# Assessment of the Accuracy of Road Flexible and Rigid Pavement Layers Using GPR

**Dr. Hussein H. Karim**
Building and Construction Engineering Department, University of Technology/ Baghdad
Email:husn_irq@yahoo.com
**Ammar M. M. Al-Qaissi**
Building and Construction Engineering Department, University of Technology/ Baghdad

**Received on: 12/5/2013 & Accepted on: 5/12/2013**

## ABSTRACT

Ground Penetrating Radar (GPR) is frequently used in pavement engineering for road pavement inspection. The main objective of this work is to validate nondestructive, quick and powerful measurements using GPR for assessment of flexible and rigid pavement thicknesses and detection of rebars and joints within the rigid pavement. To achieve this work, in-situ simulation model (1.2 m×1.2 m in dimension), consists of three layers (sub-base, flexible and rigid pavement), was made and surveyed by GPR using three antennas (250, 500 and 800 MHz). The interpretation results of 250 MHz antenna identify and assign the flexible pavement as one layer without identifying the rigid pavement layer. With the 500 MHz antenna, the flexible pavement appeared as one layer with identifying the rigid pavement boundaries. While using 800 MHz antenna, both flexible pavement and rigid pavement layers were clearly identified as in the in-situ simulation model. Therefore, the 250 and 500 MHz antennas have much more penetration, but much lower resolution. Besides, rebars and joints were clearly appeared in both 500 and 800 MHz antenna. By correlating in-situ model with radar GPR data, the results show thickness deviations (percentage error) on the order of 1% for surface layer and about 2% for both binder and rigid layers. Applying 500 and 800 MHz antennas perpendicular to steel reinforcement within rigid pavement, the rebars (with dielectric constant equal to 13.6 with velocity equal to 8.1 cm/ns) and joints (with width 0.025 m) appeared in the radargram. From the precise calculation of thickness, it can be concluded that an excellent correlation between field model and radar data.

**Keywords:** Ground penetrating radar, Road pavement, Flexible pavement, Rigid Pavement, Rebars.

# تقييم دقة طبقات الرصف المرن والجاسيء للطرق باستخدام GPR

**الخلاصة**

يستخدم الرادار الأرضي حاليا في هندسة التبليط لفحص تبليط الطرق. ان الهدف الرئيسي من هذا العمل هو التحقق من صحة هذه القياسات غير الاتلافية والسريعة والقوية باستخدام جهاز الـرادار الأرضـي (GPR) لتقييم ظروف الأسفلت / الخرسانة. لتحقيق هذا العمل، تم عمل نموذج محاكاة موقعي (بأبعاد 1.2 متر× 1.2متر)، ويتألف من ثلاث طبقات (طبقة الأساس والتبيلط المرن والتبليط الجاسيء) وبسماكات قياسية معلومة . استخدمت ثلاثة هوائيات مختلفة ( 250 و500 و800 ميكاهيرتز). باستخدام الهوائي 250 ميكاهيرتز أمكن تحديد وتعيين طبقة التبليط المرنة وظهرت كطبقة واحدة دون تحديد طبقة التبليط الجاسئة. بينما مع 500 ميكاهيرتز، بدت طبقة التبليط المرنـة كطبقـة واحدة مع تحديد حدود طبقة التبليط الجاسئة ولكن بسماكات غير حقيقية. بينما مع 800 ميكاهيرتز، حددت بوضوح كل من طبقات التبليط المرنة والجاسئة كما في نموذج المحاكاة الموقعي. وعليه بين استخدام الهوائيين 250 و 500 ميكاهيرتز عمق اختراق أكثر لكن بوضوح أقل. بالاضافة الى ان حديد التسليح والفواصل ظهرت بشكل واضح باستخدام الهوائيين 500 و 800 ميكاهيرتز. بمقارنة النتائج المستحصلة من نموذج المحاكاة مع النتائج المستحصلة من الـ GPR، بينت النتائج ان نسبة الخطأ الحاصل في الطبقة السطحية بحدود 1% وللطبقة الرابطة والتبليط الجاسيء بحدود 2% على التوالي. وعند استخدام الهوائيين 250 و500 ميكاهيرتز باتجاة عمودي على حديد التلسيح الموجود في التبليط الجاسيء، أظهرت المرتسمات الرادارية حديد التسليح (بثابت عزل كهربائي 13.6 و بسرعة 8.1 سم/ نانوثانية) والفواصل (بسمك 0.025 متر). من خلال الحسابات الدقيقة لسمك الطبقات، يمكن أن نخلص إلى وجود علاقة جيدة بين النموذج الميداني والبيانات الرادارية.

