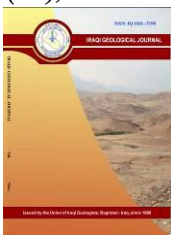
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Engineering Problems Investigation in a Construction Site, Baghdad City, by Using Ground Penetrating Radar

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Abstract

Several Ground Penetrating Radar profiles were distributed to survey the involved area, which amounted to 2600 m^2 within the construction site at Al-Mansour district within Baghdad City. The Ground Penetrating Radar profiles were distributed into two main parts: the first group in the vicinity of the study area, while the others were within the boundaries of the building. A set of filters and digital processors was adopted within the Reflexw software to improve the quality of the radargram signals in order to enhance the results and make them clearer for interpretation. The Ground Penetrating Radar results demonstrated two layers, whereas the sub-soil of the study area (inside and outside the building) was heterogeneous; however, the first superficial depth of the top soil, which is located below the Asphalt layer, is ≈ 2 m, consisting of clay material, sand, and organic material from the activity of living organisms. This layer also includes some pipes of infrastructure, voids, and weak zones. However, the second layer was thicker and relatively less heterogeneous than the first one, consisting of sand, silt, sometimes salty soil with organic materials, and some soil creep inside. Consequently, the current research demonstrates the effectiveness of using geophysical methods, e.g., Ground Penetrating Radar, to identify the weak areas in the subsoil either before or after the construction of any infrastructure.

Keywords: Ground Penetrating Radar; Soil characterization; Weak-zone identification; Geotechnical survey; Baghdad City

1. Introduction

The Ground Penetrating Radar (GPR) method is one of the geophysical methods that partially relies on the high resolution of electromagnetic wave signals, recording, filtering, and displaying. It is applicable in many different geological, environmental, and geotechnical studies (Davis and Annan, 1989; Daniels, 2004; Conyers, 2012; Lai et al., 2018). The method is characterized by being non-destructive, fast, and easy when compared to seismic survey methods. It is similar in some extent to the seismic method in terms of operating principles (Jol, 2009; Reynolds, 2011). The penetration depth of electromagnetic waves depends on the sub-soil properties. Low-frequency signals have a greater penetration depth but lower accuracy, while higher-frequency signals offer higher accuracy but shallower penetration depth (Neal, 2004; Milsom and Eriksen, 2013).

The method is used to accurately determine the size, shape, and depth of buried objects (Benedetto et al., 2017; Thabit et al., 2019). The GPR is used to explore subsurface heterogeneities, fractures, and voids which resulting from severe environmental issues (Leucci, 2019; Saintenoy and Hopmans, 2011).

It is commonly used to solve engineering and geotechnical problems, detecting weak zones in soils, and for other applications of near-surface investigations (Grote et al., 2003; Annan, 2005; Benedetto and Pajewski, 2015).

The GPR geophysical technique was used in several engineering and geotechnical applications in Iraq (Mohammed, 2025). In this study many subsurface structures were identified, like weak zones in front and in the center of the building and the weakness features that extended in depth from the ground surface to about 6 m. Many near-surface features like weak zones, creep, filling materials and collapse within 5 m depth under the foundation of the building were identified as well. The GPR technique was even used to investigate the differential settlement of the sub-soil, which occurred in the modern building in the centre of Karbala city (Mohammed, 2025). The technique was found to be efficient in identifying the weak zones of soft materials and cavities in the sub-soil beneath such building foundation down to the depth of 5.5 m, which caused a building structure drift towards the southeastern side (front side of the building).

Several engineering issues can be encountered before or after the building construction, such as soil creep, cracksand/or foundation subsidence, which can cause severe problems and risks. Some of these issues have been observed in the infrastructure of a constructed multistory building (study area) within Al-Mansour district due to the demolition and the new re-construction (construction activities) of neighbouring buildings, which probably affected the adjacent constructions; therefore, the current study aims to identify subsurface geotechnical soil properties and potential weak zones of the mentioned area using the GPR survey technique.

2. Location of the Study Area

The study area is located within Baghdad Governorate, on the Al-Karkh side, and particularly at the Al-Mansour district, as shown in Fig. 1. The study area has great economic and commercial importance. It is famous for urban renaissance and construction activities, with many malls, complexes and various commercial centers that have been built. This multistory building (site of investigation) is closely located in the middle of the Al-Mansour district. The area of the building is 2600 m^2.

