seismology, except that electromagnetic energy is used instead of acoustic energy, and reflections appear at boundaries with different dielectric constants instead of acoustic impedances. The intensity of reflected signal is primarily a function of the contrast in the dielectric constant at the interface, the size and shape of the target. The depth range of GPR is limited by the electrical conductivity of the ground, and the transmitting frequency. Higher frequencies do not penetrate as far as lower frequencies, but give better resolution [7, 8].

This study focuses upon the capability of the GPR to detect the pavement layer thickness since coring and other destructive testing was not acceptable, GPR was selected for this purpose. The capability and accuracy of GPR depends on many factors such as antenna frequency and operating setting parameters (Max Time Window, EM Wave Velocity and Point Interval).

GPR Principles and Pulse Propagation at the Interface of Two Different Materials

Ground Penetrating Radar systems use discrete pulses of radar energy with a central frequency varying from 10 MHz up to 2.5 GHz to resolve the locations and dimensions of electrically distinctive layers and objects in materials. Pulse radar systems transmit short electromagnetic pulses into a medium and when the pulse reaches an electric interface in the medium, some of the energy will be reflected back while the rest will proceed forwards (Figure. 1a). The reflected energy is collected and displayed as a waveform showing amplitudes and time elapsed between wave transmission and reflection [6]. A good summary of the GPR technique in general and it applications is given [9].

Consider the behavior of a beam of EM energy (such as microwave) as it strikes an interface, or boundary, between two materials of different dielectric constants as shown in Figure 1b. A portion of the energy is reflected, and the remainder penetrates through the interface into the second material. The intensity of the reflected energy, *AR*, is related to the intensity of the incident energy, *AI*, by the following relationship [10, 11]:

$$\rho_{1,2} = \frac{AR}{AI} = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1} \qquad ..\ (1)$$

where

$\rho_{1,2}$ = the reflection coefficient at the interface, and

η_1, η_2 = the wave impedances of materials 1 and 2, respectively, in ohms.

For any nonmetallic material, such as concrete or soil, the wave impedance is given by:

$$\eta = \sqrt{\frac{\mu_0}{\epsilon}} \qquad ..\ (2)$$

where

μ_0= the magnetic permeability of air, which is $4\pi \times 10^{-7}$ henry/meter, and

ϵ = the dielectric constant of the material in farad/meter.

Since the wave impedance of air, η_0 is

$$\eta_0 = \sqrt{\frac{\mu_0}{\epsilon_0}} \qquad ....\ (3)$$

and the relative dielectric constant ϵ_r of a material can be defined as:

$$\epsilon_r = \frac{\epsilon}{\epsilon_0} \qquad \text{....(4)}$$

where ϵ_0 = the dielectric constant of air, which is 8.85 x 10^{-12} farad/meter. Then, equation 2 may be rewritten as:

$$\eta = \frac{\eta_0}{\sqrt{\epsilon_r}} \qquad \text{.....(5)}$$

and equation 1 as

$$\rho_{1,2} = \frac{\sqrt{\epsilon_{r2}} - \sqrt{\epsilon_{r1}}}{\sqrt{\epsilon_{r2}} + \sqrt{\epsilon_{r1}}} \qquad \text{..(6)}$$

where ϵ_{r1} and ϵ_{r2} are the relative dielectric constants of materials 1 and 2, respectively. Equation 6 indicates that when a beam of GPR antenna strikes the interface between two materials, the amount of reflection coefficient ($\rho_{1,2}$) is dictated by the values of the relative dielectric constants of the two materials. If material 2 has larger relative dielectric constant than material 1, then $\rho_{1,2}$ would have a negative value, i.e., with the absolute value indicating the relative strength of the reflected energy and the negative sign indicating that the polarity of the reflected energy is opposite of that arbitrarily set for the incident energy [12].

