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Full Length Research Article

D.C. RESISTIVITY INVESTIGATION OF SUBSURFACE LAYERING FOR GEOTECHNICAL APPLICATION IN MILLENNIUM CITY, KADUNA, KADUNA STATE.

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ABSTRACT

Vertical Electrical Sounding (VES) method of Direct Current Resistivity was -carried out at the South Eastern part of the Millennium City, Kaduna, Kaduna State, North-Western, Nigeria using the Schlumberger array, with the aim of obtaining information on the subsurface layering for geotechnical application. From the interpreted data, geoelectric and geologic sections and some specialized maps were produced. It is suggestive that the area is underlain by three to five layers. The first layer resistivity and thickness are found to range from 66Ωm to 8343Ωm and 0.39m to 9.4m respectively. The weathered/fractured basement layer, which forms the aquifer, is found to have resistivity and thickness ranging from 36Ωm to 656Ωm and 10.0m to 48.7m respectively. The basement, which forms the final layer, having an infinite thickness, is found to have resistivities ranging from 1016Ωm to 14399Ωm. Competent zones for geotechnical applications within the study area were found to be at VES $L_{1/2}$, VES $L_{1/3}$, VES $L_{1/4}$, VES $L_{1/5}$, VES $L_{1/6}$, VES $L_{2/3}$, VES $L_{2/4}$, VES $L_{2/5}$, VES $L_{3/2}$, VES $L_{5/1}$ and VES $L_{5/2}$. VES $L_{1/3}$ was however, found to possess all the characteristics of competence in relation to surface resistivity, first layer thickness, basement resistivity and depth to basement and hence was considered to be the most competent.

Keywords: Competent, Subsurface, D. C. Resistivity, Geotechnical, Geologic Sections, Thickness.

INTRODUCTION

Urban development, whether it is within cities, expansion of existing cities or creation of new cities, is largely driven by economic, political and social trends. The incidence of building failures and collapses has become a major issue of concern, affecting urban development in Nigeria as a nation and even the world, as the frequencies of their occurrence and the magnitude of the losses in terms of lives and properties are now becoming very alarming. This problem is found to be as a result of faulty design, negligence, incompetence, faulty construction, foundation failures, extraordinary loads, corruption and absence of proper site and soil investigation to determine suitability of the terrain and soil's bearing capacity, which influences foundation types and spells out danger. Although ground conditions rarely prohibit development entirely, they do introduce material planning considerations including flood risk, development of contaminated land, and capacity of subsurface infrastructure Nwankwoala and Warmate, (2014).

The geotechnical evaluation of subsoil condition of a site is necessary in generating relevant data inputs for the design and construction of foundations for proposed structures Nwankwoala and Warmate, (2014). The Vertical Electrical Sounding (VES) is a Direct Current Resistivity tool of geophysics for the determination of the subsurface structure of a place. It has been used extensively for the determination of the aquifer potential for the drilling of boreholes. These days, it is used for in-depth geotechnical studies to determine the suitability of a site for the building of heavy structures including high rise buildings, bridges and stadia (Igboekwe, et al. 2012). Hence, the method can be used in the study of the subsurface layering of a place, to provide information that will help in determining the nature of soil at the site and its stratification, selecting the type and depth of foundation suitable for a given structure, determining potential foundation problems (e.g., expansive soil and collapsible soil) and determining the depth and nature of bedrock, if and when encountered.

Location and Geology of the Study Area

The study area is located at the South-Eastern part of the Kaduna Millennium City, Kaduna State, North-Western, Nigeria. The study area (Fig. 1) is approximately centred between Latitudes 10°31'00''N and 10°31'21''N and longitude 7°30'15''E and 7°30'37''E. It has a total area of about 200,000m^2 and located in the South Eastern part of sheet 123 Kaduna S.E map, at a height of about 610m above sea level.

A brief geology of the study area shows that, Kaduna State, lies within the Basement Complex of Northern part of Nigeria. The rocks of the area are mostly Precambrian in age and have been subjected to several phases of deformation, the latest being the Pan African Orogeny Aboh, (2009). During this deformation, the basement produced North-South trending basins of metasediments in the form of synclinoria. The rock types of the basement are mainly granites, gneisses, migmatites, peltic schist, metaconglomerates, marbles and calc-silicate rocks, basic schist, amphibolites and basalts, quartzites and quartz schist, charnockites and fayalite granites (Dogara, 1995). According to Eigbefo, (1978), the superficial deposits, which overlie the basement rocks, act as recharge materials, especially where they are underlain by weathered basement. The main aquifer components of the basement complex of Nigeria are weathered and fractured basement Oluwu, (1967); Adamu, (1991) and water yielding capacities of wells drilled to these components always vary.

