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Using the GPR Method to Detect Weak Zones in the Soil underneath the Foundation of the Ghaidan Building, Karbala City, Iraq

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Abstract

The study area holds great importance as it is situated in the historically significant region of Karbala, one of the most religious centers in the entire Islamic world. The Al-Hussein and Al-Abbas holy shrines are religious and archaeological sites, for more than 600 years ago. Karbala has more importance for all Islamic peoples because it is the place of Al-Imam Al-Hussein and his brother Al-Abbas holy shrines and martyr graves of Al-Hussein family and friends whom they had martyred beside him in Al-Tuff battle in the year 61 hijri. The word Karbala means soft earth, but historically, it meant life and safety. According to old Iraqi language the name of Karbala was country of safety.

Ghaidan building is located at the center of Karbala about 100 km south of Baghdad. It is a modern building that was built in 2020 on soil containing the ruins of an old building. The area of the building is 71 m^2 and its dimensions are 6.20m $\times$11.45m. A differential settlement of the soil occurred due to the dewatering process for a nearby building, which led to the withdrawal of fine soil particles and consequently the occurrence of cavities, and then differential settlement, which led to its inclination towards the southeast. The main purpose of conducting a Ground Penetrating Radar survey is to identify areas of weakness in the soil underneath the foundation of the building. The presence of cavities and weak zones in the soil underneath the foundation caused a movement of the building structure towards the southeastern side, which represents the front part of the building. It is indicated that the soil underneath the foundation down to 5.5 m is relatively loose (i.e., not compacted), which causes differential settlement and affects, to a large extent, the building structures.

Keywords: GPR method, Weak soil detection, Ghaidan building, Karbala, Iraq

استخدام طريقة GPR لتحديد مناطق الضعف في التربة تحت اسس بناية غيدان ، مدينة كربلاء، العراق

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الخلاصة

تكتسب منطقة الدراسة اهمية كبيرة لانها تقع في احد المعالم الدينية القديمة المهمة لمدينة كربلاء للعالم الاسلامي .تعتبر العتبتان المقدستان الحسينية والعباسية موقعا دينيا واثاريا منذ اكثر من 600 عام. ولمدينة كربلاء اهمية كبيرة عند كافة المسلمين في العالم لانها تضم مرقدي الامام الحسين بن علي واخيه العباس

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عليهم السلام وغيرهما من قبورالشهداء من اهله واصحابه الذين استشهدوا في معركة الطف سنة 61 هجرية. كلمة كربلاء تعني الارض الناعمة ولكن تاريخيا تعني الحياة والامان، وبحسب اللغة العراقية القديمة اسم كربلاء يعني بلد الامان.

تقع بناية غيدان في وسط محافظة كربلاء المقدسة على بعد حوالي 100 كم جنوب بغداد ، وهي بناية حديثة انشأت عام 2020 على تربة تحتوي على انقاض مبنى قديم. تبلغ مساحة البناية 71 مترا مربعا، وابعادها 6.20 × 11.45 متر. حصلت تسوية تفاضلية للتربة تحت اسس البناية بسبب عملية سحب المياه الجوفية لمبنى قريب من البناية، مما ادى ذلك الى سحب الجزيئات الناعمة للتربة وبالتالي زيادة نسبة الفراغات وحصول تجاويف ومن ثم التجلس التفاضلي، مما ادى ذلك الى ميلان البناية باتجاه الجنوب الشرقي. الهدف الاساسي من هذه الدراسة هو استخدام مسح الاختراق الراداري الارضي GPR في تحديد مناطق الضعف في التربة تحت اسس البناية. ان وجود مناطق الضعف والفجوات في التربة ادى الى تحرك هيكل البناية باتجاه الجنوب الشرقي والذي يمثل الجزء الامامي من البناية. اشارت نتائج المسح الى ان التربة تحت الاسس ولغاية العمق 5.5 متر ضعيفة نسبيا (أي غير مدمجة)، مما تسبب في تجلس تفاضلي، والتي اثرت الى حد كبير على هيكل البناية.

1. Introduction

The uses of direct and indirect geophysical methods for obtaining subsurface information before any construction have been applied by [1] and [2]. The Ground Penetrating Radar (GPR) method is a high-resolution electromagnetic technique that is applied in many different geological and geotechnical studies [3, 4]. It is a non-destructive method used to determine the size, shape and depth of buried objects with good resolution [5]. This method is commonly applied to solve geotechnical engineering problems [6], such as settlement and detection of shallow natural subsurface structures, such as water tables, voids, cavities, and man-made structures, for example, pipes, underground storage tanks and landfill [7, 8, 9]. In civil engineering, using the GPR method to explore the subsurface heterogeneities, fractures and voids resulting from dangerous collapses [10, 11]. It is also commonly applied in archaeological studies [12, 13]. Collecting and analyzing any prior information about the site can be a helpful tool for operating the GPR method [14]. The electromagnetic energy used in the GPR method can be a wide range of frequencies from 10 to 100 MHz [15], where the penetration depth of the EM wave depends on the electrical properties of the soil. Low-frequency signals have a greater depth of penetration and low resolution, while the higher-frequency signals give higher resolution and shallower-penetration depth, [16, 17].

