Indian Journal of Science and Technology Vol. 5 No. 2 (Feb 2012) ISSN: 0974- 6846

Hydrogeologic, electrical and electromagnetic measurements for geotechnical characterization of foundation beds at Afunbiowo, near Akure, Southwestern Nigeria

I.A. Adeyemo and O.G. Omosuyi
Department of Applied Geophysics, Federal University of Technology, Akure, Nigeria.
faythyemo2003@yahooo.co.uk, droluomosuyi@yahoo.com

Abstract

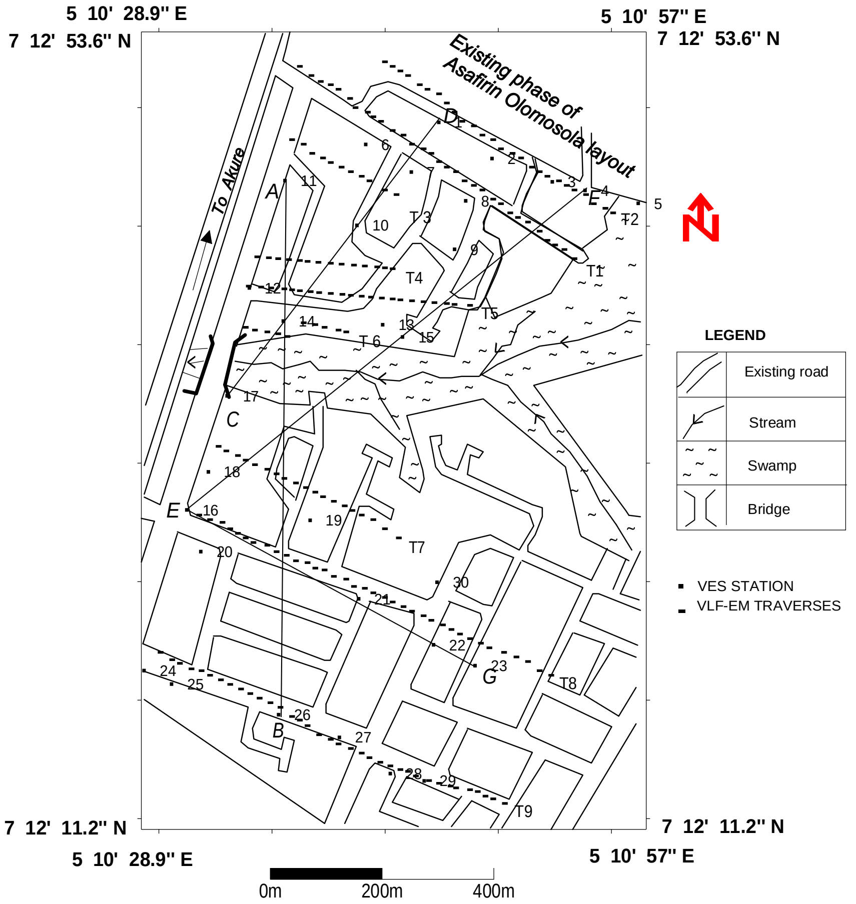
In order to evaluate layer competence for civil engineering foundation, engineering geophysical surveys (electromagnetic profiling and resistivity soundings), and hydrogeologic measurements, involving determination of depths to water table across wells, were conducted at Afunbiowo, near Akure, Nigeria. The EM raw real values vary from -44.0 to 49.9, while filtered real values vary from -43.8 to 48.5 across the study area. The Karous-Hjelt and Fraser filtered (KHF) pseudo-sections suggest the presence of clay and weathered materials in the central parts of the area. The interpretation of the geoelectrical data reveals that the near surface materials overlying the crystalline bedrock exhibit significant variations of resistivity values, ranging from 29 to 1400 ohm-m, while the bedrock resistivity ranges from 96 to 24729 ohm-m. This interpretation correlates with the high EM anomalies across the area. A pronounced low resistivity zone in the shallow subsurface is associated with saturated sands or clay rich sand. Depth to water table varies from 0.3m to 7.5m, with an average level of 4.5m. Water table occurs at shallow depths in the southwestern, central and north central segments of the area. Since a raised water table, or clay saturated with water may create a wet foundation and consequently engender geotechnical instability, building foundations in the southwestern, central and north central segments of the area must be founded on watertight concrete base.

Keywords: Hydrogeology, water, bedrock, Geophysical survey, Afunbiowo, Akur, Nigeria.