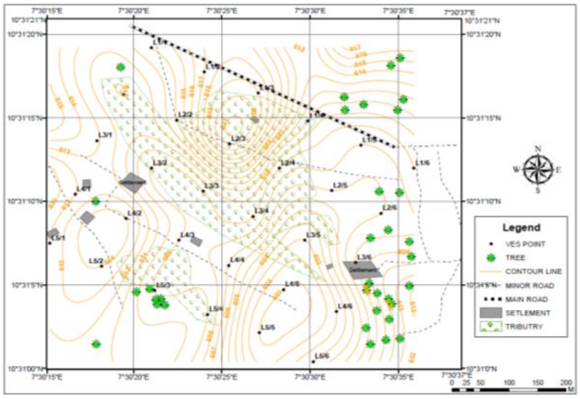

Fig. 1: Map of study area showing VES points.

Theory of Vertical Electrical Sounding

Vertical electrical sounding is a Direct Current Resistivity method which measure vertical variation of resistivity with depth (Paranis, 1986). This is achieved based on the assumption that the surface is to be homogeneous and isotropic (Abdullahi and Udensi, 2008). From Ohm's law, the current I and the potential V in a metal conductor at constant temperature are related as follows;

$$V = IR \qquad (1)$$

Where R is the constant of proportionality known as resistance, measured in ohms. The resistance R, of a conductor is related to its length L and cross sectional area A, by

$$R = \frac{\rho L}{A} \qquad (2)$$

Where ρ is the resistivity, and it is a property of the material considered. From (1) and (2),

$$V = \frac{I\rho L}{A} \qquad (3)$$

Using the Schlumberger configuration (Fig. 2), a potential gradient is measured at M and N when current electrodes located on the surface of the equipotential surface is semi-spherical downward into the ground at each electrode. The surface area will be $2\pi L^2$, where L is the radius of the sphere. Thus,

$$V = \frac{I\rho}{2\pi L} \qquad (4)$$

By deduction then, the potential at M (V_M), due to the two current electrodes, is

$$V_M = \frac{I\rho}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \qquad (5)$$

Similarly, the potential at electrode N (V_N) is given by

$$V_N = \frac{I\rho}{2\pi}\left(\frac{1}{r_3} - \frac{1}{r_4}\right) \qquad (6)$$

Where r_1, r_2, r_3 and r_4 are shown in Fig. 2.

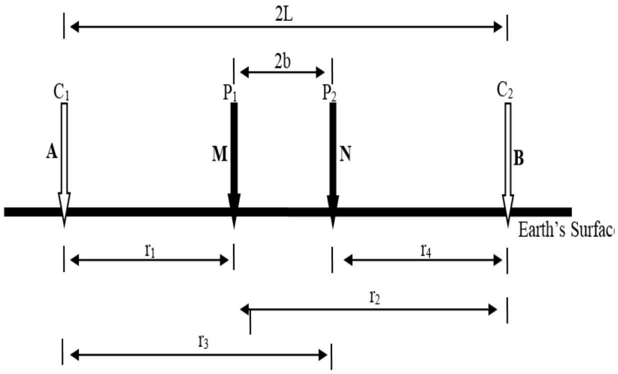

Fig. 2: Schlumberger Electrode Array

The potential difference, ΔV, across electrodes M and N is $V_M - V_N$.

$$\Delta V = V_M - V_N \qquad (7)$$

$$\Delta V = \frac{I\rho}{2\pi}\left[\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{r_3} - \frac{1}{r_4}\right)\right] \qquad (8)$$

$$\Rightarrow \ \rho = \frac{2\pi\Delta V}{I}\left[\frac{1}{\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{r_3} - \frac{1}{r_4}\right)}\right] \qquad (9)$$

If the body is inhomogeneous like the study area, apparent resistivity (ρ_a) is considered,

$$\rho_a = K\left(\frac{\Delta V}{I}\right) \qquad (10)$$

Where ρ_a is apparent resistivity in ohm-metre, and,

$$K = 2\pi\left[\frac{1}{\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{r_3} - \frac{1}{r_4}\right)}\right] \qquad (11)$$

