Journal of the Nigerian Association of Mathematical Physics
Volume 12 (May, 2008), 267 – 278

A geophysical study of structural foundations in Omolayo area, Ibadan, Nigeria

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Abstract

A surface geophysical method was used to study the various strata and depth of the layers in the strata of Omolayo area of Ibadan. Ten vertical electrical sounding (VES) data were acquired using the Wenner electrode configuration, which were subsequently processed and interpreted, based on the assessment of the iterative computer model, using a finite difference algorithm. Two geoelectric sections were generated along South-North and West-East, while their strike lengths were determined to be 80 m and 100 m respectively. These involve VES1, VES3 and VES8 along XX – XX' and VES2, VES3 and VES4 along YY – YY' sections. These sections reveal that the study area is underlain by three to four geoelectric units namely; clay/lateritic topsoil, weathered basement and fresh bedrock. Furthermore, geophysical contour maps equally revealed that the entire area is highly competent for super-structures or high-rise buildings, due to the high resistivity values obtained

Keywords: vertical electrical sounding, geoelectric, resistivity, Wenner-configuration, competence .

1.0 Introduction

The importance of foundation studies before erecting buildings or civil engineering foundations, and or highway engineering structures cannot be over emphasized. This is because the success of such structures depends on the foundation; hence a weak subsoil foundation will eventually lead to the collapse of the structures.

Foundation is simply described as an inter-phase between the soil and a superstructure. Whether shallow or deep, foundations are often designed based on the buoyancy techniques in which structures flow in the soil (Jayapalan and Boehm, 1986 [4]). Foundation study is a pre-impact assessment, which is a necessary pre-requisite before erecting any structure or super structures. This study is important in any geological terrain, as the development of fracture faults/joint/ridges, depression characterized the geologic terrain arising from tectonic activities and or geologic and environmental factors. (Rahman 1988, Folami 1998 [3])

Furthermore, man-made activities and environmental factors such as weathering and erosion could also create holes or void that are filled with weak materials at a depth within the subsurface. All these process in most cases, would not be manifested on the subsurface, hence, the need to carry out pre-impact assessment study in other to understand the nature of the terrain and also the shear strength, which is defined as the maximum shear stress that a soil can sustain under a given set of conditions. This shear strength depends largely on the degree of compaction of soil, grain shape and the water content of the soil.

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For successful design of foundations, the general knowledge of local geology combined with regional geology is required and the sequence of the strata should be well known.

The study area (Figure 1.1a) is situated in the western part of Nigeria and therefore falls within the basement complex terrain of the Country. The type of rocks found here are the undifferentiated granite gneiss, quartzite and porphyritic granite with schist impregnation (figure 1.1b). Located on about 30°N longitudes and south of the equator, the area has two distinct seasons which are wet and dry.