## INTRODUCTION

Radar generates short pulses of electromagnetic energy which penetrate into the pavement structure and reflect back from the material interfaces. The amplitude and arrival time of these return reflections are used to determine the thickness and properties of the pavement layers [1, 2].

Ground Penetrating Radar (GPR) is, actually, one of the most advanced technology in civil engineering applications (e.g. in road pavement inspection) [2, 3]. Actually, the pavement damages and defects so as the loss of mechanical properties in the subgrade represent one of the most crucial problems for safety. One of the most relevant causes of damage is often referable to water intrusion in structural layers or clay pumping in sandy subgrade. Currently, a number of accurate techniques are used, but they are intrusive, expensive, time consuming and they give punctual information, i.e. only in the measurement site. Hence, the use of non-intrusive techniques is recommended. GPR uses radar pulses to image the subsurface. This non-destructive method uses electromagnetic radiation and detects the reflected signals from subsurface structures [4].

Pavement layer thickness is an important factor in determining the quality of newly constructed pavements and overlays, since deficiencies in thickness reduce the life of the pavement, for example, a 13 mm thickness deficiency on a nominally 91 mm thick pavement can lead to a 40 % reduction in pavement life. This reduction in pavement life has significant economic implications [5].

The main objective of this work is to validate nondestructive, quick and powerful measurements using GPR for assessment of flexible and rigid pavement thickness.

Therefore, it is important to create a simulation model for road pavement to identify the results that would be obtained from GPR.

## BASIC EQUATIONS OF GPR SURVEYS

Ground Penetrating Radar systems use discrete pulses of radar energy. These systems typically have the following components: 1) a pulse generator, which generates a single pulse of given frequency and power, 2) an antenna or antennas which transmit the pulse into the medium being measured, and 3) a sampler/recorder which captures and stores the reflected signals from the medium. Once the return waveform is captured another input pulse is generated and transmitted into the medium Figure (1). The time between the reflections from electrical interfaces in road will be measured from the stored signal as well as the amplitude of the reflection [6].

The propagation and reflection of the radar pulses is controlled by the electrical properties of the materials, which comprise 1) magnetic susceptibility, i.e. magnetism of the material, 2) relative dielectric permittivity and 3) electrical conductivity [7]. The magnetic susceptibility of a soil or road material is regarded as equal to the value of the vacuum, and thus does not affect the GPR pulse propagation. The most important electrical property affecting GPR survey results is dielectric permittivity and its effect on the GPR signal velocity in the material and, as such, it is very important to know precisely how to calculate the correct depth of the target.

Dielectric permittivity is a complex number and a function of frequency. Relative dielectric permittivity $(\epsilon_r)$ (also referred to as the dielectric value or dielectric constant) is a ratio of the complex dielectric permittivity ($\epsilon$) to the dielectric permittivity of free space ($\epsilon_0$) equal to 8.85 $\times$ $10^{-12}$ F/m.

$$\epsilon_r = \frac{\epsilon}{\epsilon_0} \qquad \dots (1)$$

If magnetic susceptibility is neglected the following simple formulae can be used in practical Ground Penetrating Radar surveys [8]:

$$v = \frac{c}{\sqrt{\epsilon_r}} \qquad \dots (2)$$

where $v$ is wave propagation speed (m/ns), c is speed of light in a vacuum (0.3 m/ns) and $\epsilon_r$ relative dielectric permittivity,

$$d = \frac{vt}{2} \qquad \dots (3)$$

where $d$ is interface depth (m) from the surface of the medium and t is two-way travel time from surface of the medium to the interface depth (ns = $10^{-9}$),

$$k = \frac{\sqrt{\epsilon_{r2}} - \sqrt{\epsilon_{r1}}}{\sqrt{\epsilon_{r2}} + \sqrt{\epsilon_{r1}}} \qquad \dots (4)$$

where k is reflection coefficient, $\epsilon_{r1}$ is relative dielectric permittivity value of first layer and $\epsilon_{r2}$ is relative dielectric permittivity value of second layer.