K is called the geometric factor whose value depends on the type of electrode array used. For Schlumberger array, if $\mathrm{MN} = 2\mathrm{b}$ and $\frac{AB}{2} = L$, then,

$$K = \pi\left(\frac{L^2}{2b} - \frac{b}{2}\right) \qquad (12)$$

Data Acquisition and Interpretation

Vertical Electrical Sounding (VES) data was collected on 30 VES stations using the Schlumberger configuration. The VES stations were arranged on five profiles labelled L_1, L_2, L_3, L_4 and L_5 each of length 500m, with each of these profiles having six VES stations, 100m away from each other. The maximum current electrode separation AB/2 being 100m and maximum potential electrode spacing MN/2 being 5m was used. The data was acquired using the Ohmega Resistivity meter and its accessories and the field data was interpreted using the Computer software, *RES1D* version *1.00.07 Beta*.

RESULTS AND DISCUSSION

From the results obtained from the interpretation, a borehole well log after Ephraim, (2016) and resistivity range of earth materials after Mohammed, et al. (2007), Jatau, et al. (2013), Dogara, (1995), Talabi and Ayodeji, (2015) and Abdullahi, et al. (2014), Aboh, (2002) and geologic sections were constructed for the five profiles.

The geoelectric and geologic sections for profile 3 (Fig. 3), which gives a fair representation of the other profiles due to its centrality, shows that the profile is underlain by four layers. The resistivity of the first layer which is made up of clay soil, laterite and indurated laterite was found to range from 387Ωm to 2100Ωm, and has a thickness ranging from 0.4m at VES $L_{3/6}$ to about 4.3m at VES $L_{3/4}$. The second layer, whose resistivity values range from 271Ωm to 680Ωm and thickness ranging from 4.0m at VES $L_{3/4}$ to 11.8m at VES $L_{3/6}$, is made up majorly of Sandy/Silty clay. The third layer, made up majorly of the weathered basement, has its resistivity values ranging from 49Ωm to about 202Ωm. The thickness of this layer was found to range from 11.5m at VES $L_{3/3}$ to 24.2m at VES $L_{3/4}$. The fourth layer, which is the final layer, was found to have resistivity values ranging from 1074Ωm to 7164Ωm, and infinite thickness, suggesting that it is the fresh basement.

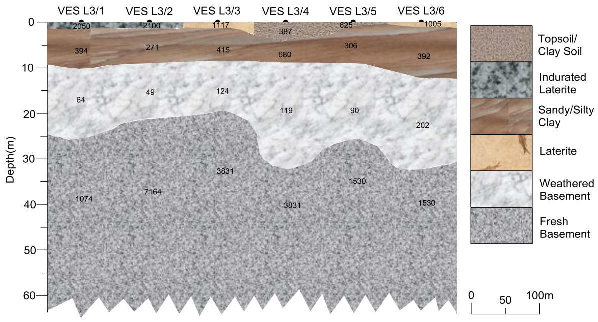

Fig. 3: Geoelectric and Geologic Section for Profile L_3

Some specialized contour maps for the first layer and basement were produced using a contouring package, *suffer version 11* to help in the determination of the competent zones for geotechnical application within the study area.

Fig. 4 was produced by contouring the first layer resistivity values obtained from the computed data for all the VES points. The map which was produced with a contour interval of 200Ωm was produced to show the variation of resistivity of the first layer. The resistivity of the first layer has an average of 1281Ωm and ranges from 66Ωm at VES $L_{1/6}$ to 8343Ωm at VES $L_{1/3}$. According to Abdullahi and Udensi, (2008), areas with high resistivity of top layer >800 Ωm consisting of consolidated thick laterite cover, may be good for engineering and construction purposes. Hence, areas coloured green and red on the map are found to be the best areas for construction purposes, with the red coloured area being the most competent. The areas with low resistivity values, coloured yellow, according to Fadele, et al. (2013) is an indication that the materials are saturated with water, and erecting massive structures along this area is not advisable, but rather structures of low load bearing capacity.

