International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:14, No:11, 2020

Geophysical Investigation for Pre-Engineering Construction Works in Part of Ilorin, Northcentral Nigeria

O. Ologe, A. I. Augie

Abstract**—**A geophysical investigation involving geoelectric depths sounding has been conducted as pre-foundation study in part of Ilorin, Nigeria. The area is underlain by the Precambrian basement complex rocks. 15 sounding stations were established along five traverses. The Vertical Electrical Sounding (VES) (three-five) conducted along each of the traverses was subjected to computer iteration using IP2Win software. Three -five subsurface geologic layers were delineated in the study area. These include the topsoil with resistivity and thickness values ranging from 103 Ωm-210 Ωm and 0 m-1 m; lateritic (117 Ωm-590 Ωm and 1 m-4.7 m); sandy clay (137 – 859 Ωm and 2.9 m – 4.3 m); weathered (60.5 Ωm to 2539 Ωm and 3,2 m-10 m) and fresh basement (2253-∞ and 7.1 m-∞) respectively. The resistivity pseudosection shows continuous high resistivity zone on the surface. Resistivity of this layer from depth 0-5 m varies from 300-800 Ωm along traverse 1 and 2. Hence, this layer is rated competent as it has the ability to support engineering structure. However, along traverse 1, very low resistive layer occurs between VES 5 and 15 with resistivity values ranging from 30 Ωm-70 Ωm. This layer was rated incompetent based on the competence rating. This study revealed the importance of geophysical survey as a pre-construction engineering survey at any civil engineering site since it can reliably evaluate the competence of the subsurface geomaterials.

Keywords**—**Competence rating, geoelectric, pseudosection, soil, vertical electrical sounding.

I. Introduction

SOIL is indispensable material on which engineering structures are constructed. Therefore a detailed geophysical investigation of the subsurface materials of any proposed construction site is an important task needed to be considered before the erection of any structure to avoid foundation failure and undue loss of lives and properties [1]. The need for pre-foundation studies has therefore become necessary so as to prevent loss of valuable lives and properties that always accompany such failures [2].

Pre-foundation study is essential before the design of foundation of any engineering construction since every engineering structure is seated on geological earth materials. It is imperative to firstly conduct pre-construction geophysical assessment of the proposed site to find out the quality, and the fitness of the subsurface/or earth materials as well as the period to monitor the construction to ensure its integrity [3], [4].

The incessant incidence of building failures is becoming alarming in Nigeria and these failures have been attributed to factors such as inadequate information about the subsurface geological material, poor foundation design and poor building materials [4], [2]. Therefore, this research work involves subsoil evaluation for pre-foundation study using geophysical approach.

II. Site Description and Geology

The study area is located at the north western part of Ilorin metropolis, Fig. 1. Its geographical coordinates lie between latitudes 8025'N and 8030'N and longitudes 4031'E and 7030'E. It covers an area of about 32,500 km^2. The topography is very gentle, with surface elevations ranging from 297.8 m to 302.4 m above sea level. The geologic setting of the area is typical of the Migmatite-Granite gneiss complex rocks of the Precambrian Basement Complex of southwestern Nigeria [5]. The local lithologic units identified in the study area are fine grained granite, medium-coarse grained granite gneiss, coarse grained granite, migmatite, and biotite granite rocks (Fig. 2). Climatic condition within the study area is essentially humid. The humid climatic condition is characterized by two distinct seasons: the wet and dry seasons with minimum average temperature ranges between 21.1 °C and 25.0 °C while, maximum average temperature ranges from 30 °C to 35 °C. The mean temperature is about 30 °C (min) and 35 °C (max) [6]. The total annual rainfall is between 1270 mm and 1524 mm, spread over the month of April to October [7].

