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ENGINEERING GEOPHYSICAL STUDY OF THE CONVOCATION SQUARE, KADUNA STATE UNIVERSITY.

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ABSTRACT

Geophysical investigation for engineering studies was carried out at the convocation square of Kaduna State University (KASU) main campus, Kaduna state, which falls within the Basement Complex of North-Western Nigeria. The study is aimed at assisting in the planning and development process of civil engineering works in the university. Vertical Electrical Sounding (VES) using Schlumberger array was carried out at ten (10) VES points. ABEM Terrameter (SAS 300 C) was used for data acquisition. Three major lithologic units were delineated from the electrical resistivity survey results comprising of topsoil, characterized by sandy/lateric materials, weathered basement and the fresh bedrock. Resistivity values for the various units range from 88 to 900 ohm-m, 111 to 247 ohm-m and 1300 to 32,000 ohm-m respectively. Depth to bedrock varies between 12 m to 42 m. Iso-resistivity maps of weathered basement, overburden and bedrock with respect to subsurface competency constructed from the VES data revealed that the study area is competent to permit constructions of engineering works. The degree of soil corrosivity varies from slightly-corrosive (80 ohm-m to 150 ohm-m) to practically non-corrosive (resistivity values >200 ohm-m). The results of this study show that corrosion prevention system should be put in place during the engineering design stages.

Keywords: Basement Complex, Soil Corrosivity, Engineering design.

INTRODUCTION

In recent times, the collapse of civil engineering structures has been on the increase for reasons associated with subsurface geological sequence (Omoyoloye et al, 2008). The foundation of any building is meant to transfer the load of the structure to the ground without causing the ground to respond to uneven and excessive movement. In order to achieve this, most buildings are supported on pads, strips and rafts or piles (Blyth and Freitas, 1988).Therefore, the knowledge of the probable cause of rampant failure of building foundations due to subsurface movements giving rise to cracks or structural differential settlements has been a great concern to geoscientists. This has helped to distinguish between a continuing movement, which is often more likely to be a problem and those of single events, which may not require repair depending on the extent of damage. However, adequate insight on the types and patterns of foundation-based cracks and their evaluation has necessitated the need to consider the geological and geophysical basis for buildings' failure and adequate precaution taken to minimize such disaster. The amount, type and direction of foundation movement are commonly noted from the bulging of brick or masonry blocks. These in turn reveal the risk or horizon dislocation. The risk of vertical collapse could be traced to the height of construction, materials used for the building, site factor, earth loading or water. Other factors include seismic action, atmospheric disaster and accident (Omoyoloye et al, 2008). The need for subsurface geophysical investigation has therefore become very imperative so that foundation evaluation of a new site would provide subsurface and aerial information that normally assist civil engineers, builders and town planners in the design of foundations of civil engineering structures (Omoyoloye et, al, 2008).Geophysical methods such as the Electrical Resistivity (ER), Seismic Reflection and Refraction, Electromagnetic (EM) and Ground Penetrating Radar (GPR) are used separately or as integrated techniques for engineering site investigations. The applications of such geophysical investigation are used for the determination of depth to bedrock, structural mapping and evaluation of subsoil competence (Burland and Burbidge, 1981). The present work applied the Vertical Electrical Sounding (VES) method at the convocation square, Kaduna State University main campus, North-West Nigeria in order to determine the suitability of the area for engineering purposes.