Following, the laws of electromagnetism, radar wave velocities change depending on the physical properties of soil materials [18]. However, the most important physical conditions that influence the behavior of radar waves in the materials are the dielectric permittivity, electrical conductivity, and magnetic permeability [19]. The ground that contains magnetic minerals, such as iron, has a high magnetic permeability and therefore transmits radar energy poorly [20]. Because earth materials such as soil are usually nonmagnetic, therefore, permeability is less important than electrical conductivity and relative permittivity concerning wave propagation [21]. Vertical resolution determines the ability of GPR to identify and define subsurface features or reflectors, where the vertical resolution increases as frequency increases, the high frequency of the short wavelength of the electromagnetic wave decreases, and ultimately, high vertical resolution can be obtained [22]. The ability of electromagnetic waves to effectively penetrate the ground to a particular depth is primarily dependent upon two factors: first is the frequency of the waves, and second is the characteristics of the ground [23], lower frequency antennas (i.e. long wavelengths) provide the deepest penetration, while high frequency (i.e. short wavelengths) are shallow depth [24].

In Iraq, (GPR) method has been used to investigate the locations of buried archaeological features in the ancient city west of Karbala in Tulul Al-Ukhaidir [25]. In addition, the seismic cross-hole method was another geophysical technique that has been used to investigate the locations of cavities and weak zones underneath the foundation in soil, and evaluate the treatment of soil by grouting [26]. The 2D and 3D electrical resistivity method has been used in civil engineering to detect shallow foundations [27, 28]. These geophysical methods are commonly applied to solve geotechnical engineering problems.

The study aims to detect the weak zones under the foundation of the Ghaidan building, and then treat the weakness to protect it from failing.

2. Location of Study Area

The study area holds great importance as it is situated in the historically significant region of Karbala, one of the most religious centers in the entire Islamic world.

Ghaidan building site is located in the province of holy Karbala, Iraq, about 100 km south of Baghdad, in longitude 32° 37′ 17″ N and latitude 44° 02′ 06″ E. The study area represents a building with an area approximately 71 m^2, as shown in Fig. 1.

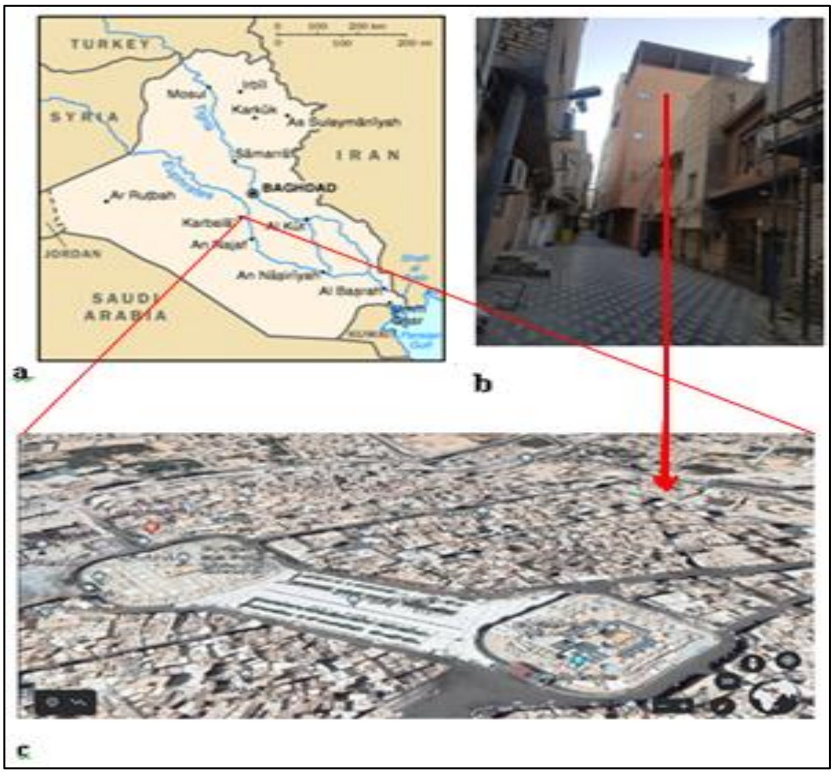

Figure 1: Ghaidan building location in the center of Karbala city.

3. Materials and Methods

The GPR technique is very suitable to explore shallow buried features such as cavities, cables, graves, and others. As the GPR signal exits the shielded antenna and travels through the medium, the antenna also receives the reflected signals, indicating that the antenna is made up of a transmitter and a receiver (Fig. 2). The depth of penetration is determined by the type of antenna used.

Field work included direct observation for cracks and the buildings movements towards the southeast. The GPR profiles were selected in the field according to the field observation.

The investigations were carried out under two antennas used in this study; the first with a frequency of 250 MHz, which is commonly used for surveys such as voids and cavities, and the second with a frequency of 500 MHz, which has good resolution at shallow penetration depth and is manufactured by MALA Sweden company. Fig. 3 [30].