Introduction

Geophysical methods are currently enjoying growing applications in engineering investigations, particularly to delineate and characterize subgrade features. In foundation study, determination of depth to, and the geotechnical integrity of the bedrock, the physical properties of foundation geomaterials (Bowles, 1984) and the groundwater condition of near surface materials are of major geotechnical significance (Sharma, 1997). The electromagnetic (EM) and electrical resistivity methods have evolved into cost-effective and powerful tools in geotechnical investigation (Savvaidis *et al.,* 1999; Pellerin, 2002; Seaton & Dean, 2004). The methods are best suited in the determination of depths to the bedrock and detecting the presence of structural features in the bedrock, or potentially dangerous subsurface conditions (Soupios *et al.,* 2007) before the erection of any engineering structure.

Fig. 1. Layout map showing EM Traverse lines and VES locations at Afunbiowo



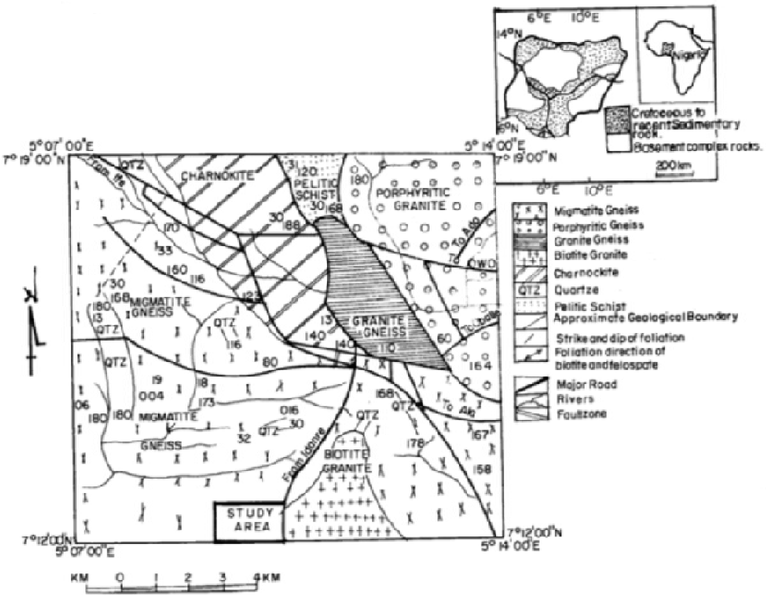
In this study, electrical and electromagnetic methods, including groundwater level measurement from existing wells were used to assess the geotechnical competence and extent of water and saturation of the near-surface materials and to map the gross subsurface geology of the study area. Geotechnical characteristics of the foundation beds in the area were construed from the physical parameters of the geophysical methods used (Savvaidis *et al.,* 1999;

Olorunfemi *et al.,* 2000; Othman, 2007). This study contributes to the decision making process for prescribing appropriate foundation footing in the area.

Location and geologic setting

Afunbiowo is a satellite town located in the outskirt of Akure, Southwestern Nigeria. The area covers a landmass of about 4.17 m^2 (Fig.1). The area is underlain by the Precambrian Basement Complex rocks of Southwestern Nigeria (Rahaman, 1989). The local geologic units are the migmatite-gneiss, biotite-gneiss and granites (Fig.2). The migmatite-gneiss is the most widespread, covering more than half of the area and occurring in the north-eastern and south-eastern parts of the area. The biotite-granite occurs in several locations, mostly in the central part. They are of porphyritic and medium-coarse-grained texture. Granites occur as intrusive in low-lying outcrops within the biotite-gneiss and occur mostly in the southwestern part of the area.

Fig. 2. Geological map of Akure area (After Owoyemi, 1996). Inset: Geological map of Nigeria



Materials and methods

The electromagnetic (EM) profiling and the vertical electrical sounding (VES) geophysical methods were used for this study with static water levels measured from existing wells across the area. The ABEM WADI VLF-EM instrument was used to measure EM responses. The EM measurements were made at 20m intervals along nine traverses, with lengths ranging from 250 to 350m (Fig. 1).

The data were presented as profiles showing plots of raw real and Fraser filtered values against station positions, and as Karous-Hjelt Pseudo-sections. The profiles were interpreted using the approach of McNeil (1990) and Pirttijärvi (2004).

Thirty vertical electrical soundings (VES) were conducted using the Schlumberger array (Dobrin and Savit, 1988). The Ohmega Resistivity Meter was used for the data acquisition. Apparent resistivity values were plotted against electrode spacing (AB/2m) on log-log graph (Orellana & Mooney, 1966). The field curves were first interpreted based on the curve matching methods (Zohdy, 1965; Keller & Frischnect, 1966; Koefoed, 1979). Geoelectric parameters derived from the manual interpretation were further refined, based on forward modeling approach of Vander Velpen (1988). The interpreted results were used to generate appropriate models and maps.