Geology and Hydrogeologic Setting of the Study Area

The study area (Fig 1) is Kaduna State University (KASU) main campus, Kaduna State. It is located with coordinates: $10^0\ 30^l\ 58.6^{"}$ N and $7^0\ 27^l\ 7.4"$E in the National grid. The study area falls within the general geology of the Basement complex of Nigeria, where two broad geologic units are recognized namely; The older precambrian unit of metamorphosed sedimentary rocks which consists of quartzite, muscovite schist, muscovite biotite schist, biotite gneiss, migmatite and marble and the younger precambrian igneous rocks comprising of biotite granite, phorphyritic granite and few plugs of diorite, gabbro and syenite (Alagbe, 1979). The study area has typical savannah climate with distinct wet and dry seasons. The raining season extends from March/April to September/October and dry season between November and March. Average annual rainfall for Kaduna is 1054 mm (Eduvie, 1998). Rainfall generally reaches its peak in August. Temperature varies between less than 15 C around December/ January and 30^0 C in March/April. Vegetation consists of broad-leaved savannah woodland which, when well developed, may be dense enough to suppress the growth of grasses. The predominant hill features in the area are inselbergs and whalebacks which belong to the category of residual hills commonly associated with massive granite bodies (Mc Curry, 1976). One of the major sources of recharge in the study area is from river Kaduna. The river is a long tributary of the River Niger and is about 550 km (140 miles) long. Rain water is another recharge source which is seasonal. The area is being discharged through river, ditches to river Kaduna (Mamman, 1992). The hydrogeology of the study area is controlled by factors such as geology, climate and structure. The rocks are predominantly gneisses and migmatites, the relief is generally low, while deep weathering is common with attendant wide spread variation in the ground water level. Appreciable porosity, permeability and storativity of aquifer in rocks of the basement complex depend primarily on secondary structural features such as fractures, fissures and joints, their extent and volume together with the thickness of the weathered zone.

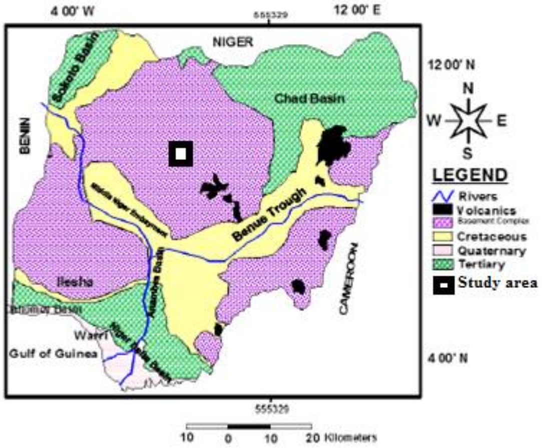

Fig. 1: Geologic Map of Nigeria showing the Study Area (Modified after Ogungbemi, et al, 2014).

Theory of D.C Resistivity Technique

The fundamental physical law used in resistivity surveys is Ohm's Law that governs the flow of current in the ground. The equation for Ohm's Law in vector form for current flow in a continuous medium is given by

$$\bar{J} = \sigma \bar{E} \tag{1}$$

where σ is the conductivity of the medium, J is the current density and E is the electric field intensity. In practice, what is measured is the electric field potential. We note that in geophysical surveys the medium resistivity ρ, which is equals to the reciprocal of the conductivity, $\left(\rho = \frac{1}{\sigma}\right)$ is more commonly used. The relationship between the electric potential and the field intensity is given by

$$\bar{E} = -\nabla \Phi \tag{2}$$

Combining equations (1) and (2), we get

$$\bar{J} = -\sigma \nabla \Phi \tag{3}$$

In almost all surveys, the current sources are in the form of point sources. In this case, over an elemental volume ΔV surrounding a current source I, located at $(x, y, z,)$ the relationship between the current density and the current according to Dey and Morrison (1979) is given by

$$\nabla J = \left(\frac{1}{\Delta V}\right)\partial(x - x_S)\partial(y - y_S)\partial(z - z_S) \tag{4}$$

where ∂ is the Dirac delta function and $x - x_S$, $y - y_S$ and $z - z_S$ are positions vectors . Equation (4) can then be rewritten as

$$-\nabla \bullet [\sigma(x, y.z)\nabla \phi(x, y, z)] = \left(\frac{1}{\Delta V}\right)\partial(x - x_S)\partial(y - y_S)\partial(z - z_S) \tag{5}$$