The Survey Methods

Ground Penetrating Radar (GPR) is one of the most important electromagnetic methods, which has, been extensively used as a nondestructive method for locating different subsurface anomalies. Saeed (2010) [13] applied GPR for detecting subsurface bodies, this study has revealed much more details about the subsurface conditions. Karim and Al-Dami (2012) [14] studied the ability of using GPR with intermediate antenna frequencies to investigate simulated GPR data obtained for shallow engineering investigation by detecting different subsurface bodies. Karim and Al-Dami (2012) [15] studied the reinforced concrete and the quantity of steel bars and their configurations in the concrete constructed in the hidden mensurations. Thus, this technique was suggested for the present study for inspecting flexible and rigid pavement layers thickness. The capability and accuracy of GPR depends on many factors such as antenna frequency and operating setting parameters such as maximum time window, electromagnetic wave velocity and point interval. To achieve this purpose, specific straight lines were chosen in the University of Technology site as tested profiles (Figure.2). In the field, the survey has been carried out on specific straight line of paved road about 1250 m long inside University of Technology site in Rasafa province in Baghdad. The road has been surveyed using GPR antennas 250, 500 and 800 MHz for all the 1250 m. The used GPR instrument is of model 2005 with system containing different parts; at the heart of this new system is the ProEx Control Unit. In addition, it is supplemented with sophisticated software's such as RadExplorer, Object Mapper and Ground Vision. After GPR survey, 56 measurements have been done.

Discussion the Results

Several inspections have been carried out to study the effect of changing the operating setting parameter of GPR. The different operating setting parameters that have been tested during the survey include the suitable antenna and EM wave velocity, the best maximum time window and point interval. Also the surface cracks were inspected too. In addition, a correlation with core has been carried out by extracting a core from this site and correlated with of GPR data. The top and bottom of pavement layers in radargram can be identified and assigned as shown in (Figure.3).

Inspection of Surface Defects and Buried Objects

In the first stage, the different operating setting parameters have been tested. Selecting suitable antenna is important in accuracy and interpretation to the pavement layer thickness. The results showed that by using 250 MHz antenna, the buried plastic pipe and the flexible pavement layer were identified. The later appeared as one layer without identifying the rigid pavement layer Figure 4. With 500 MHz antenna, the plastic pipe, rigid pavement, steel reinforcement bars and joint sheet cork appeared clearly (Figure.5). The effect of changing maximum time window is one of the important operation settings of GPR that affects the interpretation of data. Therefore, the change in maximum time window (short or medium) was applied for the three antennas (250, 500 and 800 MHz). It is found that the short type of max. time window using antenna 800 MHz appeared to be the most suitable for detecting some road anomalies (plastic pipe, cork sheet and reinforcement bars and pavement thickness) which were clearly defined (Figure. 6). Changing point interval parameter, it was noticed that the suitable point interval for final selected antenna (800 MHz) is 0.03m.

To study the effect of EM wave velocity on the accuracy of pavement layer thickness, different velocities that ranged between (10-300) m/ns have been used. It is found that the suitable radar wave velocity was 100 and 180 m/ns for estimation of the flexible and rigid pavement layer thicknesses respectively. No change is obtained with changing point interval. While, the surface cracks were undetectable with 800 MHz antenna but the cause of such crack appeared to be due to leakages in buried pipe resulting in swelling of the soil and causing the cracks (Figure.7).

Core Correlation with GPR Radargram Data

In the second stage, asphalt and concrete thickness data was correlated with core data provided by road. According to Iraqi standard specifications for roads and bridges (SSRB, 1983 and 2003) [16], a pavement core was taken for thickness measurements as a verification sample to compare thicknesses obtained through coring with those from GPR. Figure 8 shows the core sample which was obtained with its pavement layer thicknesses from location of tested profiles located in University of Technology Campus (Fig.2). The top and bottom of layers in radargram can be identified and assigned as shown in Figure 2. The 800 MHz data for the asphalt sections produced well-defined interfaces. The analysis of this data was straightforward. The continuous thickness results reveal important information regarding thickness variations. The thicknesses of the layers have been estimated through extracting from radargram for each interface between layers. The thicknesses measured from core drilling (Figure. 8) have been used to validate the GPR prediction for layer thicknesses estimated from radargram. The results of comparison show an average thickness deviation (the percentage error) of the GPR measurements on the order of 4%: about 1% for surface layer, 2% for binder layer and about 8% for rigid layer Table (1).