III. Materials and Method

The equipment employed for the resistivity field data measurements is the RD–50 resistivity meter. 15 VES were conducted in all, using the conventional Schlumberger technique, with half electrode spacing (AB/2) varying from 1 to 100 m. The procedure involved the expansion of the two current electrodes about a fixed center of array representing the point being investigated. The potential electrodes are kept fixed until the current attenuate where upon they were expanded to make the current penetrate deeper. Resistivity studies in geophysics may begin with the vector form of Ohm's law.

$$J = \sigma E = \frac{1}{\rho} = -\frac{1}{\rho}\nabla V \qquad (1)$$

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where J, E, V, σ, and ρ are; current density vector in A/m^2, electric field vector in V/m, electric potential in volts, conductivity measured in (Ωm)$^{-1}$ and resistivity in Ωm. The current density J, as given in (1), is the amount of current flowing on the earth material through each square meter. It flows on two-dimensional surface perpendicular to the direction of current flow. The amount of current I is received by each potential electrode (MN) across the surface of a half sphere with area ½(4πr^2). Ohm's law for one electrode then has the simple form:

$$J = \frac{I}{\frac{1}{2}(4\pi r^2)} = -\frac{1}{\rho}\frac{dV}{dr} \qquad (2)$$

For constant ρ, this first-order differential equation is readily integrated and yields for