This is the basic equation that gives the potential distribution in the ground due to a point current source. A large number of techniques have been developed to solve this equation. This is the "forward" modeling problem, i.e. to determine the potential that would be observed over a given subsurface structure. Fully analytical methods have been used for simple cases, such as a sphere in a homogenous medium or a vertical fault between two areas each with a constant resistivity. For an arbitrary resistivity distribution, numerical techniques are more commonly used. For the 1-D case, where the subsurface is restricted to a number of horizontal layers, the linear filter method is commonly used (Koefoed 1979). Fig. 2 shows the simplest case with a homogeneous subsurface and a single point current source on the ground surface. In this case, the current flows radially away from the source, and the potential varies inversely with distance from the current source. The equipotential surfaces have a hemisphere shape, and the current flow is perpendicular to the equipotential surface. The potential in this case is given by

$$\phi = \frac{\rho I}{2\pi r} \tag{6}$$

where r is the distance of a point in the medium (including the ground surface) from the electrode. In practice, all resistivity surveys use at least two current electrodes, a positive current and a negative current source.

The potential value caused by a pair of electrodes in a medium is given by

$$\emptyset = \frac{\rho I}{2\pi}\left(\frac{1}{r_{c1}} - \frac{1}{r_{c2}}\right) \tag{7}$$

where r_{c1} and r_{c2} are distances of the point from the first and second current electrodes. In practically all surveys, the potential difference between two points (normally on the ground surface) is measured.

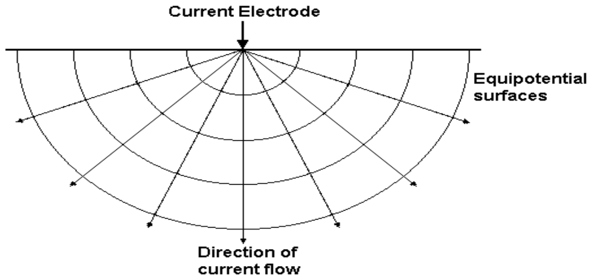

Fig. 2: The flow of current from a point current source and the resulting potential distribution

A typical arrangement with 4 electrodes is shown in Fig. 3. The potential difference is then given by

$$\Delta\phi = \frac{\rho I}{2\pi}\left(\frac{1}{r_{C1P1}} - \frac{1}{r_{C2P1}} - \frac{1}{r_{C1P2}} + \frac{1}{r_{C2P2}}\right) \tag{8}$$

The above equation gives the potential that would be measured over a homogenous half space with a 4 electrodes array.

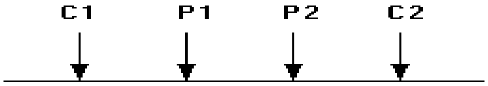

Fig. 3: A conventional array with four electrodes to measure the subsurface resistivity

FIELD METHODS AND DATA COLLECTION

The electrical resistivity data acquisition equipment used in this survey was the ABEM Terrameter 300C equipment. The four electrode Schlumberger method employing the vertical electrical soundings (VES) technique was carried out at ten (10) points along five profiles (Fig 4). A regular direction of N-S azimuth was maintained in the orientation of the profile with maximum AB/2 spacing of 80 m. The apparent resistivity measurements were plotted against electrode spacing on bi-logarithmic graph sheets. Field resistivity structures of sounding data were determined by the software, IPIWIN (version 3.0.1) developed by the Geophysics Group Moscow State University for inverse interpretation. Data were interpreted in terms of four and five layer structure. The fit between model response and the field data for the VES points were generally lower than 10%. The interpretation of the VES curves aided by lithological logs from boreholes (Fig.5) enabled the derivation of geologic sections. The VES interpretations were used for the construction of iso-resistivity maps of weathered basement, overburden and bedrock with respect to subsurface competency. Fig. 6 shows typical example of VES curves.

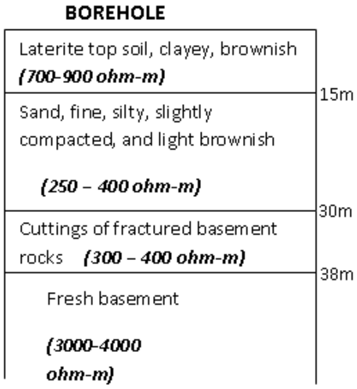

Fig. 5. Borehole lithology and interpretation modified from Aboh (2001)