## PAVEMENT LAYERS BACKGROUND

Pavements are planar-layered media with different materials composing each layer. Based on their main components, pavements are divided into three categories [9]: Flexible (Hot-Mix Asphalt) pavements (HMA), rigid (concrete) pavements (CP), and composite pavements (AC).

Flexible pavements are layered systems composed of different layers that are placed in such a way that layer strength is greater at the top, where the stresses caused by traffic loading are high. This approach allows cheaper local materials to be used in pavement construction Figure (2).

Rigid pavements are constructed of 150 mm to 300 mm Portland cement concrete (PCC) slabs. The slabs can be placed either directly on the prepared subgrade surface or on a 100 mm to 300 mm thick granular base layer.

Composite pavements are composed of concrete slabs overlaid by HMA, thus providing the simultaneous strength of concrete as a base layer and the smoothness of HMA. Due to the high cost of such pavements, they are rarely constructed as new pavements; however, they usually result from the rehabilitation of old concrete pavements by adding an HMA overlay at an appropriate thickness. Flexible pavements may also be overlaid with concrete, which is known as white topping.

## FIELD WORK

This study was carried out in Canal Amusement Park due to the availability of space for field work and heavy equipment's such as (shovel, excavator, compactor and laborers). The fieldwork for simulation model was carried out through different steps as follows Figures (3 to 5):

1. Setting out and lining the simulation model with dimensions (2.5 m × 2.5 m).
2. Starting for excavation work using excavator, then steel compactor used with weight (1 ton) to compact the natural ground after that using level instrument to achieve final elevation for excavations and compactions works.
3. Spreading and compaction of sub-base layer using steel compactor with weight (1 and 4 ton), then use level instrument to achieve final elevation for sub base layer.
4. Spreading nylon, work on frame work and install steel reinforcement with dimension (20 cm × 20 cm).
5. Casting concrete C30 in two steps to install cork with thickness 2.5 cm as a joint, then level instrument used to achieve final elevation for concrete pavement layer (rigid pavement).
6. Spreading tack coat over the rigid pavement to ensure the bonding between, then laying binder layer that is larger aggregates size and less asphalt from surface layer.
7. Steel compactor with weight (1 ton) and road compactor with weight (4 ton) are used for compaction work over binder layer, then use level instrument to achieve final elevation for Binder Layer.

8. Spreading tack coat over the Binder layer to ensure the bonding, then laying surface layer. This mix provides a balance in aggregate size, where a high resistance to traffic-load and smoother.
9. Using steel compactor with weight (1 and 4 ton) for compaction work over surface layer, then level instrument used to achieve final elevation for surface layer.

Finally, the in-situ simulation model contains three layers namely; sub-base layer, concrete pavement (rigid pavement) and asphalt pavement (flexible pavement) where their elevations and thicknesses are recorded in Table 1, and they are prepared according to Iraqi Standard Specifications for Road and Bridges.

## INSPECTION, RESULTS AND DISCUSSION

For inspecting the field model, at first three different antennas (250, 500 and 800 MHz) were used respectively on four selected profiles as shown in Figure (5, 6) shows the raw data of radargrams for this test. Then a grid (1.2 m × 1.2 m in dimension) with line spacing of 0.30 m was surveyed to study the capability of GPR for detecting bars within the rigid pavement.

Sixteen profiles have been investigated using the three antennas (250, 500 and 800 MHz) that were applied respectively on the four selected lines Figure (5) to identify the pavement layer thickness, joint location and steel bars reinforcement for the simulation model.

