Determination Variety of Pavement Layers Thickness by Using Ground Penetration Radar Technology

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Abstract

Ground penetrating radar (GPR) is a high-frequency electromagnetic method commonly applied to a number of engineering problems especially in the transportation sector. GPR surveys are routinely and successfully used for quality assurance and quality control (QA/QC) verification in many Transportation Agencies of the world in last ten years.

The present work is to apply the GPR technique for a selected roads sectors to measure variation of pavement layers thickness, (surface layer, base course) hot-mix asphalt (HMA) material, and granular subbase layer.

Keywords: GPR; pavement layer thickness; highway assessment .

تحديد تغير سمك طبقات التبليط بأستخدام تقنية الرادار الفاحص للأعماق

الخلاصة

تقنية جهاز فحص الأعماق التي تعتمد على طريقة أرسال نبضات كهرومغناطيسة عالية التردد، تستخدم بصورة واسعة لحل العديد من المشاكل الهندسية وخصوصاً في مجال الطرق. في السنوات العشرة الأخيرة أصبح أستخدام رادار فحص الأعماق بصورة شائعة وبنجاح كبيرة في عدد من مؤسسات الطرق والمواصلات في العالم، وذلك بأستخدامه لضمان جودة العمل وتوفير الأستشارة لمشاريع الطرق.

في هذا البحث تم أستخدام تقنية الرادار الفاحص للأعماق في تحديد التغير في سمك طبقات الرصف الأسفلتي للطبقة السطحية وطبقة الأساس بالأضافة الى طبقة ما تحت الأساس الحبيبية، لعدد من الطرق ولمقاطع محددة.

1. Introduction

Ground penetrating radar (GPR) is a noninvasive, continuous, high-speed tool that has been used to map subsurface conditions in a wide variety of applications. Many of these applications are well suited for evaluation of highway systems. GPR is basically a subsurface detector; as such it will map changes in the underground profile due to contrasts in the electromagnetic conductivity across material interfaces. [1]

The ground penetrating radar GPR technology has a natural application as a supplementary device for road survey techniques, it is fast, economical, and accurate means of assessment of road pavement conditions, at both the network and project levels, is of great significance to highway management and maintenance. [2]

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GPR can be used to identify valuable parameters that cannot be obtained from a visual evaluation of the road surface. These parameters include pavement-layer thickness and, potentially, damaged, or deteriorated subsurface areas. Moreover, it would be possible to obtain an more accurate characterization of the pavement structure by combining the data provided by such a non-destructive testing system with that supplied by destructive testing (coring and sampling). [2]

This paper will examine the variability in layer thickness by GPR non-destructive testing.

2. Mathematical Models

The basic constituents of a radar system are shown in Figure (1). the radar system causes the transmitter antenna (Tx) to generate a wavetrain of radiowave which propagates away in a board beam. As radio waves travel at high speeds (in air 300 000 km/s or 0.3m/ns), the travel time of a radiowave from instant of transmission through to its subsequent return to receiving antenna (Rx) is of the order of a few tens to several thousand nanoseconds (ns; 10^{-9} seconds).

The transmitter generates a pulse of radiowaves at a frequency determined by the characteristics of the antenna being used at a repetition rated of typically 50 000 times per second. The receiver is set to scan at a fixed rate, normally up to 32 scans per seconds, depending upon the system being used. Each scan lasts are along as the total two-way travel time range, which can be set from a few tens to several thousand nanoseconds. Each scan is displayed on either a video screen or graphic recorder or both. [3]

The majority of GPR applications resolves around the estimation of layer thickness using the travel time technique, where the layer thickness is presented by the time maker in the received single as shown in the figure (2).

