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Engineering Site Investigation Using 2D Electrical Resistivity Imaging, K3 Area, Western Anbar Governorate

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ABSTRACT

Subsurface cavities and weak zones have a significant influence on the long-term feasibility of infrastructure and buildings; these problems must be considered before beginning construction of buildings and town decisions. Assessing the hazard associated with these cavities requires a greater understanding of the complex behavior of the karst structure, which is best developed in a region that absences indicators on the ground surface. This study investigates the subsurface characteristics in the K3 region using 2D electrical resistivity imaging (ERI) to recognize and describe underground structures. The data acquisition has been conducted manually along four 2D traverses, each 97 m long, using a dipole-dipole array with 20 electrodes spaced at 5 m apart. The data are processed using the RES2DINV software with a robust method to generate a 2D resistivity model. The results show distinct high-resistivity anomalies; these are suggestive of several cavities with a variety of depths from 3 to 15 m below the surface, with a width of 35 m. Also, several subsurface weak zones reveal that they are more severe at depths of 1.25-5 m below the ground surface. These zones associated with subterranean channels, cavities or sinkholes lead to issues with new construction and potential foundation subsidence. The investigation successfully charted the spatial distribution, depth, and approximate size of the detected cavities and weak areas. These findings have crucial importance to the assessment of geotechnical risk and urban planning in the K3 region; the efficacy of 2D ERI in the detection of subsurface structures is demonstrated.

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استخدام تصوير المقاومة النوعية الكهربائية ثنائية الابعاد للتحري الهندسي الموقعي في منطقة K3، غربي محافظة الانبار

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الملخص

التكهفات تحت السطحية والمناطق الضعيفة لها تأثير كبير على الاستدامة طويلة الأجل للبنية التحتية والمباني، ويجب تقييم هذه القضايا قبل البدء في بناء وتخطيط المدن. تقييم الخطر المرتبط بهذه الكهوف يتطلب فهمًا أعمق للسلوك المعقد لنظام الكارست، والذي يتم تطويره بشكل أفضل في منطقة تفتقر إلى المؤشرات على السطح. يهدف هذا البحث إلى التحقيق في ظروف ما تحت الأرض في منطقة K3، باستخدام التصوير بالمقاومة الكهربائية ثنائية الأبعاد (ERI) لتحديد ووصف ميزات ما تحت الأرض. تم جمع البيانات يدويًا على طول أربعة مسارات ثنائية الأبعاد، كل منها بطول 97 مترًا، باستخدام ترتيب ثنائي القطب- ثنائي القطب مع 20 قطبًا، والمسافة بين الأقطاب تبلغ 5 أمتار. تمت معالجة البيانات باستخدام برنامج RES2DINV مع طريقة روبوست لإنتاج مقاطع عرضية ثنائية الأبعاد للمقاومة النوعية. أظهرت النتائج شذوذات مقاومة عالية مميزة تشير إلى وجود العديد من التجاويف بعمق يتراوح ما بين 3 و 15 مترًا متصلة بالسطح بعرض 35 مترًا. بالإضافة إلى ذلك، تم الكشف عن عدة مناطق ضعيفة تحت السطح تكون أكثر حدة على أعماق تتراوح ما بين 1.25 و 5 أمتار تحت سطح الأرض، وهذه المناطق مرتبطة بالقنوات الجوفية أو الكهوف أو الفجوات، مما يؤدي إلى مشاكل في المشاريع الجديد واحتمالية هبوط الأساسات. نجح التحري في رسم التوزيع المكاني والعمق والحجم التقريبي للتجاويف والمناطق الضعيفة المكتشفة. هذه النتائج لها أهمية حاسمة لتقييم المخاطر الجيوتكنيكية والتخطيط الحضري في منطقة K3، وتظهر فعالية التصوير بالمقاومة النوعية الكهربائية ثنائية الأبعاد في الكشف عن التراكيب تحت السطحية.