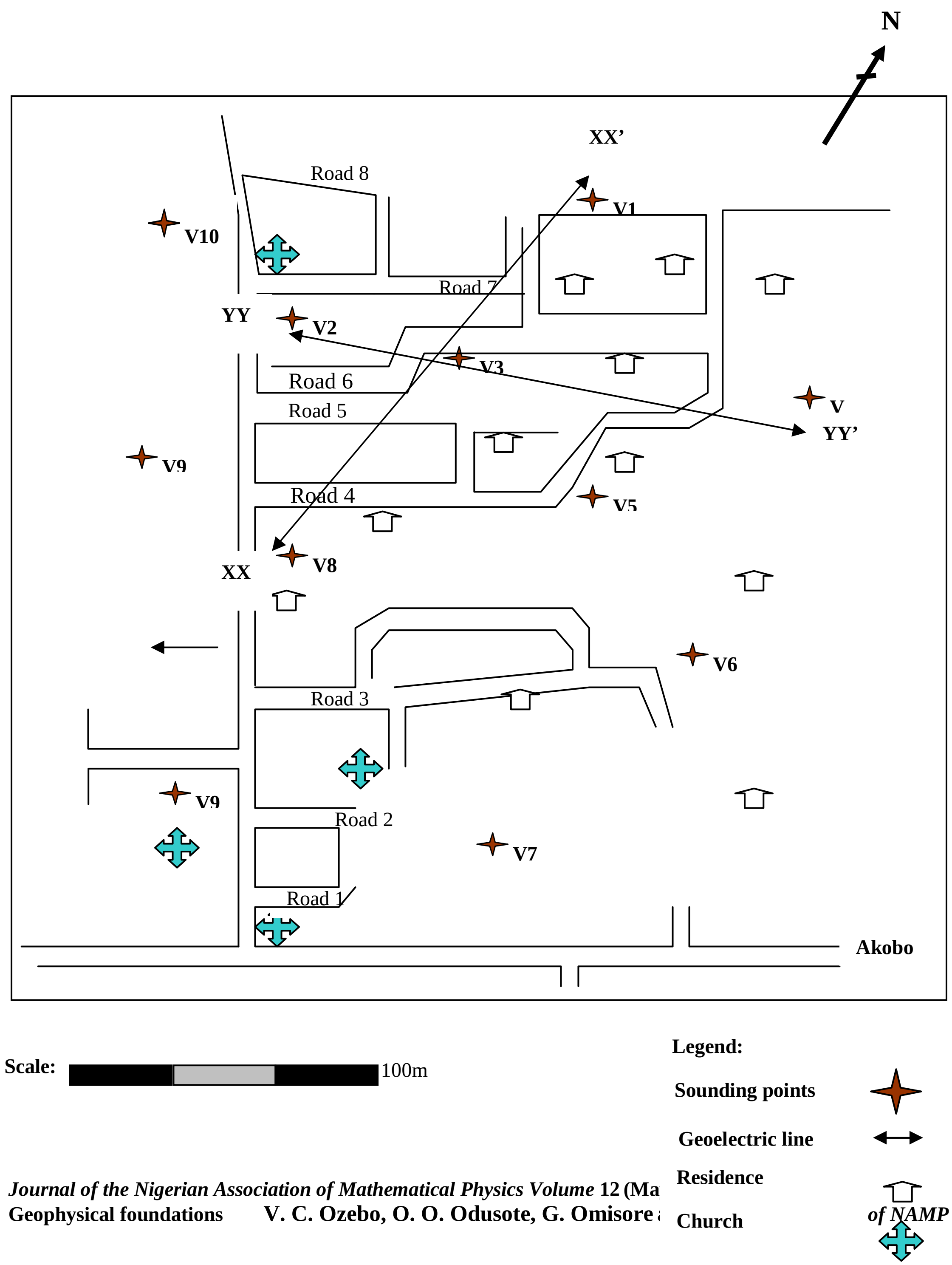


Figure 1.1a: Base map of Omolayo area, via Akobo, Ibadan**.**

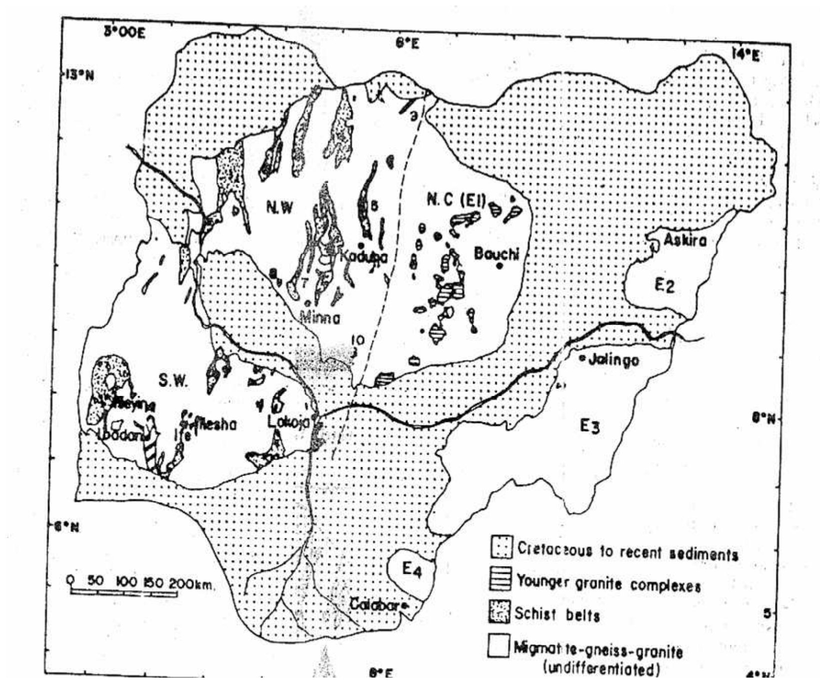


Figure 1.1b: The Geological map of Nigeria (After Ajibade and Woakes, 1989)

The wet season stars from October through February and characterized by harmmattan, with little or no rainfall; while the wet season occurs between March and October each year, with mean annual rainfall ranging approximately between 700 mm and 800 mm.

The objective of the study therefore is to determine the geo-electric parameters of the subsurface units in order to characterize the engineering properties of the immediate near surface materials and hence evaluate the competency of the founding materials

2.0 Theoretical analysis

The Resistivity method employs an artificial source of current, which is introduced into the ground through point electrodes. The potential difference due to the applied current is measured in the vicinity of the current flow. Since the current applied is also measured, it is possible to determine an effective or apparent resistivity of the subsurface. This provides information on the form and electrical properties of subsurface inhomogeneities. For a conducting material of resistance *R*, having a length λ, and a cross-sectional area *A* as shown below,

Figure 2.1: A conducting material

$$R\alpha\frac{\lambda}{A} \tag{2.1}$$

Therefore
$$R=\frac{\rho\lambda}{A} \tag{2.2}$$

Now, from Ohm's law ; $R=\frac{\Delta V}{I}$ = $\frac{\rho\lambda}{A}$

Therefore
$$\rho=\frac{\Delta V.A}{I.\lambda} \tag{2.3}$$

where ρ = Resistivity, *R* = resistance, *I* = Current and *V* = Potential.

Equation (2.3) can be used to determine the resistivity of any homogeneous or isotropic medium provided the geometry is simple. For a semi-infinite medium, the resistivity at every point must be defined. If we allow parameters A and λ to shrink to infinitesimal size, then

$$\rho=\frac{\lim\limits_{\lambda\to 0}\frac{\Delta V}{\lambda}}{\lim\limits_{A\to 0}\frac{I}{A}}$$

$$\rho=\frac{E}{J} \tag{2.4}$$

Hence,
$$J=\sigma E$$

where E = Electric field, J = Current density and σ = Conductivity .