The pulse travels back and forth inside the layer, the thickness is computed as:

$$h_{Asphalt} = v_A \frac{\Delta t_1}{2} \quad \dots (1)$$

$$h_{Base} = v_B \frac{\Delta t_1}{2} \quad \dots (2)$$

Where: the electromagnetic wave velocities v_A (in the asphalt layer) and v_B (in the base layer), are related to the dielectric constants ε_A and ε_B in each layer by:

$$v_A = \frac{c}{\sqrt{\varepsilon_A}} \quad \dots (3)$$

$$v_B = \frac{c}{\sqrt{\varepsilon_B}} \quad \dots (4)$$

(c = light speed)

The dielectric constant depends on the in-situ conditions. In practice, one may use the amplitudes of the reflected pulses to estimate the in-situ dielectric constant. Given the dielectric constant in air is equal to 1, the subsurface layer dielectric can be calculated from;

$$\sqrt{\varepsilon_A} = \frac{A_m + A_0}{A_m - A_0} \quad \dots (5)$$

$$\sqrt{\varepsilon_B} = \sqrt{\varepsilon_A} \left[\frac{1 - \left(\frac{A_0}{A_m}\right)^2 + \frac{A_1}{A_m}}{1 - \left(\frac{A_0}{A_m}\right)^2 - \frac{A_1}{A_m}} \right] \quad \dots (6)$$

Where: A_0 and A_m are the reflected amplitude from the top of surface layer and the metal plate, respectively, and A_1 is the reflected amplitude from the top of subsequent layer. [4]

3. Experimental Work

(A) GPR Equipment

The GPR equipment which used in this research has been produced by

Mala Geo Science Company, Sweden. This equipment consists of:

a) Hardware; Figure (3).
   - Object Mapper, used to visual data.
   - Radar Control Unit, used to processer radiowave signals.
   - Antenna (500 MHz), used to transmit and received radiowave pulse.
   - Passenger wheel-path, used to compute truck lane distance.

b) Software;
   Rad-Explorer processing software is used to display and processing data. [5]

(B) Data Collection

The GPR data were collected by the passenger wheel-path for tested 4 trucks lane around Building and Construction Department in University of Technology, Baghdad, Iraq.

GPR can continuously display profile shows thickness of pavement layers (surface, base, subbase), as well as it was dictated subsurface deterioration. Determination of thickness between layers depends on reflectivity of radar wave at the interfaces between layers. Both velocity and reflectivity are depending on the dielectric constant of the pavement layers.

(C) Measurement Settings:

The following settings were used:
Time window: 456 ns
Stacks: Auto
Sampling frequency: 1180 MHz
Point distance: 0.005 cm
Velocity: 100 m\µs

(D) Data Interpretation

Rad-Explorar software which is designed for GPR survey data processing and interpretation were used.

The Rad-Explorer software contains standard routines of digital GPR data interpretation that are used for improving signal-to-noise ratio, increasing resolution, etc. With the help of a variety of techniques of signal processing one shall try to reduce the undesired waves and noise, remove or at least define them on the radargrams for not taking them into account during the interpretation. These routines include: reading and visualization of radargram, DC removal, background removal, trace edit and spatial interpolation on equal profile interval, amplitude correction, deconvolution, 2D and bandpass filtering, migration, topography correction, determination of dielectric constant/electromagnetic wave propagation velocity, time to depth conversion. This does not mean that one must always apply all the routines or is not allowed changing the order of routines. One should apply only those routines that are required in every specific case.

Some of Rad-Explorar routines are applied to raw data to make a more acceptable product for initial interpretation and data evaluation. The applied routines are:

- Background Removal:

The most intensive signal received by the ground-penetrating radar is the signal that arrives directly from the transmitting antenna – a direct wave. The application of "Background removal" routine is necessary when the instrument noise blocks up the desired signal. The essence of this technique is in subtraction of the mean trace determined in the window with fixed size running along the profile from the whole set of traces.

- Stolt F-K Migration:

The "Stolt F-K Migration" routine is applied in order to restore the real location and shape of reflecting boundaries in a section plane.
The main restriction of this algorithm is that the wave propagation velocity within the limits of the section fragment that is under processing considers being constant.

§ Time Adjustment:
The "Time Adjustment" routine is meant for adjusting the zero-point of the vertical time scale to the time-zero, i.e. the moment when the wave has actually left the emitting antenna.