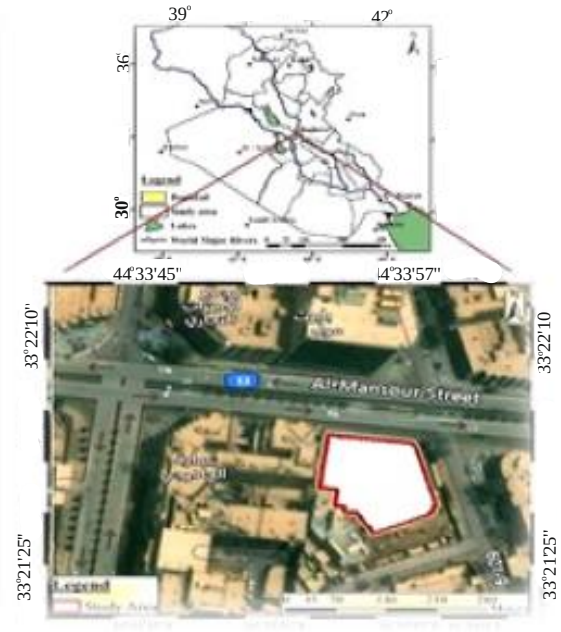


Fig. 1. Location map of the study area at Baghdad Governorate, the red rectangle in the aerial image represents the area of the building site within Al-Mansour district

3. Materials and Methods

The GPR technology is suitable for exploring shallow features that are located near the ground surface, such as cavities, monuments, cables, graves, etc. (Leucci, 2019). When the GPR signal comes out of the shielded box (consisting both the transmitter and receiver), part of the antenna is responsible for transmitting the waves and travels through the medium. It is then reflected and received by the part of the antenna which responsible for receiving the waves returning from the ground. The penetration depth is determined by the type of antenna that is used (Jol, 2009). The field work involved exploring the soil properties and their ability to support a multistory building, as mentioned before. The survey was conducted using LMX200™ (ground-penetrating device) (Fig. 2).

The 250 MHz antenna has been utilized, which is commonly used in such environmental surveys to detect voids and cavities (Sensors and Software, 2020).



Fig. 2. A photo showing the GPR device type LMX200™ during field surveying

3.1. Processing Software

The ReflexW software has been used to process the GPR data, which is constructed and developed by Sandmeier Geophysical Research (Sandmeir, 2012). It is considered one of the most important geophysical programs, as it provides two-dimensional and three-dimensional data processing and presentation. This program can be used in processing and interpreting GPR data, processing and interpreting reflective and refractive seismic data, processing VSP voltage wave data, and also in processing and results display of seismic reflection/refraction in the forms of sections and cube visualization which facilitates interpretation, and finally valuable in geotechnical, hydrogeological and borehole geological data surveys, (Sandmeir, 2012).

There are several processing filters (represented by the sixth steps) that have been applied to the raw radargram (Fig. 3). The first radargram in Fig. 3 represents the real raw data recorded by the GPR

device. The second step represents the radargram after applying the time zero correction. The third step represents radargra with using the gain filter. The fourth processing step represents the dewow filter application. The fifth step represents radargram after applying the bandpass filter. The sixth step represents radargram after applying the migration processing.

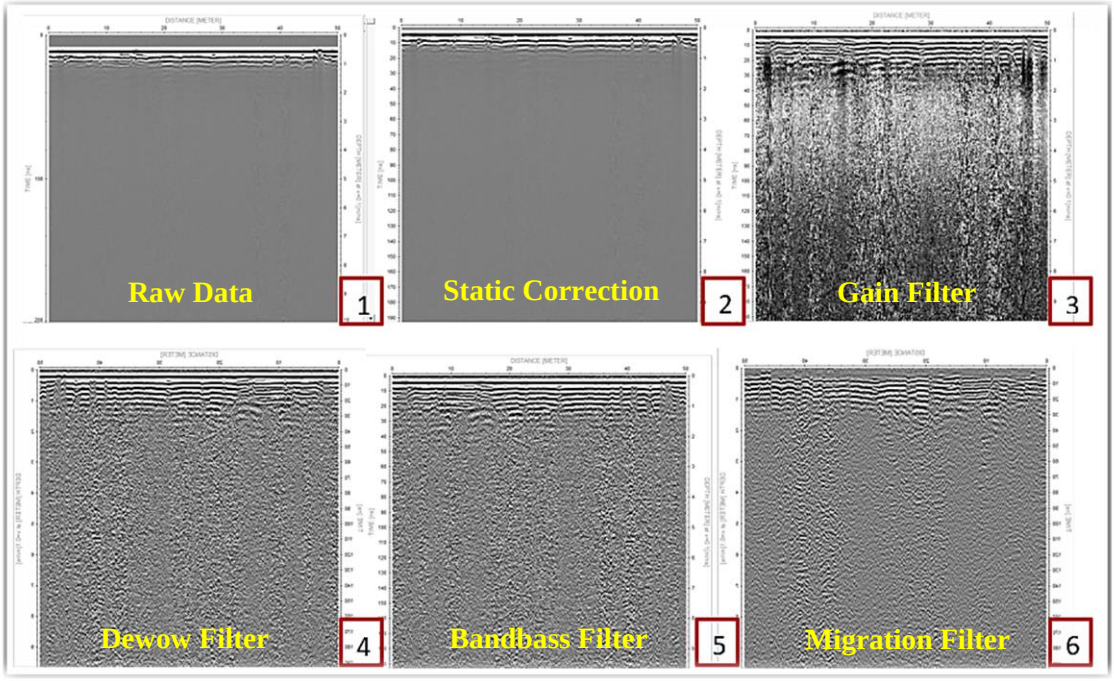


Fig. 3. The steps of processing filters applied to enhance the GPR radargrams, an example of a profile outside the building