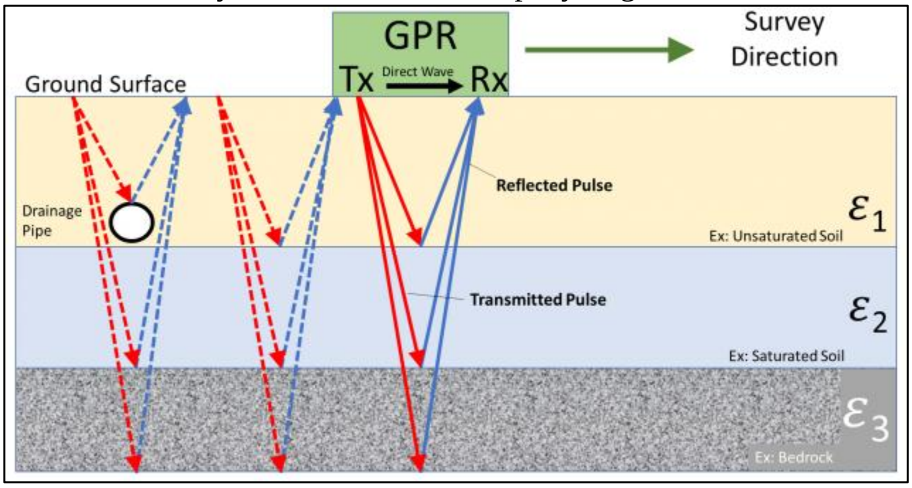

Figure 2: Schematic diagram of a GPR survey, reflected waves penetrating the subsurface travel at different velocities based on dielectric permittivity (**ɛ**) [29].

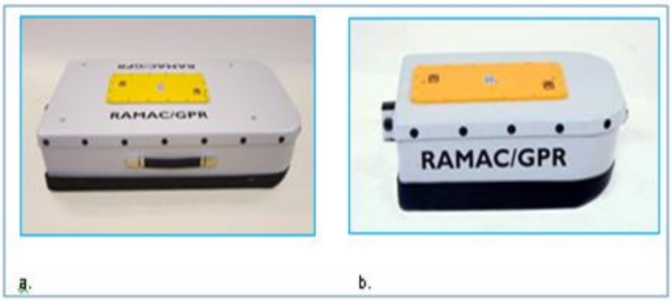

Figure. 3: a. The shielded 250 MHz antenna, b. The shielded 500 MHz antenna, [30].

3.1 Field Work

The fieldwork was carried out on Thursday (17.02.2022) to determine the ground condition and potential problems within the zones of the building, many problems exist underneath the raft foundation, which caused a differential settlement, which led to a movement. There is evidence confirming the occurrence of movement towards the front of the building and clearly at the southeastern corner of the building, in addition to the presence of a lateral displacement of the building's structures relative to the neighboring building, as shown in Fig. 4.

Figure 4: The lateral displacement of the building as a result of the differential settlement due to the weak soil.

The GPR investigation was performed in February, during the period 13-17/2/2022 at the building to depict the subsurface of buried objects. The GPR survey was conducted inside and outside the building (Fig. 5). Six profiles were chosen covering an area of 11.5 ×6.2 m^2. The lengths of the profiles were between 5 and 20.5 m, and the directions of these profiles were east-west and north-south (Fig. 6).The survey profiles inside and outside the building were surveyed by two antennas at 500 MHz and 250 MHz.

Figure 5: The GPR survey, a. outside the building, b. inside the building.

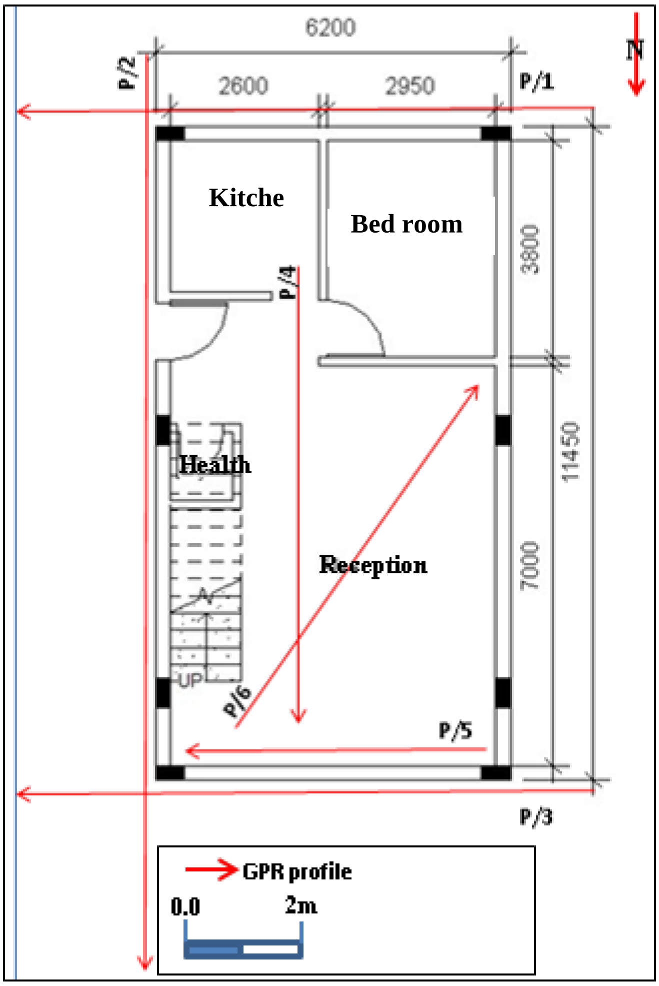

Figure 6: The GPR survey profiles within the Ghaidan building site.

The process and interpretation of GPR records were done through the use of the Ground-Vision 1.3 program [31], where suitable filters were selected to obtain the best image. Filtering techniques were applied to remove the effects of the deformation and inaccurate GPR signals [32]. The filters utilized were time-zero correction, band-pass, and gain control [33].

4. Results and Discussions

The obtained GPR sections show natural and man-made underground conditions, such as pipe, collapse, weak zones, and cavities underneath the raft foundation. Depending on field reconnaissance of the crack above the upper structure of the building, as well as the presence of relative movement between the sections of the structure along the joint, which is located around the Ghaidan building and adjacent building, which represents the boundary between them.