$$V(r) = \frac{\rho I}{2\pi r} \qquad (3)$$

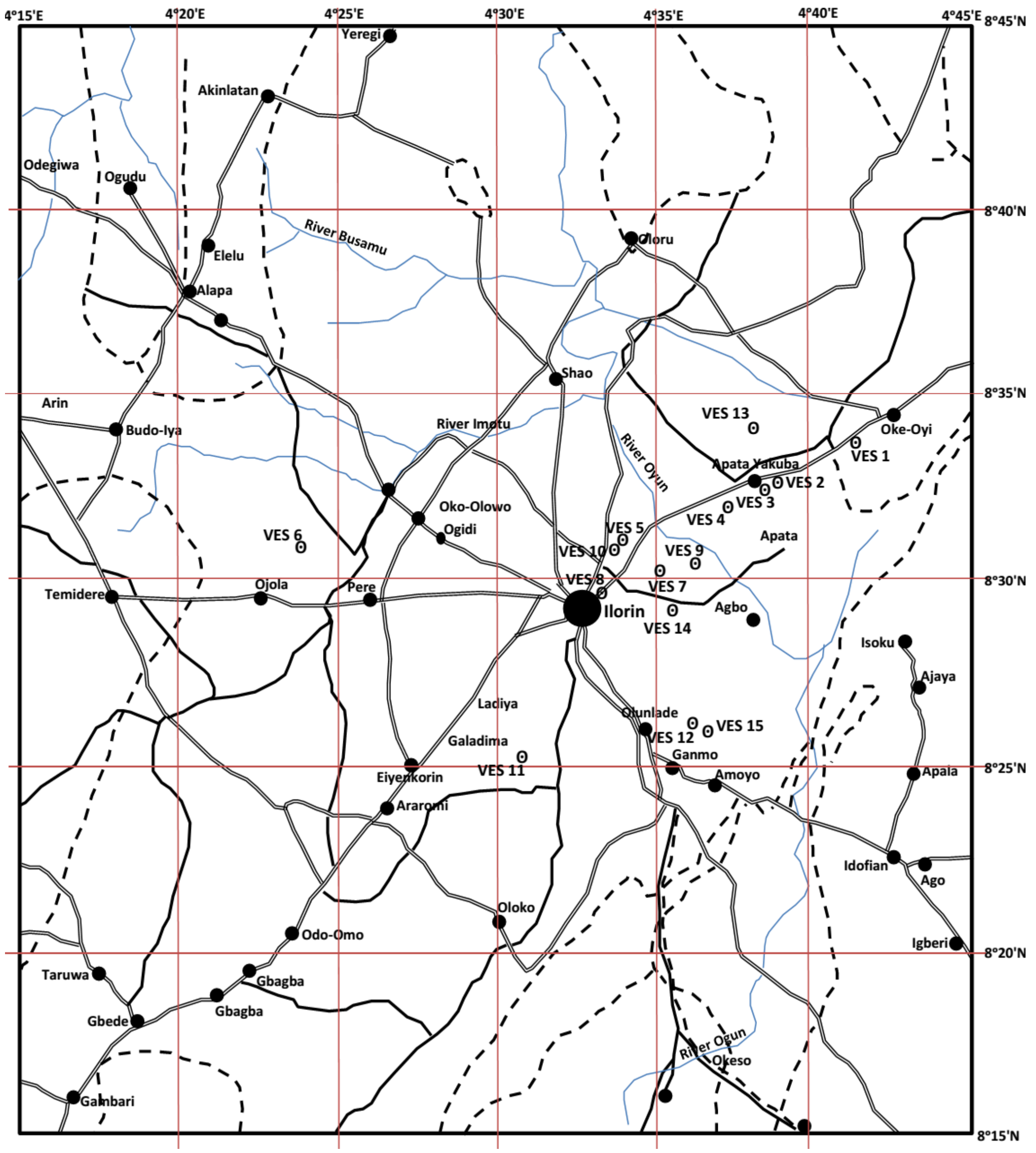

Fig. 1 Location map of the study area showing the VES

International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
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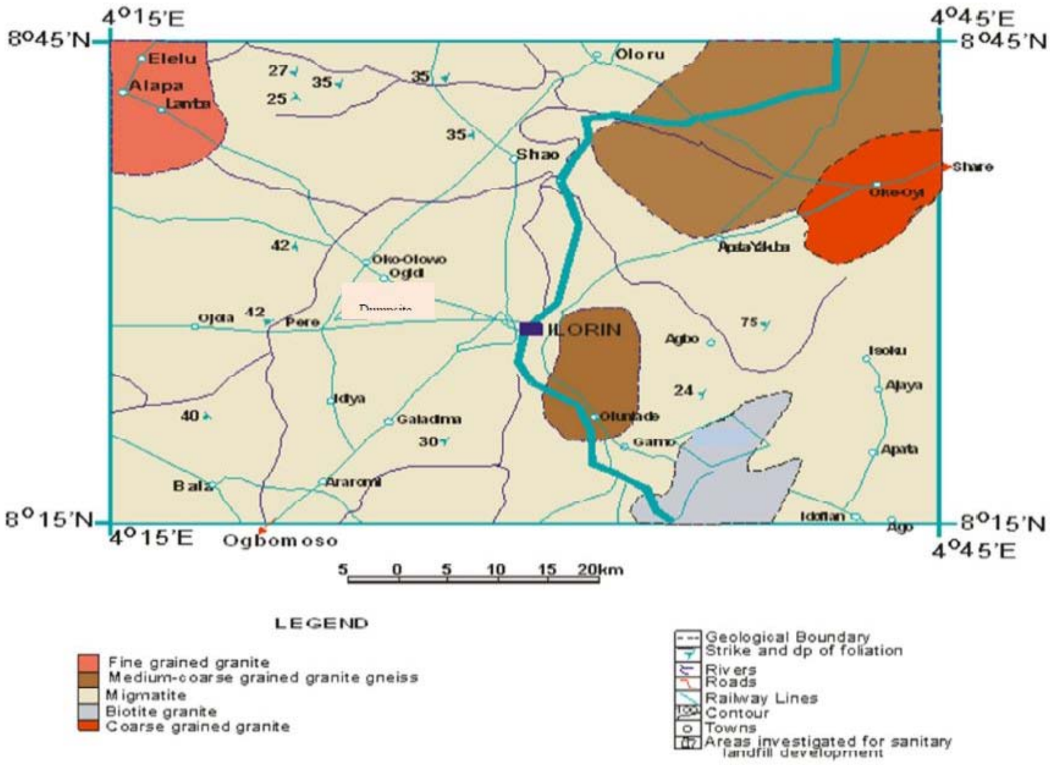