3.2. GPR Survey Setup

A detailed survey has been conducted and the surveying lines are divided into two sets of 2D GPR profiles: The first group consisting of four profiles, as shown in Fig. 4, which is conducted outside border of the building to investigate the extention of the engineering issus, e.g., potential weak zones around the construction, i.e., to see whether it extended inside and/or outside the building area, this will helps to large extend in understanding lateral changes in sub-soil layers.The second GPR survey group is conducted inside the building, which consists of five profiles in different directions, as shown in Table 1. The lengths of the second group of profiles (inside the building) were different in which it depending on the survey's accessibility to the empty area inside the building (Fig. 4).

Table. 1. The location and direction of GPR survey profiles within and around the study area

GPR profile No.	Location of GPR profiles	Direction of the survey	Fig. No.
1	Surrounding the building	N-S	Fig. 5
2	Surrounding the building	N-S	Fig. 6
3	Surrounding the building	SE- NW	Fig. 7
4	Surrounding the building	SE- NW	Fig. 8
5	Inside the building	NW-SE	Fig. 9
6	Inside the building	NE-SW	Fig. 10
7	Inside the building	S-N	Fig. 11
8	Inside the building	S-N	Fig. 12
9	Inside the building	NW-SE	Fig. 13

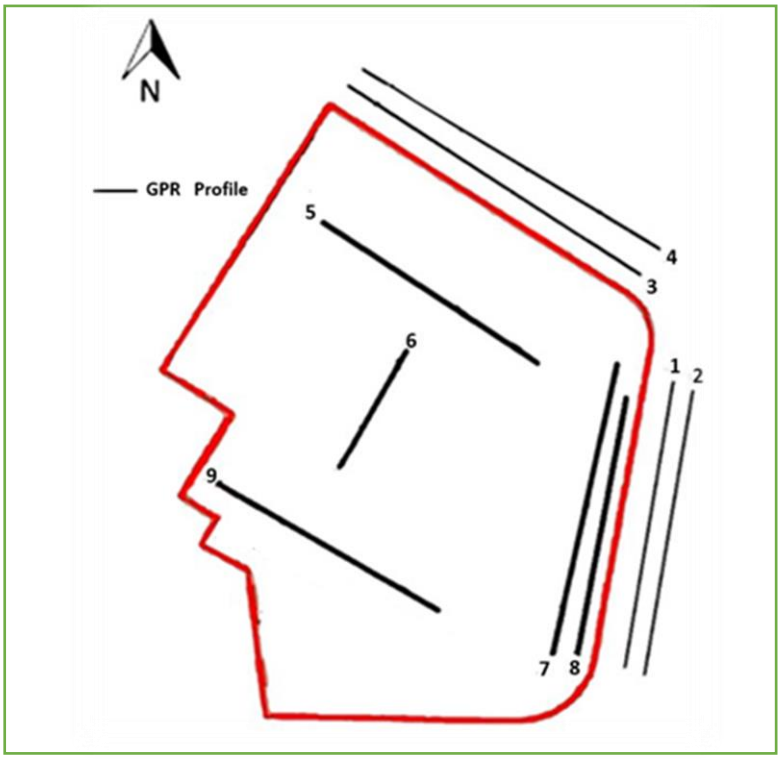


Fig. 4. The distribution of nine GPR profiles (profile lengths are not to scale) inside and outside the borders of the study area (the multi-story building) in Al-Mansour district. Each profile starts from a numbered point on the map. Directions of survey for profiles 1, 2, 6, 7, and 8 are almost in the North-South direction, while profiles 3, 4, 5, and 9 are in the Northwest-Southeast direction, as illustrated in Table 1

4. Results and Discussions

The first profile from the first group (bearing No. 1 in Fig. 4) was 50 m in length (Fig. 5). By observing the radargram obtained from surveying this profile, one can detect the following: an upper layer represents the asphalt layer and was identified by regular parallel reflections with a range of thickness 15-20 cm. In the second layer, weak reflections have been observed due to scattering and signal absorption due to the heterogeneous soil. This layer represents the backfill layer under the road. The second layer is interspersed with hyperboloids, indicating pipes at a depth of 0.5 m.

