Application of 2D Electrical Resistivity Imaging Technique for Engineering Site Investigation

Asem A. Hassan[2] Munther D. AL-Awsi[1] Mutadhid M. Al-Obaidi[3]

[1]College of Science, Diyala University, Baqubah, Diyala, Iraq, E-mail: asem.ahmed@sciences.uodiyal.edu.iq

[2]College of Science, Diyala University, Baqubah, Diyala, Iraq, E-mail: munther_hnt@sciences.uodiyala.edu.iq

[3]College of Science, Diyala University, Baqubah, Diyala, Iraq, E-mail: mutadhid@sciences.uodiyal.edu.iq

Abstract

Engineering site investigation is crucial to characterize the subsurface soil of proposed construction sites. Application of 2D Electrical Resistivity Imaging ERI technique pro- vides useful information about the subsurface geology and the condition along profiles. In this paper, numerical and field studies using 2D ERI technique were adopted for engineer- ing site investigation purposes. The Wenner-Schlumberger array was implemented along three parallel profiles at the construction site of Diyala University, northeast of Baghdad city, to detect buried utilities (pipes) left over in the area. A synthetic resistivity model of a buried pipe was designed to discuss and validate the field results. The 2D ERI sections of the model resolve clearly the buried structure, even with 5% noise level. Interpretation of the field data showed that 2D ERI technique was effective in delineating the buried pipes. The vertical and horizontal sensitivity of the Wenner-Schlumberger array for sub- surface resistivity variations made it possible to determine the position and geometry of the buried structures. The current work demonstrates the usefulness of the ERI technique as a complementary tool for engineering site investigation.

Keywords: Electrical Resistivity Imaging, Engineering Site Investigation

الخلاصة

ان تحري الموقع الهندسي مهم لدراسة خصائص التربة تحت سطح الأرض لمواقع البناء المقترحة. يوفر استخدام طريقة المقاومة النوعية الكهربائية التصويرية ثنائية البعد معلومات مفيدة عن جيولوجيا وظروف ما تحت السطح على امتداد مسارات. في هذه الدراسة، تم اعتماد النمذجة الرقمية والدراسة الحقلية باستخدام تقنية المقاومة النوعية الكهربائية ثنائية البعد لأغراض تحري المواقع الهندسية. تم استخدام ترتيب فنر – شلمبرجر للاقطاب على امتداد ثلاثة مسارات متوازية في موقع للبناء في جامعة ديالى شمال شرق مدينة بغداد للكشف عن المرافق المدفونة (أنابيب) التي تركت في المنطقة. تم تصميم موديل افتراضي لانبوب مدفون لغرض المناقشة والتحقق من صحة النتائج الحقلية. لقد بينت مقاطع المقاومة النوعية الكهربائية ثنائية البعد للموديل امكانية الكشف عن التراكيب المدفونة حتى بوجود مستوى ضجيج مقدار ٥% .لقد اظهر تفسير البيانات الحقلية أن تقنية المقاومة النوعية الكهربائية ثنائية البعد كانت فعالة في تحديد الانابيب المدفونة. ان حساسية ترتيب فنر – شلمبرجر للتغيرات الرأسية والأفقية في المقاومة النوعية الكهربائية للتربة تحت السطح جعلت من الممكن تحديد موقع وشكل هذه التراكيب المدفونة. لقد اكدت الدراسة الحالية فائدة تقنية المقاومة النوعية الكهربائية التصويرية كأداة مكملة لتحريات المواقع الهندسية.

الكلمات المفتاحية: المقاومة النوعية الكهربائية التصويرية، تحري الموقع الهندسي.

1-Introduction

Engineering site investigation provides a critical geotechnical and geoenvironmental as- sessment of the proposed construction sites. It includes detailed surface and subsurface studies to evaluate the suitability of the site for particular infrastructures. Application of ERI survey for geotechnical site characterization is useful to determine the subsurface geology and the condition of the proposed site [1] .

Recently, ERI technique has increasingly been integrated with geotechnical site investigations [2] [3] [4] . It offers non-invasive and cost effective information to identify the subsurface condition and to determine the appropriate location of test borings needed for site investigation [5] .