GPR data interpretation and visualization softwares (RadExplorer, Object Mapper and Ground Vision) for roads are used for detecting layer interfaces and individual objects from the GPR data and transforming the GPR data time scale into depth scale. The interpretation results of 250 MHz antenna identify and assign the flexible pavement as one layer without identifying the rigid pavement layer Figure (7). With the 500 MHz antenna, the flexible pavement appeared as one layer with identifying the rigid pavement boundaries Figure (8). While using 800 MHz antenna, both flexible pavement and rigid pavement layers were clearly identified as in the in-situ simulation model Figure (9). Therefore, the 250 and 500 MHz antennas have much more penetration, but much lower resolution. Besides, steel bars and joints were clearly appeared in both 500 and 800 MHz antenna.

Table (2) shows a correlation between in-situ model with radar GPR data. The results show thickness deviations (percentage error) on the order of 1% for surface layer and about 2% for both binder and rigid layers. From this precise calculation of thickness, it can be concluded that an excellent correlation between field model and radar data.

Applying 500 and 800 MHz antennas in trends perpendicular to steel reinforcement within rigid pavement, the steel bars and joints appeared, with spacing 0.25 m (1in) in radargram as shown in Figure (10). The reinforcement bars in rigid pavement clearly appeared before processing as five types; flat, up, down, peak and wiggle. With the assistance of RadExplorer software to interpret the appeared anomalies in the radargrams, the reinforcement bars appeared with dielectric constant equal to 13.6 with velocity equal to 8.1 cm/ns as shown in Figure (11).

## CONCLUSION REMARKS

1. The interpretation results of 250 MHz antenna identified the flexible pavement but it is assigned as one layer without resolving the rigid pavement layer.
2. Applying 500 MHz, the flexible pavement appeared as one layer and identified the rigid pavement boundaries.
3. Rebars and joints clearly appeared when 500 and 800 MHz antenna are used.
4. Using 800 MHz, both flexible pavement and rigid pavement layers were clearly resolved as in the in-situ simulation model.
5. The comparison of the thicknesses obtained from GPR prediction and in-situ simulation model states that the error in the thickness measurements of GPR resulted in about 1% for surface layer and about 2% for both binder and rigid layers.
6. Applying 500 and 800 MHz antennas perpendicular to steel reinforcement within rigid pavement, the rebars (with dielectric constant equal to 13.6 and velocity equal to 8.1 cm/ns) and joints (with spacing 0.25 m) are appeared in the radargram.

## REFERENCES

[1]. Kenneth R. and Maser, P.E., “Ground penetrating radar survey of pavement on MN/Road sections”, Minnesota Department of Transportation Office of Research Administration, Final Report, 1994.

[2]. Yuejian, C., Bojan, B. Guzina, Joseph, F. Labuz, “Pavement Evaluation using Ground Penetrating Radar”, Department of Civil Engineering University of Minnesota, USA, 2008.

[3]. Evans, R. D.,“Optimising Ground Penetrating Radar (GPR) to Assess Pavements”, Ph.D. thesis in Engineering submitted to Loughborough University, 2009.

[4]**.** Benedetto, A. and Benedetto, F.,“Super resolution signal processing of GPR spectra for pavement engineering applications”, Geophysical Research Abstracts Vol. 13, EGU2011-7057, General Assembly, 2011.

[5]. Infrasense, "Non-Destructive Measurement of Pavement Layer Thickness", Submitted to the California Department of Transportation, 2003.

[6]. Saarenketo, T. and Scullion, T., “Ground penetrating radar applications on roads and highways”, Research report 1923-2F, Texas Transportation Institute, College Station, Texas, 36 pp, 1994.

[7]. Saarenketo, T.,”Electrical Properties of road materials and subgrade soils and the use of Ground Penetrating Radar in traffic infrastructure surveys”, University of Oulu, Finland, Acta Univ. Oul. A 471, 2006.

[8]. Rhazi, J., Dous, O. and Kaveh, S., “Detection of fractures in concrete by the GPR tecghnique”, University of Sherbrooke, Canada, 2002.