The second profile of the outside building group (bearing No. 2 in Fig. 4) is 50 m in length (Fig. 6), and its radargram shows two layers. The first one represents the asphalt layer with around 20 cm thick, which was confirmed by a clear and regular reflective layer, indicating homogeneity in the paving material. This layer resembles the shape and regularity of the first layer as in the first profile. In the second layer, a gradual fading of radar reflections has been observed, with distortion and a lack of clarity in the layer structure due to the presence of loose clayey-soil particles, which leads to high absorption of the GPR signal.The second layer is interspersed with hyperboloids, indicating pipes at a depth of 0.5 m.

These two adjacent profiles outside the building boundaries in which their direction were almost in the north-south direction. There are some observed anomalous features located between the distances 38-46 m probably indicate the presence of weakness or heterogeneity in the sub-soil.

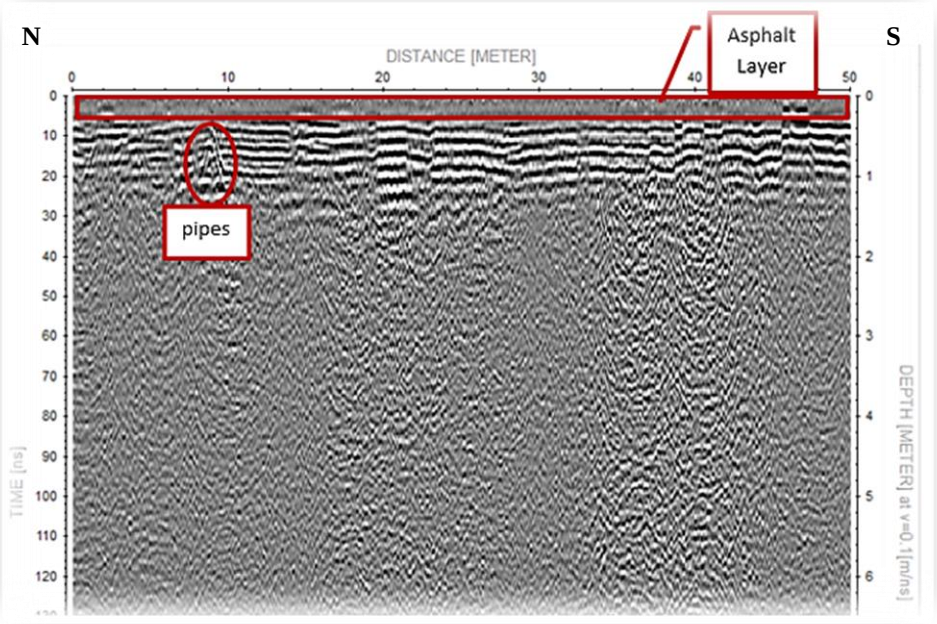


Fig. 5. The first GPR profile from the outside building survey group

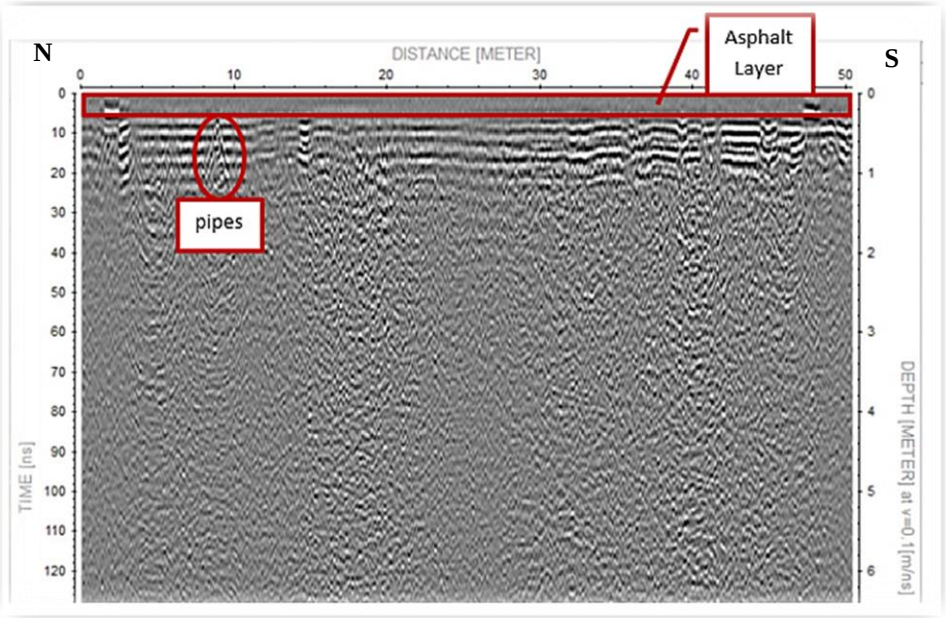


Fig. 6. The second GPR profile of the outside building group. The voids and weak areas in the soil were confirmed by drilling a well in the study area