If the current source is located at the centre of a spherical body of radius r, the current density at the spherical surface is $J=\frac{I}{4\pi r^2}$ and $E=\frac{\rho I}{4\pi r^2}$ but E = -∇V , therefore

$$\frac{dv}{dr}=-\frac{\rho I}{4\pi r^2} \tag{2.5}$$

and,
$$V=\int-\frac{\rho I}{4\pi r^2}dr$$

Therefore,
$$V=\frac{\rho I}{4\pi r} \tag{2.6}$$

In practice, the earth structure is an approximate of hemi-sphere, hence $J=\frac{I}{2\pi r^2}$ and $E=\frac{\rho I}{2\pi r^2}$,

therefore
$$\frac{dv}{dr}=-\frac{\rho I}{2\pi r^2}$$

Therefore
$$V=\int-\frac{\rho I}{2\pi r^2}dr \quad =\frac{\rho I}{2\pi r} \tag{2.7}$$

Equation 2.7 is the potential at a point P due to current at another point C at the surface of the earth. For a four electrode on the surface of the earth,

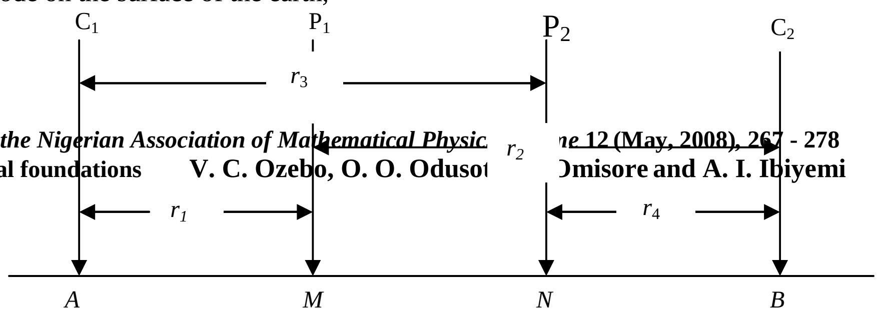


Figure 2.2: General Electrode Configuration for Electrical Resistivity

Potential at P_1 due to current at C_1

$$V_{c_1}^{p_1} = \frac{\rho I}{2\pi r_1}$$

Potential at P_1 due to current at C_2, $V_{c_2}^{p_1} = \frac{\rho I}{2\pi r_2}$

Potential at P_1 due to current at C_1 & C_2

$$\Delta V_{c_1 c_2}^{p_1} = \frac{\rho I}{2\pi}\left\{\frac{1}{r_1} - \frac{1}{r_2}\right\} \tag{2.8}$$

Also, Potential at P_2 due to current at C_1 & C_2

$$\Delta V_{c_1 c_2}^{p_2} = \frac{\rho I}{2\pi}\left\{\frac{1}{r_3} - \frac{1}{r_4}\right\} \tag{2.9}$$

The Potential difference between P_1 and P_2 due to current at C_1 and C_2, $\Delta V_{c_1 c_2}^{p_1 p_2} = \frac{\rho I}{2\pi}\left\{\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right\}$

Hence resistivity ρ is given by the equation

$$\rho = \frac{2\pi \Delta V}{I}\left\{\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right\}^{-1} \tag{2.10}$$

where $2\pi\left\{\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right\}^{-1} = K$, the geometric factor of the electrode configuration.

In Wenner configuration, used in this study, the current and potential electrode pairs have a common mid-point and the distances between adjacent electrodes are equal, so that $r_1 = r_4 = r$ and, $r_2 = r_3 = 2r$; hence for Wenner, configuration (Lowrie, 1997),

$$\rho_a = 2\pi \frac{\Delta V}{I} r \tag{2.11}$$

3.0 Survey methodology

The electrical resistivity method was adopted for this study and vertical electric sounding was done using the Wenner electrode configuration with the aid of an ABEM DC resistivity meters; SAS 300c (with SAS 2000 booster). The data from the field survey was processed to obtain the apparent resistivities. These were first plotted against the electrode spacings on a log-log transparent sheet. The best smooth curves through the points were interpreted quantitatively by a method of partial curve matching, using a 2-layer master and auxiliary curves (Orellana and Mooney, 1972). The results were then fed into the computer as initial models and subjected to repeated iterations until a satisfactory fit to the field data was obtained.

4.0 Results and Discussions

The processed data were used in obtaining the resistivity curves, geo-electric sections and maps. Visual inspection of the resistivity curves based on their distinct characteristics was used to classify them into four groups and order:

Group A : KH
Group B : QH
Group C : KQ
Group D : HA

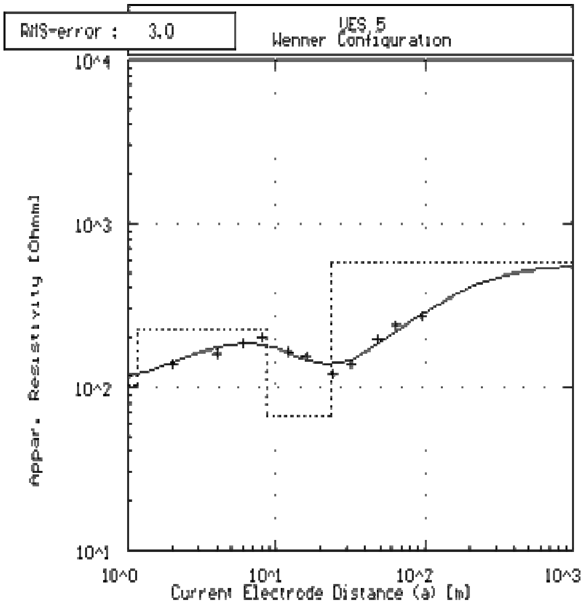
Figure 3.1 shows four curves, one fro each group, obtained from the computer iterations, with VES numbers as indicated.