Results and discussion

Typical EM profiles and 2D sections from the study area are presented in Figs. 3a-d. The EM anomalies vary significantly: the raw Real values range from -44.0 to 49.9 while filtered Real values vary from -43.8 to 48.5 across the study area. An analysis of vertical electrical sounding (VES) curves from the area shows that the H type constitutes about 50% of the entire curves (Fig. 4). The VES interpretation summary reveals three to five geoelectric layers: the topsoil, the lateritic/weathered layer and the weathered/fresh bedrock.

The topsoil resistivity varies from 76 to 1400Ω-m, while in the second layer (weathered layer), resistivity values range from 29 to 1136Ω-m. The resistivity values in the third layer (fractured/fresh bedrock) vary from 96 to 24,729Ω-m. Layer thicknesses also vary from 0.5 to 4.1m, and 0.9 to 38.2m in the first and second layers respectively. The depth to the bedrock generally ranges from 1.9 to 39.1m across the study area.

Lithologic/geotechnical characterization

Zones with peak positive filtered real anomalies in the EM profiles often reflect zones with high conductivity, characteristics of clay or water-filled features (Alvin *et al.,* 1997), or effect of appreciable depth to bedrock, or lithologic discontinuity within the bedrock (White *et al.,* 1988).

The Fraser filtered curves and Karous-Hjelt sections (Karous & Hjelt, 1983) show the presence of clay and weathered materials in traverses 1, 3 and 6, or lineament features (red colour) in traverses 2, 5, 8 and 9 (Fig. 3a-d). Fissures within the bedrock and lithologic inhomogeniety within the basement regolith may endanger the foundation of overlying engineering structure.

Fig.5a-c shows the contour maps of apparent resistivity at three depth slices of AB/2 = 6m, AB/2 = 15m and AB/2 = 40m respectively. Their corresponding depths, based on the equation of Barker (1989), are 1.14m, 2.85m and 7.6m respectively. Fig. 6a (AB/2 = 6m) shows that apparent resistivity values range from 104Ω-m to 3335Ω-m. Most part of the near surface has resistivity values below 400Ω-m, except for the northwest, northeast and south-south segments. Since apparent resistivity is a reflection of degree of porosity and permeability, the near

Fig. 3a-d. Typical VLF-EM Raw Plots, Fraser Filtered Plots and Karous-Hjelt Pseudosections from Afunbiowo.

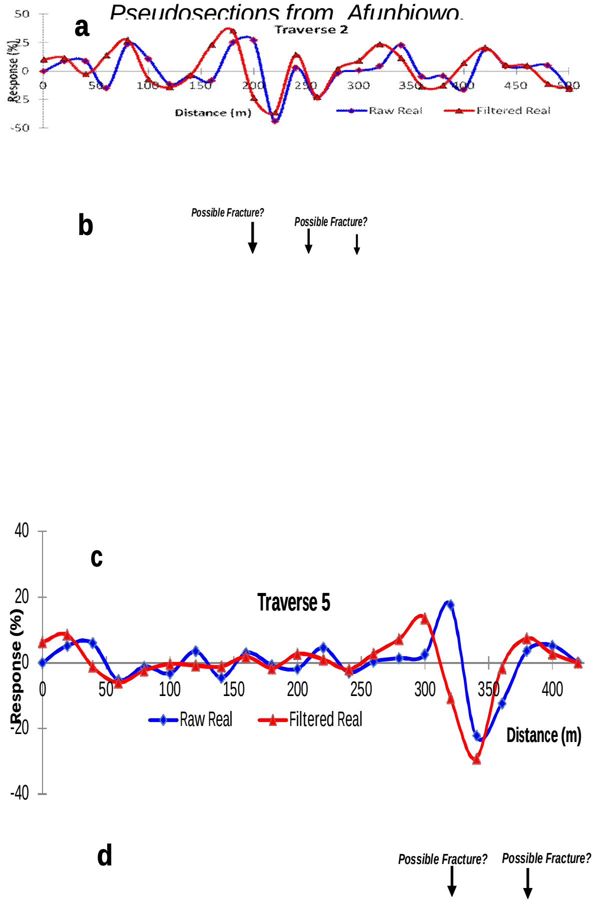


Fig. 3. Continues...