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Introduction

Engineering site investigations play a crucial role in assessing the ground conditions and determining avoid risks that may be encountered on an infrastructure project. This is important, especially in the K3 region, where the structures are mostly made of carbonate rocks (limestone and dolomite). These carbonate formations are particularly sensitive to chemical weathering as well as dissolution, which causes the evolution of karst features as subsurface cavities, sinkholes, and other types of voids (Sissakian and Al-Mousawi, 2007). Such features can pose a severe danger to the construction of buildings and engineering projects, human life, and the solidity of the ground, since the failure of these voids may cause ground subsidence and the sudden formation of sinkholes. Additional human involvement in the form of building and exploiting natural resources has increased the frequency of subsidence and sinkhole development (Gutierrez et al., 2008). In site investigation, geophysical techniques, including 2D Electrical Resistivity Imaging (ERI) procedures, are used more often to identify these hazards. 2D ERI is a geophysical method used for imaging the subsurface dependent on variations in electrical resistivity (Zhou et al., 2002; Chalikakis et al., 2011; Metwaly and Alfouzan, 2013; Abbas et al., 2024a). This technique is useful in detecting underground features such as voids, cracks, water-saturated areas, weak areas, and layers of gypsum soil (Abdulrazzaq et al., 2020; Salman et al., 2020; Al-Jumaily et al., 2022). 2D ERI offers a clear image with great resolution to determine underground features and the suitability for building (Loke, 2004; Al-Saady et al., 2022; Elawadi, 2001). Also, this procedure is very useful in evaluating the possible subsidence or collapse risks, which are dangerous in planning for infrastructure and hazards (Ahmed et al., 2022; Abbas et al., 2024b). ERI provides a broader identification of such structures that are localized, which depends on a more continuous view of the ground conditions (Van Schoor, 2002; Dahlin, 2001). Many studies explained the efficiency of 2D ERI in several geohazard assessments (Berhi and Al-Saadi, 2024; Al-Awsi and Abdulrazzaq, 2022; Abed et al., 2021).

This study aims to determine subsurface geology, the location and extent of karst features, and evaluate their potential effects on safe engineering and construction projects using two-dimensional electrical resistivity imaging.

Location of the Study Area

The studied area is located in the K3 area between Baghdadi and Haditha districts within Anbar Governorate, about 177 Km west of Ramadi City (Fig. 1). It is located in the western part of Iraq along the Euphrates River. The topographic elevation of the K3 area is about 175 meters above sea level. It is mostly flat with undulations and occasional escarpments, which have been built through layers of sedimentary rocks. Geologically, the studied area includes the Anah Formation and Euphrates Formation (Fig. 2). The Anah Formation (Late Oligocene–Early Miocene) is represented by hard recrystallized reefal limestone rocks, which are overlained by white porous limestone rocks at the top, having a thickness of about 7 m (Al-Ghreri, 2007). The base of the formation in the area is conformable, while the top contact is always of an angular unconformity with the Euphrates Formation. Euphrates Formation (Early Miocene - Middle Miocene) comprises a basal conglomerate fining upward with 3 m thick, besides the layers of oolitic limestone, dolomitic limestone in the upper part with 18 m thick (Al-Ghreri, 2007; Alrawi et al., 2023). The Formation is sitting unconformably above Oligocene layers by the basal conglomerate with a thickness ranging between 1 to 5 m. These conglomerates are composed of pebbles that originated predominantly from the Anah Formation (Al-Ghreri, 2007).

