Iraqi Bulletin of Geology and Mining *Vol.12, No.1, 2016* *p 31 – 39*

USING VERTICAL ELECTRICAL SOUNDING IN BUILDING SITES INVESTIGATION; A CASE STUDY IN SOUTH OF BAGHDAD, IRAQ

Jassim M. Thabit[1], Ahmed S. Al-Banna[1] and Mundher D. Al-Awsi[2]

Received: 31/ 12/ 2014, Accepted: 04/ 08/ 2015
Key words: VES, cross Vertical electrical sounding, Buildings site investigation, Baghdad City, Iraq

ABSTRACT

Vertical Electrical Sounding is used for engineering purposes at Al-Jadiriya area, within Baghdad University site .Two different electrical resistivity techniques were applied using Schlumberger array. These are the vertical electrical sounding (VES) and cross vertical electrical sounding (CVES) technique. The measurements of VES were carried out at 38 points distributed as much as possible to cover the area. Three main layers were delineated; these are the top soil, unsaturated layer of clayey sand or silty sand and saturated layer of sand to clayey sand and sand mixed with gravel at some places. The resistivity of the top soil varies from 11 – 600 ohm.m, and thickness ranges from 0.7 – 2.8 m. The unsaturated layer has resistivity values varying from 46 – 320 ohm.m, and thickness ranging from 2.0 – 7.2 m. The resistivity of the saturated layer varies from 11 – 60 ohm.m, and thickness ranges from 4.6 – 13.8 m. There are also lenses in some places within the layers, 1.2 – 2.45 m. thick, which have high resistivity 800 – 900 ohm.m or low resistivity 9.6 – 29 ohm.m that may represent fill material and clay lenses respectively. The average depth of the groundwater surface ranges between 5 – 8 m. The measurements of CVES were taken along two perpendicular directions around fixed central point, at 5 points. The results are presented as radial graphs to show the variation of resistivity with direction; these graphs show that the sediments are heterogeneous in their vertical and horizontal distribution; especially for the top soil. Finally, it is concluded that three major causes of failures prevail in the buildings in Baghdad University. The first cause is the lateral inhomogeneity of the subsurface sediments. The second is the presence of lenses, and the third is the variation in the groundwater level. These failures may cause many engineering problems such as cracks in the foundation and walls of buildings.

[1] Department of Earth Sciences, College of Sciences, University of Baghdad, Al-Jadryia, Baghdad, Iraq, e-mail: jassimthabit@yahoo.com; jassimthabit@scbaghdad.edu.iq; e-mail: geobanna1955@yahoo.com

[2] Dept. of Petroleum and Minerals Geology, College of Science, University of Diyala, Diyala, Iraq, e-mail: munther_alawsi@yahoo.com

استعمال التحري الكهربائي العمودي لدراسة مواقع إنشائية؛ دراسة حالة، جنوب بغداد، العراق

جاسم محمد ثابت، أحمد شهاب البناء و منذر ظاهر نصيف الأوسي

المستخلص

استخدم الجس الكهربائي العمودي للأغراض الهندسية في منطقة الجادرية (موقع جامعة بغداد). إذ تم تطبيق اسلوبين هما الجس الكهربائي العمودي والجس الكهربائي العمودي المتقاطع، وباستعمال ترتيب شلمبرجر للأقطاب في 38 نقطة جس موزعة في منطقة الدراسة قدر المستطاع. واستخدم أسلوب الجس المتقاطع في خمسة مواقع ضمن منطقة الدراسة للتعرف على طبيعة تجانس الرواسب، حيث أجريت القياسات الكهربائية باتجاهين مختلفين لهما نفس مركز الترتيب. أظهرت المقاطع الجيوكهربائية وجود اربعة أنطقة كهربائية.