Presence of natural (e.g. Cavities and sinkholes) and man- made (e.g. Pipes and channels) structures in the engineering construction sites brings significant geotechnical and geoenvironmental problems. The determination of these structures is important to facilitate the proposed construction site with respect to the shallow and deep foundations. Traditional “ground-truth” test borings are commonly implemented for geotechnical site investigations. However, these methods are expensive and limited to a point [3] . In comparison, 2D ERI surveys are less expensive and can be conducted along profiles to obtain 2D resistivity sections [6] .

Several authors have adopted 2D ERI technique for engineering site investigation to detect subsurface structures such as cavities and sinkholes [7] [8] [9] [10] [11] [12] , fractures [13] [14] , faults [15] , buried utilities [16] , walls [17] , cracks [18] and tunnels [19] .

Recently, an extensive campaign of building of new facilities has taken place in Diyala University northeast of Baghdad city. Delineation of buried utilities and construction materials left over in the area is vital to facilitate the site for future engineering projects [20] . Thus, in this study, numerical and field studies are adopted to detect buried utilities (pipes) in the construction site of Diyala University. The resistivity measurements are collected using Wenner-Schlumberger array along three parallel profiles. A synthetic resistivity model is designed to discuss and validate the interpretation of the field data.

2-2D Electrical Resistivity Imaging Technique

2D Electrical Resistivity Imaging ERI technique is based on using a larger num- ber of electrodes arranged along a profile and connected to the electrical resistiv- ity system via a multi core cable [21] . The apparent resistivity measurements of Wenner-Schlumberger array, adopted in the current study, are acquired using cur- rent (C1 and C2) and voltage (P1 and P2) electrodes for different electrode spacing (a) and acquisition levels (n) Figure (1). The Wenner-Schlumberger array is a hy- brid combination between Wenner and Schlumberger arrays. It was chosen as it has good signal strength and sensitivity to resolve horizontal and vertical resistivity variations [22] .The subsurface resistivity values acquired are arranged in apparent resistivity pseudo-sections which give a qualitative approximations of the subsurface resistivity distribution. An inversion procedure, therefore, is required to obtain a true 2D resistivity section from the field data.

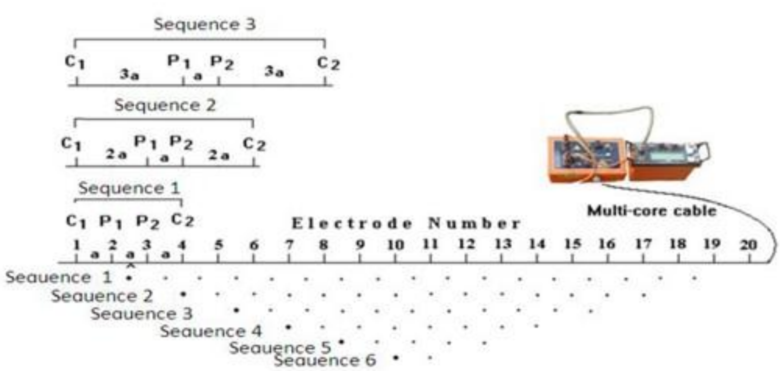

Figure (1) The sequence of 2D ERI measurements using a Wenner-Schlumberger array adopted in the current study

3-Field Work

2D ERI survey using a Wenner-Schlumberger array was conducted along three parallel profiles, 1m apart, located in Diyala University, northeast of Baghdad city Figure (2). According to the geotechnical soil borings drilled in the area [3] the surface soil consists of light to dark brown low plasticity clay (CL) layer up to 13m Figure (3). The study area has recently witnessed an extensive expansion campaign of building new teaching facilities. Presence of buried structures such as pipes and construction materials left over in the area are expected Figure (4). Geotechnical site investigation is necessary to explore the subsurface condition and to locate buried structures for future engineering projects.