§ Trace Edit:
The "Trace Edit" module allows the user to exclude the invalid and undesired traces and record intervals from the initial record.

(E) Data Processing

The ground penetrating radar pavement layer thickness analysis is carried out by computing the arrival times and amplitudes of the reflections from the different layers. The waveform contains a record of the properties and thickness of the layers within the pavement, as shown schematically in Figure (4).
The GPR data was processed using Rad-Explorer / Ramac software. The sequence of scans shown on the Figure (5) is frequently coded in color or gray scale to produce the scan profile representation. The scan provides the equivalent of a cross sectional view of the pavement, with the individual pavement layers showing up as colored pavement layers by using software techniques represented by apply wiggle traces and variable amplitude, picking modes and interpretation polygons.

4. Conclusions and Results

1- GPR is an efficient technique for measuring the thickness of pavement layers because it's fast non destructive test and cheap comparing with core test.
2- GPR test is more reliable because it's making profile along road comparing with core test which is depend on making holes every 1000 m2.
3- The average difference in pavement layers thickness measurements using GPR as follows:
   - Asphalt surface layer (10.4 cm – 12.2 cm).
   - Asphalt base layer (12.6 cm – 17.5 cm).
   - Granular subbase layer (12.5 cm – 25.0 cm).

5. References

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[5] **Rad-Explorer User Manual**, "The software for GPR data processing and interpretation". Mala Geoscience, Moscow, 2005.

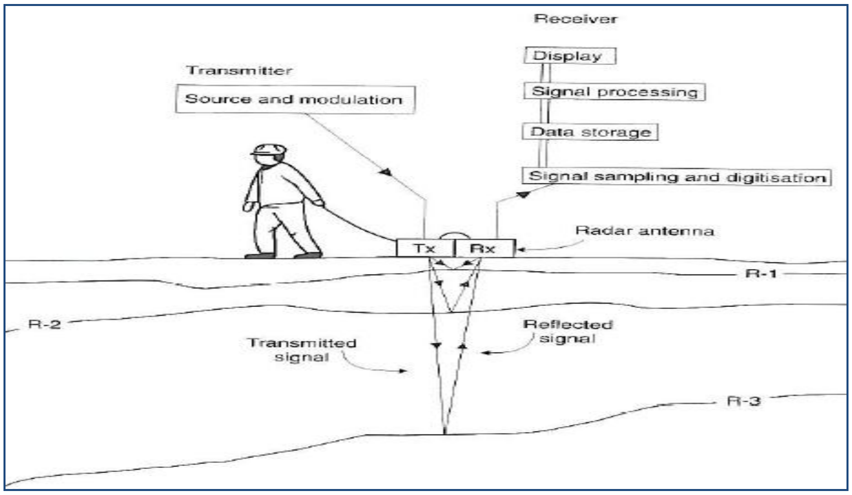

Figure (1) Sketch of basic components of a GPR system and principle of operation. [3]

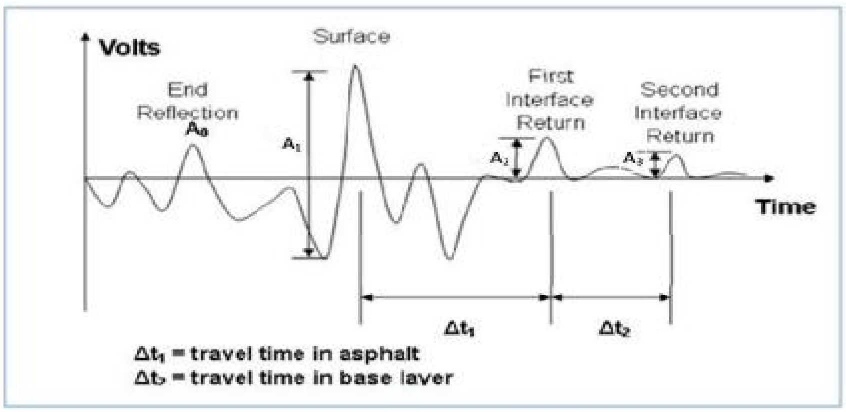

Figure (2) GPR waveform in time. [4]

