Non-Destructive Testing of Concrete Structures Using GPR Technique with an Intermediate Frequency Antennas

Dr. Hussein H. Karim
Building and Construction Engineering Department, University of Technology/ Baghdad
Email:husn_irq@yahoo.com
Haidar Abbas N. Al-dami
College of Engineering, University of Al-Qadisiya /Al-Diwaniya

Received on: 11/10/2011 & Accepted on: 5/4/2012

ABSTRACT

Ground penetrating radar (GPR) is a geophysical technique of imaging the subsurface structures at high resolution and it is a non-destructive technique can consequently be applied in many civil engineering fields and sensitive environments. The amount of data collected however can be very large and take a significant level of subjective experience to interpret. This study focuses upon the ability of using the GPR with 250 MHz and 500 MHz antennas (intermediate frequencies) to investigate the reinforced concrete to indicate the quantity of steel bars and their configurations in the concrete constructed in the hidden mensurations. The recent study shows the ability of using the intermediate frequency antennas for such fields.

Keywords: Ground penetrating radar, Antenna frequency, Dielectric constant, Creeping waves, Concrete structures, Steel bar reinforcement

الفحص اللااتلافي للتراكيب الكونكريتية باستخدام تقنية الرادار الأرضي بهوائيات متوسطة التردد

الخلاصة

ان الرادار الأرضي تقنية جيوفيزيائية تستخدم لتصوير التراكيب تحت السطحية بقـدرة تمييز عالية وهي تقنية لاأتلافية وبالتالي يمكن استخدامها في مجالات الهندسة المدنية المتعددة وفي البيئات الحساسة. ان كمية المعلومات الكبيرة المستحصل عليها تحتاج الى مسـتوى ذي شأن من الخبرة في مجال التفسير. تتركز الدراسة الحالية على امكانية استخدام تقنية الرادار الأرضي بترددات 250 و500 ميكاهيرتز(ترددات متوسطة) من اجل استكشاف التراكيـب الكونكريتية المدعمة والتعرف على كمية حديد التسليح المستخدم وترتيبـه فـي الكونكريـت المستخدم في التراكيب المخفيـة. أظهـرت الدراسـة امكانيـة اسـتخدام هوائيـات ذات الترددالمتوسط في مثل هذه المجالات.

INTRODUCTION

There are several practical geophysical methods that have been adapted to provide solutions more specific to a variety of engineering problems. The GPR geophysical method, originally developed for high resolution imaging of the subsurface, is now used routinely in condition evaluation of foundations, pavements, concrete slabs and walls.

Ground penetrating radar (GPR) is a geophysical non-destructive technique with a wide range of potential applications in the testing of concrete. It is gaining acceptance as a useful and rapid technique for non-destructive detection of delaminations and the types of defects, which can occur in bare or overlaid reinforced concrete decks. It also shows potential for other applications such as measurement of the thickness of concrete members and void detection [1].

Non-destructive evaluation of reinforced concrete structures is an increasingly important field in the construction and civil engineering community. One tool that has gained considerable popularity has been that of GPR (ground penetrating radar). GPR offers the capability to detect and evaluate subsurface features in concrete structures quickly, in a completely non-invasive way and with access to only one surface needed. Detection of reinforcing bars in concrete has become one of the most widely used applications of GPR in civil engineering [2].

The aim of this study is to investigate and inspect the reinforced concrete to indicate the rebars quality and quantity and their configurations by using GPR with an intermediate frequencies (250 and 500 MHz).

GPR CONCEPTS

GPR measurements are based on the transmission and reflection of an electromagnetic (EM) wave in the studied medium [3]. The radar system causes the transmitter antenna (*TX)* to generate a wavetrain of radiowaves which propagates away in a broad beam [4]. Variation in the electrical properties (conductivity, σ and dielectric constant, ϵ) of the subsurface cause part of the transmitted signal to be reflected then this signal is detected by the receiver [5] Figure.(1).