Group A consists of four –layer curves with resistivity characteristic of $\rho_1 < \rho_2 > \rho_3 < \rho_4$ and is typical of VES 1, 5, 6 and 8. Their first layer is the top soil while the second is a weathered basement, with the third being highly weathered. This shows a sign of fracture, hence, the presence of water. The

implication is that foundation of any engineering structure may not be cited in the third layer. However, the fourth layer is a fresh bedrock with high resistivity values (which implies a hard formation) and is highly competent to withstand the weight of any foundation.

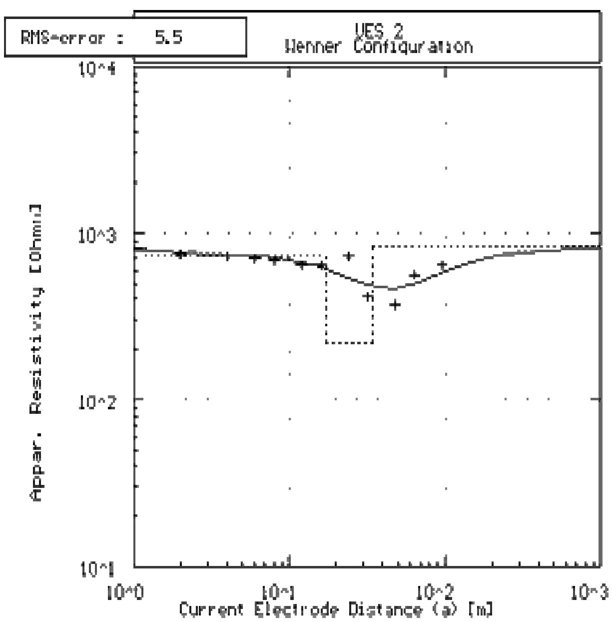
Group B which comprises VES 2 is also made up of four layers, with resistivity characteristics of $\rho_1 > \rho_2 > \rho_3 < \rho_4$.. The topsoil (first layer) is 1.2 m thick has a resistivity value of 812.4 ohm-m, the

(a)



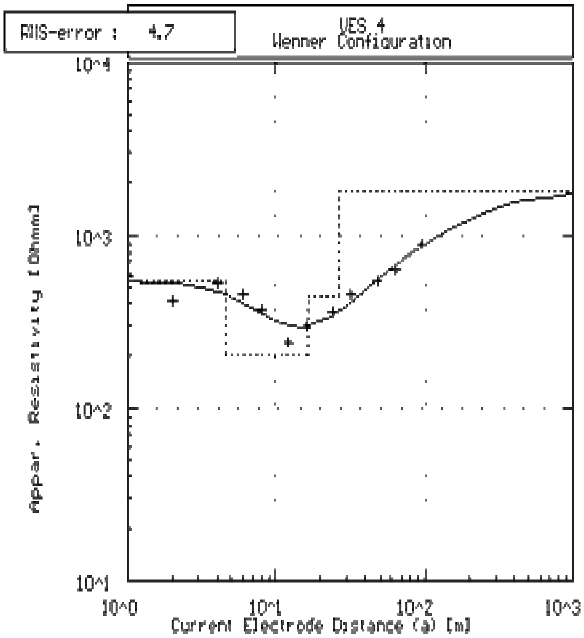
No	Res	Thick	Depth
1	102.5	1.1	1.1
2	228.8	7.3	8.5
3	66.6	15.2	23.7
4	569.5	-.-	-.-

(b)



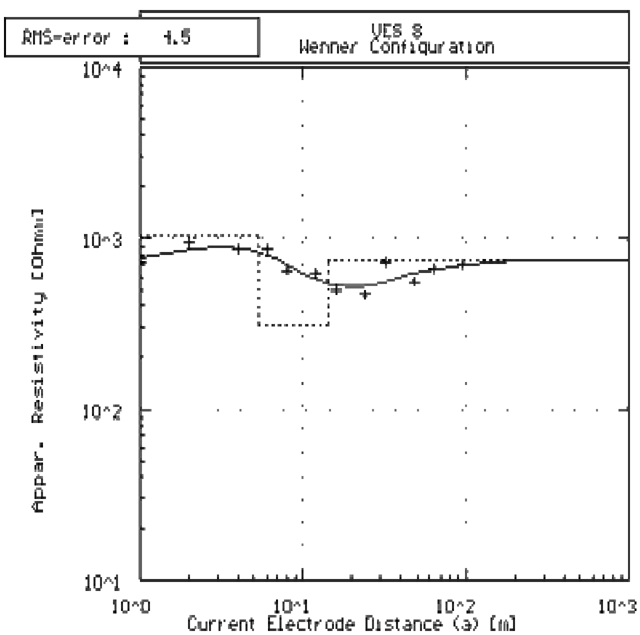
No	Res	Thick	Depth
1	812.4	1.2	1.2
2	724.9	15.9	17.1
3	222.9	17.3	34.4
4	833.7	-.-	-.-

(c)



No	Res	Thick	Depth
1	539.6	4.5	4.5
2	200.0	12.0	16.5
3	439.1	10.0	26.4
4	1788.2	-.-	-.-

(d)



No	Res	Thick	Depth
1	690.7	0.8	0.8
2	1033.0	4.6	5.4
3	315.1	8.9	14.3
4	756.7	-.-	-.-

second and fourth layers are fresh bedrock with resistivity values of 724.9 ohm-m and 833.7 ohm-m; and thicknesses of 15.9 m and infinity respectively. The resistivity value of the third layer is comparatively low (22.9 ohm-m) indicating a presence of water. However, this area is highly competent for engineering structures with any fear of collapse.