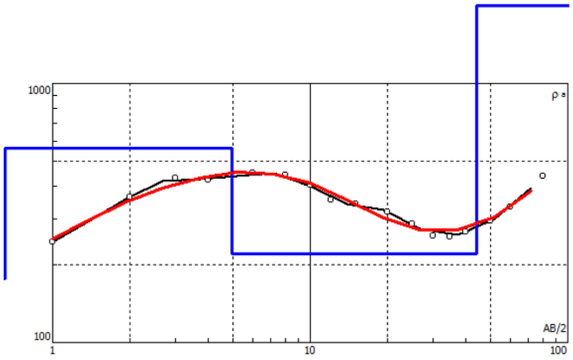

Fig 6.Typical VES curve (VESA$_1$)

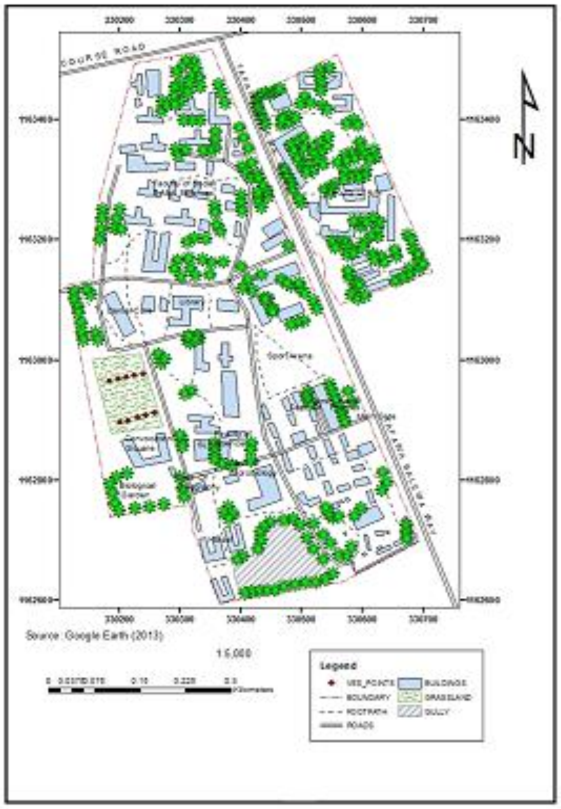

Fig 4. Topographic map of the study area showing the VES points

RESULTS AND DISCUSSION

Profile A

Fig (7) shows the resistivity cross section along profile A. The VES points underneath both VES A$_1$ and VES A$_2$ consists of four layers each. The top soil is characterized by resistivity values of 176 ohm-m and 252 ohm-m for VES A$_1$ and VES A$_2$ respectively and is interpreted as dry sandy soil. The thickness of the top soil beneath both VES points is 0.5 m. The second layer for VES A$_1$ has resistivity value of 564 ohm-m and thickness of 4.47 m, while for VES A$_2$; the resistivity value is 1696 ohm-m and thickness of 1.15 m. This layer is typical of laterite. The third layer for VES A$_1$ consists of weathered basement rock having a resistivity value of 219 ohm-m and thickness of 39.4 m while beneath VES A$_2$; the material typifies dry sandy soil with a resistivity value of 247 ohm-m and thickness of 33.1 m. Fresh basement rock with an infinite thickness forms the fourth layer beneath VES A$_1$ and VES A$_2$. The resistivity of this layer ranges from 1308 ohm-m to 18330 ohm-m.

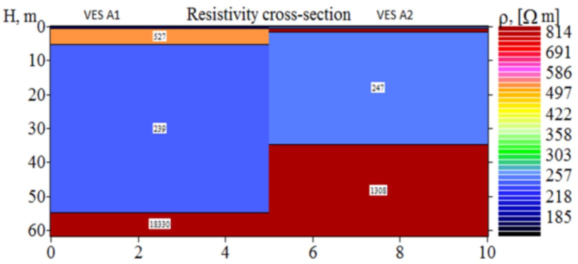

Fig 7: Resistivity cross-section for Profile A.