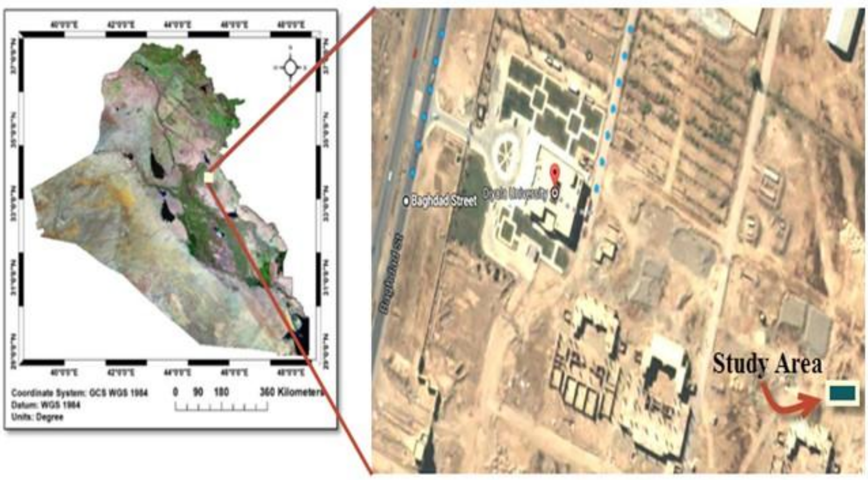

Figure (2) Map of study area

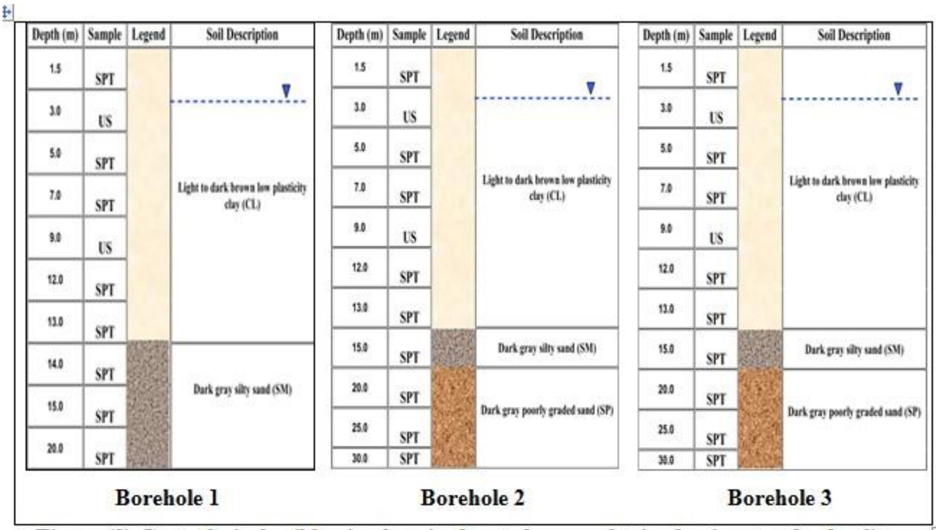

Figure (3) Geotechnical soil boring logs in the study area obtained using standard split spoon samplers used in the Standard Penetration Test (SPT) and Undisturbed Samples (US) (Shelby tubes) (Al- Ebdaa, 2015)

Figure (4) Buried pipes in the study area

2D ERI profiles were centered over an existing buried pipe to investigate the suitability of the Wenner-Schlumberger array for delineating shallow buried (pipes) structures. For each profile, twenty electrodes with a minimum electrode spacing of 0.5m was connected to ABEM SAS 4000 resistivity system to collect the apparent resistivity data. RES2DINV software ver. 3.71 [23] was used to generate 2D ERI sections from the apparent resistivity data. RES2DINV uses finite difference method based on the regularized least squares optimization procedure [24] [23] to produce a true 2D model of the subsurface resistivity distribution from the apparent resistivity data. The software iteratively determines the model blocks resistivity that will closely produce the measured apparent resistivity data. The software offers L1 norm (Blocky) and L2 norm (smooth) optimization methods. In the current study, the L1 norm optimization method was adopted as it is more suitable in areas of sharp resistivity boundaries [25] , such as buried pipes investigated.