Group C is made up of VES 3 with four layers and resistivity characteristics of $\rho_1 < \rho_2 > \rho_3 > \rho_4$. The first, second and third layers in this formation has high

4.1 Geo-electric section along XX – XX'

This section is taken in the south – north direction of the study area and it comprises of VES 8, 3 and 1, covering a total distance of 80 m. Figure 4.2a shows the geo-electric section along XX - XX'. The top layer which is the lateritic/top soil has resistivity between 691ohm-m-1674ohm-m and its thickness ranges from 0.8m-4.0m. The second layer has a resistivity ranging from 315 -713 ohm-m with thickness of 6.1-8.9 m. The last layer is the fresh bedrock with an infinite thickness and it is formed in between the second and the last layer in VES 8 with resistivity 1033 ohm-m and its 4.6 m thick, it also covered the second, third and the fourth layer of VES1 and VES 3 with resistivity range from 1030-1852 ohm-m with thickness of 6.1-8.0 *m*.

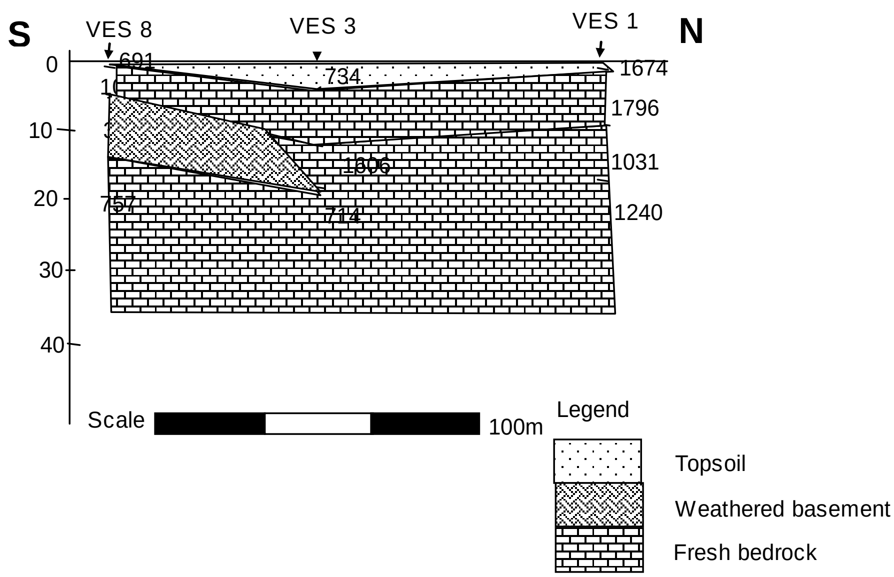


Figure 4.2a: Geo-electric section along XX – XX'

4.2 Geo-electric section along YY-YY'

This section is oriented along West-east direction having a strike length of 100m. It consists of VES 2, VES 3 and VES 4. As a result of hard or solid formation of the group, it only has three layers.

The first layer is the top soil and lateritic soil which has resistivity ranging from 539ohm-m,-812ohm-m and its thickness ranges from 1.2m-4.5m. the second layer is weathered basement, its formed in the third layer of VES 2 with resistivity value of 223ohm-m and its thickness is 17.3m and is also formed in between the second and third layer of VES 4 with resistivity of 200ohm-m 439ohm-m and its thickness ranges from 10-12m, third layer is fresh bedrock which the formation lies in the second layer of VES2 with resistivity of 724 ohm-m and has an appreciable thickness of 15.9m. This formation is continuous in the fourth layer of VES 4 and its resistivity and thickness is 833ohm and infinity respectively.

Fresh bedrock lies in VES 3 on the second, third and fourth layer with thickness of 6.1m-infinty, this formation extended to VES 4 but only on the fourth layer with resistivity 1789ohm-m and the thickness is infinite. This shows the competence of the area that is the soil formation can withstand the load or foundation of engineering structures. See Figure 4.2b

4.3 Geophysical Maps

Geophysical maps are used in delineating structural trend of buried rock or deposit, location fractures and buried river channels. For the present study, four iso-resistivity maps at electrode separation of AB/3 = 32 m, 45 m, 65 m and 96 m are generated,, also, top soil contour map and the isopach contour maps of the study area are presented

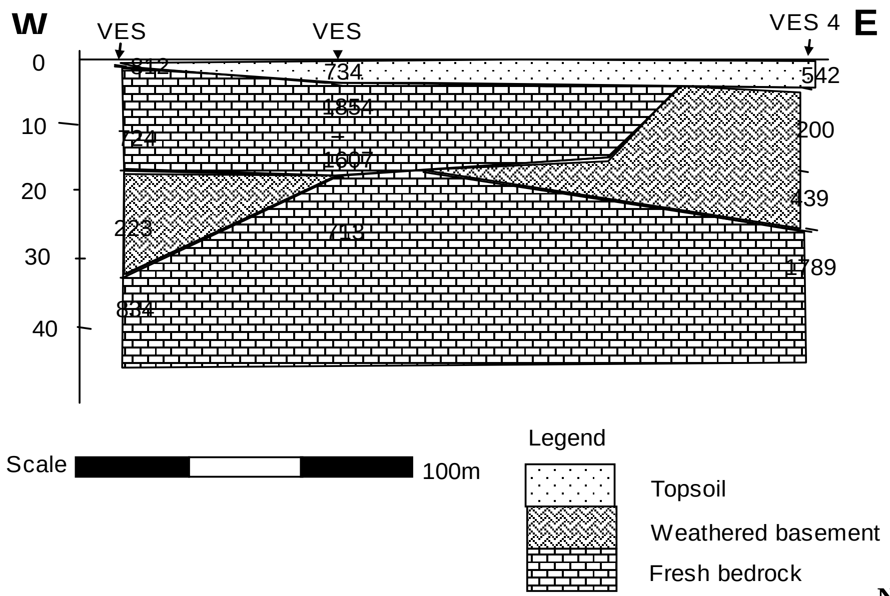


Figure 4.2b: Geo-electric section along YY – YY'