The dewatering by the adjacent neighboring building caused a push of the fine material of soil and cavities to occur underneath the foundation of the building, which led to differential settlement and the movement toward the southeastern corner of the building. The weak zones of the soil start from beneath the foundation to 5.5 m or more.

The GPR surveys by 250 and 500 MHz antennas show the buried objects from the ground surface to about 5.5 m depth as shown in Figs. 7 through 15.

In general, the GPR sections made it clear that the soil underneath the raft foundation of the building and around is weak. There are weak zones and heterogeneous burial materials, as the presence of these conditions assisted in getting a differential settlement in the soil and thus the movement of the building, which was towards the front, especially in the southeastern corner of the building.

The sections of GPR profile No. 1, which is located adjacent to the Ghaidan building from the southern part, as shown in Figs. 7 and 8, Fig. 7 represents the GPR result of the 500 MHz antenna, while Fig.8 represents the result of the 250 MHz antenna, which penetrates to greater depths. The results of these geophysical surveys indicated the locations and depth of the weak zones in the soil underneath the foundation, which had a fundamental role in the occurrence of differential settlement in the soil and thus the movement of the building structure and its inclination towards the southeast.

The GPR sections of profile No. 1 showed that the weak zone range extends from a depth of 1 m to 5.5 m below the foundation of the building. In addition, the foundation is located on an old building with old striped brick walls and brick foundations that have not been removed and are saturated due to the rise in the water table towards the surface of the earth at a depth of approximately 2 meters. Therefore, the process of dewatering the multi-story building (neighboring building) site adjacent to the building from its southern side, which is approximately 4 meters helped greatly to withdraw fine soil particles and thus increase the volume of voids in the soil of the area, including underneath the foundation of the building.

In Fig. 7, there are four pipes located at a depth between 0.5 and 1 m from the ground surface, two of them for water pipelines and the other for sewage. Below these four pipes, there is a weak zone that extends to a depth of 2.5 m. It is expected that there will be seepage of water from the water pipelines. This may also contribute to the weakening of the soil underneath the foundation.

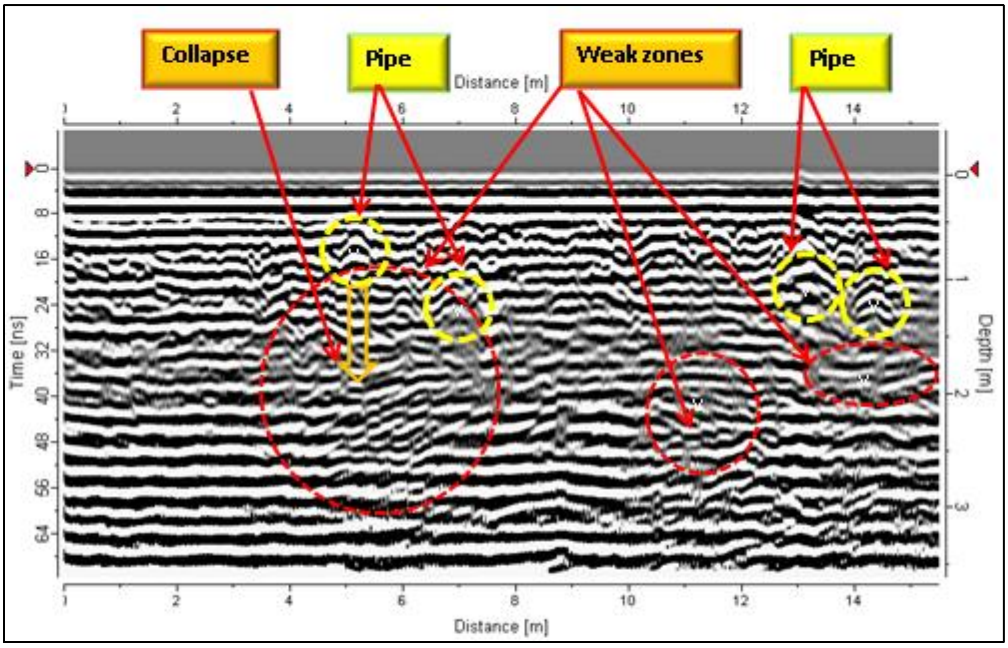

Figure 7: The GPR section shows locations of water pipelines and weak zones in profile No.1 using 500 MHz antenna.