[9]. Lahouar, S., “Development of Data Analysis Algorithms for Interpretation of Ground Penetrating Radar Data”, Ph.D. Thesis, Faculty of the Virginia Polytechnic Institute and State University, 2003.

[10]. Department of Transportation (DOT), “Feasibility of using ground penetrating radar (GPR) for pavements, utilities, and bridges”, Federal Lands Highway program; Borehole logging, 2006, http://www.cflhdgov/agm/index.htm.

**Table (1) Layers elevation and thickness for in- situ simulation model.**

| Layer | Elevation (m) | Thickness (m) |
|---|---|---|
| Sub-Grade | -0.555 | |
| Sub-Base | -0.334 | 0.221 |
| Rigid Pavement | -0.16 | 0.174 |
| Binder ( Flexible Pavement) | -0.056 | 0.104 |
| Surface ( Flexible Pavement) | 0.018 | 0.074 |

**Table (2) Thicknesses obtained from radargram and in-situ simulation model.**

| Layer | Average Thickness (cm) | | Percentage Error in measurements of thickness from GPR |
|---|---|---|---|
| | From GPR | in-situ simulation model | |
| Surface | 7.48 | 7.4 | ≈1% |
| Binder | 10.18 | 10.4 | ≈2% |
| Rigid | 17.06 | 17.4 | ≈2% |
| Total | 34.72 | 35.2 | ≈1% |

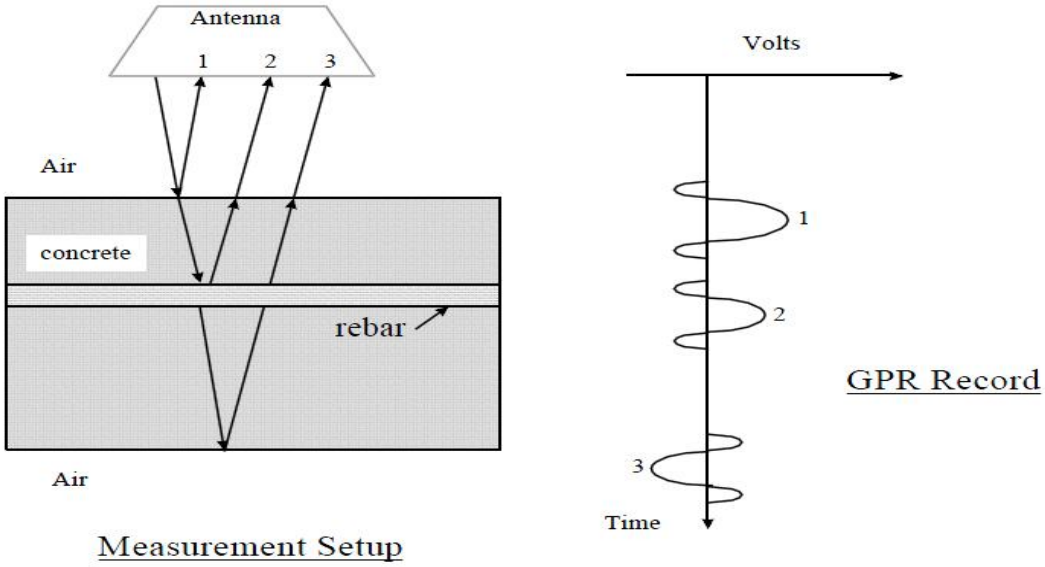


**Figure (1) Antenna setup and measurement: Basic antenna setup (single antenna) is used for bridge deck or pavement evaluation at high speed. Individual Ground Penetrating Radar methods [10].**