The first pulse will be the wave that travels directly through the air because the velocity of air is greater than any other material, and the second recorded pulse that is that travels through the material and is scattered back to the surface. The second signal travels at a velocity determined by the permittivity (s) of the material. The resulting record measured at the receiving antenna is similar to one of the time amplitude plots shown in figure (2), with the "input" wave consisting of the direct wave that travels through air, and the "output" pulse consisting of the wave reflected from the buried scattering body. The recording of both pulses over a period of time with receiving antenna system is called a "trace," which can be thought of as a time-history of the travel of a single pulse from the transmit antenna to the receive antenna, and includes all of its different travel paths. The trace is the basic measurement for all time-domain GPR surveys. A scan is trace where a color scale, or a gray scale, has been applied to the amplitude values [6].

Behavior of GPR at the Interface of Two Different Materials

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 Figure.(3). 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:

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

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.

It is worthy to mention that metals are perfect reflectors of EM waves as their wave impedances are zero.

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:

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

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

$$\eta = \frac{\eta_0}{\sqrt{\epsilon_r}} \quad (5)$$

and equation 1 becomes

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

where ϵ_{r1} and ϵ_{r2} are the relative dielectric constants of the media (or 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 [7].

CREEPING WAVES

Figure (4) illustrates two distinct features seen in the scattered field waveform. The first is a sharp pulse almost duplicating the incident field waveform, but with opposite polarity. This is the specular reflection produced when the incident field first contacts the sphere and begins to induce a current on the sphere surface.

The second feature, is called the creeping wave, which occurs at a time approximately (2π) *a/c* seconds after the specular reflection, where a = radius of material, c = velocity of light (3×10^8 m.s^{-1}).

This represents the field radiated back along the incident direction by a wave of current excited by the incident field at the tangent point, which travels around the sphere at approximately the speed of light in free space. Although this wave continues to traverse the sphere, its amplitude is reduced so significantly by radiation damping that only a single feature is seen [8].

In a low-frequency limit, the interference between the direct and creeping waves deep in the shadow region, the results in a large increase in the backscattering wave intensity. On the other hand, in the high-frequency limit, only the specularly reflecting points at the surface contribute to the scattered fields and therefore the effect of creeping waves becomes almost negligible [9].

STUDY AREA

This study is carried out in two sites located in the University of Technology. The 1st site is chosen along the passageway of the first floor of Building and Construction Engineering Department while the second site is chosen on the foundations of the Plumping Unit. The length of the investigated profiles are 27 and 20 m in the two sites respectively.

INSPECTION, RESULTS AND DISCUSSION

Many studies concerning the investigation of the reinforced concrete and its conditions suggested the use of high antenna frequency (>800 MHz). The present study deals with the assessment of the ability of investigating the reinforced concrete and detecting the quantity, configuration and network of the reinforced steel bars in concrete elements using intermediate antennas frequencies (250 and 500 MHz) instead of using high frequencies antennas (>800 MHz) that are recommended to be used in such studies.

By using the 500 MHz antenna in the passageway of the 1st site (1st floor of Building and Construction Engineering Department), the reinforced bars appear together as a telescopic picture even with the interpretation with the assistance of RadExplorer program as shown in figure 5. But by using the 250 MHz antenna, the steel bars can be distinctive and identified with their quantity in the investigated radargram. These bars have not been interpreted by using the hyperbola tool in the RadExplorer program, but their distinction was indicated by the creeping waves Figure. (6).

Regarding the 2nd site (Plumping Unit), the reinforced bars appear more clearly than that of the 1st site as the size of these bars in the foundation of the 2nd site is larger with greater spacing between bars Figure (7). In similar way by using the 250 MHz antenna, the bars also are well distinct with their numbers in the section Figure.(8) for the above mentioned reason concerning the creeping waves phenomena which have more effect as the wave length is greater than that of 500 MHz but with the boundary of antenna resolution.

From above results and discussion, it is preferable to use different antenna frequencies for studying any concrete structure to get a better picture and subsurface map by overcoming any ambiguity appeared in the investigated radargrams.