Profile B

Fig. 8 shows maximum of four (4) layers for both VES points (B_1 and B_2). Resistivity of the first layer ranges from 88.90 ohm-m to 372 ohm-m while their thickness varies from 0.5 m to 2.25 m. This is most likely to be dry sandy soil. The second layer has resistivity values ranging from 441 ohm-m to 1105 ohm-m and thickness values varying from 1.99 m to 5.38 m. The material of this layer is considered as laterite. The third layer whose resistivity values vary from 169 ohm-m to 1940 ohm-m is interpreted as sandy and gravel soil going by the characteristic resistivity values for the earth materials found within the study area and the lithologies of the borehole log (Fig. 5). This layer has maximum thickness of 29.7 m. The fourth layer whose resistivity values vary from 16912 ohm-m (VES B_1) to 32766 ohm-m (VES B_2) defined fresh basement rocks with an infinite thickness.

Profile C

Fig. 9 shows the resistivity cross-section along profile C. Four (4) layers were delineated along this profile with the first layer having resistivity value ranging from 125 ohm-m to 468 ohm-m and average thickness of 0.7765 m. This layer corresponds to dry sandy soil. The second layer is the lateritic soil whose thickness and resistivity values range from 2.68 m to 3.08 m and 658 ohm-m to 718 ohm-m respectively. The third layer which constitutes the weathered basement, has resistivity value ranging from 111 ohm-m to 237 ohm-m while its thickness varies from 10.3 m to 22 m. Low resistivity values (less than 1000 ohm-m) in the fourth layer beneath both VES points denote fractured basement in the bedrock. The thickness of this layer is infinite.

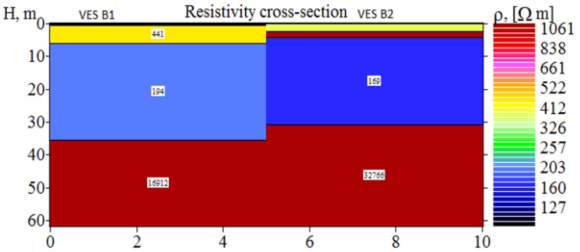

Fig 8: Resistivity cross section for Profile B.

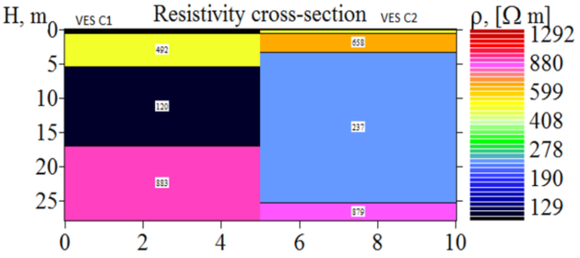

Fig 9: Resistivity cross-section of Profile C

Profile D

Fig. 10 shows a maximum of four (4) geo-electric layers along this profile. The top soil has an average resistivity value of 132 ohm-m and average thickness of 0.754 m. This layer is characteristic of clayey sand. The second geo-electric layer is interpreted as laterite. The average resistivity and thickness values of this layer are 951 ohm-m and 2.93 m respectively. The third layer is characteristic of sandy clay. The average resistivity and thickness values of this layer are 64.2 ohm-m and 6.28 m respectively. The fourth layer has resistivity value of 758 ohm-m and infinite thickness for both VES points. It is interpreted to be fractured basement.

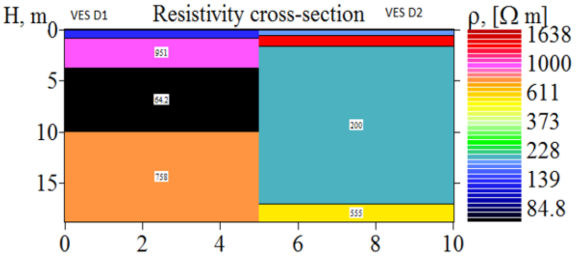

Fig. 10: Resistivity cross-section of Profile D

Profile E

Fig. 11 shows the resistivity cross-section along profile E. Four layers were delineated beneath both VES points. The first layer typifies dry sandy soil and has resistivity value ranging from 128 ohm-m to 900 ohm-m and thickness value ranging from 0.5 m to 1.37 m. The second layer is laterite. The resistivity values of this layer vary from 349 ohm-m to 1,288 ohm-m and its thickness varies from 1.11 m to 4.51 m. The third layer is diagnostic of weathered basement with resistivity value ranging from 162 ohm-m to 181 ohm-m and mean thickness of 12.9 m. The fourth layer beneath this profile with infinite thickness corresponds to fractured basement. The resistivity value varies from 534 ohm-m to 567 ohm-m.