CONCLUSIONS

1. Several inspections have been carried out to study the effect of changing the operating setting parameters of GPR on the data accuracy and interpretation for paved roads damages and the pavement layers thicknesses.
2. The interpretation results showed that, working with 250 MHz antenna, the buried plastic pipe and the flexible pavement layer are identified. The flexible pavement layer appeared as one layer while the rigid pavement layer is unresolved.
3. With 500 MHz antenna, the plastic pipe, rigid pavement, steel reinforcement bars and joint sheet cork appeared clearly.
4. It was found that the short type of the Max. Time Window using antenna 800 MHz is the most suitable for detecting some radar anomalies (plastic pipe, cork sheet and reinforcement bars and pavement thickness) which were more clearly defined. While, no data were appeared on radargrams with the medium type using the same antenna frequency.
5. No change is noticed on radargrams when applying different point intervals. However, the suitable point interval for the 800 MHz antenna is 0.03m.
6. The suitable radar wave velocity for estimating the thicknesses of the surface, binder and rigid pavement layers were 80, 160 and 180 m/ns respectively.
7. The surface cracks width and extensions were undetectable with 800 MHz antenna which may be due to leakage of buried pipe causing soil swelling and in turn cracking the road surface layer.
8. Correlation GPR thickness data with the core data, states that the error of the thickness measurements from GPR resulted in average deviation (the percentage error) of about 4%.
9. It is recommended to use the high antenna frequency (>800 MHz) to evaluate pavement conditions (asphalt densities, moisture content of base materials, identifying stripping zones in asphalt layers, detecting air-filled, locating subsurface vertical cracks etc.).

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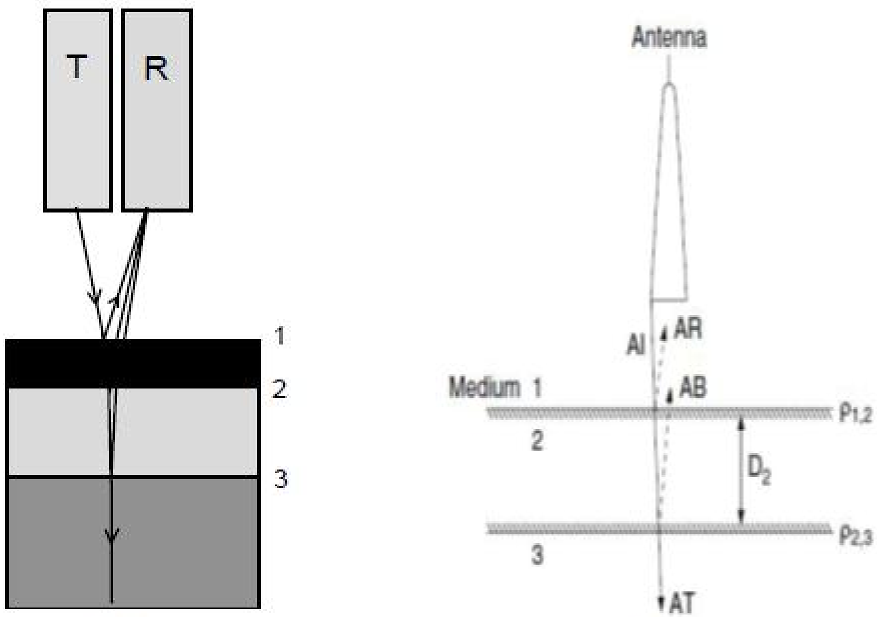
Table (1) Thicknesses obtained from radargram for EM wave velocity 100 m/ns and core drilling.

Layer	Thickness (cm)		Percentage Error (%) in measurements of thickness from GPR
	Average From GPR	Core Drilling	
Surface	8.52	8.35	≈ 2
Binder	6.77	6.70	≈ 1
Rigid	18.67	20.30	≈ 8
Total	33.96	35.35	≈ 4



(a) **(b)**

Figure (1) Basic principle GPR technique with antenna for pavement examination. (a). T represents the transmitting antenna and R the receiver antenna. Interface 1 presents the air-asphalt interface, 2 presents the asphalt-base course interface and 3 presents the base-sub base interface. (b). Propagation of EM energy through dielectric boundaries [3].

(a) (b) (c)

Figure (2) Fieldwork inspection with GPR antenna frequencies using: (a) 250 MHz, (b) 500 MHz, and (c) 800 MHz