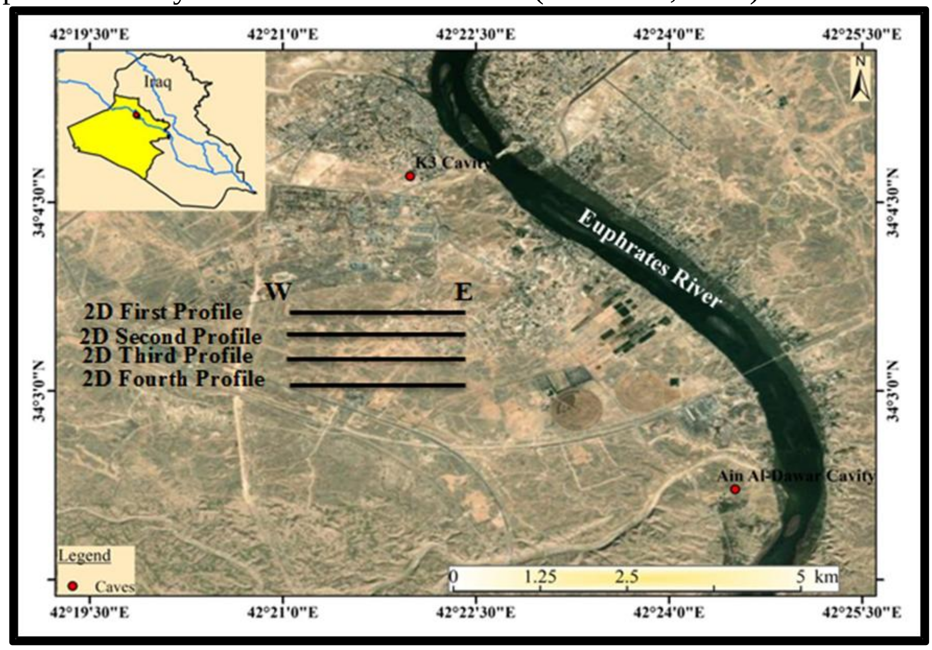

Fig. 1. Location of the studied site with a 2D resistivity profile survey.

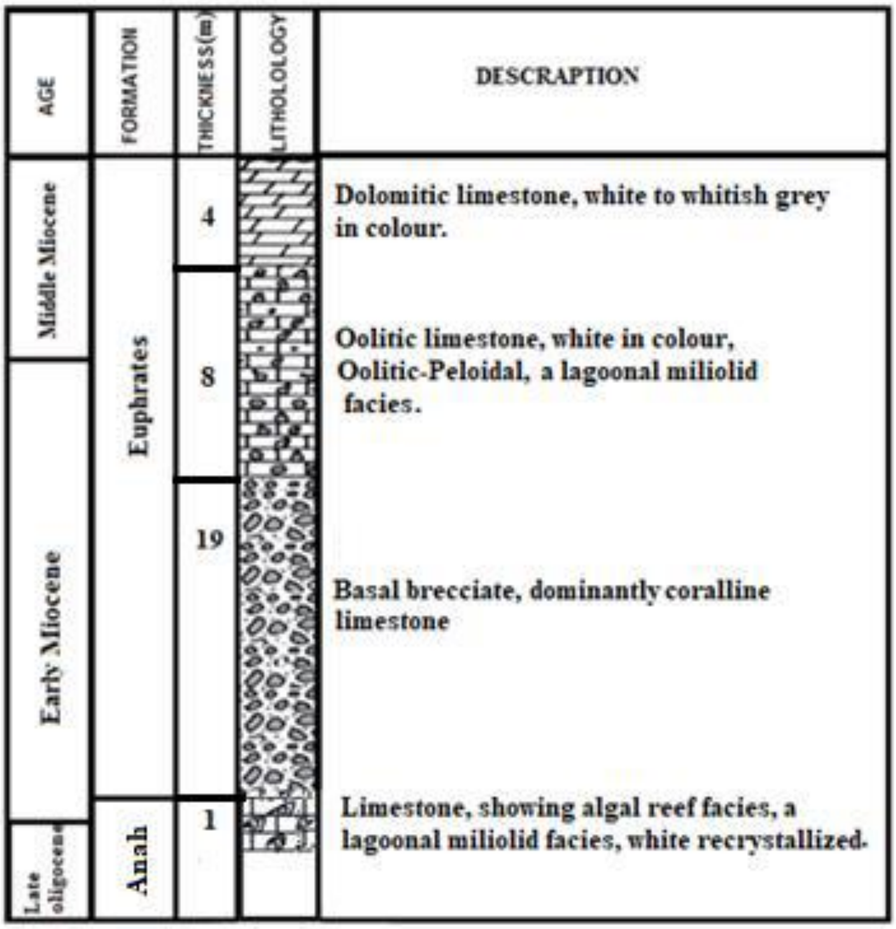

Fig 2. Stratigraphic column of the studied site (Al-Jibouri et al., 2022).