4-Numerical Modelling

Numerical modelling using synthetic resistivity model was used to simulate the buried pipes in the study area. ERI numerical modelling is useful to examine the method adopted and to validate the interpretation of the field data. The procedure consists of two steps [26]
: (1) a synthetic resistivity model is designed based on the user prior information using forward modelling software from which the apparent resistivity section is calculated; (2) the model is then inverted to reconstruct the subsurface true resistivity distribution Figure (5).

To simulate the buried pipes in the study area, a synthetic resistivity model of a buried pipe in clay soil Figure (6) was designed and discretized using RES2DMOD software ver. 3.01 [27] . An air filled pipe of high resistivity (10000 Ohm.m), buried in a wet clay soil of low resistivity (5.0 Ohm.m) was examined. The resistivity values of the model components were chosen within the range of the materials reported in the literature [28] . The apparent resistivity section for Wenner-Schlumberger array with smallest electrode spacing of 0.5m was first calculated using RES2DMOD software. To simulate real situations, a scattered 5% noise value was added to the model. Once the apparent resistivity sections are calculated, RES2DINV ver. 3.71 software was used to produce the inverse 2D ERI sections of the model from the apparent resistivity data.

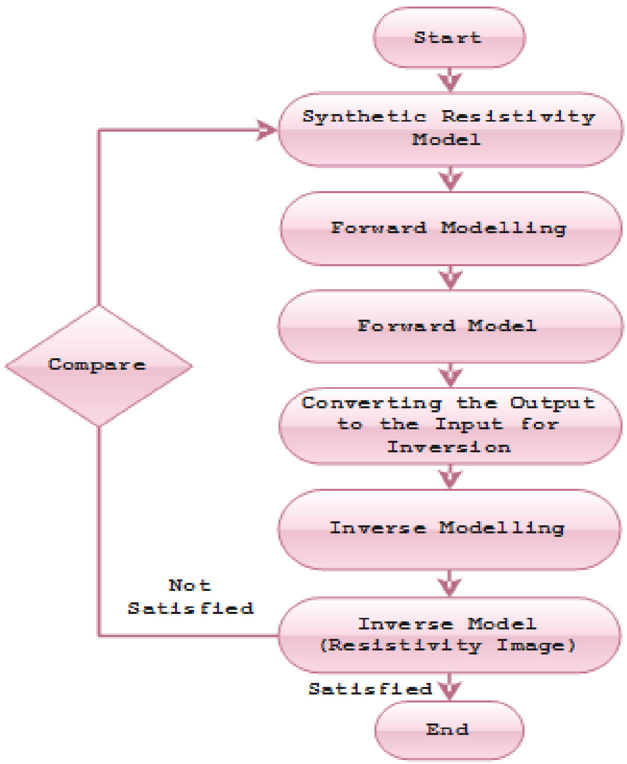

Figure (5) Numerical modelling steps using the ERI technique {26}

5-Discussion and Discussion

Figure (7) shows the calculated apparent resistivity section of the synthetic resistivity model. Although the resistivity signature of the buried pipe is indicated, the apparent resistivity section gives a qualitative interpretation of subsurface resistivity variations. Figure (8) presents the 2D ERI section calculated from the apparent resistivity data with no noise added. It can be seen that the buried pipe is clearly reflected in the section at the center of the profile. The high resistivity contrast between the modelled pipe and the sur- rounding medium made it easy to resolve the sharp resistivity variations. To simulate real situations, a scattered 5% noise value was added to the model. Figure (9) depicts the 2D ERI section of model with 5% noise level. The modelled object can still be resolved. The