CONCLUSIONS REMARKS

The following conclusion remarks may be highlighted as follows:

1. Intermediate antenna frequencies (250 and 500 MHz) have been used instead of high antenna frequencies (>800 MHz) for studying rebar condition in the concrete elements.
2. The ability of using the 250 MHz antenna to investigate the reinforced steel bars and their configuration and network that are used in hidden mensuration of the 1st site.
3. The ability of using the 500 MHz antenna for investigating and identifying the subsurface reinforced concrete in the foundation of the 2nd site.

4. For studying any concrete element, it is preferred to use different antenna frequencies to get a better picture and to overcome any ambiguity appeared in the investigated redargrams.

REFERENCES

[1] IAEA (The International Atomic Energy Agency), "Guidebook on non-destructive testing of concrete structures", The IAEA in Austria, Vienna, 2002.

[2] Shaw, M. R. , Millard, S. G. Molyneaux T. C. K., Bungey, J. H. and Taylor M. J., "Location of steel reinforcement in concrete using ground penetrating radar and neural networks", pp.1-8, 2011. www.openpdf.com/ebook .

[3] Chanzy, A., Tarussov, A., Judge, A. and Bonn, F., "Soil water content determination using a digital ground-penetrating radar", Soil Science Society of America Journal, Vol. 60, pp. 1318-1326, 1996.

[4] Reynolds, J. M.,"An Introduction to applied and environmental geophysics", West Sussex, John Wiley & Sons Ltd, 1997.

[5] Davis, J. L. and Annan, A.P., "Ground penetrating radar for high-resolution mapping of soil and rock Stratigraphy", Geophysical Prospecting, Vol. 37, pp. 531-551,1989.

[6] Daniels, J., Ehsani, M. R., and Allred, B. I.,"Handbook of agricultural geophysics", Chapter 7, Ground-Penetrating Radar Methods (GPR), pp.129-145, 2008.

[7] Clemeña, Gerardo G.,"Non destructive testing of concrete", 13 Short-Pulse Radar Methods, CRC Press LLC, 2004.

[8] Rothwell, E. J. and Cloud, M. J.,"Electromagnetic", CRC Press, QC670. R693, 2001.

[9] El-Ocla, H., "Backscattering from conducting targets in continuous random media for circular polarization", Waves in Random and Complex Media, Vol. 15, No. 1, pp. 91– 99, 2005.

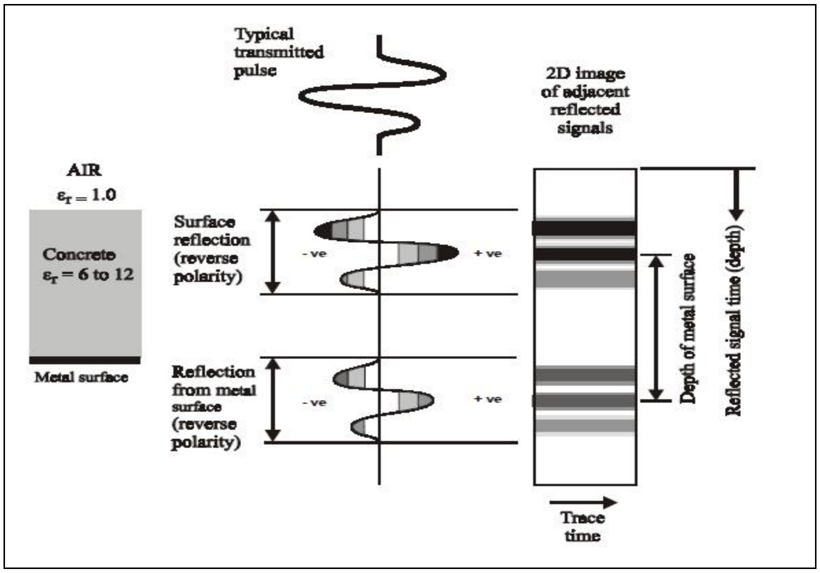
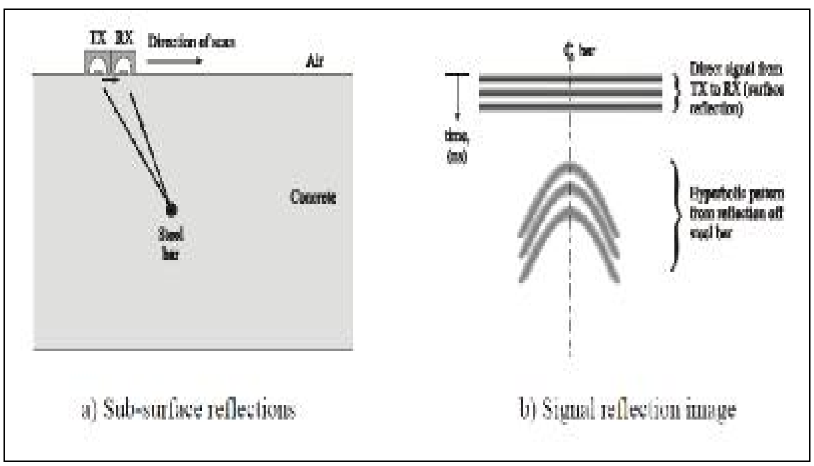