Fig. 5 is the map of the first layer thickness, shows how thick or thin various points of the first layer are within the entire study area. The first layer thickness ranges from 0.39m at VES $L_{3/6}$ to 9.4m at VES $L_{2/3}$, with an average of 2.7m. The areas coloured green and red are areas where the thickness is greater than 1.5m. According to Nwankwoala and Warmate (2014), the normal shallow foundation level range from 1.0 to 2.0 metres. Hence, the regions coloured green and red in the map are seen to have thicknesses greater than the minimum depth of the normal shallow foundation, which imply their suitability for siting structures, example high rise buildings, bridges, etc.

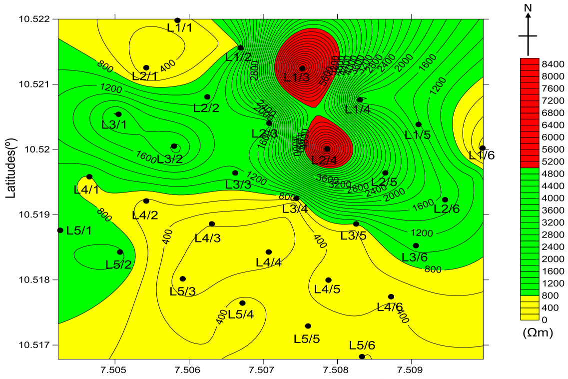

Fig. 4: Isoresistivity Map of First Layer

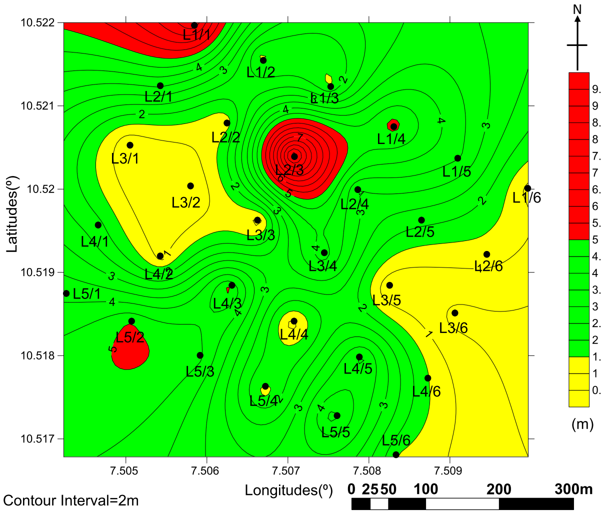

Fig. 5: First Layer Thickness Map

A comparison of figures 4 and 5, shows that all the areas of high resistivity (with the exception of VES $L_{2/6}$, VES $L_{3/1}$, VES $L_{3/2}$ and VES $L_{3/6}$) coincide with areas of thickness greater than the minimum depth of normal shallow foundation, making them areas capable of accommodating heavy structures.

Fig. 6 is the fresh basement resistivity map having a contour interval of 500Ωm. The resistivity of the fresh basement is found to range from 1016Ωm around VES $L_{4/1}$ to 14399Ωm around VES $L_{1/3}$, with an average of 3462Ωm. According to Abdullahi and Udensi (2008), regions with high fresh basement resistivity (>6000)Ωm) are areas of high competence, hence in this work, the regions coloured red are competent areas for civil works. Aboh and Osazuwa (2000), Aboh (2002) and Abdullahi and Udensi (2008) said that the resistivity of the basement is a function of the degree of weathering and hence its strength. This implies that basement rocks with low basement resistivity values <2000Ωm within the study area should be avoided for siting any heavy structure.

The depth to basement map (Fig. 7) and the orthographic projection map of overburden thickness (Fig. 8) were produced using the values of depth to basement, to show the variation in thickness of the overburden. The depth to basement varies from 13.6m at VES $L_{4/2}$ to 55.6m at VES $L_{2/4}$, having an average of 34.2m. The regions coloured red in the map (Fig. 6) show areas of shallow depth <30m (after Abdullahi and Udensi, (2008)). According to Mohammed, et al. (2007), areas with shallow basement and high resistivity values imply the areas are favorable for high - rise structures. Therefore, comparing the map of basement resistivity (Fig. 6) and that of depth to basement (Fig. 7), it can be seen that the areas of red colour coincidence are found only at VES $L_{1/3}$, VES $L_{1/6}$ and VES $L_{3/2}$, making them part of the competent zones.