النطاق الأول يمثل الطبقة السطحية التي تتألف من ترسبات الطين أو الغرين وبنسب مختلفة، والحاوية في بعض الأحيان على الرمل أو بقايا مواد البناء، تتراوح المقاومة النوعية لهذا النطاق من 11 – 600 اوم.متر، اما سمكه فيتراوح من 0.7 – 2.8 متر. النطاق الثاني يظهر بشكل عدسات غير مستمرة ويتراوح سمكة من 1.2 – 2.45 متر. أما مقاومتة النوعية فقد كانت منخفضة في بعض المواقع حيث تراوحت من 9.6 – 29 أوم.متر وتشير إلى الترسبات الطينية الحاوية على نسبة قليلة من الرمل في بعض الأحيان. وفي بعض المواقع الأخرى تراوحت مقاومتها النوعية من 800 – 950 أوم.متر وهذه تشير إلى عدسات من الحصى أو بقايا مواد الدفن. ويمثل النطاق الثاني نطاق الترسبات الرملية غير المشبعة بالمياه الجوفية والحاوية على نسب مختلفة من الغرين أو الطين، وتتراوح مقاومتة النوعية من 46 – 320 أوم.متر، أما السمك فيتراوح بين 2 – 7.2 متر. النطاق الرابع يمثل نطاق المياه الجوفية في منطقة الدراسة ويتألف من الرمل الحاوي على نسب مختلفة من الغرين أو الرمل الحاوي على الطين، ومن المحتمل أن يكون حاوي على القليل من الحصى الناعم في بعض المواقع. تراوحت مقاومته النوعية من 11 – 60 أوم.متر، أما سمكه فيتراوح بين 4.6 – 13.8 متر. وتبين إن رواسب منطقة الدراسة غير متجانسة في خصائصها وفي توزيعها الأفقي والعمودي وذلك بناءا على نتائج الجس الكهربائي العمودي المتقاطع. كذلك أظهرت المقاطع الجيولوجية عدم استمرارية الرواسب وتواجدها بشكل عدسات تتغير من موقع لآخر وضمن مسافات قليلة خاصة نطاق الطبقة السطحية وترسبات الرمل الطيني. وأظهرت منطقة الدراسة الوسطى عدم تجانس واضح في خواص ومكونات الترسبات الرملية غير المشبعة بالمياه الجوفية، حيث يكثر وجود الترسبات الرملية ذات المحتوى المائي القليل والحاوية على نسب متغيرة من الغرين، في حين تنتشر الترسبات الرملية الحاوية على الطين أو الرطوبة في الشمال الشرقي والجنوب الغربي. لذلك يعتقد بأن تشقق جدران بعض البنايات سببة تأثير عدم تجانس الرواسب حيث يؤدي ذلك إلى حدوث تجلس متباين في التربة التي تقام عليها البنايات، بالإضافة إلى تأثير ارتفاع منسوب المياه الجوفية في مواقع هذه البنايات ووجود تذبذب في منسوب هذه المياه.

INTRODUCTION

In Baghdad University site, land has been recently allocated to construct new buildings. After construction,vertical and near vertical cracks or discontinuities were noticed in the walls of some buildings, in addition to many settlements in some of the neighboring streets. Therefore, construction of any building needs subsurface information that can be obtained through geophysical methods.

The study area is located within Baghdad University site (Al-Jadiriya area), south of Baghdad city, at the east bank of the Tigris River. It lies between (33° 16' – 33° 17') N and (44° 23' – 44° 24') E as shown in Fig.1.

The aims of the present study are to determine: the subsurface layers, overburden thickness, depth to the groundwater, weak zones, and sediments condition such as heterogeneity in order to give a clear picture of variations in soil horizons to assist in foundations studies.

GEOLOGY

Baghdad city lies within the Mesopotamia basin which is characterized by thick sedimentry cover. Most of these sediments are fluvial (Jassim and Goff, 2006). Three major horizons can be distinguished at the study area as obtained from the data of the National Center for Construction Labs (NCCL, 2002) as shown in Fig.2.

1. Fill zone: contains brown silty clay or clayey silt and sandy silt, as well as pieces of bricks and concrete.
2. Second zone: the upper natural subsoil strata, being of high to medium stiffness, include brown silty clay or clayey silt and sand or gravel sometimes.
3. Third zone: the lower natural subsoil strata contains brown to gray sand mixed with various amount of silt and clay or clay lenses and silty clay lenses. This zone is of less cohesion than the second one.