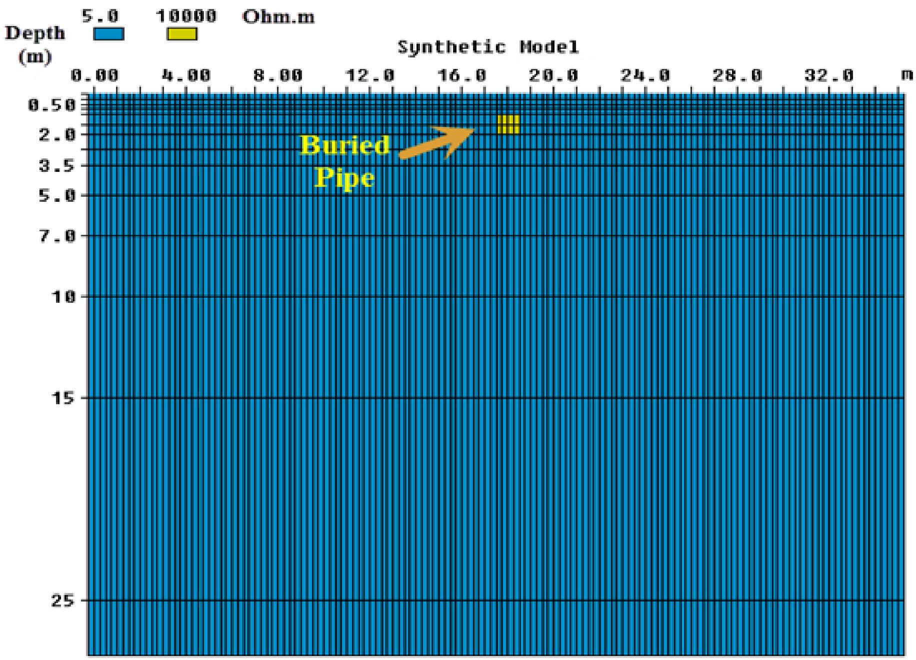

Figure (6) Synthetic resistivity model of a buried pipe

Interpretation of the synthetic resistivity model demonstrates the effectiveness of 2D ERI methods using Wenner-Schlumberger array to detect the buried pipes in clay soil. In the literature, recent studies have reported the efficiency of the Wenner-Schlumberger array for resolving buried structures such as fractures and cavities [9] [11] ; buried utilities [16] and buried walls [17] .

Field resistivity measurements were conducted along three profiles using the same array. For each profile, a minimum electrode spacing of 0.5m was used and the resistivity readings were collected for 7 (n) acquisition levels. Figure (10) shows the arrangement of model blocks and apparent resistivity data points of the field data. High data quality was achieved as shown in Figure (11). Therefore, there is no need to exterminate bad data points.

The 2D ERI sections were calculated from apparent resistivity using L1 norm (blocky) optimization method. Figures (12), (13), and (14) present the 2D ERI sections of the field data along L1, L2, and L3 profiles, respectively. A low (Abs.) error (1.12- 1.86%) was achieved after five iterations which indicates a good data quality. It can be seen that the buried pipe at the center of the resistivity profile was resolved reasonably well in all the 2D ERI sections. The geometry and position of the buried pipe were reflected in these sections. 2D ERI sections of the field data confirmed the previous findings of the synthetic

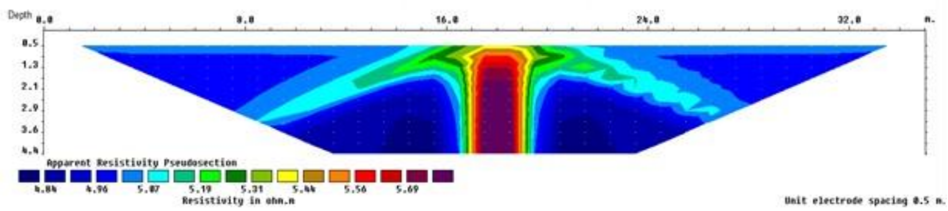

Figure (7) The calculated apparent resistivity section of the buried pipe model

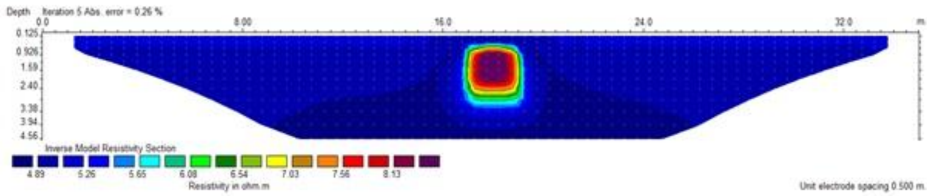

Figure (8) 2D ERI section of the buried pipe model (no noise added)