Figure (3) GPR Equipment

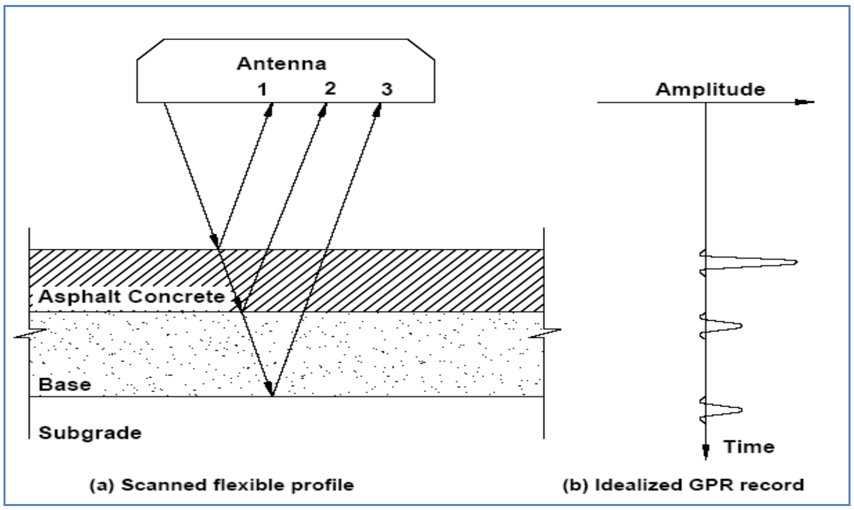

Figure (4) Methodology of determination pavement layer thickness by GPR.