Materials and Methods

A 2D electrical resistivity imaging survey has been conducted using ABEM Terrameter SAS 4000 to delineate the subsurface condition of the studied area. Field resistivity data were acquired using four 2D imaging profiles with a dipole-dipole array (Fig. 3). The 2D resistivity data are manually created and oriented in the W-E direction. Where the number of electrodes, spacing, the distance between profiles, and n-factor are 20, 3, 15, and 6, respectively. The profile's survey depth is estimated at 19.58 m with a 97 m. These profiles were generated using the Electra Pro program. The resistivity measurements were used to construct the pseudo-section to provide a 2D image of the subsurface, and the data processing was performed using the RES2DINV program. The inversion routine is based on the smoothness-constrained least squares method using finite difference forward modeling and Quasi-Newtonian techniques (Loke et al., 2003). In these methods, the subsurface is segmented into a set of dimensional blocks, where cell size increases with depth (Fig. 4). Inversion procedures use numerical techniques to generate a subsurface resistivity model that best fits the available data set. The conventional least-squares optimization method is often used in inversion algorithms to solve the non-uniqueness problem in order to construct a good 2D inverse model to which the data should be homogeneous (Loke and Dahlin, 2002).

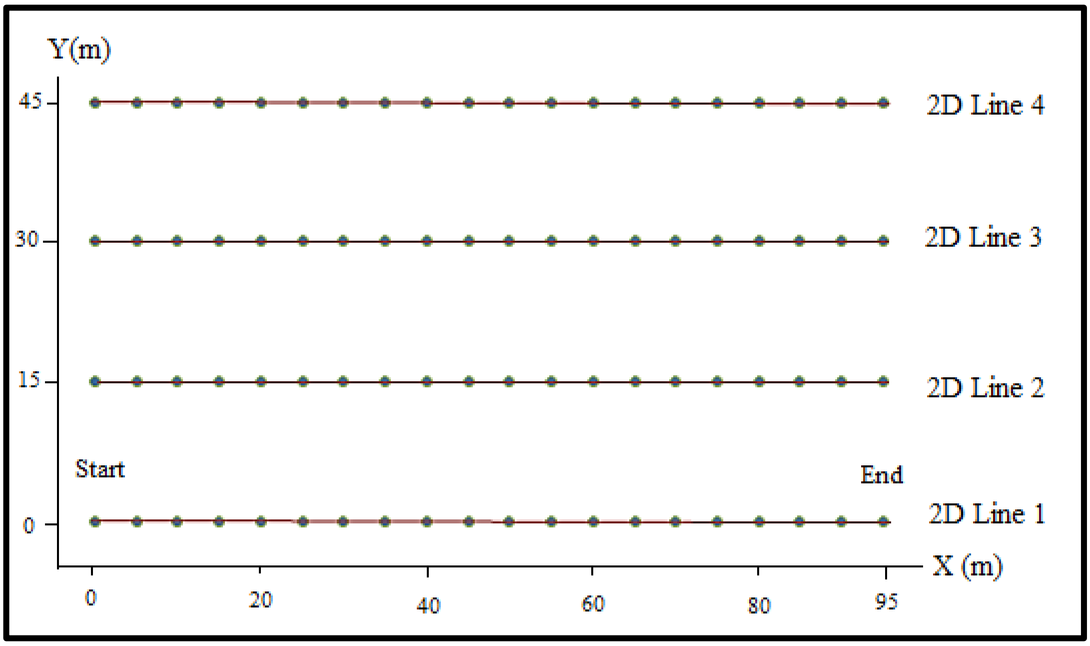

Fig 3. Four 2D imaging profiles were surveyed using a dipole-dipole array in the studied area.