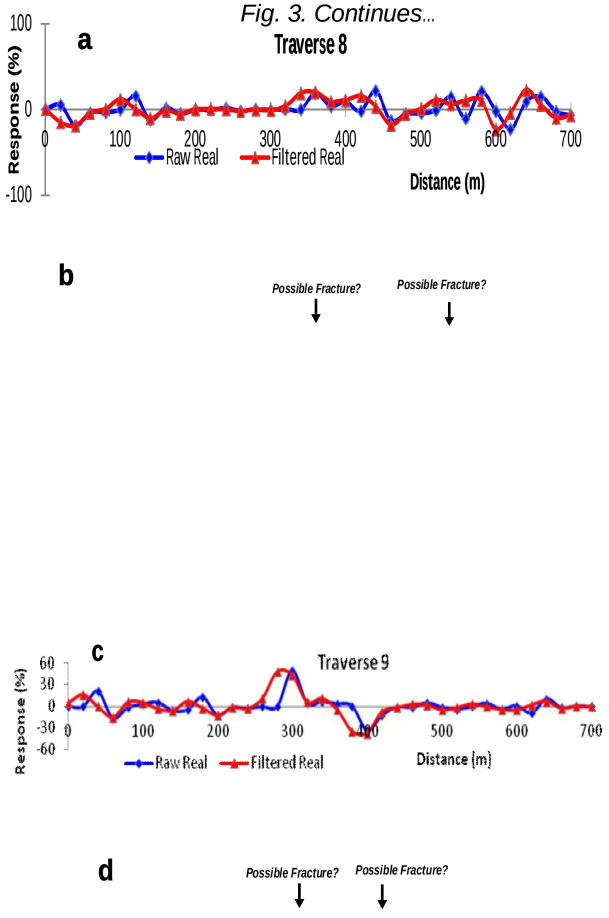
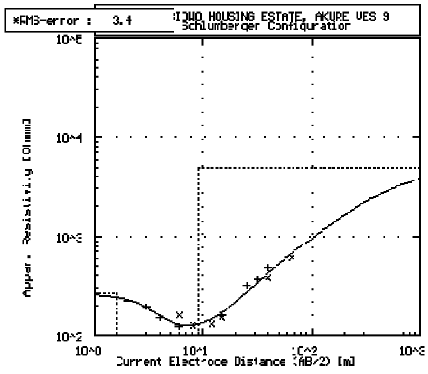
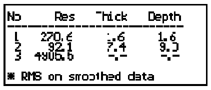


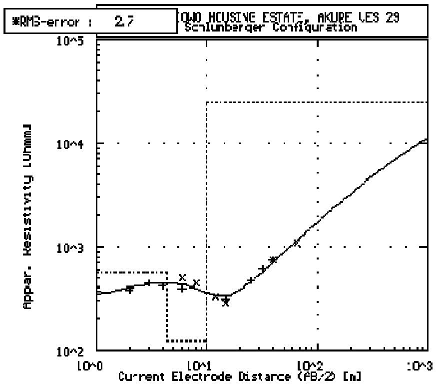
Fig. 4. Typical VES curves from Afunbiowo.

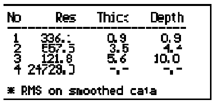




No	Res	Thick	Depth
1	270.6	1.6	1.6
2	92.1	7.4	9.0
3	4905.6	-.-	-.-

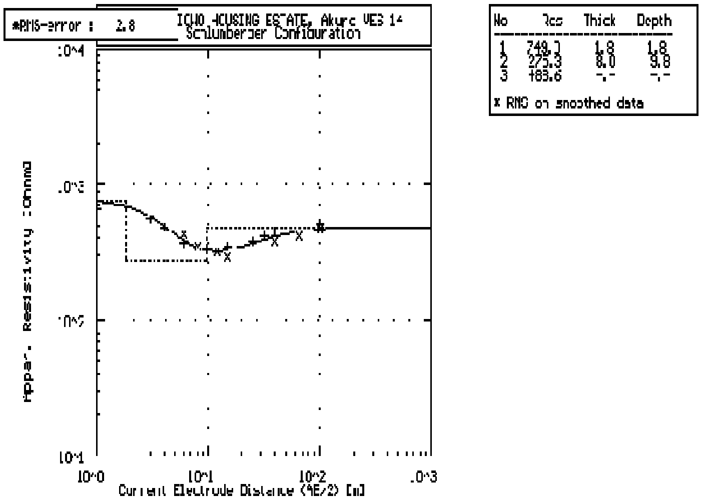
* RMS on smoothed data





No	Res	Thick	Depth
1	336.1	0.9	0.9
2	657.5	3.5	4.4
3	121.8	5.6	10.0
4	24728.0	-.-	-.-

