Estimation of Soil Burial and Pavement Thickness using GPR Technique (Case Study)

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Abstract. The ground-penetrating radar (GPR) transmits an electromagnetic wave, and it is a non-destructive test that can be used in geotechnical applications. One of the main benefits of this device is to explore buried underground objects. The study is proposed to find asphalt thickness and compare it with the core test (destructive test) and their error rate. The survey was also intended to detect buried services utilities (pipes, electrical cables, manholes, groundwater level). The current study focuses on finding the device's error rate using an antenna with medium frequencies of 450 MHz in exploring a network of buried pipes, manholes, and electrical cables and comparing them with the actual execution to find the percentage error of the device. The GPR has relatively high accuracy with an error rate for buried utilities and pavement thickness compared with the actual execution is between 4.3% and 10%.

Keywords: GPR, Buried service utilities, Pavement thickness

1. Introduction
GPR is an important geophysical tool that has become increasingly popular due to its high resolution and the need to better understand near-surface conditions. GPR as a non-destructive method uses electromagnetic radiation in the microwave band (UHF/VHF Frequencies) of the radio spectrum and detects the reflected signals from subsurface structures. Ground-penetrating radar (commonly called GPR) is a high-resolution electromagnetic technique designed primarily to investigate the shallow subsurface of the earth, building materials, roads, and bridges [1]. The shape and type of the object discovered by the GPR device depend on the contrast of the energy reflected from the object, while the depth depends on the wave's travel time. GPR has different antenna frequency types such as (80, 160, 450, 750, and 1000) MHz. Selecting a suitable antenna depends on the resolution and depth required [2,3].

Many applications for geotechnical engineering have been investigated by GPR such as: buried foundations, depth of bedrock, various problematic conditions that might exist below the ground such as discontinuities of strata, cavities, soil failure, creep in soil, landfill, pavement layers, mine shafts, buried channels, cracks, water table, reinforcement, location of utilities (pipes, cables, etc.) and other applications [4]. Several studies applied this technique along with electrical imaging resistivity (EIR) to investigate the capability of both techniques to detect the pavement layer thickness and the buried utilities as fast methods for detecting the location and depth of buried features [5,6].

The main aims of the current study are to determine pavement asphalt thickness, detect the different buried bodies in the study site, and determine the error rate between results obtained by GPR and that obtained by actual execution. The device easily detects objects in which the reflected wave energy has
a high contrast with the surrounding soil, but clay soils with high saturated confusion the results, metal objects located on the surface make it difficult to see what is under it.

2. Theoretical background

A basic understanding of electromagnetic wave propagation phenomena is necessary to understand the method. GPR methods use electromagnetic energy at high frequencies (10 to 4000 MHz) to probe the subsurface. The propagation of the radar signal depends on the electrical properties of the ground at a high frequency [7]. The GPR methods measure the velocity and attenuation of the radar waves. These can be used to determine the dielectric constant or relative permittivity, which is the major electrical property of geological materials at high frequencies [8]. In this method, the travel times of the waves reflected from subsurface interfaces are recorded as they arrive at the surface, and the depth, D, to an interface is derived from [9]:

\[
\text{Thickness (or depth)} = \text{velocity} \times \frac{\text{time}}{2} = VT/2
\]

Where:
- D is the depth of the reflector.
- V is the velocity of the radar wave pulse through the subsurface material.
- T is the two-way travel time to the reflector (taken from the GPR trace).

The velocities of propagation of radar signal are related to the relative dielectric constant and relative permittivity (or relative dielectric constant) \((\varepsilon_r)\) [10]:

\[
V = \frac{C}{(\mu_r \varepsilon_r)^{1/2}}
\]

Where \(\varepsilon_r\) \((=\varepsilon/\varepsilon_0)\) is the ratio of the dielectric permittivity of the medium to the dielectric permittivity of free space \((=8.85\times10^{-12}\text{F/m})\), \(\mu_r\) \((=\mu/\mu_0)\) is the relative permeability of the medium is about unity for most earth soils and rocks, and \(c = 3\times10^8 \text{ m/s} (=0.3 \text{ m/ns})\) is the velocity of EM waves in free space. Since \(\mu_r\) is close to unity for most rock materials (accept a few strongly magnetic rocks), radar velocity is primarily controlled by the dielectric constant of the medium as \(\mu_r \approx 1\) [10,11]:

\[
V = \frac{C}{(\varepsilon_r)^{1/2}}
\]

The thickness of asphalt is known by the wave time of the device, according to Equations 1 and 4:

\[
h = \frac{(cext)}{2\sqrt{\varepsilon_r}}
\]

Where:
- \(h\) = layer thickness, in m
- \(c\) = speed of light in free space \((\approx 300 \text{ m/s})\)
- \(t\) = two-way travel time, in s
- \(\varepsilon_r\) = dielectric constant of the material as shown in Table 1.