Fig. 2 Geological Map of the Study Area

For the potential V, having a distance r, from the electrode as given in (3), the total current is therefore flowing from one current electrode to the other through the earth materials. The electric potentials measured at potentials electrodes point M and N in linear array are superpositions of the potential of due to each of the two outer current electrodes placing at position A and B. The distances between these electrodes were named as AM, MB, etc., when V = 0 infinitely far from the current source. Thus, the potentials due to M and N are:

$$V_M = \frac{\rho I}{2\pi}\left(\frac{1}{AM} - \frac{1}{MB}\right) \quad (4)$$

$$V_N = \frac{\rho I}{2\pi}\left(\frac{1}{AN} - \frac{1}{NB}\right) \quad (5)$$

The total potential difference between the electrodes M and N is thus

$$V_{MN} = V_M - V_N = \frac{\rho I}{2\pi}\left[\left(\frac{1}{AM} - \frac{1}{MB}\right) - \left(\frac{1}{AN} - \frac{1}{NB}\right)\right] \quad (6)$$

This may be rearranged to yield

$$\rho = \frac{V_{MN}}{I} K \quad (7)$$

where

$$K = 2\pi\left[\left(\frac{1}{AM} - \frac{1}{MB}\right) - \left(\frac{1}{AN} - \frac{1}{NB}\right)\right]$$

where K is the ‘‘geometric factor’’ that will acquire a particular value for a given electrode spacing.

The VES data acquired during the course of this work were processed using the software IP2Win. The IP2Win was used to compute vertical variation in the resistivity of the lithological layers and corresponding thicknesses of layers.

IV. Results and Discussion

Electrical resistivity data obtained from subsoil evaluation for the pre-engineering construction work were subjected to computer iteration. The results of the computer iterated sounding curves are presented in Fig. 3 with the respective geoelectric sections presented in Fig. 4. Co-linear VES points were also processed to obtain resistivity pseudosection in the study area presented in Fig. 6. From the resistivity curves the number of geoelectric layers varies from three to five earth model layers. The geoelectric layers delineated correspond to the top soil, lateritic, sandy clay, weathered/fractured basement and fresh basement. The resistivity and thickness of the top soil vary from 1.3 Ωm-2160 Ωm and from 0.46 m-5.95 m respectively. The second layer is probably laterites or clayey sand which is very important in engineering construction works. Reference [8] shows that clayey substratum and ponded embankment toe could contribute to pavement failure. The third/fourth layer represents the weathered/fractured basement. The resistivity of this layer varies from 11.7 Ωm-590 Ωm and from 3.1 m to 42.8 m respectively, the fracture seated in this layer can affect the stability of engineering structure if it extends to the surface. The last layer is the fresh basement which has resistivity which ranges from 60.5 Ωm to 2539 Ωm. The resistivity pseudosection shows continuous high resistivity zone on the surface (Fig. 4). These high resistivity or low conductivity zones were regarded as the competent layer. However, between VES5 and VES 15 along profile 1, low resistivity layer was delineated. The geoelectric sections show variation in lithology from one VES point to another (Fig. 4).