Figure (1) Reflection of radar signal [2].



Figure(2) Hyperbolic reflection image from steel bar in concrete [2].

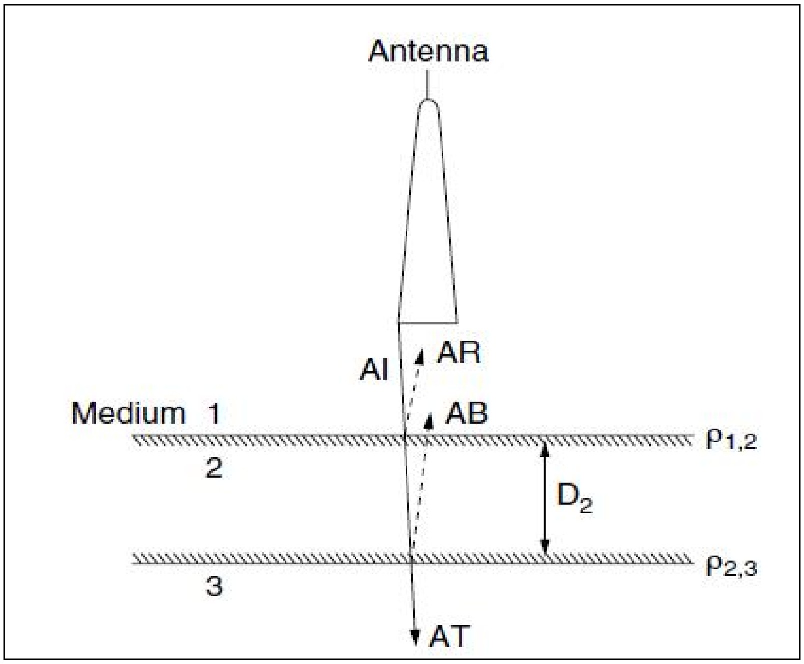


Figure (3) Propagation of EM energy through dielectric boundaries.

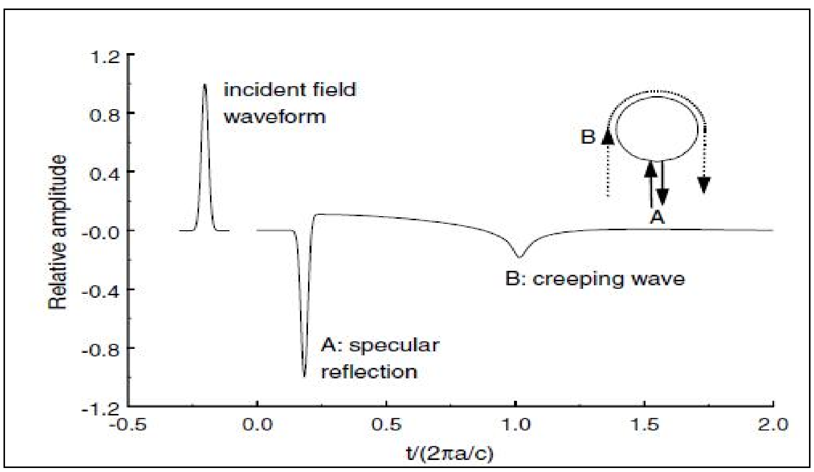


Figure (4) Back-scattered by a conducting sphere [8].