The third profile of the outside building group (bearing No. 3 in Fig. 4) is about 45 m long. This radargram consists of two main layers, as shown in Fig. 7, the first layer which is located at the top, is thinner and represents the asphalt layer (≈ 20cm), while the second one represents the soil layer under the asphalt, which is thicker than the first, from west to east, contains probably voids or/and weak zones at a distance of 2 m and depth of approximately 1 m, a distance of approximately 20 m and a depth of 1m and at a distance of 37 m and depth of less than 1 m, respectively (Fig. 7). Pipes were appeared in two places, the first layer at a distance of approximately 24 m, whereas the second one at a distance of 33 m,

both at a depth of less than 1 m, and appeared clearly from the hyperbola feature. The last weakness zone was appeared at a distance of 42 to 45 m and depth of approximately 1 m. These results were confirmed by the well information which drilled within the study area.

The fourth profile of the outside building group (bearing No. 4 in Fig. 4) is about 45 m length. This radargram (Fig. 8) consists of two main layers: the first is thinner, located at the top, represents the asphalt layer, while the second represents the soil layer under the asphalt, which is thicker than the first one displaying from west to east radargram, contains a group of voids at different distances. Four areas of voids or weak zones features are observed, and it is noticed that they are all similar in location to the third profile due to their proximity to each other. The first void appears at a distance of 2 m and depth of less than 1 m, the second void appears at a distance of 22 m and depth of 1 m, while the third and fourth voids appear at distances of 33 to 39 m and depth of 1 m. These are noticed from the nature of the reflections in the radargram.

The third and fourth profiles represent the second section of the first group (profiles outside the building boundaries), and their direction was Northwest-Southeast, as illustrated in Table. 1.