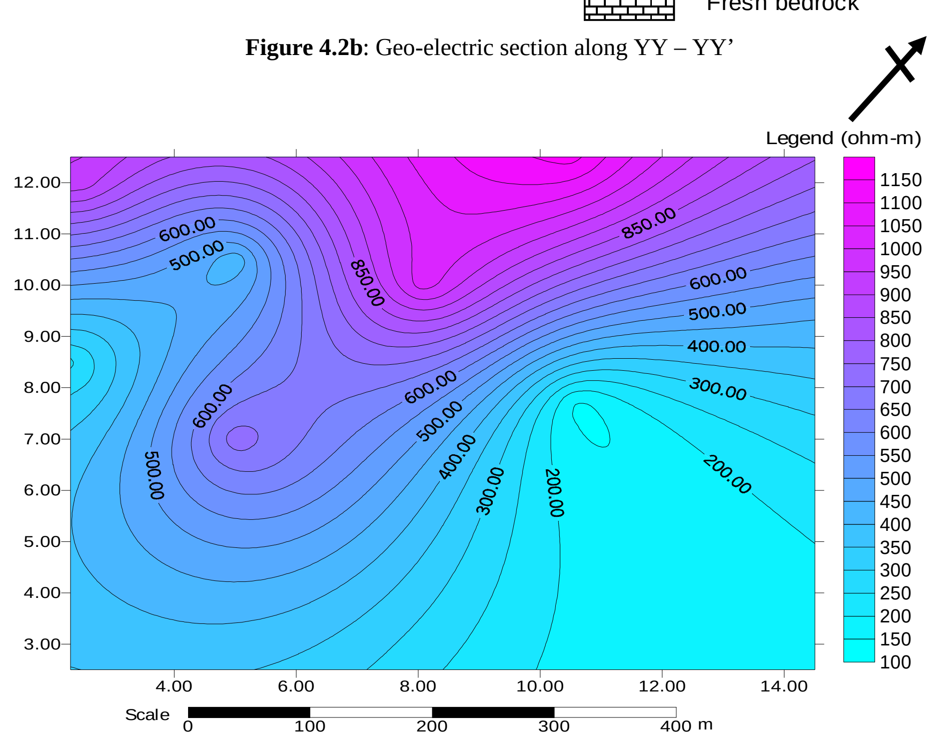


Figure 4.3a: Isoresistivity map at AB/3 = 32m

An iso-resistivity map depicts the resistivity distribution within an area of study (Fasunwon et al.2005). The Isoresistivity map at electrode separation of 32m is shown in figure 4.3a.The areas with closely packed lines are with high resistivity values and are hence capable of withstanding the heavy weigh of foundations.

Figure 4.3b shows the isoresistivity map at AB/3 = 45m. It is obvious that the geology formation of the electrode separation of 32 m is more competent compared to the present case (that is, for AB/3).

Figure 4.3c depicts the resistivity distribution at AB/3 = 65 m. The north-east part of map is the area with high resistivity value, increasing outwardly and hence, the only area in this separation competent for any engineering structures.

Figure 4.3d shows the iso-resistivity map at AB/3 = 95. This contour forms a closure at resistivity of 300 ohm-m, with most of the area evenly spaced, indication a probable gently surface. The southern part is however scattered showing low resistivity value. Meanwhile, solid foundation lies in the region with high resistivity value.