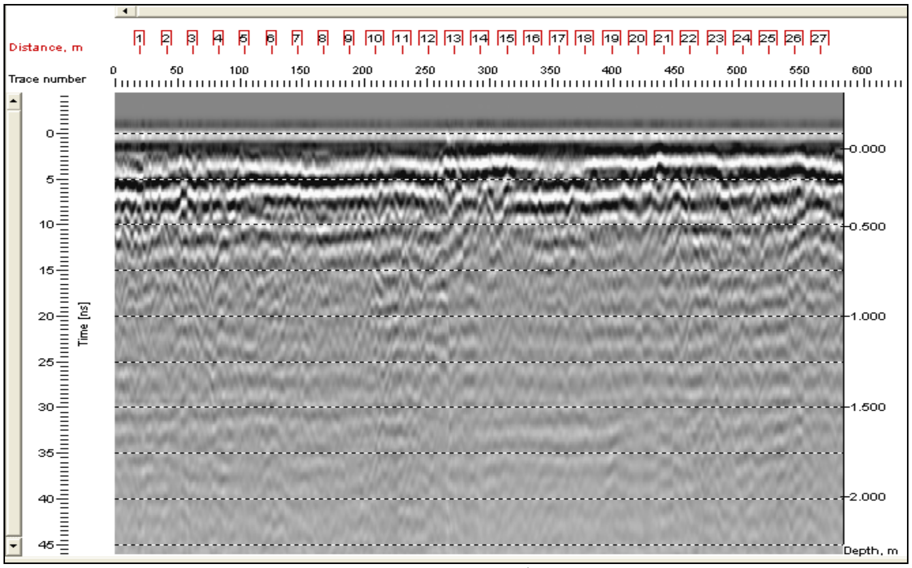


Figure (5) Reinforced bars of the roof of 1st site using 500 MHz antenna.

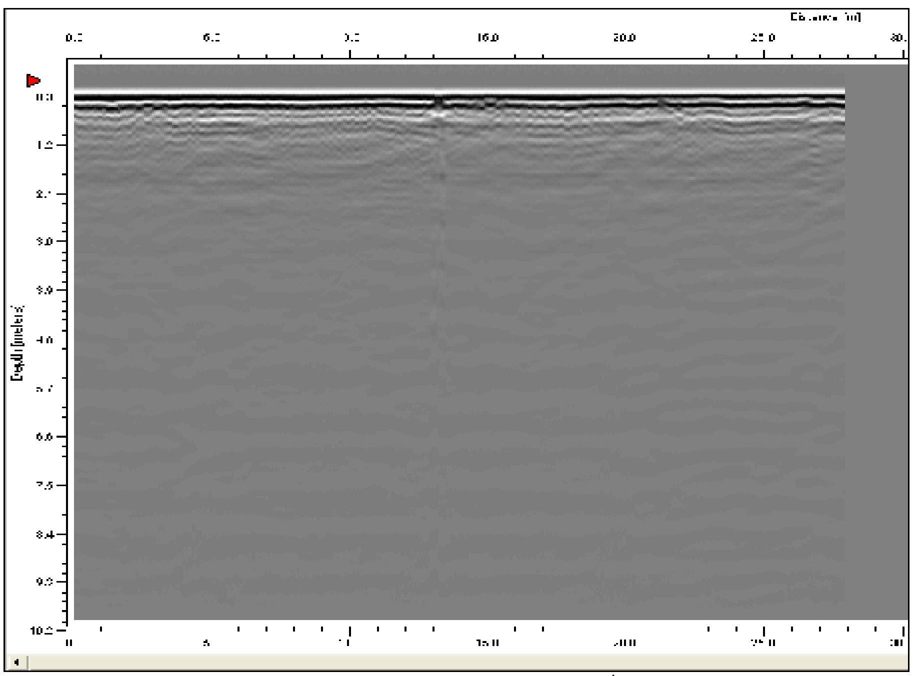


Figure (6) Reinforced bars of the roof of the 1st site using 250 MHz antenna.

