Investigation structural settlement by Ground Penetrating Radar (Case study)

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Abstract. Electromagnetic wave is transferred by the GPR (ground penetrating radar), and A geotechnical application may benefit from this non-destructive test. This study is proposed to estimate the type and soil problem location that causes differential settlement of a structure (pumping station) by GPR surveying. The survey is achieved before and after the treatment by cement injection method to identify the locations that took cement injections as a full injection, partial or not at all using two types of antennas (160,450) MHz. The study also will estimate the thickness of the foundation by GPR and comparing it with actually executed. The results showed the creeping soil has occurred in some parts of the soil under the foundation, and after soil treatment, most of these parts were taken injection, and others did not. Also, it was found the relatively high accuracy of GPR for detecting the thickness of the raft foundation.

1. Introduction

Due to its non-destructiveness and the need to better understand near-surface conditions, ground penetrating radar (GPR) has become a commonly used geophysical instrument. As a non-destructive technique, GPR makes use of microwave radiation (UHF/VHF Frequencies) to find reflected signals from underground objects. Building materials, roads, bridges, and other subsurface infrastructure may all be studied using ground penetrating radar, which is a type of electromagnetic wave used primarily to probe the earth's low-depth subsurface. The GPR instrument detects soil or rock deformation by comparing the energy reflected off the body to the energy emitted, with the depth being estimated by the time it takes for the wave to travel. Antenna frequencies in GPR range from 80 MHz to 1000 MHz (each with a different number of channels). The accuracy and depth required dictate which antenna is best [2, 3].

The GPR has been used to inspect many geotechnical engineering applications, including solid rock depth, buried foundations, and a variety of problematic conditions that may occur below the ground, such as cavity formation, discontinuities in layers, soil collapse, landfill creeping, and other uses [4]. In previous studies, Bakir H. B (2008) [5] detected weak zones at a proposed dam site by using the ground penetration GPR technique with the electrical resistivity (ER) technique, which is located in Koya city- Sulaimanya, north of Iraq. In this study, a 100 MHz unshielded antenna was used with the portable control unit. Many anomalous like limestone rock blocks and a large zone of cavities in addition to groundwater table have been detected. The main aims of this study are estimation the type and locate soil problem that causes differential settlement of the pumping station structure by GPR and surveying the soil before and after the soil treatment (cement injection method) to identify the locations that took cement injections or not and estimation the thickness of foundation by GPR and comparing it with that found in the actual design using two types of antennas (160, and 450 MHz).
Karim and Al-Dami (20012a) [6] studied the ability to use the GPR with 250 MHz and 500 MHz antennas (middle frequencies) to explore the reinforced bar of concrete to show the number of steel bars and their configurations in the concrete constructed in the hidden mensuration. Another study by Karim and Al-Dami (2012b) [7] was achieved to simulate GPR data got by 250 and 500 MHz antennas for low deep inspected by discovering different underground bodies.

2. Theoretical Background

To understand the procedure, you must first understand the fundamentals of electromagnetic wave transmission processes. To investigate the underground, GPR systems use extremely high rates of electromagnetic energy. The dielectric characteristics of the substance at a high frequency determine the transmission of the radar signal [8].

The radar waves' speed and attenuation are measured using GPR techniques. These can be used to determine the dielectric value or relative permittivity of geological layers at very high frequencies [9]. The travel periods of reflected waves from subsurface boundaries are documented as their reach at the surface in this technique, and the depth, D, to boundary lines is calculated using [10]:

\[ D = \frac{TV}{2} \]  

Where:
- D: the reflector's depth.
- V: the speed at which the radar signal pulses through the subterranean bodies.
- T: the time it takes to get to the reflector in both directions.

The thickness of a pavement is found by the wave period of the device, as to equations (1) and (4):

\[ h = \frac{(c \times t)}{2 \sqrt{\varepsilon_r}} \]  

Where:
- h: The thickness of a layer is measured in meters.
- c: free-space light speed (≈ 300 m/s)
- t: time in both ways, in seconds.
- \( \varepsilon_r \): constant of dielectric property of the substance material as shown in Table 1.
Table1. Dielectric constant of some materials [11, 12].

| Materials | $\varepsilon_r$ |
|-----------|----------------|
| Asphalt   | 4 - 8          |
| Water     | 80             |
| Air       | 1              |
| PVC       | 3 - 4          |
| Concrete  | 5 - 8          |

3. Field Work and Methodology

3.1. Location and Geology of the Site Study
The site of this study represents the pumping station which is located in the southeast of Baghdad-Iraq; the site has dimensions (45 * 90) square meters.
The soil has been indicated by four boreholes (BH1, BH2, BH3, BH4) at the site study with depth each one of 30 m. represents the soil section in these boreholes and the geotechnical properties of the tested soil.
Rotary Auger drilling was used to carrying out the field investigation with core barrel for continuous coring and thin wall tube samplers according to standards of the American Society for testing and materials (ASTM D6151-08).
The visual classification and grain size analysis results indicate that the soil ranged in classification and was composed mostly of two main layers clayey soil layer with color dark brown till about 13.0 m depth can be classified generally as low plasticity clay (CL) then follow about (13.0 to 30.0) m by sandy to silty soil with dark gray color soil can be classified generally as silty sand (SM).