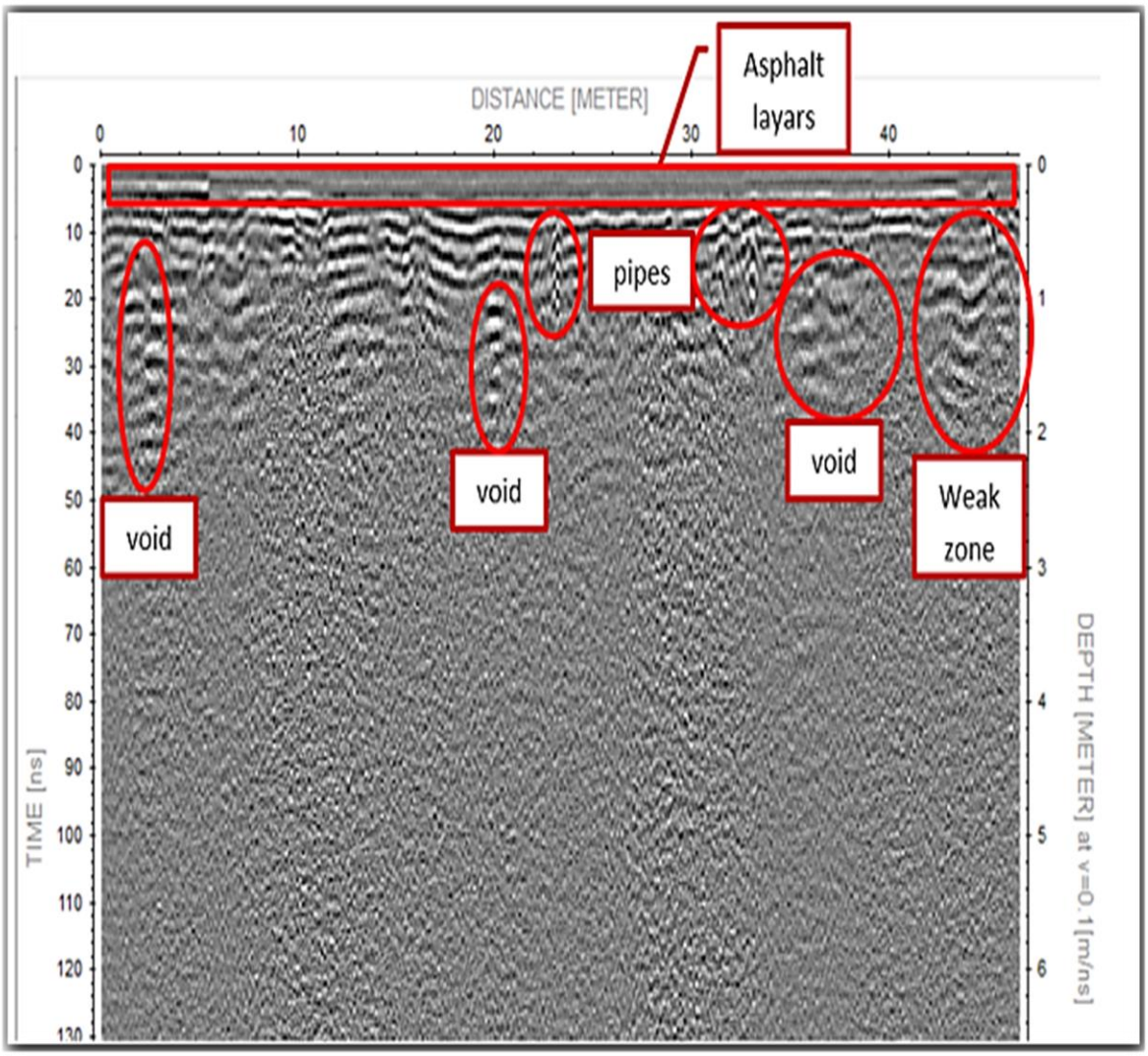


Fig. 7. The third GPR profile of the first group outside the building

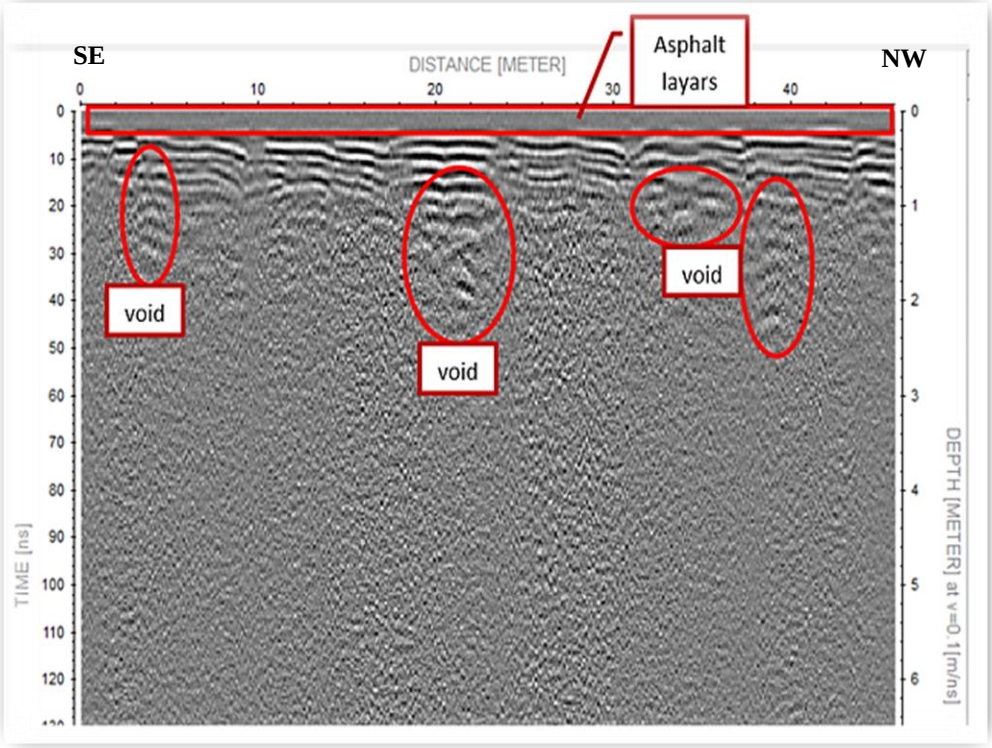


Fig. 8. The fourth GPR Profile of the outside building group

The first profile of the second group inside the building (beairng No. 5 in Fig. 4) is 16 m in length. The radargram (Fig. 9) shows areas of potential soil creep, located at distances between 4-5 m and 10-14 m, respectively. A distinctive horizontal reflection in the upper part of the record between 0-1.5 m represent relatively undisturbed layer. The distortions and discontinuities in the reflections at depths of 2.5-4 m indicate probably slow soil movement. The soil creep was confirmed by the information of the drilling well which is existed in the study area and in comparison with the results of the neighboring profiles.