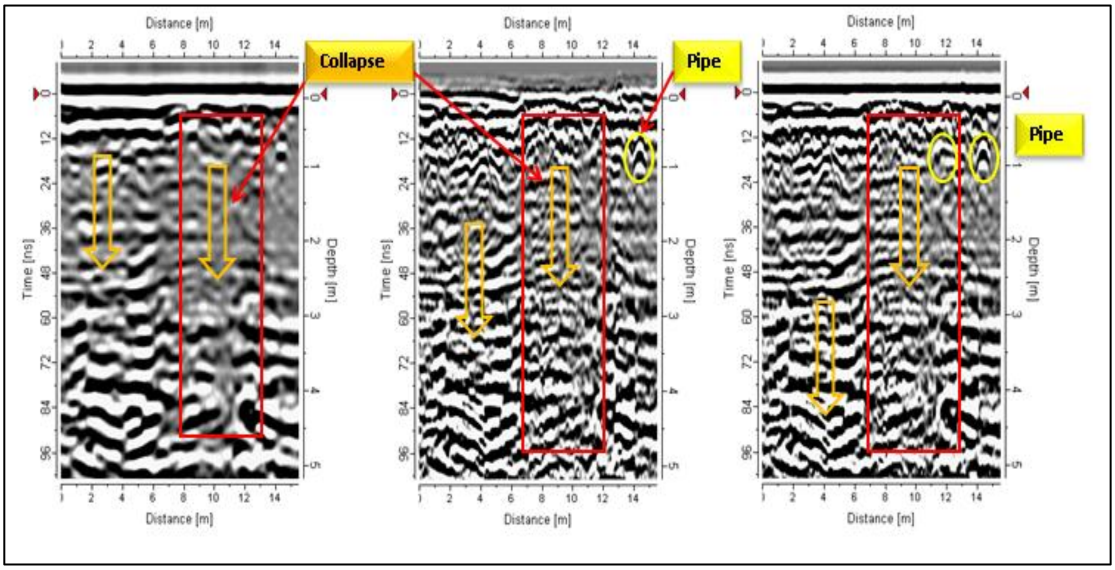

Figure 8: The GPR section shows locations of water pipelines and collapsed soil in profile No.1 using 250 MHz antenna.

The sections of GPR profile No. 2, which is located on the front side of the Ghaidan building from the eastern part, as shown in Figs. 9 and 10, Fig. 9 represents the results of the survey using the 500 MHz antenna, while Fig. 10 represents the results of the 250 MHz antenna. The results of the GPR surveys indicate the locations and depths of potential weak zones in the soil, which resulted in a differential settlement and thus the movement of the structure of the building, which was inclined toward the southeastern corner. Because the pipe was located at adepth of 1 m on the south side of profile No. 2, which probably resulted in seepage due to potential damages.

The GPR sections of profile No. 2 showed that the weak zone range extends from a depth of 1 m to 5.5 m. Moreover, the sections showed a manhole and two pipes located on the north side of the building. The water table was located at 2 m depth, and the saturated zone was located at 2 m depth, because of the spread of weakness in the soil below 1 m to the end of the survey depth, which led to the structure's collapse.

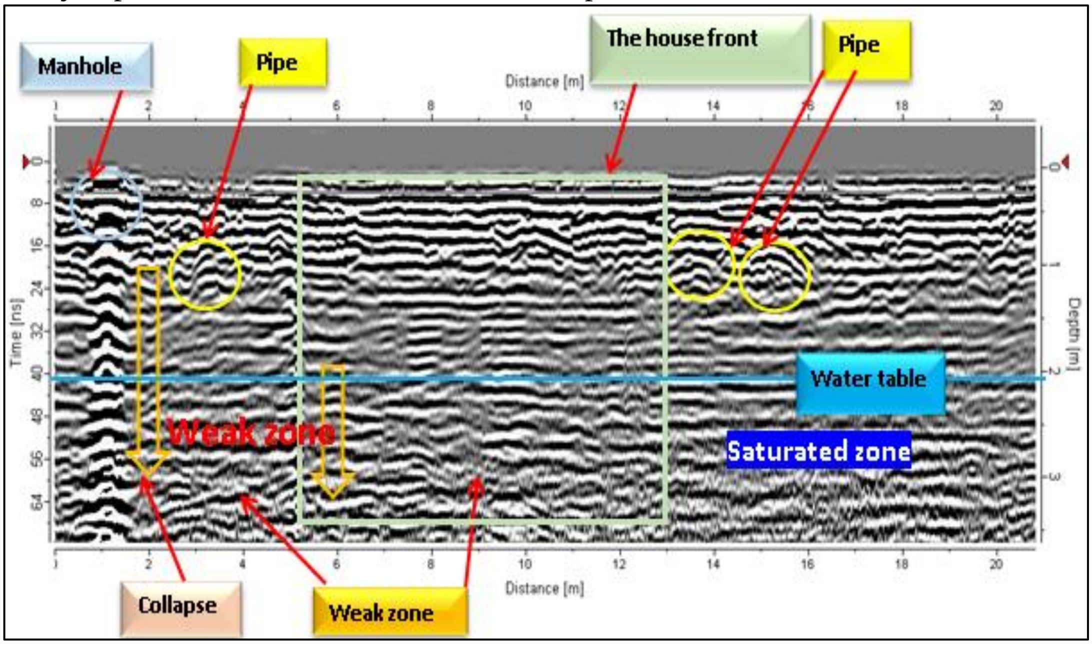

Figure 9: The GPR section shows the locations of the water table, water pipelines, weak zone, and the width of the house in profile No.2 using a 500 MHz antenna.