* RMS on smoothed data



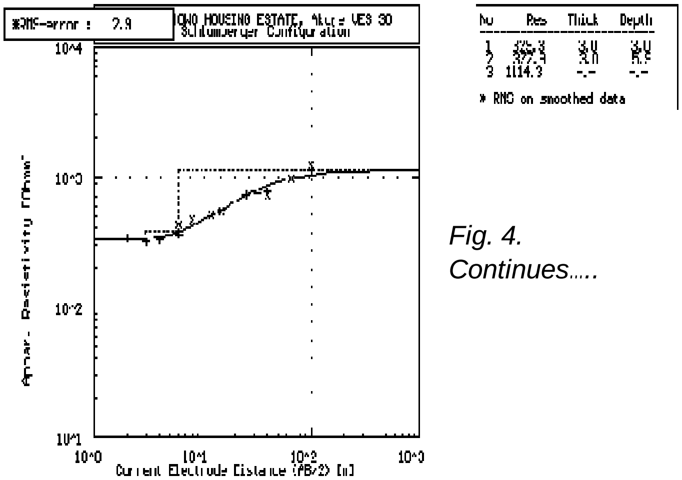


Fig. 4. Continues.....

Fig. 5a. Depth-slice map of apparent resistivity at AB/2=6m.

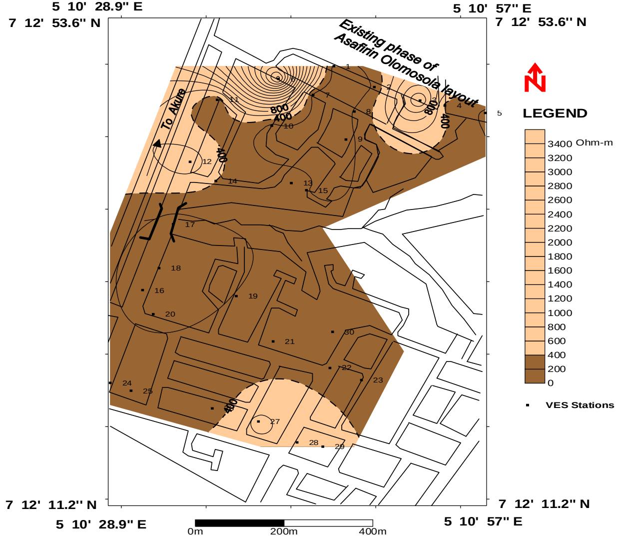


Fig. 5b. Depth-slice map of apparent resistivity at AB/2=15m.

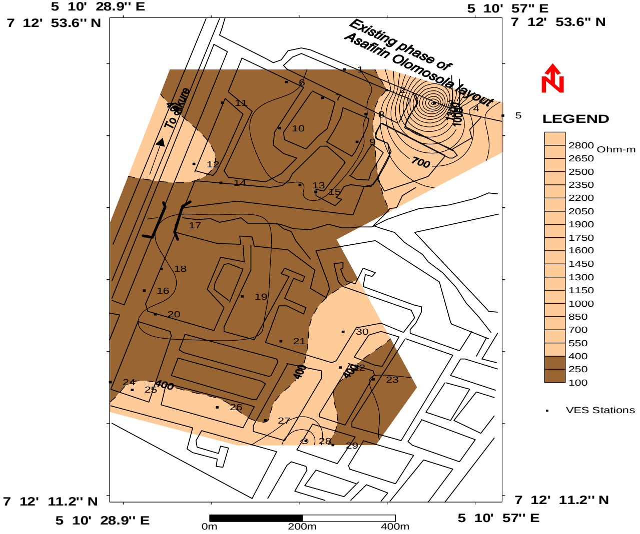


Fig. 5c. Depth-slice map of apparent resistivity at AB/2=40m

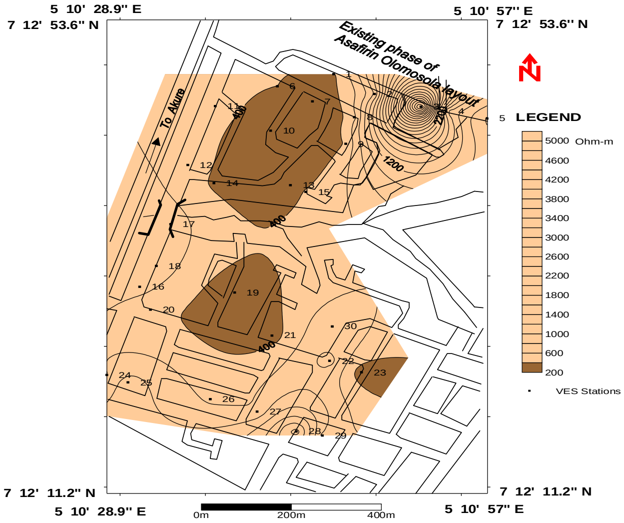


Fig. 6a. N-S Geoelectric Section Connecting VES 11, 14, 19 and 26 along Profile AB