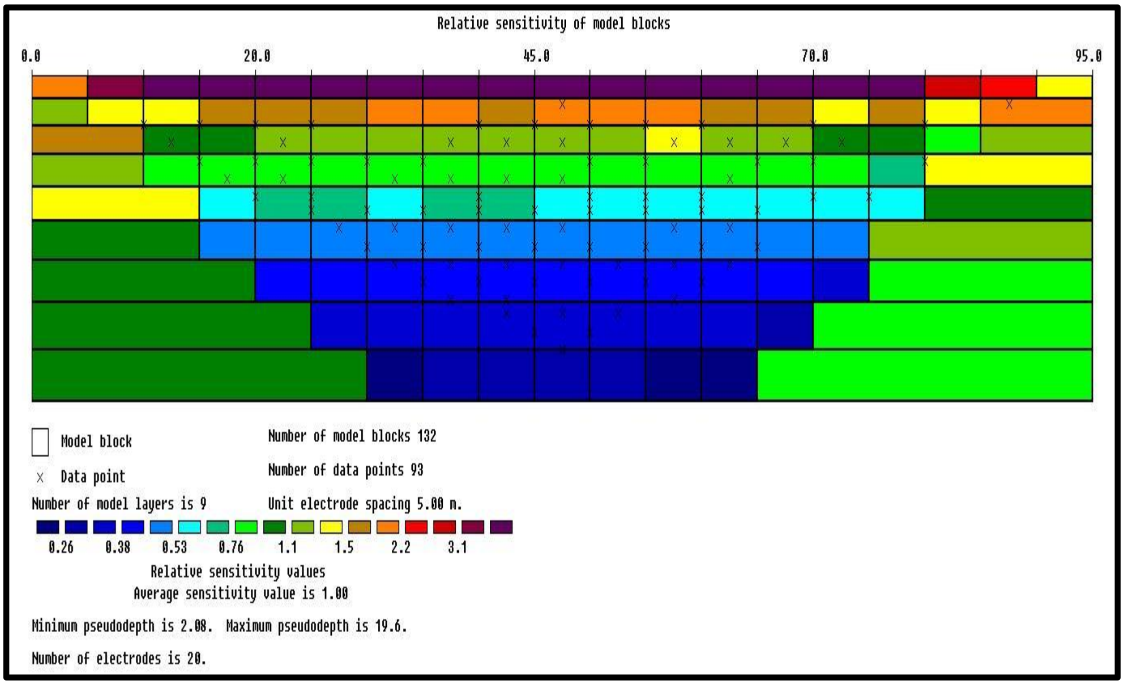

Fig 4. 2D block of subsurface studied area in profile- 2.

Results and Discussion

The first model (Fig. 5) represents a weathering zone near the earth's surface characterized by a lower resistivity value of 20.4 Ω.m. This low resistivity is due to increased water content. Areas of high resistivity values ranging from 145 to 527 Ω.m indicate the presence of voids or cavities within the subsurface. The first cavity is located to the left of the survey line and has high resistivity values ranging from 145 to 275 Ω.m. This cavity starts at a depth of about 3 m and extends to about 11 m below the surface. A larger cavity is present on the right side of the survey line, approximately 60 m to 85 m away from the starting point. This cavity extends to a depth of approximately 10 m. The high resistivity values within the cavity may be relatively dry, which has a higher resistivity than the surrounding rocks. There are some small caves in the middle of the survey line with irregular shapes and boundaries.

The limits of caves are more obvious on the left side, indicating that the voids are more distinct or better defined than those on the right side.

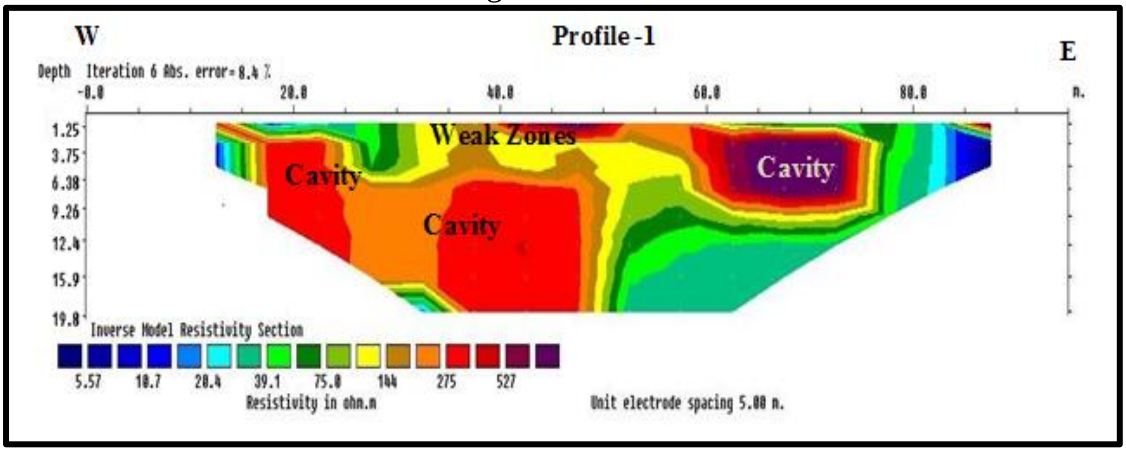

Fig 5. 2D resistivity inverted model for the first profile.