**Figure (2) Flexible pavement road section.**

**Figure (3) Excavation and casting concrete works (Rigid Pavement).**

**Figure (4) Asphalt pavement works (Flexible Pavement).**

**Figure (5) Inspecting the in-situ simulation model by GPR.**

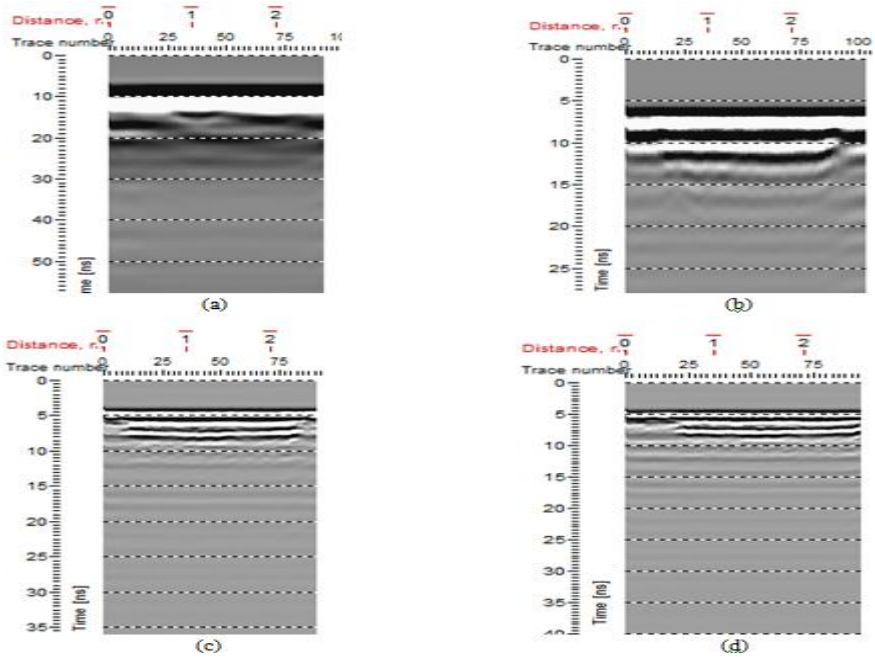