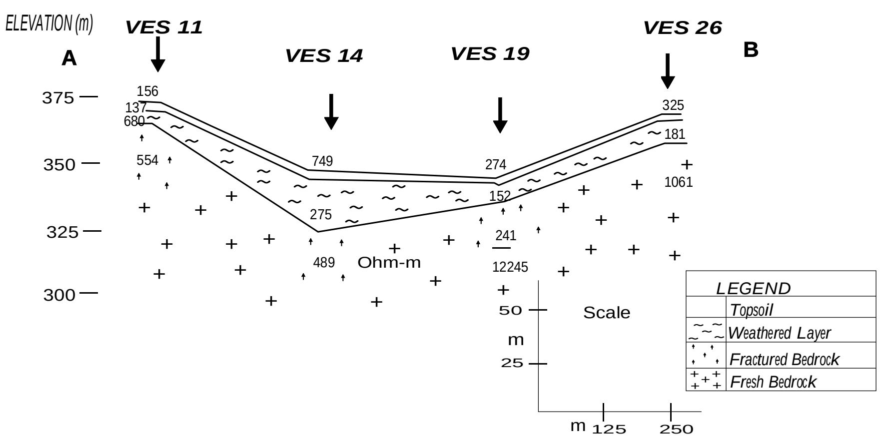


Fig. 6b. NW-SE Geoelectric Section Connecting VES 16, 21, 22 and 23 along Profile EG

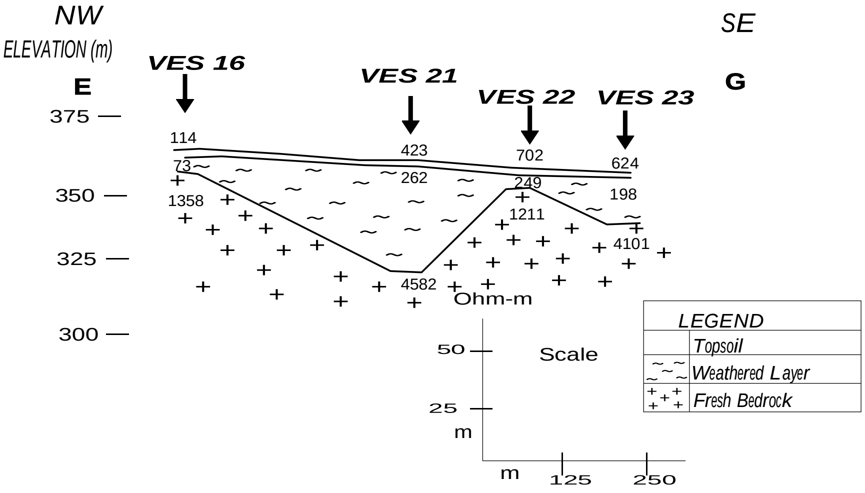
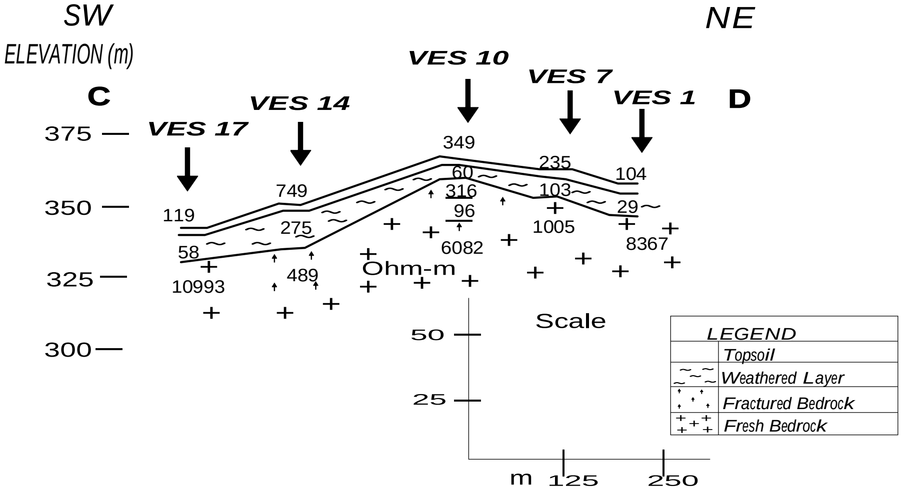