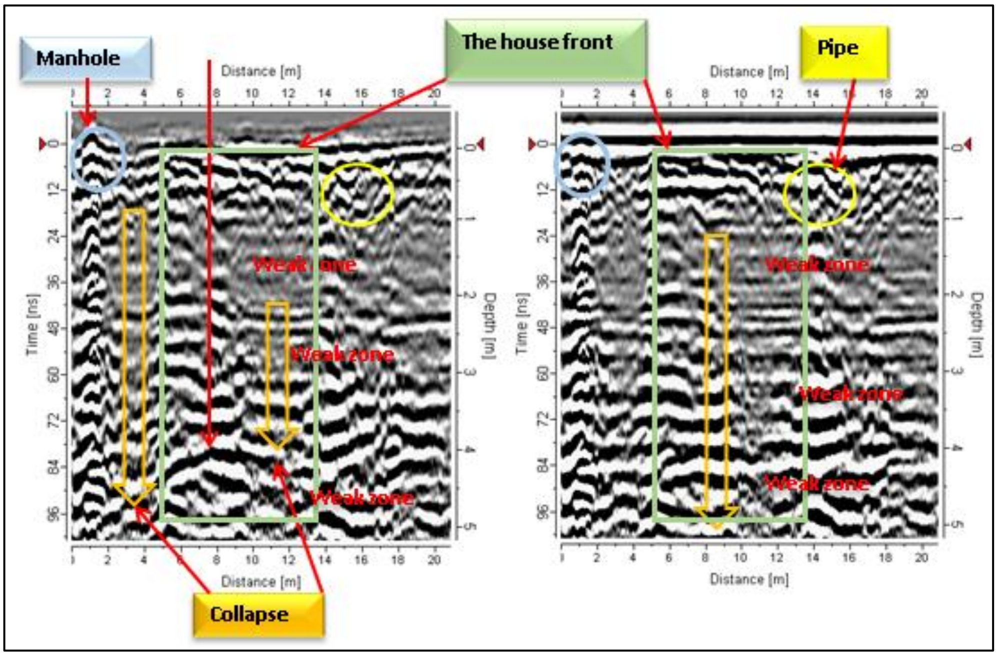

Figure 10: The GPR section shows the locations of the water table, water pipelines, weak zone, and the width of the house in profile No.2 using a 250 MHz antenna.

The sections of the GPR survey for profile No. 3, which is located adjacent to the Ghaidan building from the northern part, as shown in Figs. 11 and 12, Fig. 11 represents the results of the survey using the 500 MHz antenna, while Fig. 12 represents the GPR survey with the 250 MHz antenna.

The GPR sections of profile No. 3 showed that the weak zone range extends from a depth of 1 to 5.5 m below the surface of the earth. In addition, it showed the old brick wall located at a depth of 3 m and a collapsed area. The abovementioned profiles 1, 2, and 3 investigate the soil outside the Ghaidan building.

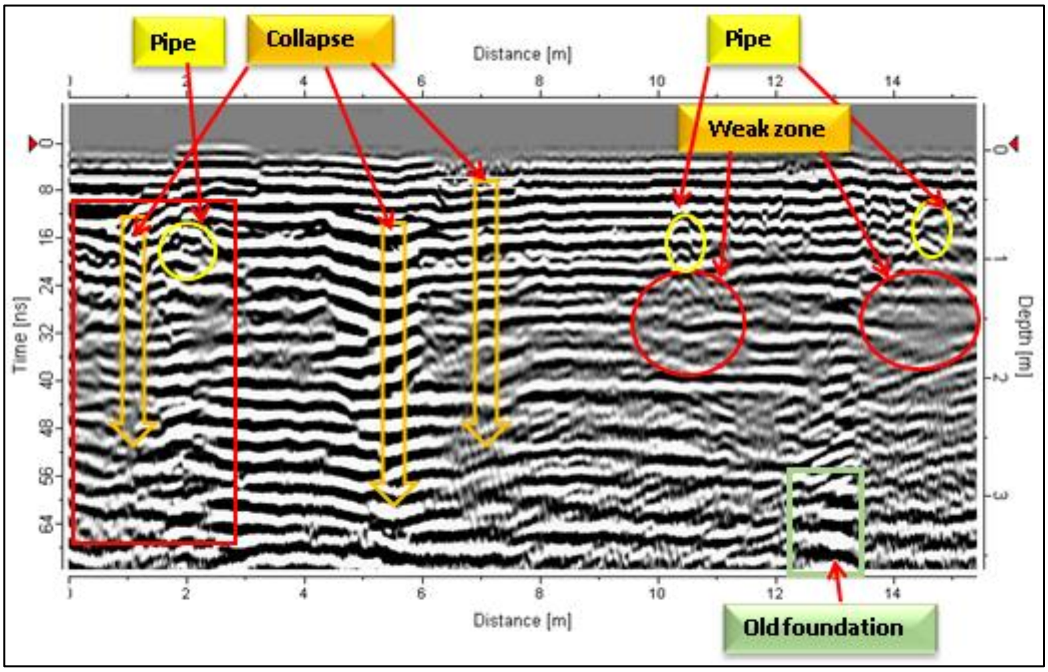

Figure 11: The GPR section shows the locations of water pipelines and collapses in profile No. 3 with 500 MHz antenna.