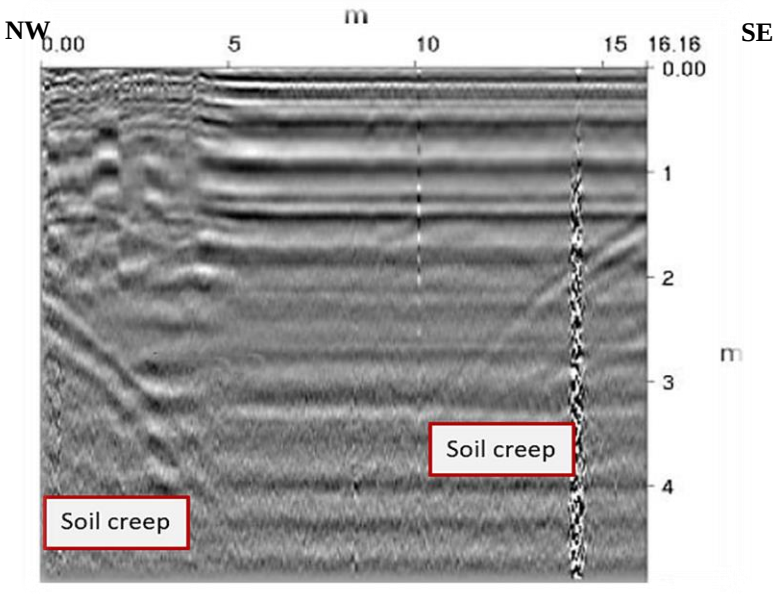


Fig. 9. The fifth GPR profile from the second group inside the building

The second profile of the second group inside the building (bearing No. 6 in Fig. 4) is 16 m in length, as shown in Fig. 10. By inspecting the obtained radargram of this profile, one may distinguish the location of the drainage pipe which displays as high reflectivity of radar waves. This highly reflective waveforms appear at the pipe drainage site in two locations: one at depth of 1.2 m whereas the other at depth of 4 m, where they display as sharp, closely spaced, almost vertical reflections below the pipes. The layers begin to gradually deform. Meanwhile, the creep zone appears between depths of 2.5 m and 4 m, where appered as curved, downward-sloping ripples, which probably represent soil creep or even airwave from the adjacent building walls. It was suggested to reperesent a creep in the soil due to the features (creep) which extending into the soil and displayed in other surveyed profiles within the study area. Another observed reflector at 5-7 m was appeared as well, which probably represents a plastic or PVC pipe of infrastructure.

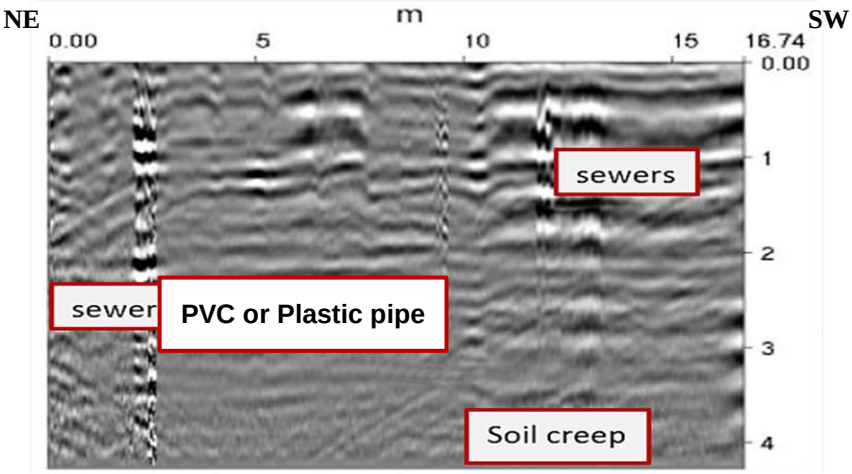


Fig. 10. The sixth GPR profile from the second group inside the building

The third profile of the second group inside the building (bearing No. 7 in Fig. 4) is 32 m length (Fig. 11). The area from the beginning of the profile to a distance of 10 m (i. e, left part of Fig. 11) shows undulating layers that commence with a horizontal regularity in the upper part of the record and then begin to deform at depth of 2-4 m. The area between 24 m to the end of the profile (i. e, right part of Fig. 11) shows also similar deformations, but in a softer manner. The layer undulations display sloping upwards and downwards, due to the soil creep. It was suggested that these features represent a creep in the soil, not a reflection from the walls due to the creep extending into the soil which is displayed in other surveyed profiles within the study area, in addition to the information that available from the well dug existed within the study area which confirms this subsurface feature.

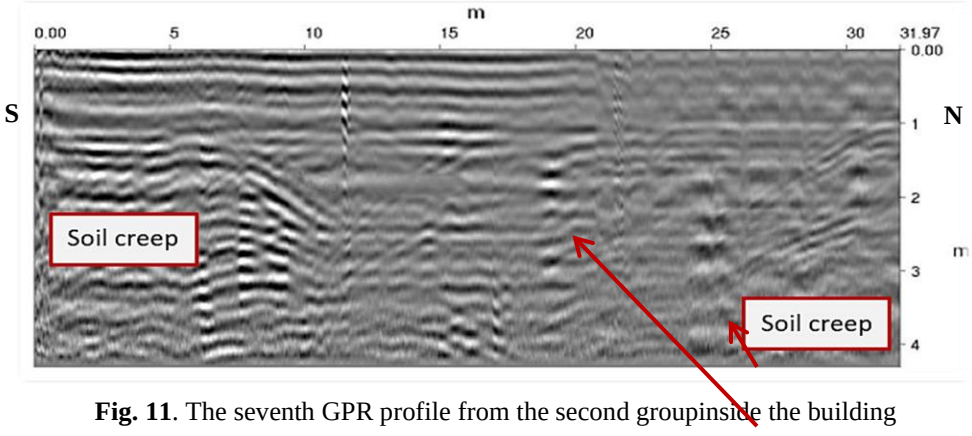


Fig. 11. The seventh GPR profile from the second groupinside the building

The fourth profile of the second group inside the building (bearing No. 8 in Fig. 4) is 23 m in length, as shown in Fig. 12. From the ground surface to a depth of 2.5 m, the layers were relatively undisturbed where clear horizontal reflections are identified. At a depth of approximately 4 m and over several distances, irregular areas appeared with distortions in soil layers due to areas of potential soil creep (Fig. 11).