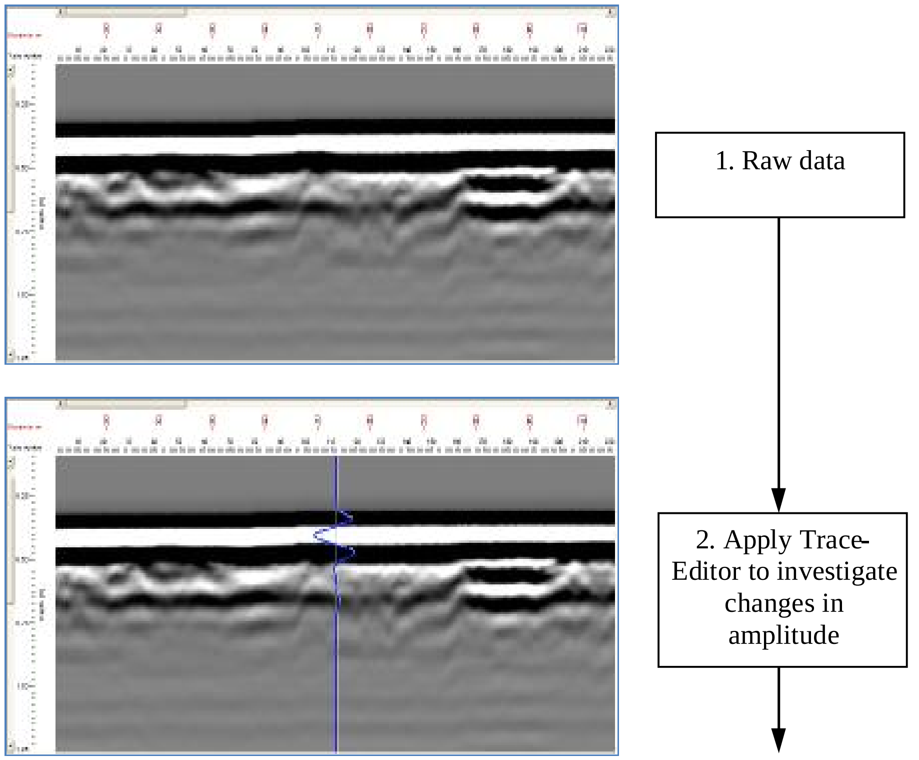

Figure (5) Typical stages in GPR data processing and presentation

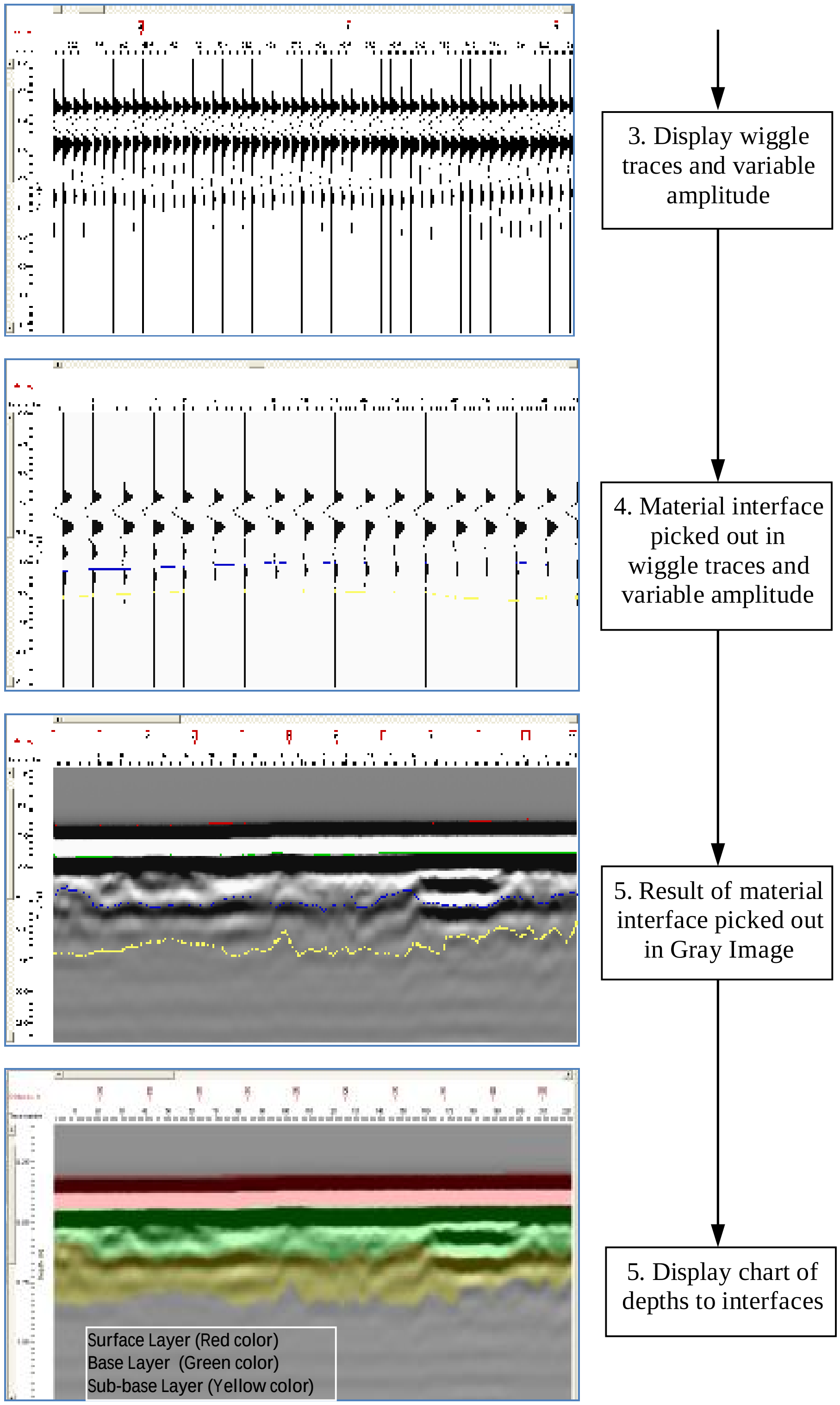

Figure (5) (continued): Typical stages in GPR data processing and