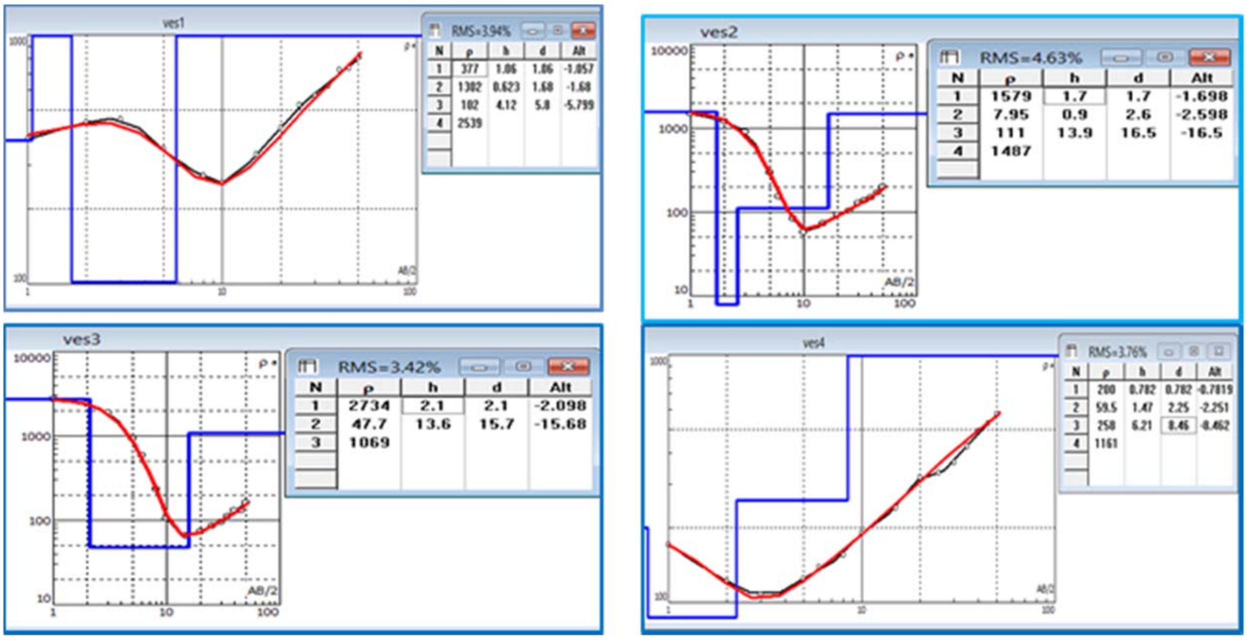

Fig. 3 Typical Sounding Curves from the Study Area

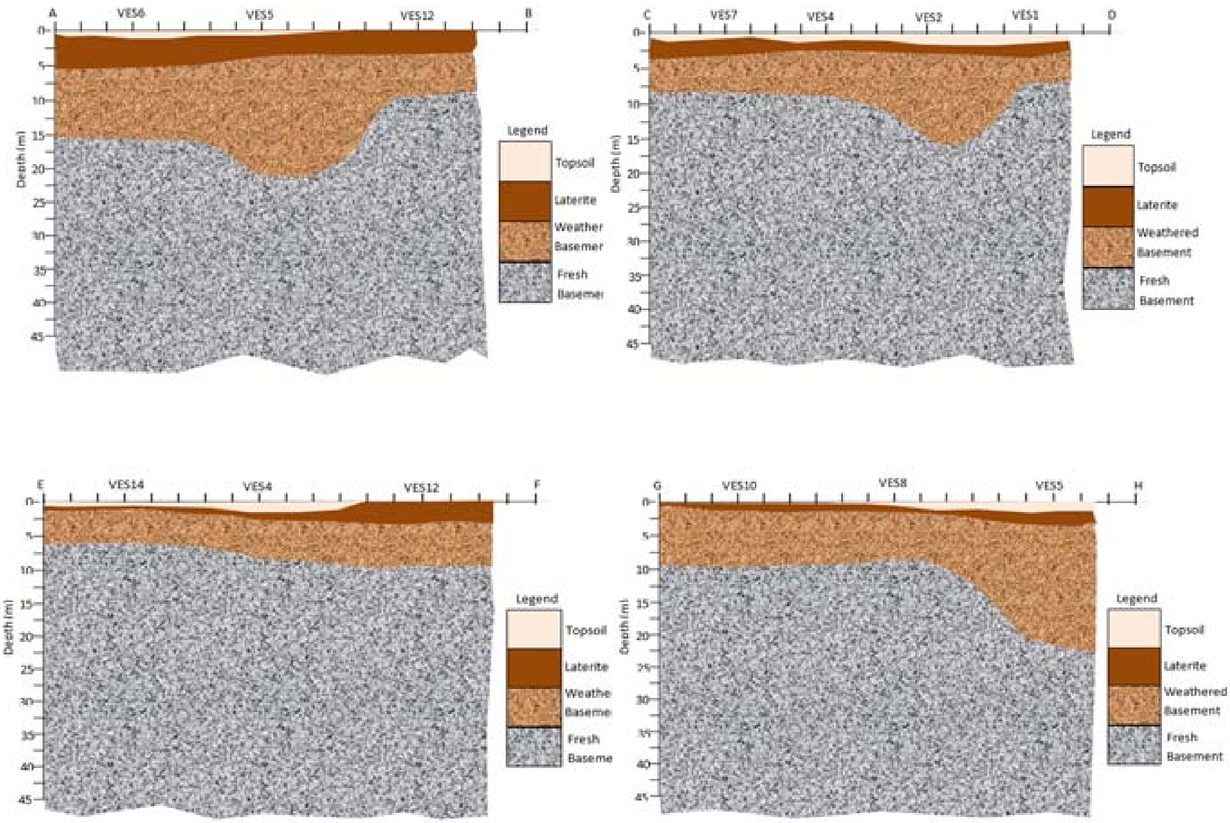

Fig. 4 2D Geo-electric sections along: (a) West-Eastern (b) South-Eastern (c) Northsouthern, and (d) Central portion cross sections

International Journal of Earth, Energy and Environmental Sciences
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The geoelectric sections were generated along East-West, East-South, North-South and Central portion within the study area.

Figs. 4 (a)-(d) are geoelectric sections drawn through the entire study area in the West-Eastern (b) South-Eastern (c) Northsouthern, and (d) Central region between the West to East direction indicates the geoelectric layers. These cross sections revealed the lithologic units identified as top soil, lateritic, sandy clay, weathered basement and fresh basement.

A. Isoresistivity and Isopach Maps of the Lateritic Layer

The isoresistivity maps of the lateritic layer showed that the resistivity of this layer is high in the eastern part (Fig. 5) and hence, that evaluates high competence. The overburden thickness in the study varies from 0 to 6m. The Isopach map of overburden showed that the lateritic material has its maximum thickness at the central and western.