**Figure (6) raw data for radargrams for the in-situ simulation model.**

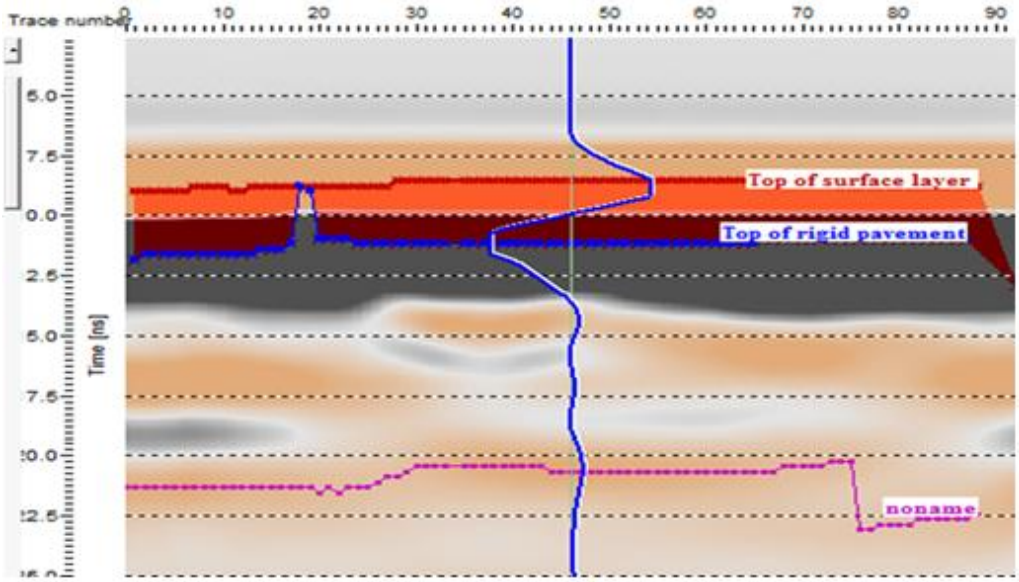


**Figure (7) Using antenna 250 MHz on in-situ simulation model.**

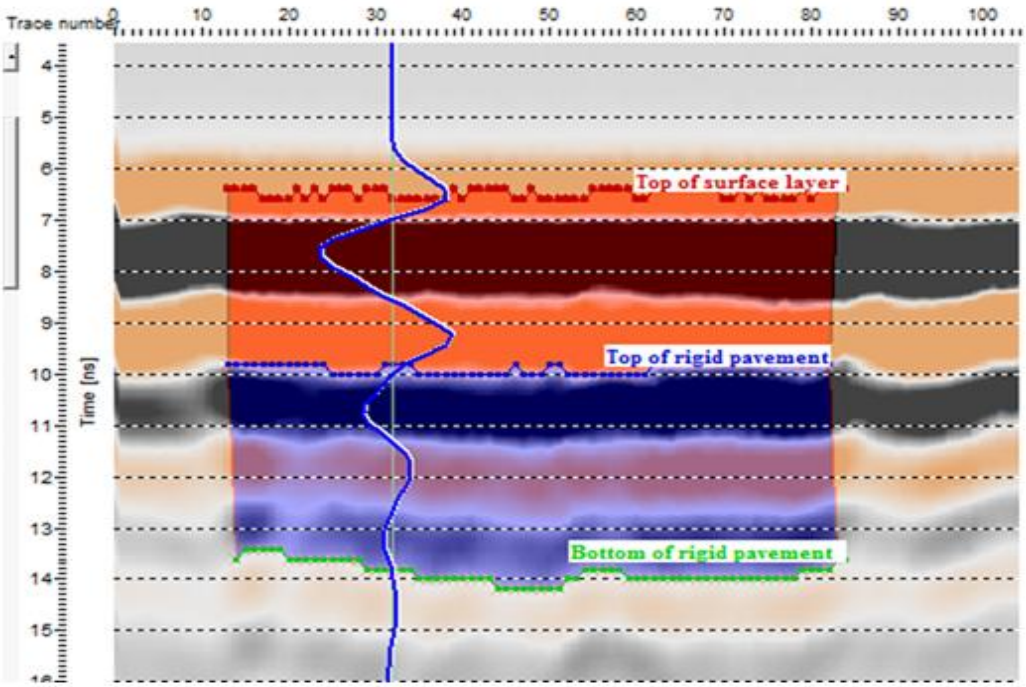


**Figure (8) Using antenna 500 MHz on in-situ simulation model.**

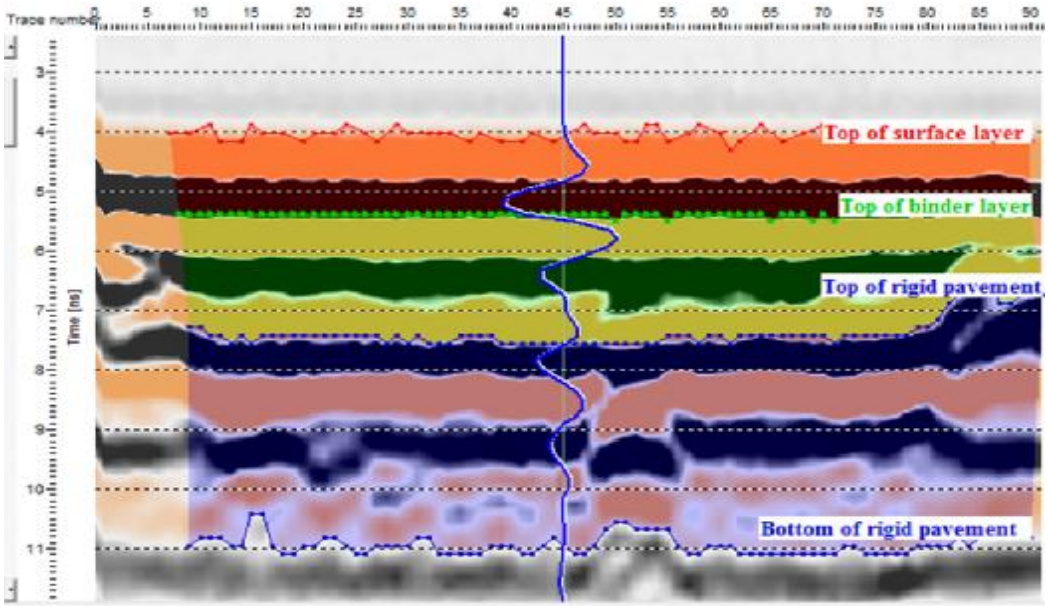