Table2. Results of different soil tests.

| Tests                                    | Results               |
|------------------------------------------|-----------------------|
| The value of liquid limits for plastic material | 30.0%-44.0%           |
| The specific gravity GS for clay soil    | 2.60 to 2.64          |
| standard penetration test (SPT)          | (9-37) blows          |
| the cohesion at depths (7.5m-8.0m)       | (82-283) kPa          |
| angel friction at depths (7.5m-8.0m)     | 19°-36°               |
| unconfined compressive strength at depths (7.5m-8.0m) | (246 – 472) kPa       |
| the cohesion (19.5m-20.0m)               | (3-4) kpa             |
| angle of friction at depths (19.5m-20.0m) | (41°-43°)             |
| the organic material content (OM)        | (3.88-5.84%)          |
| the carbonate percentage                 | (8.0-10.0%)           |
| the chloride                             | (0.03%-0.5%).         |

3.2. Instrument and Software Used
The version of the GPR device that was used in this study (MALÅ GX) with a system containing different parts (monitor, antenna, other tools) as seen in ‘Figure 1’, Ground vision Program was used in this study. 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.

![MALA GX version of GPR](image)

**Figure1.** MALA GX version of GPR.

### 3.3. The first scanning works by a GPR device (before cement injection process)

The number of the surveyed paths inside the station is 118 paths*2 antennas = 236 paths, and 19 paths*2 antennas = 38 paths outside the station and the distance between the path and other was 1.0-3.0 m as a grid lines as illustrated in ‘Figure 3’. To detect the cause of the soil problem, the antennas type 160 MHz GX and 450 MHz GX were used along the aforementioned paths.

### 3.4. Improvement the soil by cement injection

To improve the properties of the soil under the foundation of the structure in which the settlement problem occurred.

The cement liquid was injected by pumps through two sets of tubes:

1) Pipes 3-inch vertical tubes with different depths (6, 14, and 18 m) in a 3-row shape around the structure to be doing in the form of a concrete wall in the soil around the structure that prevents the exit of any injected later with a group of half-inch diameter tubes to let water out of the soil during the injection.

2) Pipes of diameter 3 inches inclined at an angle of 45 degrees, starting from the surface around the structure and ending under the foundations of the building, with length pipes of 18 to 24 meters. More than 600 tons of sulfate resistant cement (SPC) was used in the injection process as seen in ‘Figure 2’.
Figure 2. Sets of pipes for injection to improve the soil.
Figure 3. Paths design of GPR surveying in the site of south Baghdad for before and after soil treatment.
3.5 The second scanning (re-surveying) works by a GPR device (after cement injection process) 
The process of re-surveying was carried out by the GPR device after treating the soil under and around 
the structure by using cement injection and for the same paths that were surveyed before the injection 
process to compare the places that were successfully injected and the places that were not injected well 
as illustrated in ‘Figure 4’.

The structure was surveyed by the GPR device using an antenna with a frequency of 160 and 450 MHz 
that included a complete survey from the inside and outside around the site study.

![Image of GPR device](image1)

**Figure 4.** Surveying by GPR inside and outside the pump station.

4. Results, Processing, and Interpretation of Field data
The GPR was used for the pumping station structure to find out the cause of the problem that led to an 
irregular settlement on one side of the structure. It was found through the survey and after data 
processing using filters by the Ground Vision program that the creep in the sandy soil and weak zones 
has occurred in the soil as shown in ‘Figure 5’. The reason for this case may be due to the continuous 
withdrawal of water with small soil particles from the well without using a filter specially designed for 
this type of soil, this well was created during the excavation process.

![Image of GPR survey](image2)

**Figure 5.** Creep with weak zones in the sandy soil by GPR surveying.
All paths in ‘Figure 3’ have been processed and interpreted, but the paths in this article were selected as examples for clarification. After the soil treatment by using cement injection data processing using the program’s filters and then interpreting them, it was found that there are places in the soil that have taken the cement injection, while there are other places in the soil that have taken the injection partially, while there are places in the soil under the structure that the cement injection did not reach it at all by using 160 and 450 MHz antennas as illustrated in ‘Figure 6’.

![Figure 6. Partially grouted through GPR surveying.](image)

On the other side, the thickness of the foundation (raft type) of the structure was measured using the GPR device and compared with the thickness in the planning using two types of antennas (160 and 450 MHz). It was found that the GPR is high accuracy with an error rate of 4% for this type of measurement using the 450 MHz frequency antenna as seen in ‘Figure 7’.

![Figure 7. Estimating thickness of the raft foundation by GPR.](image)
5. Conclusions
The GPR device can be used to identify the type of problem in the soil such as creep and weak zones, as well as the saturated conditions of the sandy soil and the level of groundwater. GPR gives good results concerning detection of the places in the soil that took the cement injection (improved soil) as a good injection, partially, or did not take the injection at all. The thickness of the raft foundation using GPR with an antenna frequency of 450 MHz was found with a rate of error of 4% compared with that actually executed. In this work, the re-surveying by the GPR is recommended for the places that did not take cement injections as partial or at all after re-injected them again.

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