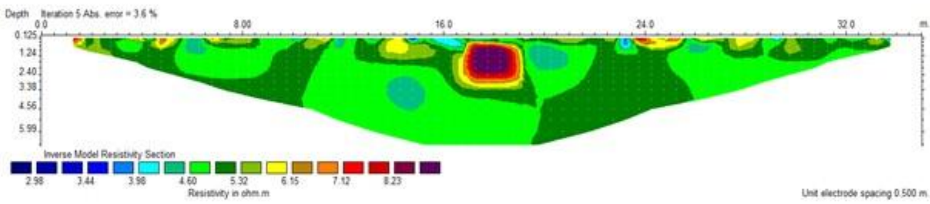

Figure (9) 2D ERI section of the buried pipe model (5% noise added)

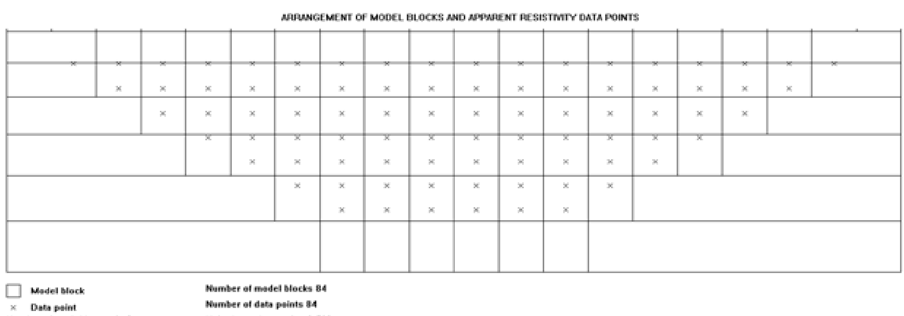

Figure (10) Arrangement of model blocks and apparent resistivity data points of the field survey

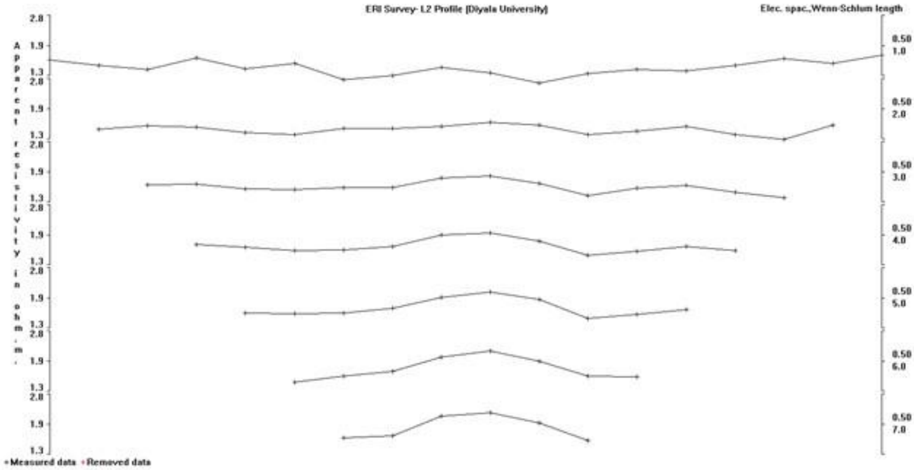

Figure (11) The apparent resistivity data of L2 profile

Resistivity model. The Wenner-Schlumberger array of the three profiles was succeeded in detecting the buried pipe. The high performance of the Wenner-Schlumberger array can be attributed to its characteristic features and sensitivity for detecting subsurface resistivity variations. It has good signal strength and moderate features that compromise between the ability to resolve horizontal and vertical resistivity variations [22].