**Figure (9) Using antenna 800 MHz on in-situ simulation model.**

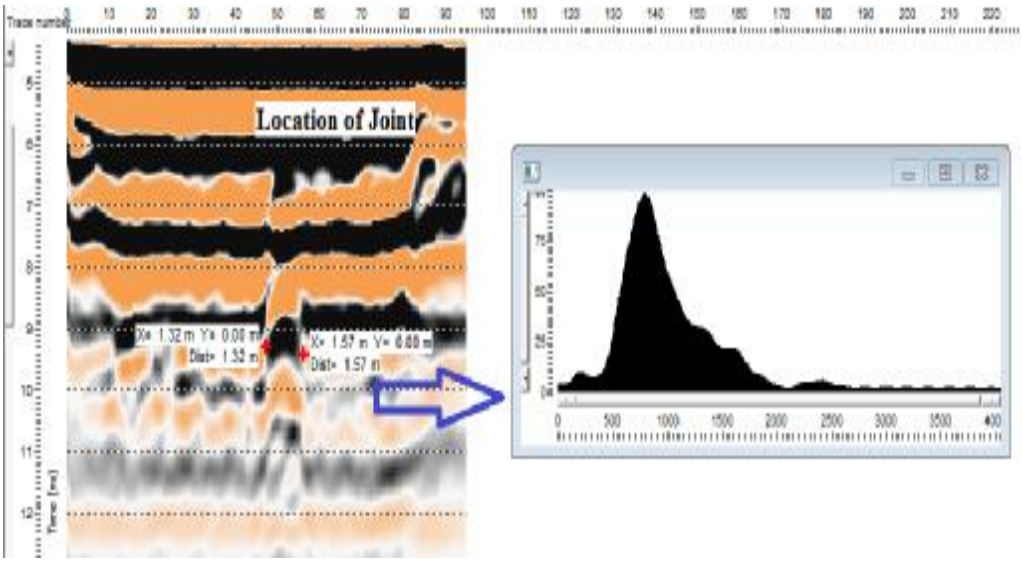


**Figure (10) Radar profile shows joint with its location and width.**

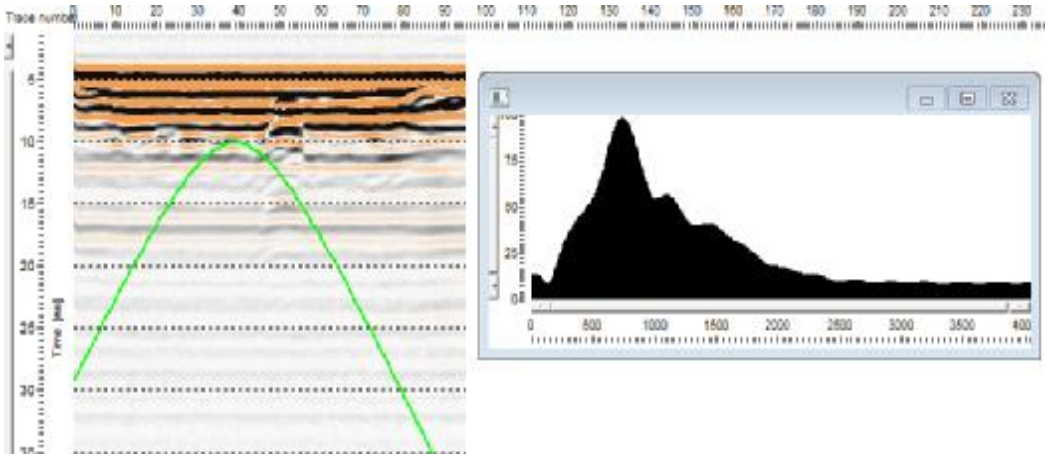

**Figure (11) Radar profile shows steel reinforcement bars with its location and width.**