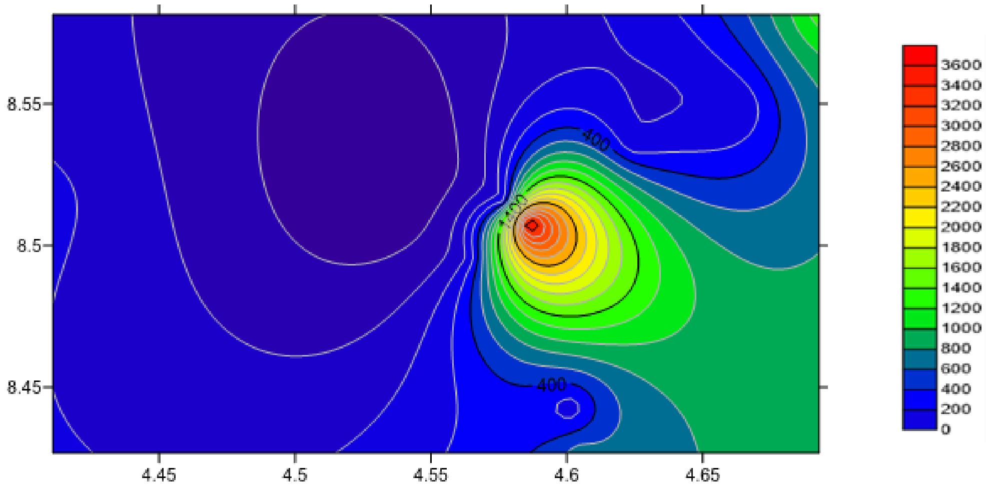

Fig. 5 (a) Isoresistivity Map of the Lateritic Layer

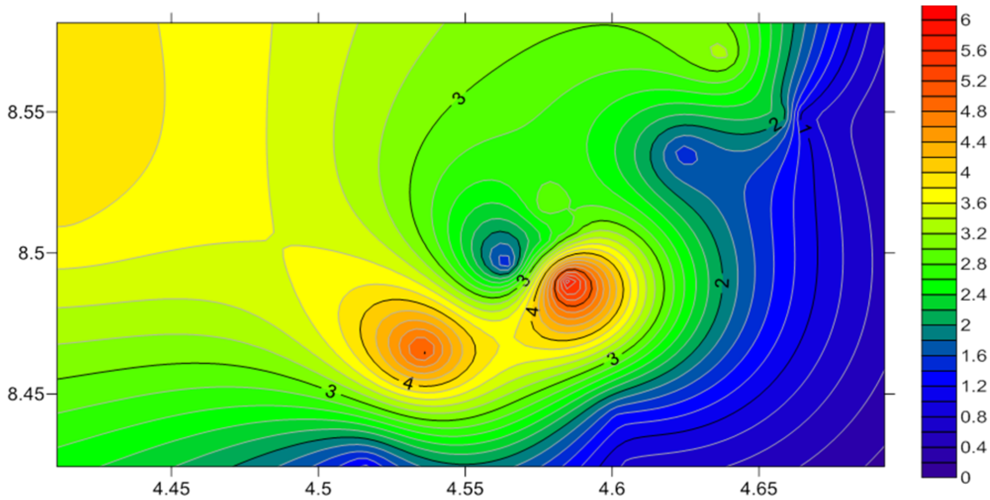

Fig. 5 (b) Isopach Map of the Lateritic Layer

B. Soil Competence Evaluation

Soil competence and its usability for construction purposes vary with resistivity. From Table I, competence of soil for engineering construction purposes varies from incompetent to highly competent. Soils with resistivity values less than 100 Ωm are regarded as incompetent such as clay. Also, soils with resistivity values ranging between 100-350 Ωm are regarded as moderately competent are sandy clay. Furthermore, soil with higher resistivity values between 350-750 Ωm are regarded as competent such as clayey sand. Sand, laterite and bedrock usually have resistivity values greater than 750 Ωm and are regarded as highly competent. Hence, the presence of laterite is desirable in engineering construction as long as it does not contain active clay.

In the study area, the pseudosection (Fig. 6) showed the resistivity and depth of the layer along profile 1 and 2 ranging from 300 Ωm-800 Ωm and 0-5 m respectively. Hence, this layer is rated competent to highly competent (Table I). Also, the lithological unit is made up of clayey sand and possibly the bedrock may be encountered very close to the surface. Therefore this layer has the ability to support engineering structure. However, along profile 1, very low resistive materials occur between VES 5 and 15. The resistivity of this layer varies from 30 Ωm-70 Ωm. This layer can be rated as incompetent based on the competence rating by [9]. Hence, this layer is not suitable for supporting engineering construction works.

TABLE I
SOIL COMPETENCE RATING [9]

S/No	Apparent Resistivity (Ωm)	Lithology	Competence Rating
1	<100	Clay	Incompetence
2	100 - 350	Sandy Clay	Moderate Competence
3	350 - 750	Clayey Sand	Competence
4	>750	Sand/Literite/Bedrock	High Competence