The second model (Fig. 6) reveals the presence of multiple subsurface cavities and a shallow weak zone characterized by varying degrees of resistivity. The areas in the left model exhibit high resistivity values ranging from 145 to 454 Ω.m at distances between 12-28 m and a depth of 3 -11 m, which may represent a dry cavity or a sediment-filled cavity. In the middle section of the model, there are variable resistivity values at distances of 38-55 m and a depth of 5- 15 m. These variations are interpreted as indicative of a cavity. The right side of the model shows a very high resistivity value at a distance between 60- 85 m with a depth extension of approximately 16 m. These extreme values represent a major cavity. Areas along the model with small low resistivity values are interpreted as small caves or voids, while areas with very low resistivity values are indicative of a weathered zone due to an increase in moisture content within the rocks.

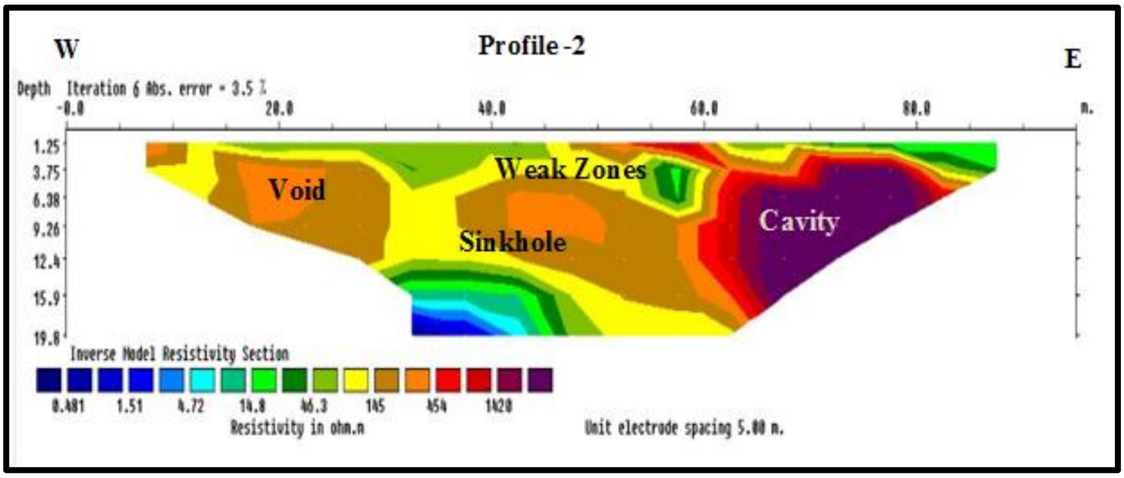

Fig 6. 2D resistivity inverted model for the second profile.

The third model (Fig. 7) indicates three main cavities. The first cavity is located on the left side of the model, recognized by a high resistivity value of 187 Ω.m. This cavity appears at a distance between 13 to 24 m and a depth of 2- 7 m. A second cavity is located in the middle section at a distance of 48- 58 m and a depth of 6 to 16 m. The last cave is found on the right side of the model, with a very high resistivity value of 389 Ω.m. It is located at a distance of 60 m to 83 m with a depth ranging from 3 to 10 m. Also, the model shows numerous weathered zones and voids on both right and left sides of the main cavities. These areas exhibit low resistivity values ranging from 0.606 Ω.m and 2.21 Ω.m.