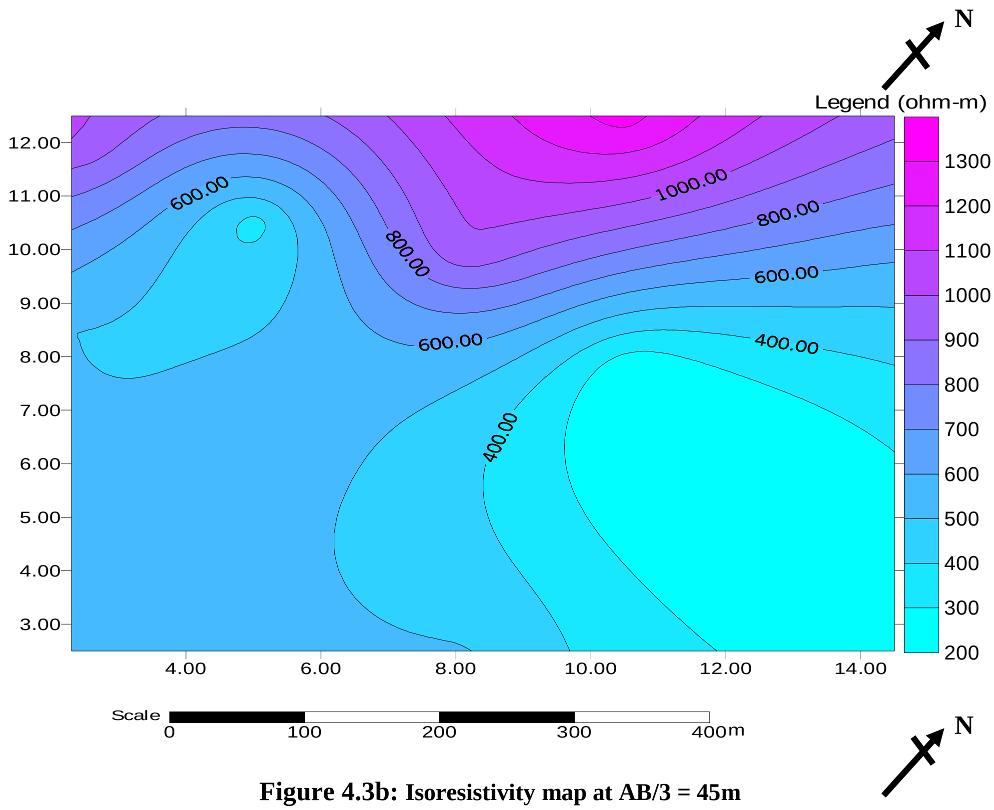


Figure 4.3b: **Isoresistivity map at AB/3 = 45m**

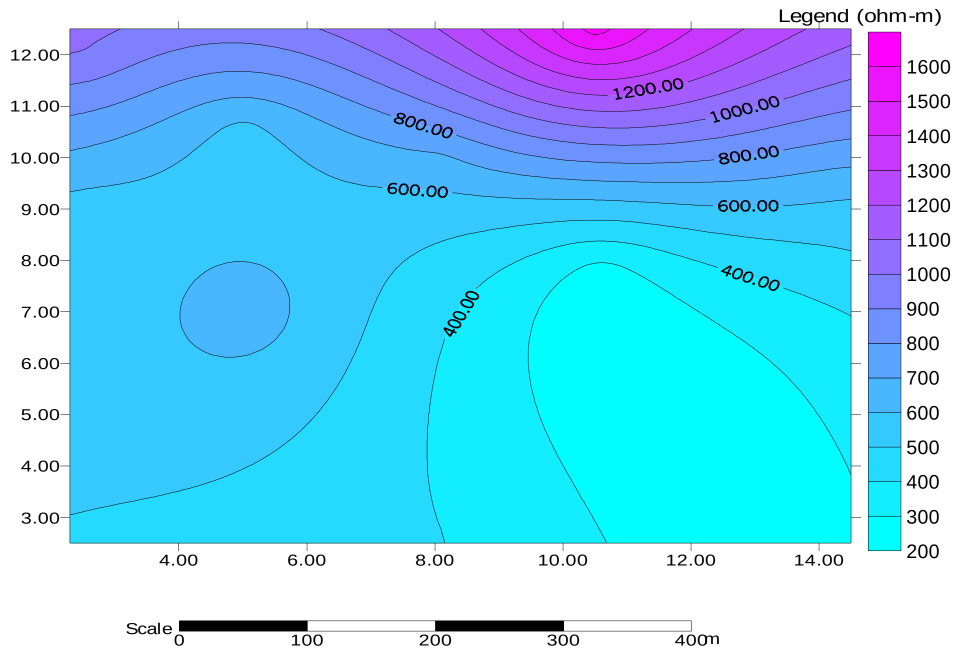


Figure 4.3c: Isoresistivity map at AB/3 = 65m

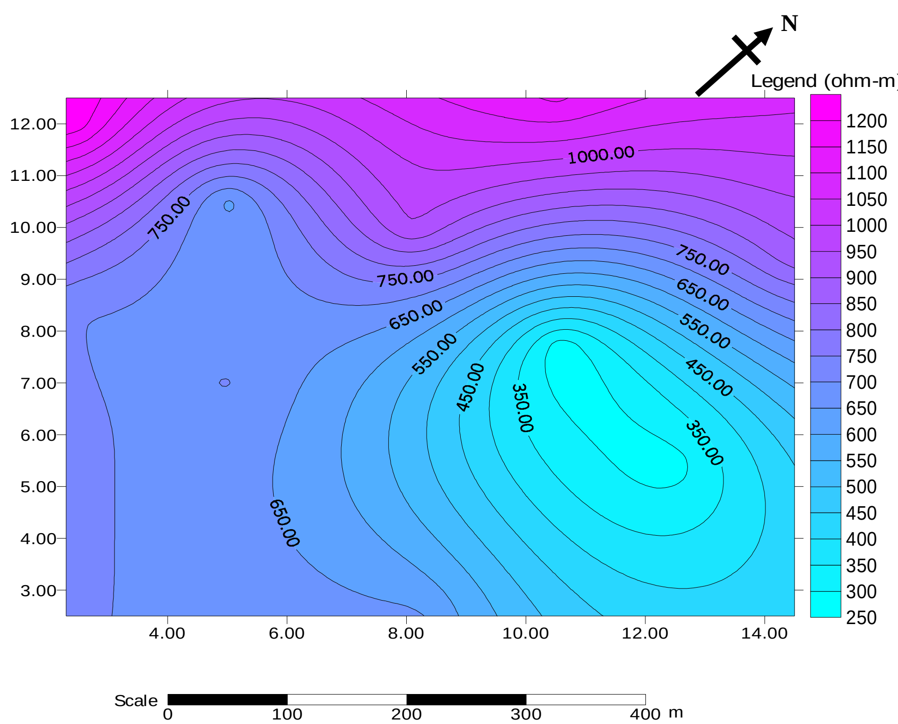
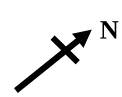