Fig. 6c. SW-NE Geoelectric Section Connecting VES 17, 14, 10, 7 and 1 along Profile CD



surface materials within this horizon may not be geotechnically competent to sustain heavy loads. Fig. 6b shows the depth slice at AB/2 = 15m. At this horizon, apparent resistivity values vary from 155Ω-m to 2816Ω-m. The central part of the study area has resistivity values below 400Ω-m, while the northwestern, northeastern and the southern parts have resistivity values in the upward of 400Ω-m. The depth slice at AB/2 = 40m (Fig. 6c) reveals apparent resistivity value range of 278Ω-m to 5191Ω-m. Along this horizon, considerable portion of the central part have resistivity values of over 400Ω-m, suggesting geotechnically fairly competent materials.

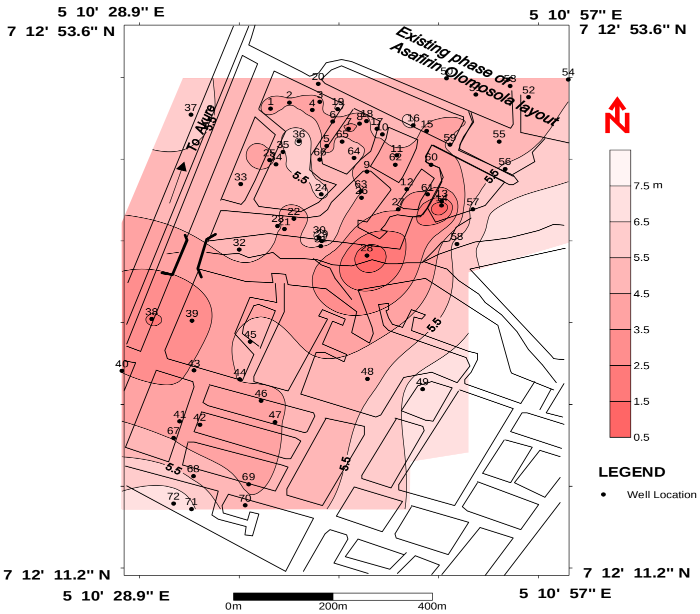
Geoelectric sections (Figs. 6a to 6c) are often useful to show a continuous two-dimensional picture of the earth (Seaton and Dean, 2004). The resistivity values from the quantitative interpretation of the geoelectric data across the area exhibits significant variations. Resistivity values vary from 76 to 1400 ohm-m, with thickness ranging from 0.5m to 4.1m across the topsoil. The weathered materials overlying the metamorphic bedrock have resistivity varying between 29 and 1136 ohm-m. The bedrock resistivity ranges between 96 and 24729 ohm-m. The bedrock is located 1.0-39.1m below the surface across the area. A pronounced low resistivity zone in the shallow subsurface is associated with saturated sands or clay rich sand. In the bedrock, low resistivity zone depicts fractured or sheared zone.

An important factor often considered in foundation design is water table and water table fluctuation (Bowles, 1984; Coduto, 1998). Fig. 7 shows the contoured map of depth to water table across the area. Water table generally varies from 0.3m to 7.5m, with an average level of 4.5m. The map shows that in the southwestern, central and north central segment of the area, water table occurs at shallow depths. This correlates with areas having low resistivity. Soils below the groundwater tables are generally saturated (Coduto, 1998). In addition, a raised water table may create a wet basement or foundation, and consequently engender instability of the overlying structure (Bowles, 1982; Othman, 2005).

Conclusion

In this study, EM survey was used to identify anomalous conductive zones and the resistivity soundings to characterize the vertical resistivity structure, while depths to water table were used

Fig. 7. Map showing depth to water table at Afunbiowo



to determine the extent of groundwater saturation in the area. The EM and resistivity surveys revealed near surface high conductivity and low resistivity values respectively in the southwestern, central and north central segments of the area. These zones, which correlate with zones with raised water table across the area, are regarded as anomalous subsurface zones apparently susceptible to subsidence or differential settlement. These areas are incompetent to bear the load of engineering structures.

The approach outlined in this work allows for a rapid geotechnical characterization of near surface formations that can guide site investigations in a way different from but complementary to the routine engineering approach. Geophysical surveys can contribute significantly to the delineation of potential source of structural problems in any scale of engineering construction projects.