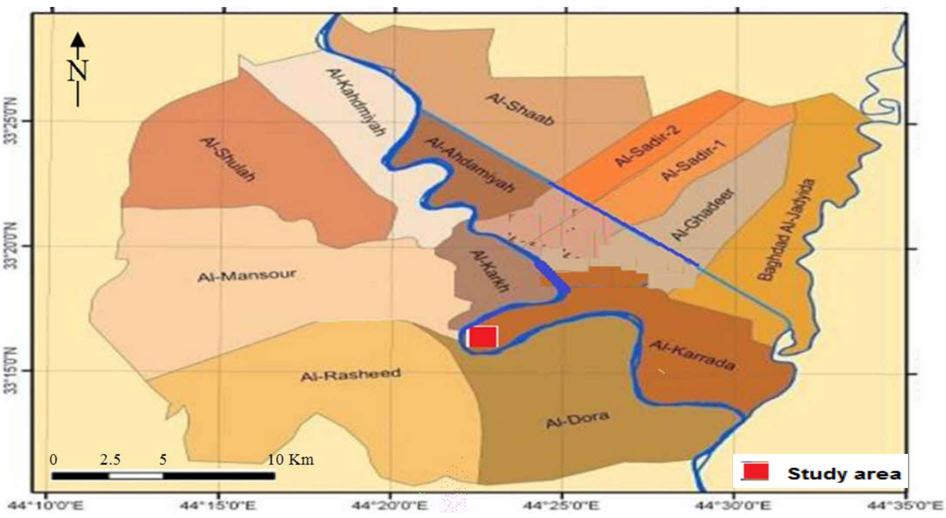


Fig.1: Location of the study area at Baghdad city
(Modified after Baghdad Mayoralty, 2011)

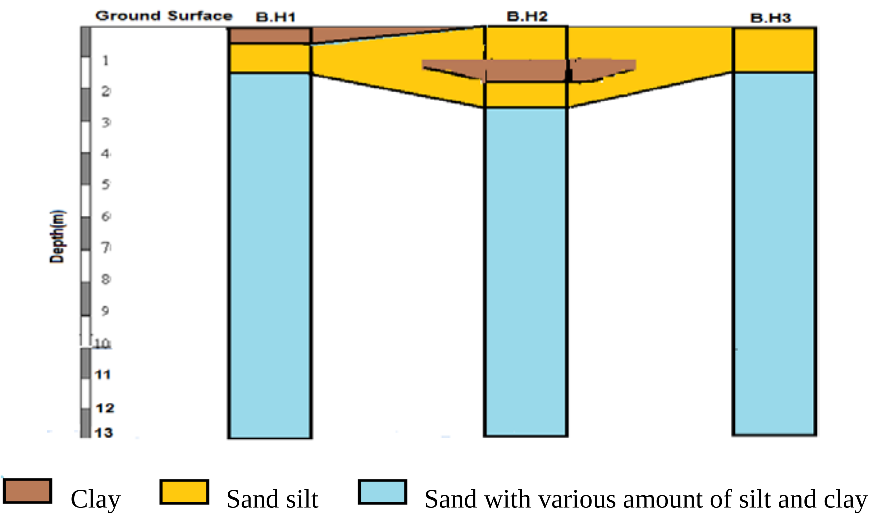


Fig.2: Soil section in B.H.1, B.H.2 and B.H3 in the study site,
(Modified after National Center for Construction Labs., 2002)

METHODOLOGY

Two resistivity techniques are used in this study (vertical electrical sounding and crossed sounding techniques). VES technique is applied using Shlumberger array at 38 points distributed over the study area (Fig.3). Terrameter SAS 300 is used for the survey; the maximum distance between current electrodes (AB) is 120 m and the maximum distance between potential electrodes (MN) is 10 m. The measurements were taken according to a modified table from Bhattacharya and Patra (1968) and Al-Ane (1998), in which the ratio of MN/AB ranges between 1/5 – 1/12, to reduce the theoretical displacement between curve segments, and to recognize the effect of lateral heterogeneity on field curves.

The field curves of apparent resistivity are interpreted manually through partial matching of these curves with theoretical curves using Ebert method, and also interpreted by computer through Win Resist 1.0 version software (the results of manual interpretation are improved and supported by the help of computer). The computer results are used to construct four electrical sections. The lithological sections of wells and other geological and hydro-geological information have been used to convert the electrical sections to geological sections.