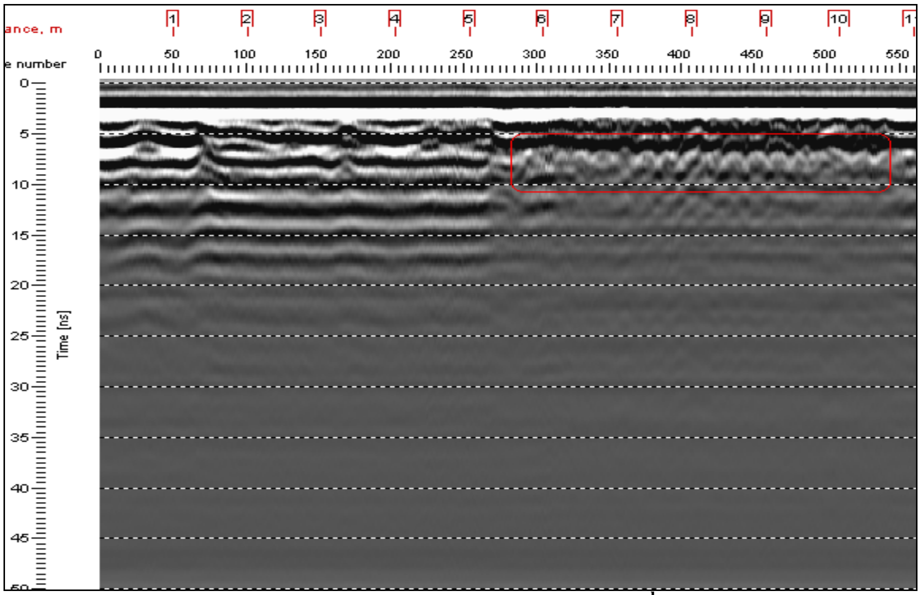


Figure (7) Reinforced bars in the foundation of the 2nd site using 500 MHz antenna.

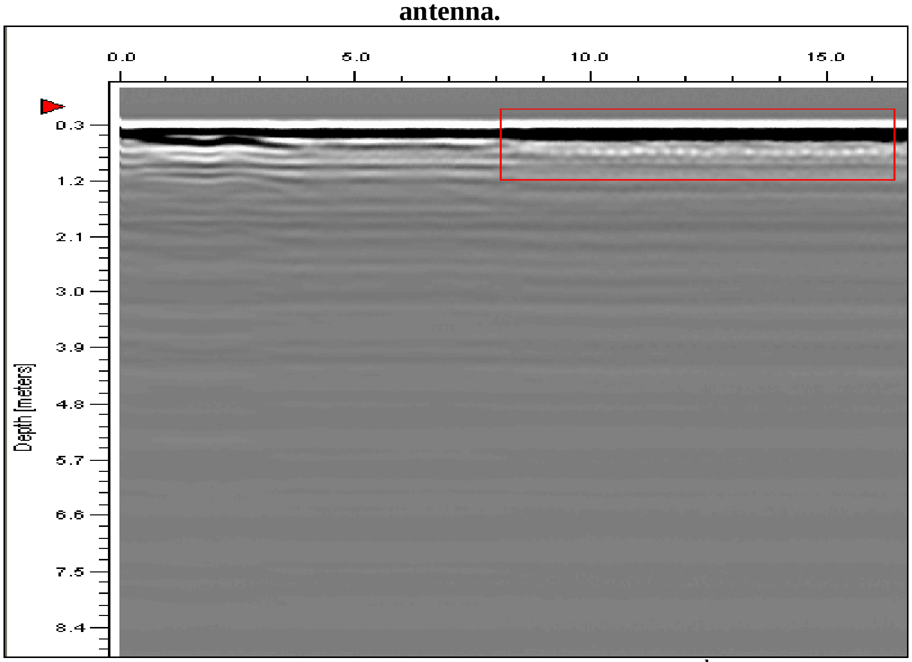


Figure (8) Reinforced bars in the foundation of the 2nd site using 250 MHz antenna.