Acknowledgment

The involvement of Mr. M. Bawallah in the geophysical data acquisition is profoundly appreciated. The geophysical equipment used in the data acquisition belongs to the Department of Applied Geophysics, Federal University of Technology, Akure, Nigeria. This is equally acknowledged and appreciated.

References

1. Alvin KB, Kelly LP and Melissa AS (1997) Mapping groundwater contamination using DC resistivity and VLF geophysical methods: A case study. *Geophys.* 62(1), 80-86.
2. Barker RD (1989) Depth of investigation of collinear symmetrical four-electrode arrays. *Geophys.* 5(8), 1031.
3. Bowles JE (1982) Foundation analysis and design. *McGraw-Hill Book Company*. pp: 580.
4. Bowles JE (1984) Physical and geotechnical properties of soils. *McGraw-Hill Intl.* Edi., *Civil Engg. Series London.* pp: 1004.
5. Coduto SA (1998) Geotechnical engineering: Principles and practices. *Prentice Hall Inc*. pp: 759.
6. Dobrin MB and Savit CH (1976) Introduction to geophysical prospecting. *4th Edi. McGraw Hill Book Co.*, NY. pp: 867.
7. Karous M and Hjelt SE (1983) Linear filtering of VLF Dip-angle measurements. *Geophys. Prospec.* 31, 782-794.
8. Keller GV and Frishchnecht FC (1966) Electrical methods in geophysical prospecting. *Pergamon Press*, NY, pp: 96.
9. Koefoed O (1979) Geosounding principles 1. Resistivity measurements. *Elsevier Scientific Publi.*, Amsterdam, Netherlands. pp: 275.
10. McNeil JD (1990) Use of electromagnetic methods for groundwater studies. *Geotechnic. & Environ. Geophys.1. Rev. & Tutorial Ed S. N. Ward* (Tulsa, OK: Society of Exploration Geophysics), pp: 191-218.
11. Olorunfemi MO, Ojo JS, Sonuga FA, Ajayi, O and Oladapo MI (2000) Geoelectric and Electromagnetic Investigation of the failed Koza and Nassarawa earth dams around Katsina, Northern Nigeria. J. Mining & Geol. 36, 51-65.
12. Orellana E and Mooney HM (1966) Master tables and curves for vertical electrical soundings over layered structures. *Madrid Interciancia.* pp: 34.
13. Othman AAA (2007) Construed geotechnical characteristics of foundation beds by seismic measurements. *J. Geophys. Engg.* 2, 126-138.
14. Owoyemi FB (1996) A Geological-Geophysical Investigation of rain-Induced erosional features in akure metropolis. Unpublished. M.Tech Thesis. *Federal Univ. Technol*: Akure, Nigeria. pp: 11-18.
15. Pellerin L (2002) Applications of electrical and electromagnetic methods for environmental and geotechnical Investigations. *Surveys in Geophy.* 23, 101-132.
16. Pirttijärvi M (2004) Karous-Hjelt and fraser filtering of VLF measurements. *Manual of the KHFFILT Programme.*
17. Rahaman MA (1989) Review of the basements geology of southwestern Nigeria. In Kogbe, C.A., (ed.) *Geol. Nigeria*. pp: 39-56.
18. Savvaidis A, Tsokas G, Soupios P, Vargemezis G, Manakou M, Tsourlos P and Fikos I (1999) Geophysical prospecting in the Krousovitis dam (N Greece) by seismic and resistivity geophysical methods *J. Balkan Geophys. Soc.* 2**,** 128-139.
19. Seaton WJ and Dean T (2004) Engineering site characterization with electrical resistivity surveys. *North American Soc. Trenchless Technol.* (NASTT). Paper C-4-03-1 to C-4-03-8.
20. Sharma PV (1997) Environmental and engineering geophysics. Cambridge: *Cambridge Univ. Press*. pp: 475.
21. Soupios PM, Georgakopoulos P, Papadopoulos N, Saltas V, Andreadakis A, Vallianatos F, Sarris A and Makris JP (2007) Use of engineering geophysics to Investigate a site for a building foundation. *J. Geophy. & Engg.* 4, 94-103.
22. Vander Velpen (1988) Resist version 1.0". M. Sc. Research Project. ITC, Delft, Netherlands.
23. White CC, Huston JFT and Baker RD (1988) The victoria province drought relief project 1. Geophysical sitting of Boreholes. Groundwater, 26(3).
24. Zohdy AAR (1965) The auxiliary point method of electrical sounding Interpretation and its relationship to Dar Zarrouk Parameters. *Geophys.* 30, 644-650.