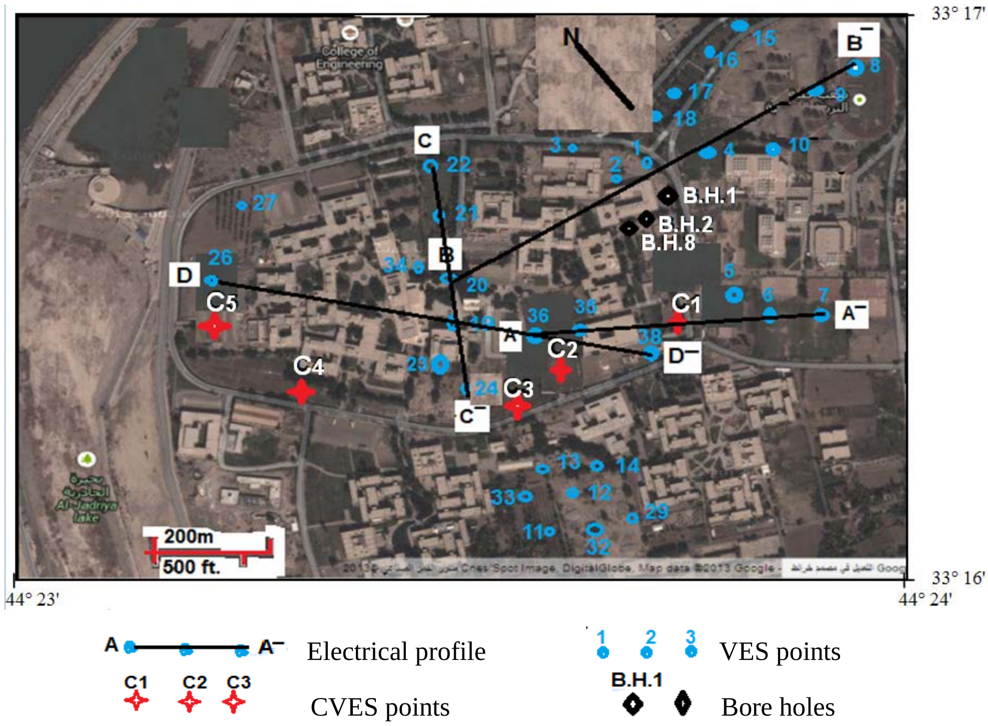


Fig.3: The distribution of VES and CVES points and electrical profiles

CVES was used to detect the inhomogeneous sediments at five sites (Fig.3). In this technique electrical measurements were taken along two perpendicular directions around fixed central point with N – S and E – W directions. Resistivity as a function of azimuth in crossed coordinates were plotted to produce polygons of anisotropy in order to show the variation of resistivity values with direction. The coefficient of anisotropy (λ) for current electrodes space (AB/2 = 1.5 m, 5 m, 10 m and 20 m) was calculated according to the following equation (Stienich *et al.*, 1997).

$$\lambda = \frac{\rho_{max}}{\rho_{min}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where: (ρ_{max}) apparent resistivity measure along the ellipse major axis.
(ρ_{min}) apparent resistivity measure along the ellipse minor axis.

The purpose of CVES is to determine the variation in subsurface resistivity, because of its sensitivity to lateral inhomogeneity (Boris and Merriam, 2002, Abdullahi *et al*., 2012). The lateral variation of resistivity may be caused by changes in lithology and/or change in quantity and quality of the pore space water (Stienich *et al*., 1997).If this survey is applied to homogenous and isotropic horizontal layers, the resulting curves will show no change on its form and type. But, if there is lateral inhomogeneity, the resultant curves will be different in its form and types (Chandra *et al*., 2004).

RESULTS AND DUSCUSION

- **Vertical Electrical Sounding (VES)**

Profile AA' (Fig.4) shows essentially three layers: a top layer, is a soil of 1.4 – 2.0 m thickness and variable resistivity. The variable resistivity is probably due to variable water content. The second layer may be unsaturated sand. Its thickness varies between 4.6 – 6 m and its variable resistivity is again due to water content and probable increase of clay content. The lower layer, of a verage low resistivity, is saturated sand with clay.

The other profiles of BB' (Fig.5), CC' (Fig.6) and DD' (Fig.7) show nearly the same picture with the three mentioned layers. The characteristics of each section are given in the above figures. A probable thin clay lens may occur below VES 4, 9 and 8 in profile BB'. A similar clayey lens may occur below VES 24 in profile CC'. A thin gravely lens or fill material of high resistivity is found below VES 26 of profile DD'.