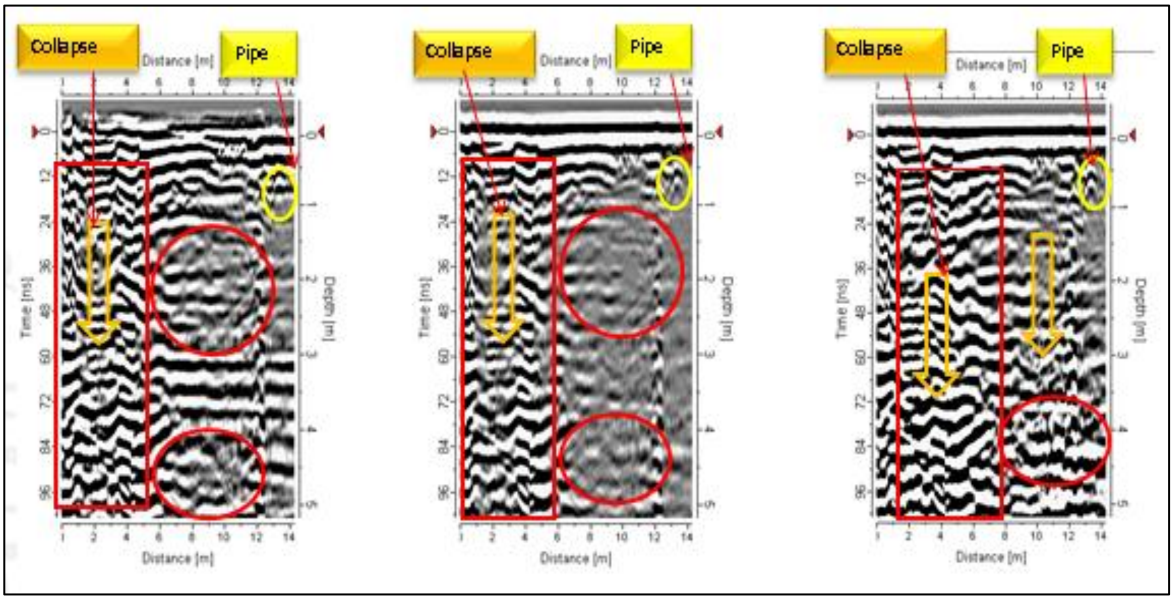

Figure 12: The GPR section shows the locations of water pipelines and collapses in profile No. 3 with 250 MHz antenna.

The GPR profiles 4, 5, and 6 are located inside the building; the length of these profiles was shorter than the outside profiles. Their lengths were between 4.5 and 8 m. These three profiles were surveyed using the 500 MHz and 250 MHz frequency antennas as well.

The sections of GPR profiles 4, 5, and 6 are represented in Fig. 13, 14, and 15. The results of the GPR surveys indicated the determination of the locations of the weak zones in the soil underneath the raft foundation to the end of the depth of the test. The sections showed the thickness of the raft foundation, which extended from the surface of the earth to approximately 1 m depth, and the soil underneath the raft foundation was weak and collapsed.

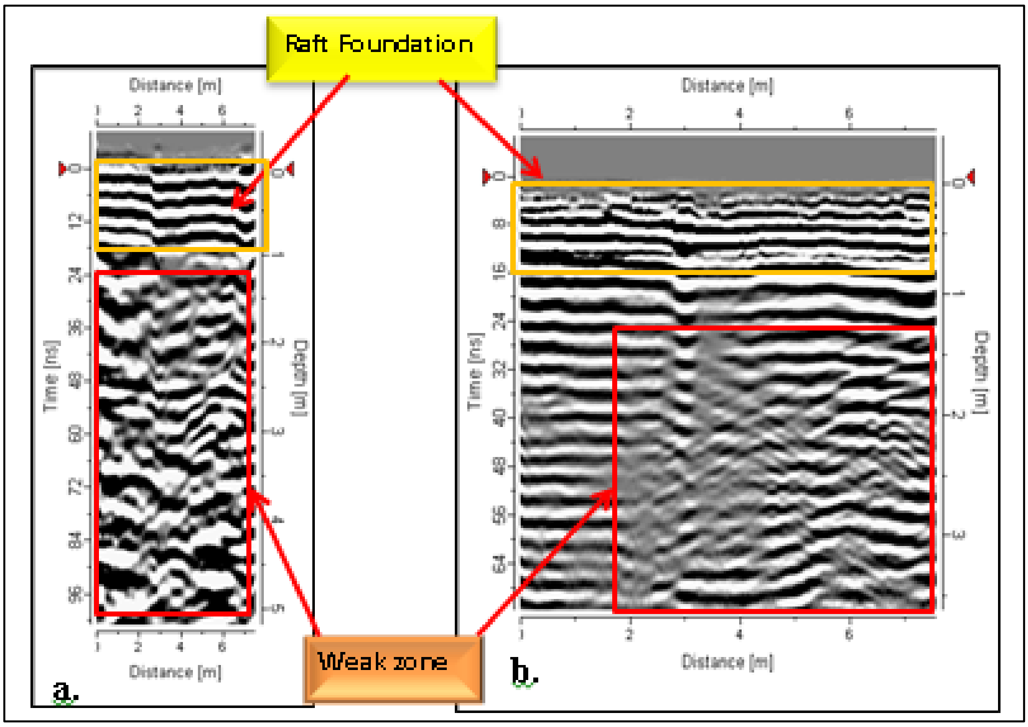

Figure 13: The GPR section shows the locations of the raft foundation and weak zone in profile 4 with a. antenna 250 MHz, and b. antenna 500 MHz.