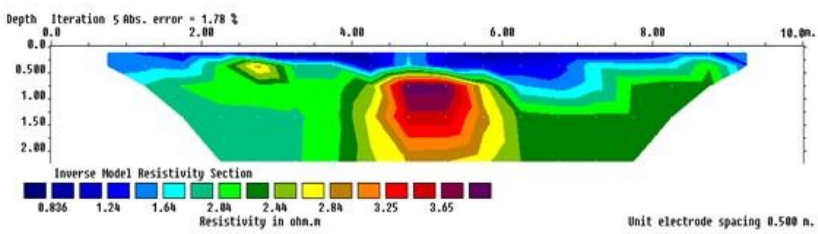

Figure (12) 2D Inverse ERI section of L1 profile

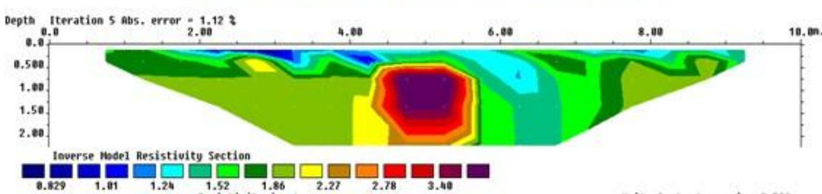

Figure (13) 2D Inverse ERI section of L2 profile

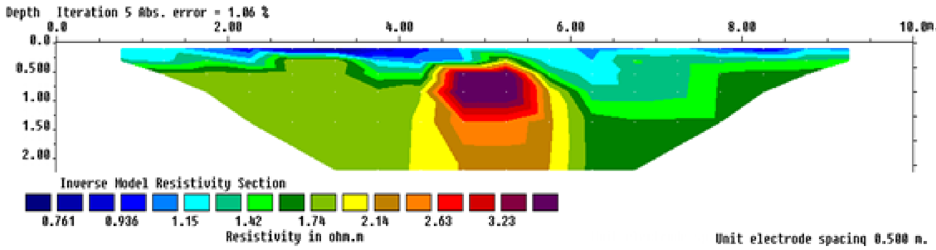

Figure (14) 2D Inverse ERI section of L3 profile

6- Conclusions

2D ERI survey was carried out using a Wenner-Schlumberger array along three parallel profiles to detect buried pipes at Diyala University site northeast of Baghdad city. The results of field data were validated using a synthetic resistivity model. Both numerical and field data interpretations indicated that the 2D ERI technique was effective in re- solving the buried structure. Geometry and position of the buried pipe were reasonably reflected in the 2D ERI sections. The results showed that the Wenner-Schlumberger array was sensitive enough to the horizontal and lateral resistivity changes in the subsurface soil resulted due to presence of the buried structure. The current study demonstrated the benefits of numerical modelling using 2D ERI technique for planning of resistivity field surveys. The results also indicated that 2D ERI method can be useful if integrated with other geotechnical site investigation tools to detect buried pipes commonly found in the engineering construction sites.

References

[1] H. H. Karim, M. A. Al-Neami, and W. M. Y. Mohammad, *Soil Site Investigations Using 2D Resistivity Imaging Technique, Eng*, 2013.

[2] E. Elawadi, G. El-Qady, A. Nigm, F. Shaaban, and K. Ushijima, “Integrated geo-physical survey for site investigation at a new dwelling area, egypt,” *Jour. Env. & Eng. Geophy*, vol. 11, no. 4, pp. 249–259, 2006.

[3] Al-Ebdaa, “Soil investigation report for the new buildings of diyala university part,” p. 210, 2015.

[4] K. Sudha, M. Israil, S. Mittal, and J. Rai, “Soil characterization using electrical resis-tivity tomography and geotechnical investigations,” *Journal of Applied Geophysics, Elsevier*, vol. 67, pp. 74–79, 2009.

[5] A. M. Youssef, H. El-Kaliouby, and Y. A. Zabramawi, “Sinkhole detection using electrical resistivity tomography in saudi arabia,” *Journal of Geophysics and Engi-neering*, vol. 9, no. 6, p. 663, 2012.

[6] M. H. Loke, J. E. Chambers, D. F. Rucker, O. Kuras, and P. B. Wilkinson, "Recent developments in the direct-current geoelectrical imaging method," *Journal of Applied Geophysics, 95,* vol. pp:, pp. 135–156, 2013.

[7] M. V. Schoor, "Detection of sinkholes using 2d electrical resistivity imaging.journal," *of Applied Geophysics*, vol. 50, no. 4, pp. 393–399, 2002.

[8] W. Zhou, B. F. Beck, and A. L. Adams, "Effective electrode array in mapping karst hazards in electrical resistivity tomography," *Environmental geology,* vol. 42, no. 8, pp. 922–928, 2002.