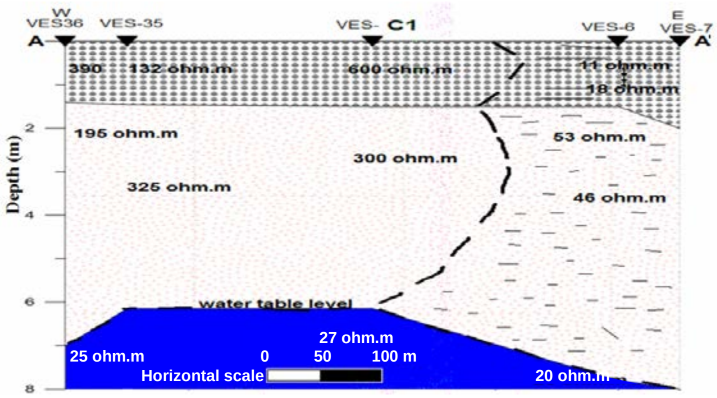


Fig.4: Electrical and geological section along profile AA'

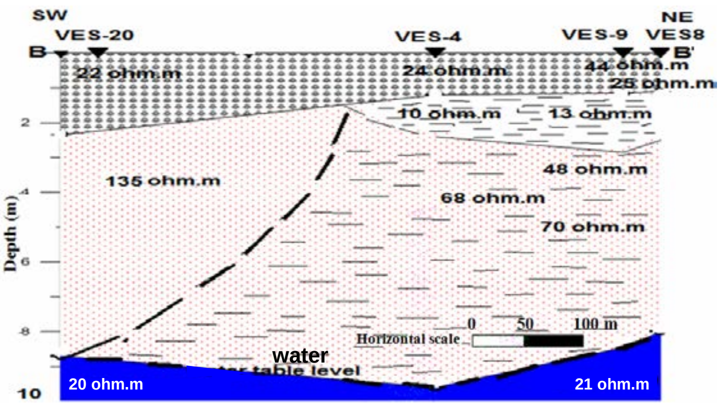


Fig.5: Electrical and geological section along profile BB'

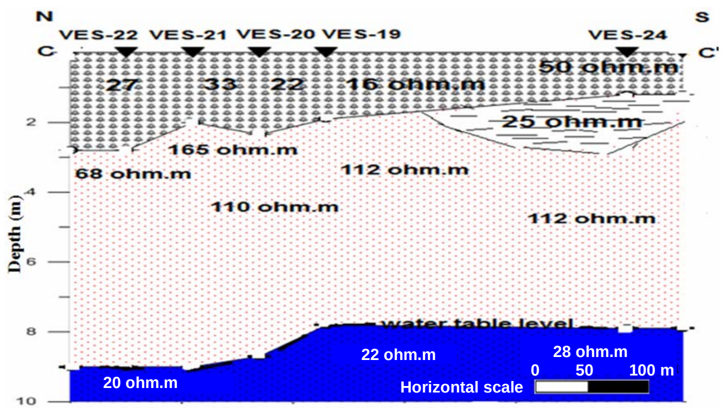
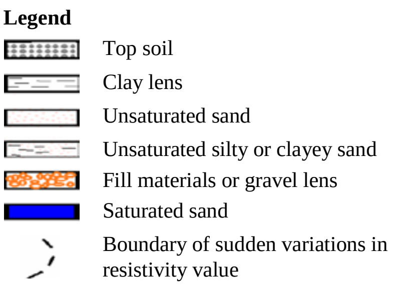


Fig.6: Electrical and geological section along profile CC'



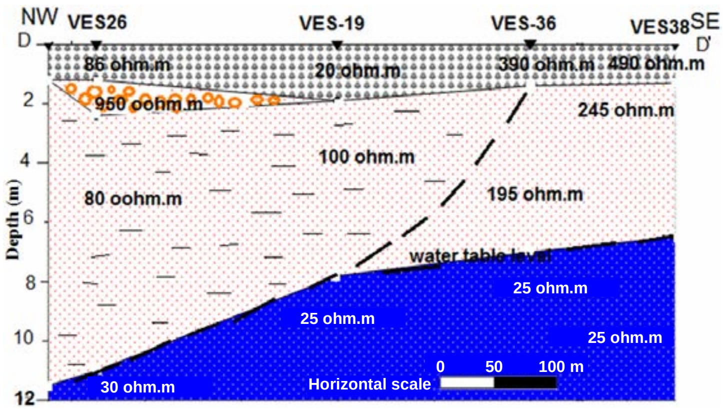


Fig.7: Electrical and geological section along profile DD'