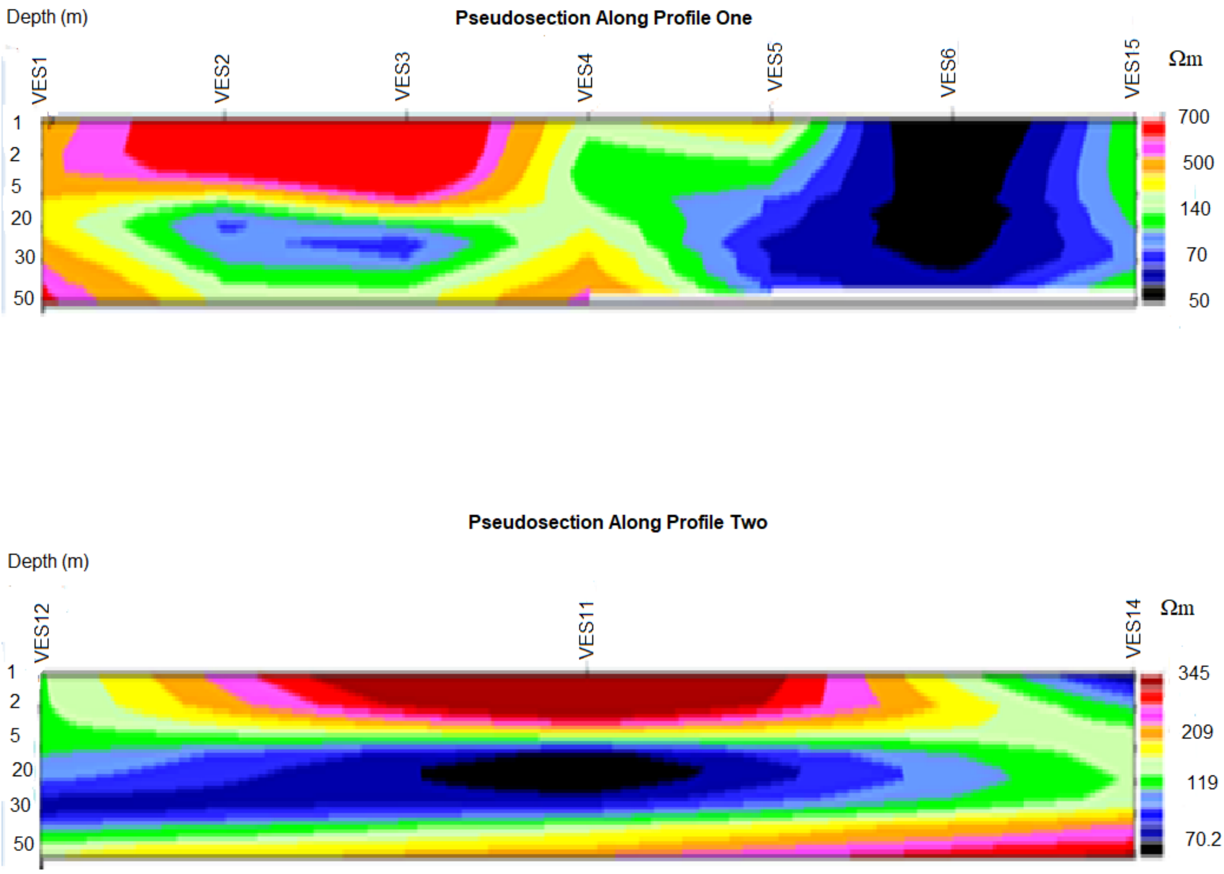

Fig. 6 Resistivity Pseudosection along Profile 1 and Profile 2

V. CONCLUSION

It can be concluded from the resistivity survey in the study area that number of geoelectric layers in varies from three to five layers. These layers correspond to the top soil, lateritic, sandy clay, weathered basement and fresh basement. The resistivity and thickness of the top soil varies from 1.3 Ωm-2160 Ωm and from 0.46 m-5.95 m respectively. The second layer is probably laterites or clayey sand. Its resistivity varies with degree of saturation. The layer is very important in engineering construction works. The third/fourth layer represents the weathered/fractured basement. The resistivity of this layer varies from 11.7 Ωm-590 Ωm and from 3.1 m to 42.8 m respectively. The fracture seated in this layer can affect the stability of engineering structure if it extends to the surface. The last layer is the fresh basement having the resistivity values ranging from 60.5 Ωm to 2539 Ωm. The resistivity pseudosection shows continuous high resistivity zone on the surface. Resistivity of this layer from depth 0-5 m varies from 300-800 Ωm along profile 1 and 2. Hence, this layer is rated competent to highly competent. Also, the lithological unit is made up of clayey sand and possibly the bedrock may be encountered very close to the surface. Therefore this layer has the ability to support engineering structure. However, along profile 1, very low resistive layer occurs between VES 5 and 15. The resistivity of this layer varies from 30 Ωm-70 Ωm. This layer can be rated as incompetent based on the competence rating of [10]. Hence, this layer is not suitable for siting foundation of engineering construction works.

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