[9] M. A. Metwaly and F., "Application of 2-d geoelectrical resistivity tomography for subsurface cavity detection in the eastern part of saudi arabia," *Geoscience Frontiers*, vol. 4, no. 4, pp. 469–476, 2013.

[10] T. J.M. and A. M. Abed, "Detection of subsurface cavities by using pole- dipole array (bristow's method)/hit area-western iraq," *Iraqi Journal of Science,* vol. 55, no. 2, pp. 444–453, 2014.

[11] J. M. Thabit and A. S. Al-Zubedi, "Evaluation of three important electrode arrays in defining the vertical and horizontal structures in 2d imaging surveys," *Iraqi Journal of Science,* vol. 2015, no. 56, pp. 1465–1470, 2015.

[12] A. A. Amini and H. Ramazi, "Crsp, numerical results for an electrical resistivity array to detect underground cavities," *Open Geosci*, vol. 9, pp. 13–23, 2017.

[13] S. W.J. and B. T.J, "Evaluation of two-dimensional resistivity methods in a fractured crystalline rock terrane," *Journal of Applied Geophysics,* vol. 51, pp. 21–41, 2002.

[14] R. E. Chávez, C.-N. G., A. Tejero, J. E. Hernández-Quintero, and D. Vargas, *Special 3D electric resistivity tomography (ERT) array applied to detect buried fractures on urban areas,* San, 2014.

[15] F. Nguyen, S. Garambois, D. Jongmans, E. Pirard, and M. H. Loke, "Image processing of 2d resistivity data for imaging faults," *J Appl. Geophys. 57,* vol. pp:, pp. 260–277, 2005.

[16] H. H. Karim, K. H. Ibrahim, and A. H. Al-Rubaye, "Detection of buried utilities using electrical resistivity imaging (eri) technique, eng," *&Tech. Journal*, vol. 33, 2015, part (A), No.3.

[17] A. S. Al-Zubedi, "Evaluation of five electrode arrays in imaging subsurface shallow targets: A case study, iraqi bulletin of geology and," 2016.

[18] A. A. Hassan and M. D. Nsaif, "Application of 2d electrical resistivity imaging technique for detecting soil cracks: Laboratory study," *Iraqi Journal of Science,* vol. 2016, no. 57, pp. 930–937, 2016.

[19] M. Ebrahimi, A. A. Taleshi, A. Arab-Amiri, and M. Abbasinia, *Two and Three-Dimonsional ERT Modelling for a Buried Tunnnel*, 2016, vol. 7, no. 3.

[20] Al-Ebdaa, "Soil investigation report for the new buildings of diyala university part," p. 210, 2015.

[21] M. H. Loke, J. E. Chambers, and O. Kuras, "Instrumentation, electrical resistivity, solid earth geophysics encyclopedia (2nd," pp. 599–604, 2011.

[22] A. Samouëlian, I. Cousin, A. Tabbagh, A. Bruand, and G. Richard, "Electrical resistivity survey in soil science: A review, soil tillage," 2005.

[23] M. H. Loke, "Res2dinv ver. 3.71: Rapid 2-d resistivity & ip inversion using the least-squares method. geotomo software," 2012.

[24] Y. Sasaki, "Two-dimensional joint inversion of magnetotelluric and dipole-dipole resistivity data," *Geophysics*, vol. 54, pp. 174–187, 1989.

[25] M. H. Loke, I. Acworth, and D. T., "A comparison of smooth and blocky inversion methods in 2d electrical imaging surveys," *Exploration Geophysics*, vol. 34, pp. 182–187, 2003.

[26] P. Giao, Q. N. Cuong, and M. H. Loke, *Monitoring the chemical grouting in sandy soil by electrical resistivity tomography (ERT), Berichte Geol*, B.-A, 2011.

[27] M. H. Loke, "Res2dmod ver. 3.01: Rapid 2d resistivity forward modeling using the finite-difference and finite-element methods, geotomo software," 2014.

[28] ——, "Tutorial: 2-d and 3-d electrical imaging surveys, geotomo software," 2016.