- **Cross Vertical electrical sounding (CVES)**

One of the most employed technique for studying the lateral heterogeneity is the crossed sounding or as it is called azimuthal resistivity technique, because of its sensitivity for lateral heterogeneities (Boris and Merriam, 2002; Abdullahi *et al.*, 2012). In this technique, an electrode array is rotated about its center, so that the apparent resistivity is observed in several directions (Taylor and Fleming, 1988). Recent research indicates that any observed change in apparent resistivity with azimuth is indicative of fracture anisotropy. However, interpretation of CVES data is actually more complicated, as azimuthal variations in apparent resistivity are also produced by the presence of dipping beds and other lateral changes in formation resistivity (Watson and Barker, 1999).

In this study, the CVES was used to detect the sediments heterogeneity at five sounding points. The measurements were taken at two perpendicular directions (N – S and E – W) around fixed central point. The effect of fracture anisotropy and dipping stratigraphy was canceled, because the deposits are mainly fluvial; therefore any variations in apparent resistivity with azimuth represent probable weak zones due to the effect of lateral heterogeneity.

Figure 8 shows the radial graph of CVES point (C1) for spacing (AB/2) equals 1.5, 5, 10 and 20 m. The departure of the measured resistivity outline from the circular pattern (elliptical shape) is an indication of subsurface heterogeneity. On the other hand, circular outlines represent homogenous isotropic subsurface. The coefficient of anisotropy (λ) varies between 1 and 1.27. Three probable weak zones at apparent depth of spacing (AB/2) equal 1.5, 5, and 10 m are observed. The value of anisotropy ($\lambda = 1$) at apparent depth (AB/2 = 20 m) indicates that the sediments are homogeneous. The (E – W) direction of minimum apparent resistivity value is interpreted as the direction of weak zone, and it locates at apparent depth (AB/2 = 1.5 and 10 m). Also, the weak zone appears in (N – S) direction at apparent depth of (5) m. The other values of apparent resistivity are constant with different direction at apparent depth of (AB/2 = 20 m); this indicates presence homogeneous sediments at this depth.

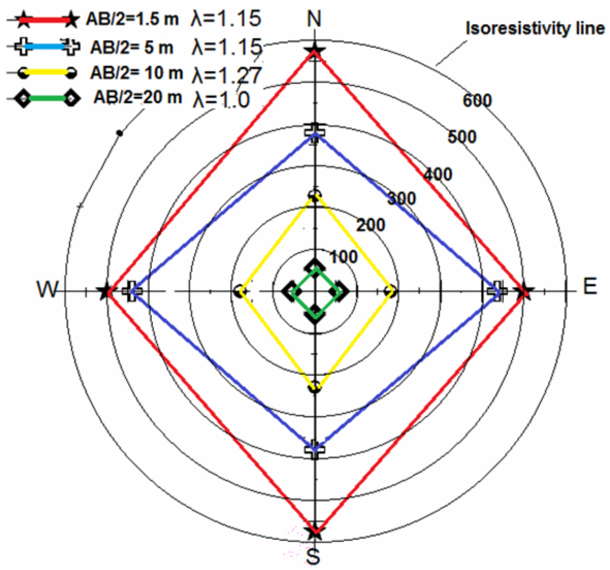


Fig.8: Radial graph along CVES point (C1)

Figure 9 shows the radial graph of CVES about point C2. The values of anisotropy coefficient (λ) vary nearly from 1.07 – 1.29. The direction of minimum apparent resistivity is interpreted as the direction of weak zones, and it represents the (E – W) direction for all spacing.

The radial graph for CVES point C3 (Fig.10) show departure of the measured resistivity outline from the circular pattern (elliptical shape) indicating that the sediments are homogeneous in the (E – W) direction. The values of anisotropy coefficient (λ) vary from 1.01 – 1.33 approximately. The direction (N – S) of minimum apparent resistivity is constant for all spacing.

The radial graph along CVES point C4 does not show departure (elliptical shape) of the measured resistivity outline from the circular pattern (Fig.11). It indicates homogenous sediments, because all the measurements of apparent resistivity are nearly the same at different direction. The values of anisotropy coefficient (λ) vary from 1.01 – 1.02. Therefore the site of CVES point C4 is more suitable for construction in the study area. The CVES point C5 have departure radial graph (Fig.12) which indicates heterogeneous sediments, and the direction of low resistivity values is at (E – W) direction.