**Table 1. Dielectric constant of the pavement materials [12]**

| Materials   | \(\varepsilon_r\) |
|-------------|-------------------|
| Asphalt     | 4 - 8             |
| Water       | 80                |
| Air         | 1                 |
| PVC         | 3 - 4             |
| Concrete    | 5 - 8             |
3. Fieldwork and methodology

3.1 Study Site
The site of this study is located in Alrashdia, around 30 km north of Baghdad- Iraq Figure 1. The site consists of several streets and car parks covered with two layers of asphalt and provided by many buried utilities such as pipes, manholes, and electrical cables.

![Figure 1. The survey site along paths by GPR device in Baghdad- Iraq.](image)

3.2 Used equipment and fieldwork
In the current study, a version of the GPR device was used of MALA/ Sweden type (MALÅ GX HDR) in fieldwork which consists of a screen, antenna, battery, and cart. The antenna used in starting fieldwork is with frequencies 160 and 450 MHz in the GX-series antennas for buried utilities. But it was noted that a more clear picture was obtained by using 450 MHz because the depth of the burials does not exceed 4 m, and using medium frequency antenna in this study to find the thickness of asphalt. The GPR surveying was achieved along 30 paths in a total length of 1050 m and covering a total area of 4,500 m$^2$. The paths are in the form of grids with perpendicular lines to show the possible details for buried objects (such as pipes, manholes, and electrical cables) by using a 450 MHz antenna since most service burials depth is usually within 4 m, as mentioned above, see Figures 2 and 3. The paths are numbered in the plan to match the path number in the device data, as shown in Figure 4.

On the other side of this study site, six-core tests (destructive test) were performed in different places in the site to determine the thickness of the asphalt (binder and surface) layers and comparing its results with that of the GPR (non-destructive test) in the same places using the medium antenna (450 MHz) as shown in Figure 5.

![Figure 2. Plan with paths as grid perpendicular lines.](image)
3.3 **Software used**

In this study, Groundvision Program was used. Many filters were used within this program, filtering of radar data is used as an attempt to remove the unwanted signals (noise), and correcting the position of reflectors on the radar record, filtering such as (Band Pass, DC removal, Automatic gain control, Running Mean Trace, Background Removal, Subtract Mean Trace). One can use more than one filter for the same radargram to show the results more clearly as needed.

4. **Results, processing, and interpretation of field data**

4.1 **Pavement**

Six core samples were inspected in the core test with different site locations to show the thickness of the asphalt (binder, surface) layers, as shown in Table 2 below.
Table 2. Laboratory testing (core test) for binder and surface layers (asphalt).

| Inspection Point | Type of layer | Thickness (cm) | Field density (g/cm$^3$) | Lab. density (g/cm$^3$) | Compaction (%) |
|------------------|---------------|----------------|--------------------------|--------------------------|----------------|
| Core 1           | Binder        | 9.4            | 2.224                    |                          | 98.0           |
| Core 2           |               | 8.1            | 2.231                    |                          | 98.3           |
| Core 3           |               | 7.0            | 2.179                    | 2.269                    | *96.0          |
| Core 4           |               | 6.8            | 2.179                    |                          | *96.0          |
| Core 5           |               | 7.0            | 2.193                    |                          | *96.7          |
| Core 6           |               | 8.8            | 2.165                    |                          | *95.4          |
| Core 1           | Surface       | 6.9            | 2.179                    |                          | 97.0           |
| Core 2           |               | 8.0            | 2.219                    |                          | 99.3           |
| Core 3           |               | 6.8            | 2.210                    | 2.234                    | 98.9           |
| Core 4           |               | 5.3            | 2.212                    |                          | 99.0           |
| Core 5           |               | 5.8            | 2.169                    |                          | 97.1           |
| Core 6           |               | 5.3            | 2.186                    |                          | 97.8           |

Then, GPR surveying was performed in the same places from which a core test was achieved. Processing data with suitable filters are using (DC removal, Automatic gain control, Background Removal, Subtract Mean Trace) and interpretation of radargrams to find the thickness of the asphalt along to the grids taken in the fieldwork, such as shown in Figure 6.

Figure 6. A sample of GPR radargram after using filters for pavement thickness (path 1197).