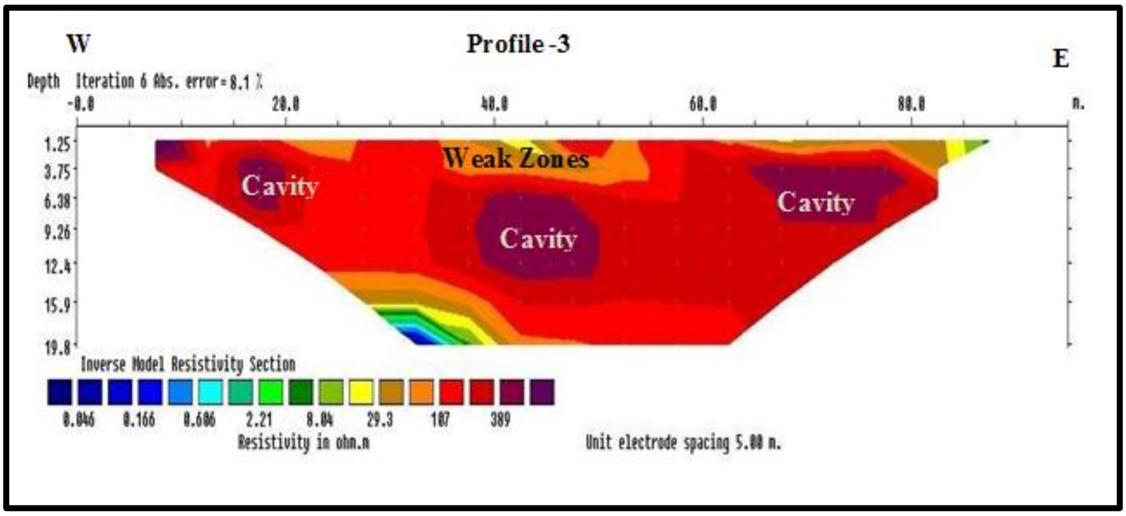

Fig 7. 2D resistivity inverted model for the third profile.

The fourth model (Fig. 8) displays two near-surface caves that are distributed over the left and right sides of the model. These caves are distinguished by high resistivity values that are greater than 345 Ω.m. It is located at distances 12-40 m and 55-82 m, respectively, with a depth of 4-16 m and 3-14 m, respectively. There are greater dangers in the meters study area for new construction stretches to a depth of about twelve meters. Resistivity begins to decrease beyond this depth.

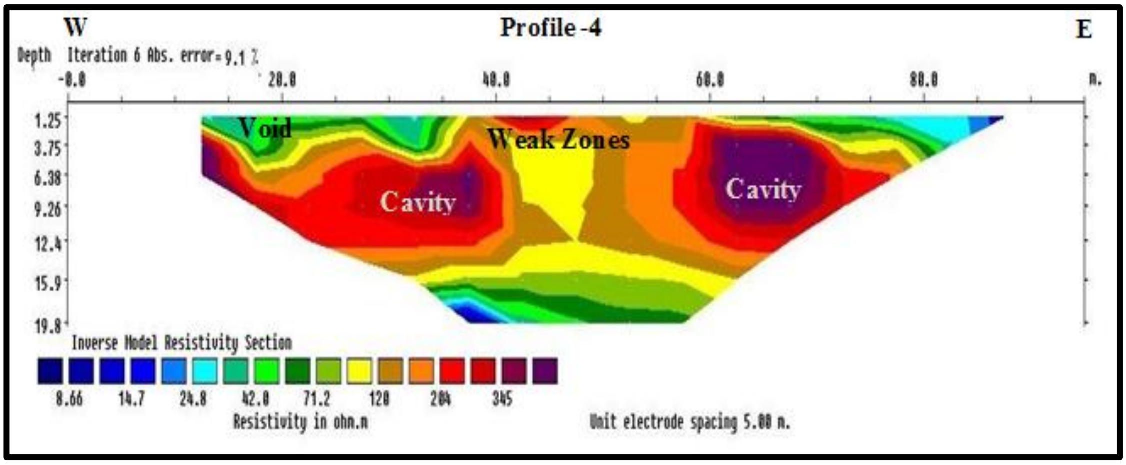

Fig. 8. 2D resistivity inverted model for the fourth profile.

Conclusion

The engineering site exploration using 2D electrical resistivity imaging has considered important findings relevant to geotechnical assessments. The studied area comprises predominantly limestone, which has an excessive increase in activity. Exploring the depth of the shallow weak zones and imaging the risk of subsurface cavities are important procedures before building and surface foundation structure. The study effectively detects differences in resistivity, which is representative of the presence of possible cavities, weak areas, voids, and cracks within the Euphrates Formation that pose risk areas for building and the safety of the structure. All 2D models suggest substantial anomalies as markers for these cavities, with several depths documented below the surface, starting from 3 m and extending down to more than 15 m. Additionally, various subsurface weak areas and cracks are designated through low and intermediate resistivity values, representative potential areas of instability. These regions are recognized to be more obvious at depths between 1.25 m and 5 m below the surface, suggesting complex geological settings that may include dissolution developments through groundwater movement. The description of underground cavity and weak zones emphasizes areas that may comprise risks to structural integrity and require more research using geotechnical assessment.

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