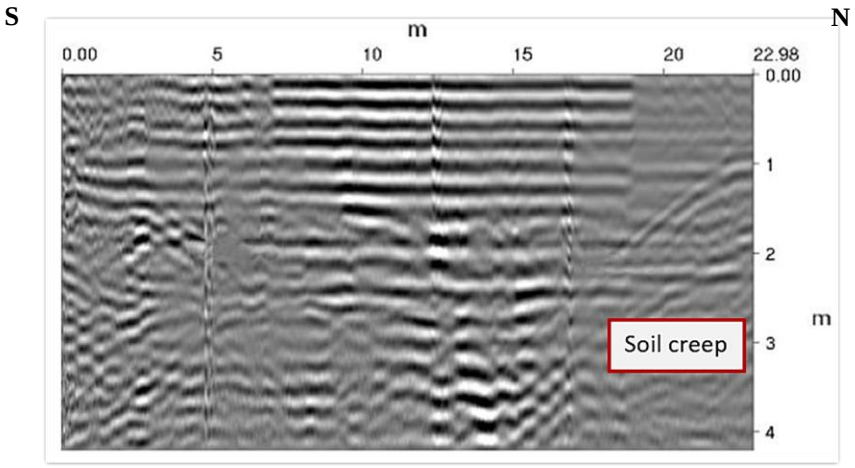


Fig. 12. The eighth GPR Profile from the second groupinside the building

The fifth profile of the second group inside the building (bearing No. 9 in Fig. 4) is 14 m length, as shown in Fig. 13. The upper layers of the soil appeared as horizontal and almost undisturbed on the right side of the GPR section. From a depth of ≈ 2-4 m, slanted distortions or irregular undulations in the layers are visible due to potential soil creep. Hyperbolas are also visible and symmetrical at the horizontal coordinates 0-2 m and 5 -7 m, probably indicating the presence of a cylindrical features or tubes (Fig. 13).

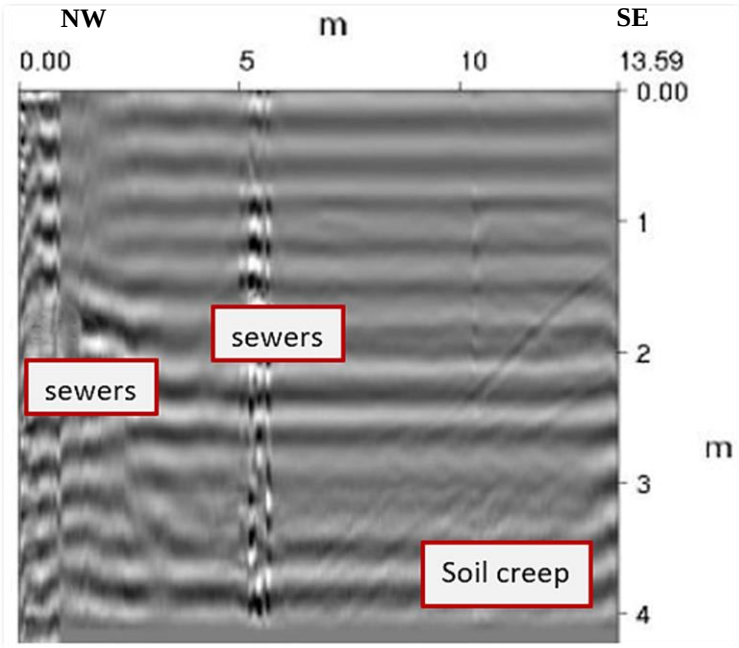


Fig. 13. The ninth GPR Profile from the second group inside the building

5. Conclusions

The GPR radargrams demonstrated that the sub-soil of the study area (inside and outside the multistory building) is heterogeneous, where the first superficial depth layer (≈ 2 m) of the soil below the Asphalt layer contains pipes of infrastructure, voids and potential weak zones because it is considered as irregular disturbed features within the soil layers and does not appeared in all profiles within the study area. Moreover, the second layer was thicker and relatively less heterogenety than the first layer with noticing of some potential soil creep in the subsurface soil of the building. Consequently, the GPR survey technique was efficient in characterizing the sub-soil features of the study area.

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