The total asphalt thickness of the two layers (binder and surface) that were inspected by the core test is compared with the thickness of the asphalt using the GPR device, as shown in Figure 7. It was found that the rate of error of the GPR device, compared with the actual (core test) for the average asphalt thickness, is 5.6% using a medium frequency antenna, as shown in Table 4.
4.2 Detecting buried utilities

GPR surveying was performed along 1050 meters in length and covered a total of 4,500 m² distributed on 30 paths of different lengths. The survey was intended to detect buried services utilities (pipes, electrical cables, manholes, groundwater level) and their details compared with the actual to find the accuracy of the GPR device. Thirty paths have been studied and analyzed with their interpretations, two lines only will be mentioned as examples:

4.2.1 Line (1211):
The length of this path is 30 meters, and it was surveyed on the centerline for manholes. After processing the radargram by using several types of filters with its interpretation, the locations and depths of the manholes in addition to the location of the pipes, their direction (cross or longitudinal), length, and slope were found. Along this path, two manholes were found from a distance 0 to the distance 30; one of them is located at a distance of 2 meters from the path with a depth of 2.21 meters. Another manhole at a distance of 30 meters from the path with a depth of 2.11 meters, as shown in Figure 8. Concerning the pipe which connects two manholes with different levels (10 cm), with a slope of 0.36% per 1m, as calculated by equation 5. While the slope of the pipe in actuality is 0.30%, and the plan is 0.25% per 1 m as shown in Figures 9 and 10.

\[
\text{Slope} = \frac{0.10}{(30-2) \times 100} = 0.36\% 
\]  

In path 1211, two electrical cables were found as cross-sections of two hyperbolas, one at a distance of 10.20 m in the path and a depth of 60 cm, while the other cable appears at a distance of 18.40 m in
the path and a depth of 80 cm. It is worth noting that these cables were not fixed in the plan (as built), but GPR detects them, so the Company considered this note, and it was informed to drawing it in the plan (as built).

4.2.2 Line (1210)

The length of the path (1210) is 390 m. It was taken on the centerline for manholes. After radargram processing using several types of filters, the program will identify the locations and depths of the manholes in addition to the location of the pipes, their direction, length, and slope, as shown in Figure 11-a, Figure 11-b. It was found in part of this path (from 108 m to 143 m) two manholes; the 1st with depths of 100 cm at the distance of 115 m while the 2nd at depth 107 cm and at the distance of 140 m. Regarding the pipe connecting between the two manholes, at a distance of 108 m, the depth of the center of the pipe is 95 cm. At the distance of 143 m, the depth of the center of the pipe is 110 cm, where the difference is 15 cm due to the inclination over a distance of 34 m.

\[
\text{Slope} = \frac{0.15}{(143-108)} \times 100 = 0.43\% \quad (6)
\]
The results for this path were obtained by the GPR, which has been compared with the actual execution, and the results are shown in Figure 12 and Figure 13. Concerning groundwater level, GPR detected it according to the change in the shape of the received signals of the radargram.

Figure (11-a). Line (1210) by GPR after using filters in Groundvision program.

Figure (11-b). Cross-section pipe by GPR after using filters in line (1199).

Figure 12. Results for depths manholes and diameter of the buried pipe in line (1210).
After studying all of the 30 paths that the GPR surveyed, Table 5 represents the error rate between the GPR and the actual for the location, depth, and slope of pipes, water table, location and depth of manholes, and cables.

Table 4. Percentage of GPR errors for the buried utilities.

| Type                        | Depth of pipes | Slope of pipe | Water table | Depth of manhole | Depth of cable |
|-----------------------------|----------------|---------------|-------------|------------------|----------------|
| Percentage of error         | 4.3%           | 10%           | 5.1%        | 8%               | 5.5%           |

5. Conclusions

- The results showed that it is possible to measure the thickness of the asphalt by GPR device using a medium frequency antenna (450 MHz) with an error ratio of 5.6% for the GPR.
- Several buried service utilities (sewage pipes, electrical cables, manholes, groundwater level) have been detected using GPR with a 450 MHz antenna.
- The results showed that the GPR error rate for buried sewage pipes compared with the actual is 4.3% and for the slope is 10% using the GPR.
- The study concluded that it is difficult to find the depth of the manhole if its cover is made of metal due to signal confusion, but it can be detected by knowing the depth of excavation of soil around the manhole and with the percentage of error is 8%.
- After analyzing and processing the results, the error rate of the GPR in finding the depth of electrical cables is 5.5%, while for detecting the groundwater level by the GPR and compared with the actual is 5.1% using the GPR.

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