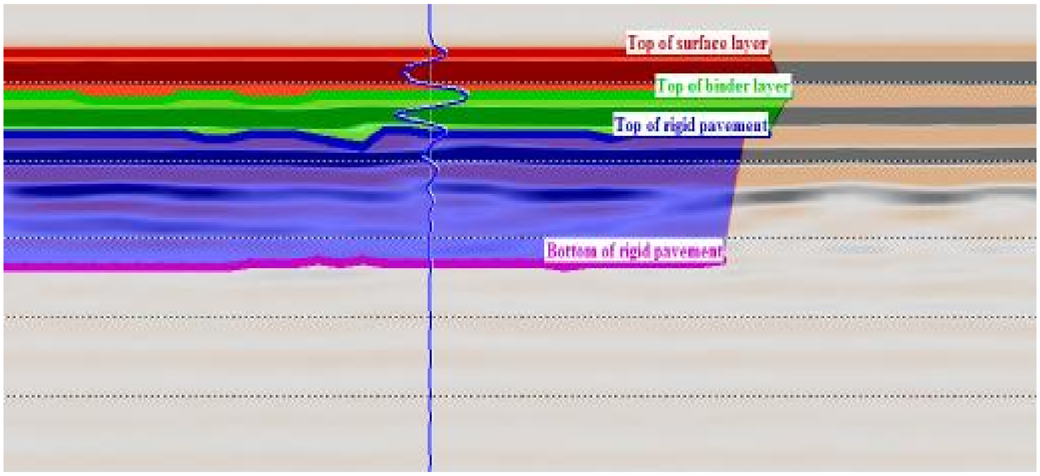


Figure (3) Identifying the boundary of layers using pick and fill the layer using the model option.

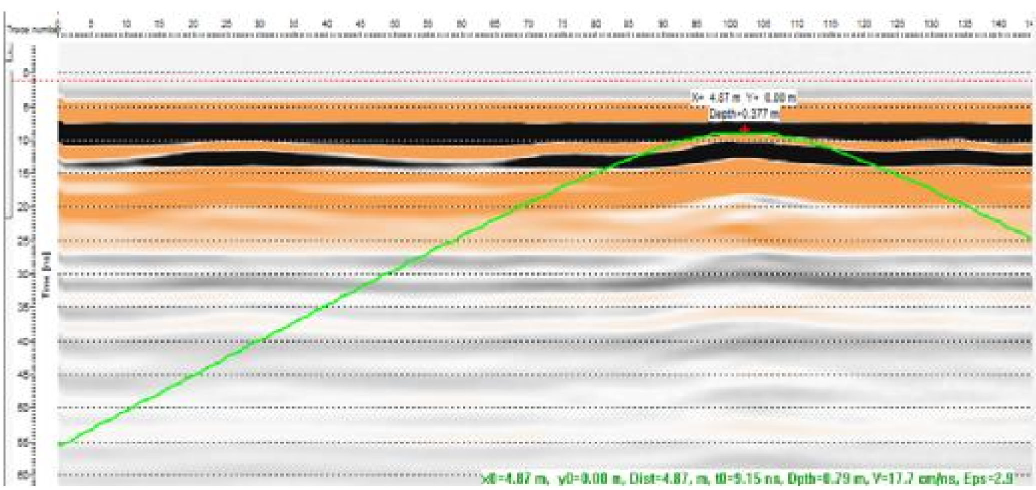


Figure (4) Using antenna 250 MHz where plastic pipe was appeared while flexible pavement appeared as one layer.

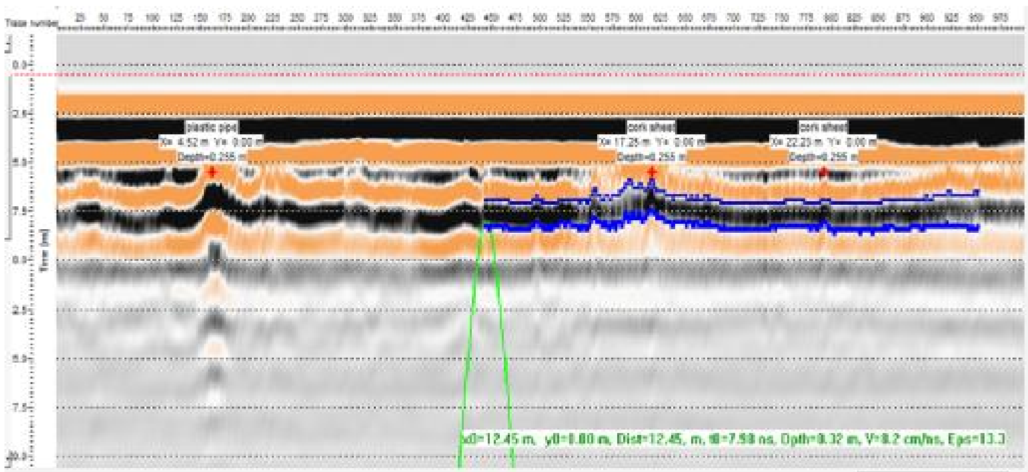


Figure (5) Using antenna 500 MHz where cork sheet, plastic pipe and steel reinforcement bars were appeared.