Figure 4.3d: Isoresistivity map at AB/3 = 96m



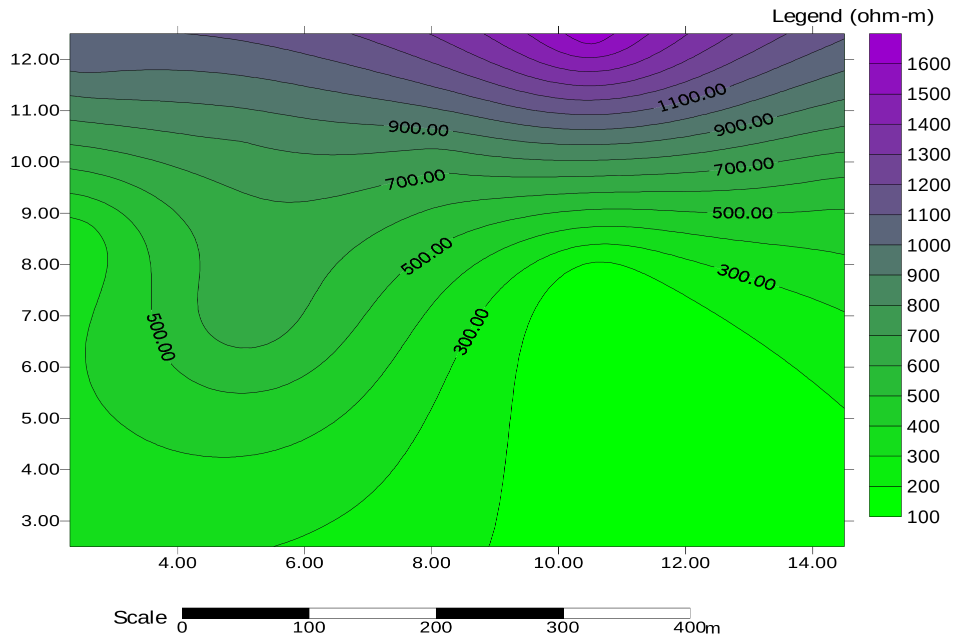


Figure 4.4: Top Soil Contour Map Of The Study Area

Figure 4.4 shows the topsoil contour map, which indicates the resistivity distribution of the areas that are very close to the surface. The lines at the top surface are scattered, showing low resistivity values, however, the lines becomes closer as we move deeper into the soil . The implication is that foundations cannot be put on a shallow depth.

Figure 4.5 depicts the isopach contour, showing the overburden thickness contour of depth to the bottom layers in meters, of the study area. The depth ranges from 14m-36m and has a contour separation of 2m. At 30m the soil formation is very solid the area is more compacted indicating the competence of the formation for citing high-rise structures.

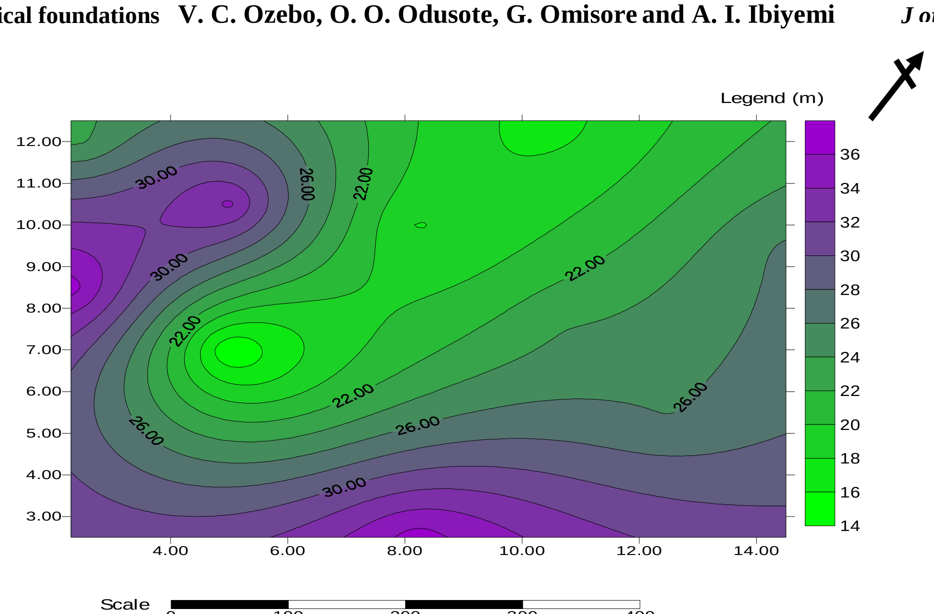


Figure 4.5: Isopach Contour Map Of The Study Area

5.0 Conclusions

This geophysical study was carried out using the engineering geology and engineering geophysics method. These techniques were employed to evaluate the competence of the subsurface material serving as founding materials for buildings.

The result of this study provide information on the engineering properties of the near subsurface soil materials. Also the geophysical parameters of the subsurface unit were determined such as the top layer resistivity and thickness of the regolith materials, the bedrock configuration, bedrock structural pattern and weathered layer sequence among others. The subsurface integrity determination and characterization is important and a pre-requisite before any engineering structure is put in place. In fact, it is a necessary tool and should be a parameter for the choice of a potential building site, the design and the structure and the weight of the load to be put on it. Moreover, it decides the cost implication and economic viability of such project. The area under study is highly competence for high rising buildings because the area has a hard formation which can withstand the weight of any load on it.

The campaign for a geophysical subsurface evaluation before erecting structures should be encourage among developers, the use of integrated techniques and methods should be encourage in foundation studies before the usual foundation test. Foundation study test must not be limited to the near surface or shallow depth because the depth of occurrence goes beyond near surface depth.

The pre-assessment study is important and should be encouraged among the construction companies in order to ensure lifespan of the structures and safety of human lives.

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