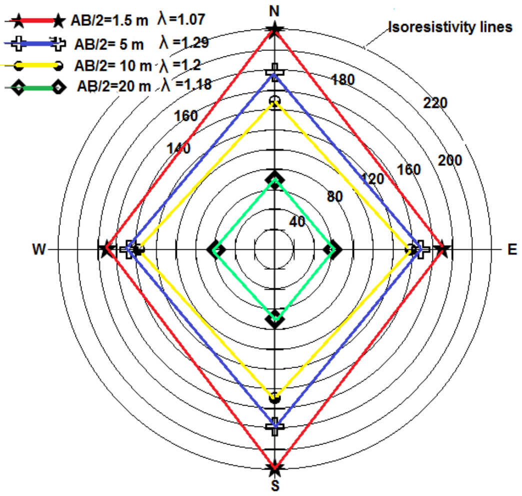


Fig. 9: Radial graph along CVES point C2

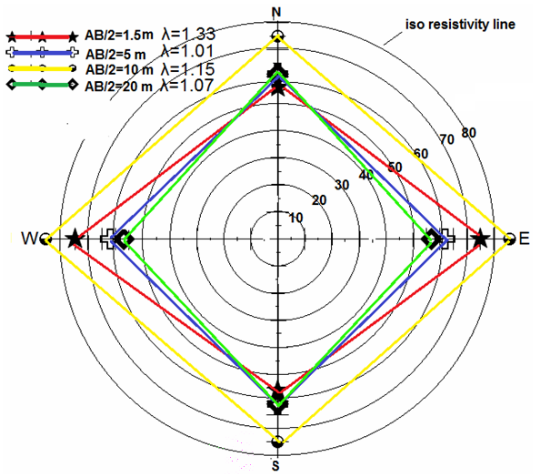


Fig.10: Radial graph along CVES point C3

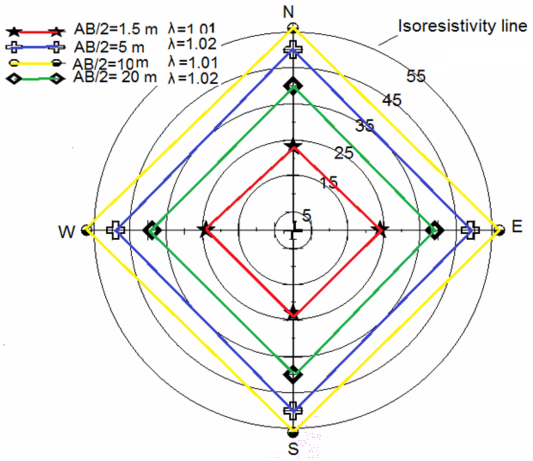


Fig.11: Radial graph along CVES point C4

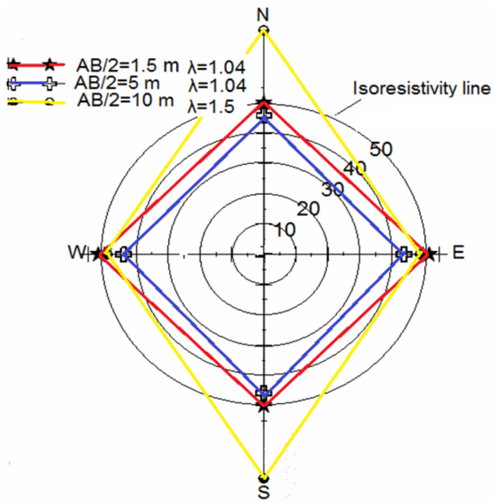


Fig.12: Radial graph along CVES point C5

CONCLUSION

The resistivity results indicate three layers, which are the topsoil, unsaturated layer and saturated layer. The top soil is generally thin with thickness varying between 0.7 – 2.8 m. It is composed mainly of silty clay, clayey silt, and sandy silt. The unsaturated layer is composed of clayey sand or silty sand, and its thickness ranges between 2.0 – 7.2 m, while the saturated layer is composed of sand to clayey sand and sand mixed with gravel at some places, with a thickness ranging between 4.6 and 13.8 m. Also there are thin lenses with high and low resistivity, which appear in some places, and represent fill material and clay lenses respectively; its thickness ranges from 1.2 – 2.45 m. The electrical and geological sections show the depth to the ground water to be between 5.0 – 8.0 m. The results of CVES show that the sediments of the study area are heterogeneous in properties, in its vertical and horizontal distribution, especially with the top soil.