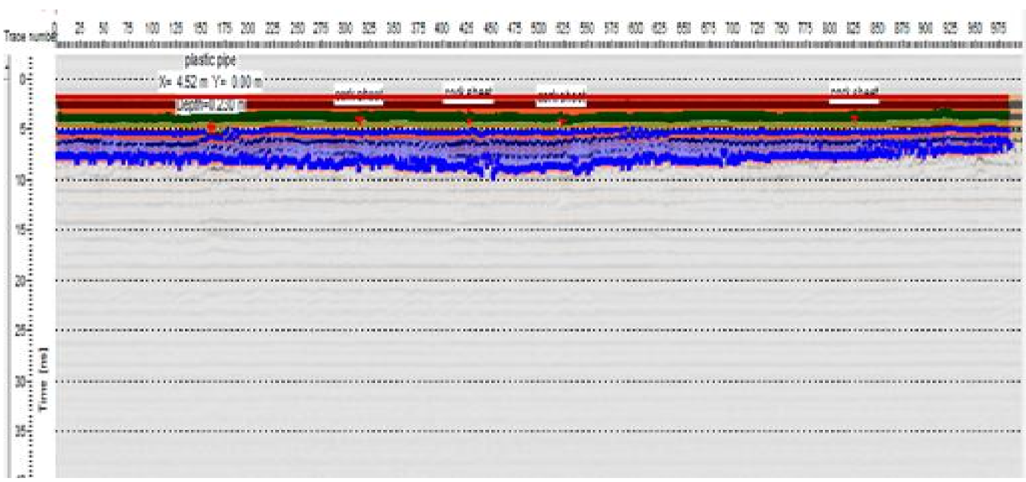


Figure (6) Using antenna 800 MHz where cork sheet, plastic pipe, steel bars reinforcement and pavement layer thickness were appeared.

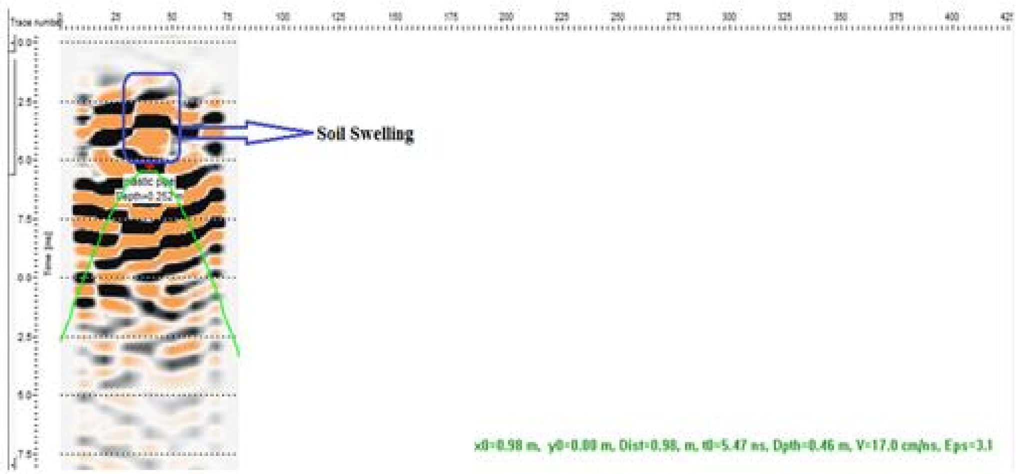


Figure (7) Applying antenna 800 MHz with short max time window on grid after using background filter showing plastic pipe and swelling soil.

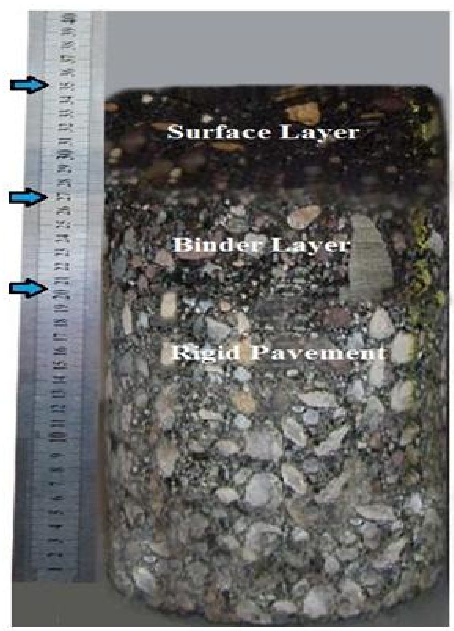


Figure (8) Core sample with pavement layer thicknesses.