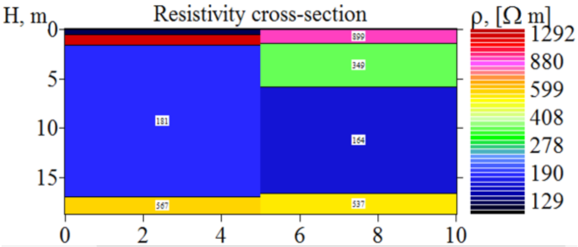

Fig. 11: Resistivity cross-section of Profile E

Depth to Bedrock

Fig. 12 shows the depth to bedrock map which indicates that the depth to bedrock in the study area varies between 10 m around profiles C and D which correspond to basement highs to 26 m around profiles A and B which are the deepest points in the study area and correspond to basement depression. According to Adagunodo et al. (2013), who rated overburden greater than 15 m (about 50 ft) as thick, it could be seen from figure 10 that with the exception of VES C_1, D_1 and D_2 that has the value of 14.4 m, 9.97 m and 10 m respectively, other VES stations have depth to bedrock greater than 15 m. Thus overburden in the study area is relatively thick and zones with depth to bedrock greater than 15 m are good for a high-rise building without an artificial basement before the foundation is laid (Adagunodo, et al, 2013).

Weathered Layer Iso-Resistivity Map

According to Lenkey, et al, (2005) the thick weathered basement layer (containing less percentage of clay) above the basement rock constitutes a water-bearing layer. Optimum aquifer potential is attained in the mid-range of saprolite resistivity (100 to 400 ohm-m) while resistivity values less than 80 ohm- m indicate clays (Wright, 1992). Based on this, the weathered basement layer which either forms the second or third layer was considered as the aquifer units in the study area. The resistivity map of the weathered layer (Fig.13), shows the resistivity values ranging from 70 to 240 ohm-m. This revealed the highly heterogeneous variation in the composition of the weathered basement from clay, sandy clay, and clayey sand. According to Odusanya and Amadi(1990) the electrical resistivity of this layer which forms the water bearing zone depends on the sand to clay ratio and degree of saturation. The zones with resistivity > 100 ohm-m is characteristics of clayey and sand and it indicates good aquifer formation while the lower end (<100 ohm-m) typifies clay which lowers the aquifer potentials. The result showed that the resistivities of the weathered layer beneath VES C_1 and D_1 constitute little and medium weathering processes with poor potential for groundwater. Therefore, water cannot be transported from the subsurface to the supporting walls of the building.

Fig. 14 shows the iso-resistivity map of the top soil resistivity map. From the figure, the degree of corrosivity within the convocation square of Kaduna State University according to table 1, varies from slightly- corrosive on the Southern flank to practically non-Corrosive in the North-Western flank and North-Southern flank.

Table 1: Classification of Soil Resistivity in terms of the Corrosivity (Baeckmann and Schweak, 1975; Agunloye, 1984).

Soil Resistivity (Ohm-m)	Soil Corrosivity
Up-10	Very Strongly Corrosive (VSC)
10-60	Moderately Corrosive (MC)
60-180	Slightly Corrosive (SC)
180 and above	Practically Non Corrosive (PNC)