Therefore for building constructions, the topsoil must be excavated to a reasonable depth at which the soil becomes adequately competent, and the choice of foundation material must take into account the characteristics of the clayey material and lenses. The permanent direction of weak zones as determined by CVES is the (E – W) direction for most cross sounding points and depths, except the sounding point C3 which shows a (N – S) direction. Finally from the resistivity investigation, three major causes of failure are identified. These causes may be the lateral in homogeneity of the subsurface layers, presence of the thin lenses, and the variation of ground water level.

ACKNOWLEDGMENTS

The authors wish to thank the dean of the College of Science and the head of the Department of Geology for providing field requirement. They also thank their friends Ali Kais, Osama Saad, Zead Dhaher and Emmad Dhaher for helping in field work.

REFERENCES

Abdullah, N.K., Batu, M.A. and Masanawa, A.A., 2012. Fracture Determination Using Azimuthal Schlumberger and Offset Wenner Array in Basement Complex of Northwestern Nigeria. J. Environ. Earth sci., Vol.4 (7), p. 747 – 755.

Al-Ane, J.M., 1998. Theoretical and application consideration for the effect of geometry on Shlumberger and dipole configurations. Ph.D. Thesis, Baghdad University, Geology Department, 98pp.

Al-Awsi, M.D.N., 2005. Study of the sediments nature by using electrical resistivity method at Al-Jadiriya site (Baghdad University). M.Sc. Thesis, Baghdad University, Geology Department, 128pp.

Baghdad Mayoralty, 2011. Plans, maps and statistics on Baghdad City report. Baghdad (internal report).

Bhattacharya, P.K. and Patra, H.P., 1968. Direct current electrical sounding. Elsevier publishing company, Amsterdam, 131pp.

Boris, M. and Merriam, J., 2002. Azimuthal resistivity to characterize fractures in glacial till. Geophysical Prospecting, Vol.48, p. 677 – 687.

Chnadra, S., Anandrao, V. and Singh, V.S., 2004. A combined approach of Schlumberger and axial Pole-dipole configurations for groundwater exploration in hard rock area. Current science, Vol.86 (10), p. 1437 – 1442.

Fatoba, J.O., Salami B.M. and Adesida, A., 2013. Structural failure using electrical resistivity method: A case study of Amafor Ihuokpala, Enugu, Southeastern Nigeria. Journal of Geology and Mining Research, Vol.5 (8), p. 208 – 215.

Jassim, S.Z. and Goff, J., 2006. Geology of Iraq. Dolin, Prague and Moravian Museum, Brno, 341pp.

National Center of Construction Lab. (NCCL), 2002. Project of science and media colleges building at Baghdad university site. Directorate of soil investigation, 50pp.

Ozegin, K.O., Oseghale A.O., kolie E.C. and Ujuanbi O., 2011. Integration of very low-frequency electromagnetic (VLF-EM) and electrical resistivity methods in mapping Sub-surface geologic structures favorable to road failures. Int'l Jour. of Water Res. and Environ. Eng., Vol.3 (6), p. 126 – 131.

Rajiv, K.S. and Rajeev, C., 2011. Correlation between vertical electric sounding and conventional methods of geotechnical site investigation. (IJAEST), Vol.4 (2), p. 42 – 53.

Stienich, B., Simon, I., Chararria, A.A. and Marin, L.E., 1997. Geophysical investigation of the vadose zone in the valley of Hermosillo aquifer, sonoro. Mexico, Geofisica internacional, Vol.36 (3), p. 191 – 200.

Taylor, R.W. and Fleming, A.H., 1988. Characterizing jointed systems by azimuthal resistivity surveys, Ground Water. Vol.26 (4), p. 464 – 474.

Waltham, T., Bell, F. and Culshaw, M., 2005.Sinkholes and Subsidence: Karst and Cavernous Rocks in Engineering and Construction. Chichester, England, Springer, 382pp.

Watson, K.A. and Barker, R.D., 1999. Differentiating anisotropy and lateral effects using azimuthal resistivity offset Wenner soundings. Geophysics, Vol.64 (3), p. 739 – 745.