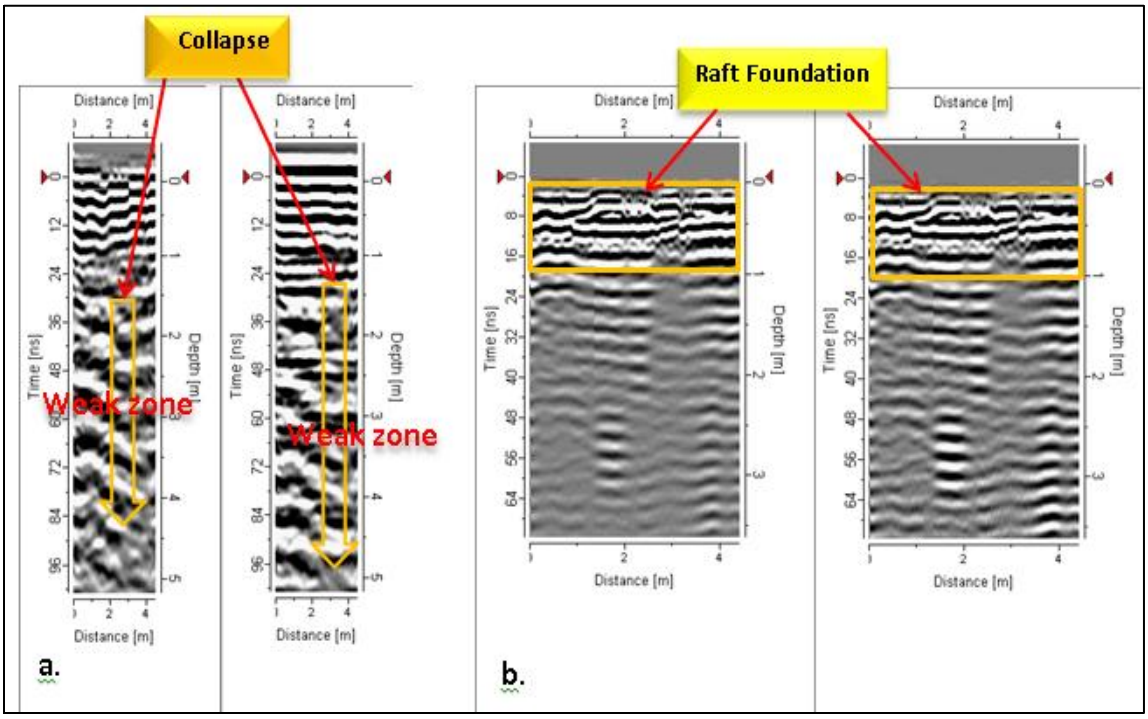

Figure 14: The GPR section shows the locations of the raft foundation and weak zone in profile 5 with a. 250 MHz antenna, and b. 500 MHz antenna.

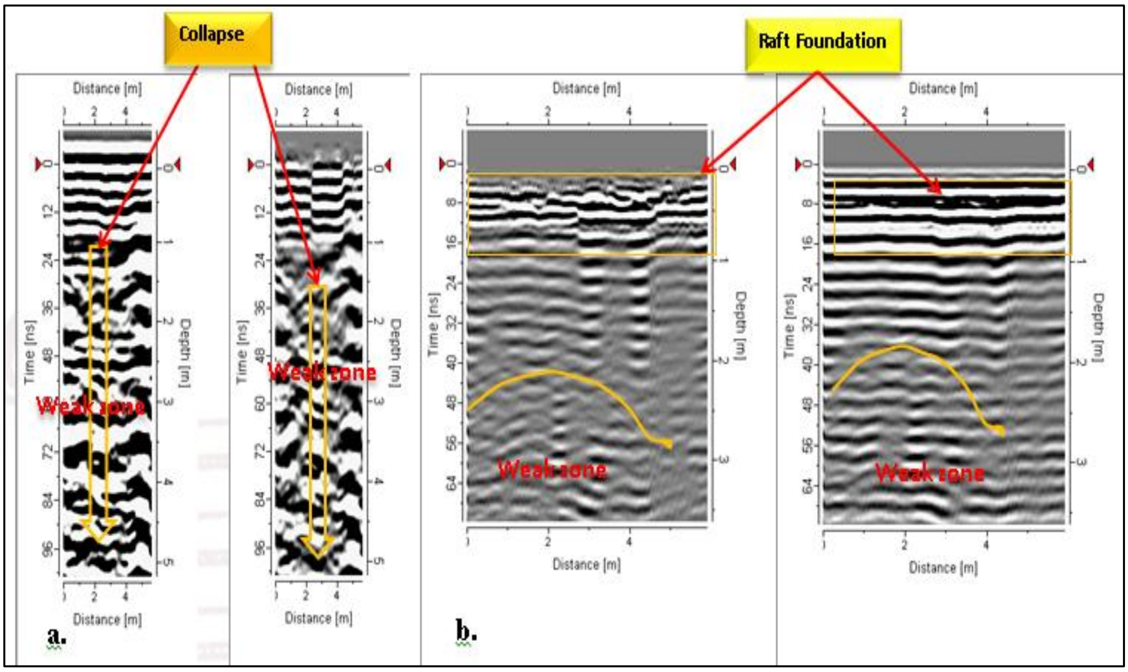

Figure 15: The GPR section shows the locations of raft foundation and weak zone in profile 6 with a. 250 MHz antenna, and b. 500 MHz antenna.

5. Conclusions

The GPR sections of profiles inside and outside of the Ghaidan building explain the lateral and vertical extensions of the weak zones in the soil under the foundations from 1 to 5.5 m. The sections also determine the water pipeline and sewage lines underneath the building, especially in south-eastern directions, and show weak soil and collapse under those pipelines, which indicate potential damages to the pipelines water seepage. For all of these reasons, a differential settlement was occurring in the soil under the foundations. To stop the settlement and improve the engineering properties of soil, it is necessary to treat the weakness of soil, especially surrounding the building and under the foundations, by filling it with suitable material, such as cement, according to an appropriate injection procedure. The GPR method proved to be a suitable geophysical method for determining the locations and depths of weak zones underneath the foundations of the structure.

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