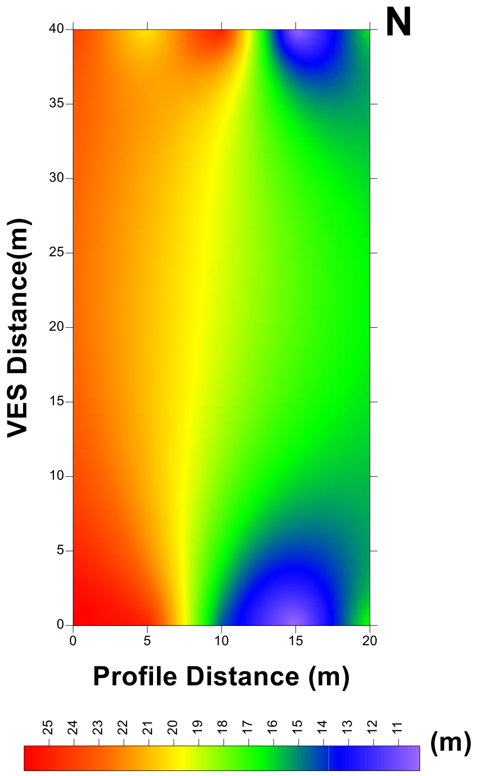

Fig. 12: Depth to Bedrock Map

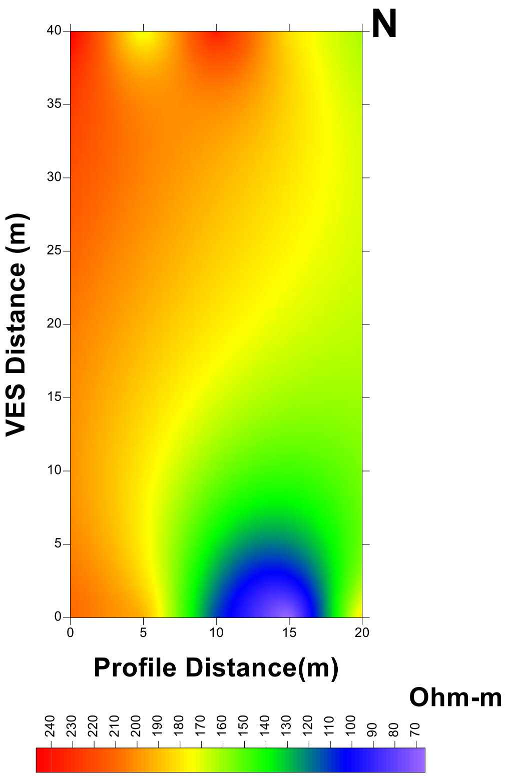

Fig. 13: Weathered Basement Layer

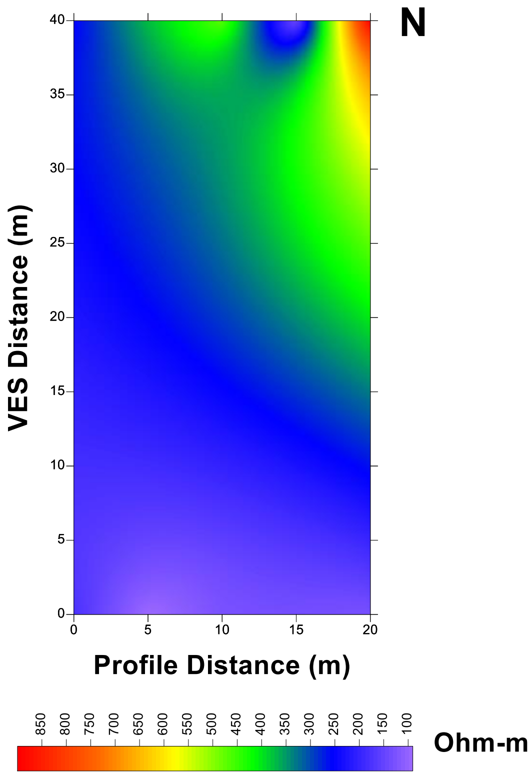

Fig. 14: iso-Resistivity Map of the Top soil.

Conclusion

The results of this study show that overburden in the study area is largely relatively thick and therefore good for civil work. Also, the study area has medium weathering processes with poor potential for groundwater. Thus, water cannot be transported from the subsurface to the supporting walls of the building. The result also shows that the degree of corrosivity of the study area varies from slightly-corrosive to practically non-corrosive; hence corrosion prevention system is recommended to be put in place during engineering design stages.

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