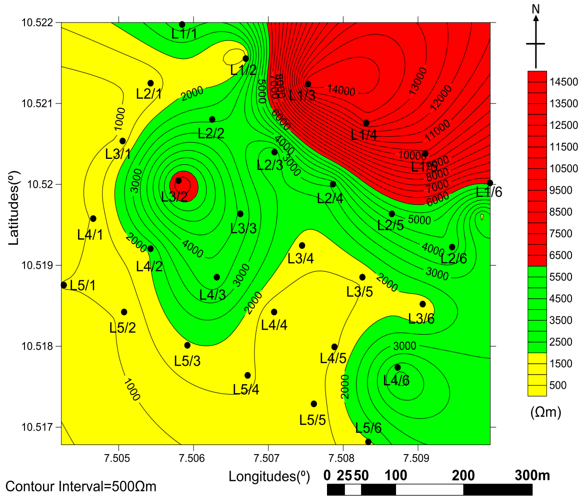

Fig. 6: Isoresistivity Map of Fresh Basement

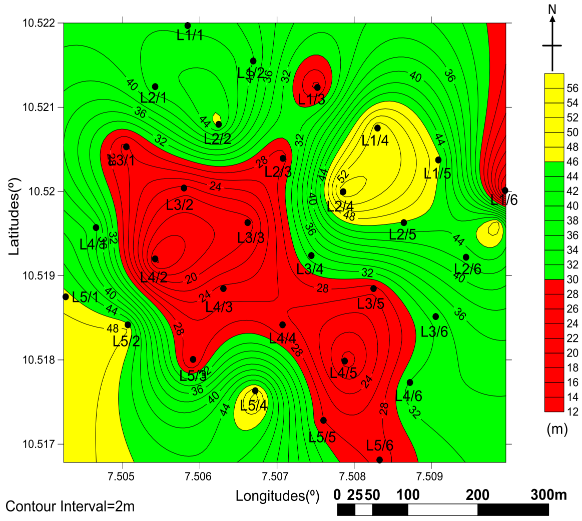

Fig. 7: Depth to Basement Map

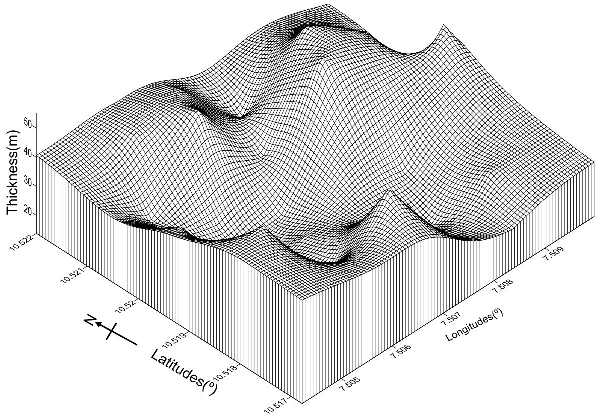

Fig. 8: Orthographic Projection Map of Overburden Thickness

Also, Abdullahi and Udensi (2008), said that areas with depth to basement >45m might be buried valleys or underground structural traps, which might be suitable for usage as seawage or disposal sites. Hence, areas on the map coloured yellow are recommended for construction of waste disposal structures. However, due to their relatively high basement resistivity values, VES $L_{1/4}$, VES $L_{1/5}$, VES $L_{2/4}$ and VES $_{2/5}$ have been found to be the best areas for the construction of waste disposal structures within the study area, since the underlying basement rocks at these points are not fractured or heavily weathered, and therefore could not serve as contaminant transport pathways.

Conclusion

From this work, the areas found to meet the conditions of high resistivity value and high thickness of top layer for siting heavy structures are VES $L_{1/2}$, VES $L_{1/3}$, VES $L_{1/4}$, VES $L_{1/5}$, VES $L_{2/3}$, VES $L_{2/4}$, VES $L_{2/5}$, VES $L_{5/1}$ and VES $L_{5/2}$. Also, areas found to meet the conditions of high basement resistivity and shallow depth to basement, are found to be at VES $L_{1/3}$, VES $L_{1/6}$ and VES $L_{3/2}$. Hence, these areas have been found to be the competent zones within the study area, and are good for the construction of high – rise buildings, roads and bridges. However, within these, there are areas that exhibit both acceptable properties of competence in surface resistivity, surface thickness, depth to basement and basement resistivity. The VES that satisfies these conditions is VES $L_{1/3}$, and hence could be described as the most competent

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