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**Research Paper**

# The need for ENVIRONMENTAL GEOPHYSICS: the case of abandoned complex behind UBA and FIDELITY banks near Greenhouse at Nsukka campus of University of Nigeria

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***Abstract***
*Subsurface geologic structure around an abandoned building at the University of Nigeria, Nsukka campus was investigated to ascertain the cause or reason for abandonment. 2-D resistivity method was employed in the study. Three electrical resistivity tomography (ERT) profiles and one vertical electrical sounding (VES) profile were conducted around the building using SSR-MP-ATS resistivity meter. Winresist software and RES2DINV software were used to process the VES and ERT data respectively. The result of the analysis of the VES data showed a six layered earth model with the resistivity and depth respectively for each layer. The results of the ERT revealed that the area is covered with a conductive top-layer to a depth of about 15 m coupled with fault zone that passed through the building site. These results showed that the foundation of the building was laid without priori or adequate geologic information about the site before commencement of the building. Geologically, the areas with a conductive layer or fault zone have earth materials with low or poor engineering strength that could lead to collapse of engineering structure either by sinking or by fall and which is the case with this site we have studied.*

***Key word:*** *Environment, ERT, VES, Fault zone, Resistivity*

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## I. INTRODUCTION

### Introduction

Frequent collapse of engineering structures like dam, roads, pavement, and building have been linked to so many factors. One of the factors attributed to this building and foundation failures in most developing countries is the lack of adequate information about the subsurface characterization prior to construction. Other factors include presence of low strength materials, bad design, poor supervision and use of inferior materials (Meyerhof, 1956; Adesunloye, 1987; Olorunfemi and Mesida 1987; Oyedele et al., 2011; Ayolabi et al., 2013). The effects of failed engineering structures include loss of lives and properties, in addition to the cost of repairing, rehabilitating and reconstruction of failed engineering. Buildings are engineering structure that contribute to the well-being and sustainable development of a people, therefore, it is important to make adequate plan for building constructions that will stand the test of time (Akpabot et.al, 2019; Ede et.al, 2017). Foundation materials should have sufficient strength to withstand structural load (Adeoti, et al. 2016), also, it is necessary to take into account structural analysis and good understanding of the subsurface geology which are prerequisites for stable foundation base design (Aizebeokhai, et. al, 2017; Ubido, Igwe, Ukah, & Idris, 2017). Hence, to avoid foundation failures and collapse of buildings, there is need for detailed geophysical and/or geotechnical investigations.

A major aspect that has always been omitted in the engineered structural plan is the adequate information on the nature of the hosting Earth material, which defines subsurface conditions prior to construction exercise. Several researchers have used integrated geophysical and geotechnical investigations to delineate subsurface with a view of understanding its suitability for road and building constructions (Al Fouzan

& Dafalla, 2013). For instance, Adewoyin et al. (2019) adopted the use of seismic refraction geophysical method to determine engineering properties of a site prior to development and used these parameters to develop a model equation for purpose of subsurface soil characterization. Oladunjoye et al. (2017) employed geoelectrical resistivity and seismic refraction methods to characterize the subsurface of a proposed conference center in order to understand the soil profile at the site. Al Fouzan and Dafalla (2013) successfully used integration of geotechnical and geophysical methods to characterize the subsurface for possible cracks and ground distress in Saudi Arabia. According to Ayolabi et al. (2013) geophysical methods can be employed to ascertain the subsurface geology with reference to different lithology before siting any engineering structure. Ozegin et al. (2011) is of the opinion that among other factors to be considered during the erection of foundation to guarantee high durability, structural integrity and live safety is the soil strength (stiffness) of the founding layer of the foundation of all engineering structures which are usually implanted within the Earth surface. This will guarantee for high bearing capacity and competent foundation. Foundation investigation of a site therefore needs to be taken into consideration in the economy and the engineering performance of a structure for an acceptable level of service over its intended life.

Geophysical method reveals the response of the heterogeneous soil particles to some physical parameters that governs the subsoil competency. Its usefulness cannot be underestimated when comparing its cost effectiveness and ability to give the true lithological arrangement of the subsoil formation. Detailed information of the subsurface soil meant for foundation of engineering structures can be obtained by using either geotechnical, geophysical method or both (Al Fouzan & Dafalla, 2013; Ayolabi et al., 2013; Oladunjoye et al., 2017 and Adewoyin et al., 2019). Geotechnical method which include drilling, sampling, and boring are good techniques in obtaining the details of soil strength/stiffness. Apart from the cost effectiveness, they are point test that is in lack of information of the entire study area compared to geophysical methods (Olorunfemi et. al., 2002 and Akintorinwa and Adesoji, 2009). The choice of the geophysical method is usually determined by the geologic set up and the existence of significant contrast in the physical properties of the subsurface layers (Olorunfemi et. al., 2002). The aim of this work is to examine the cause of abandonment of a Complex in the University of Nigeria, Nsukka Campus using electrical resistivity technique (ERT and VES). The objectives are; to identify the type of structural defects responsible for the abandonment, to obtain the subsurface apparent resistivity and some geo-hydraulic of the soil around the complex, and to propose methods of maintenance to prevent similar foundation failure in the future. Electrical resistivity technique is very efficient and applicable in various contexts such as groundwater exploration, engineering site investigations, determination of compaction and soil horizon thickness, archaeological prospecting, assessment of soil hydrological properties and foundation stability assessment (Aizebeokhai, et. al, 2017; Aizebeokhai & Oyeyemi, 2014; Aizebeokhai, et. al, 2016; and Aizebeokhai, et.al, 2015). This technique is particularly applicable to engineering site investigations because it measures apparent electrical resistivity within the subsurface which is a function of several factors such as grain sizes distribution, mineralogy, soil porosity and permeability, degree of water saturation, electrical resistivity of the interstitial fluid (Ayolabi et al., 2013; Oladunjoye et al., 2017 and Adewoyin et al., 2019). In addition, electrical resistivity technique, as a non-destructive method for subsurface characterizations, gives spatial and temporal variations of many physical properties of the subsoil such as soil structure and stratification, and fluid composition or water content without digging (Olorunfemi et. al., 2002).

## Location and Geology of the Study Area

This study was carried out within the University of Nigeria, Nsukka Campus, Enugu State, which lies within latitude $6°\,51'\,37.4''$ N to $6°\,51'\,48.0''$ N and longitude $7°\,25'\,01.0''$ E to $7°\,25'\,37.6''$ E. Geologically, Ajali and Nsukka Formations are the two geologic formations in the study area (Fig 1.1) and lies within the Benue Trough whose rocks are upper cretaceous in age. The Ajali Formation is underlain by shaley impermeable units of Mamu Formation that trapped the Ajali aquifers. According to Agagu et al. (1985), the Ajali Sandstone (upper Maastrichtian) is about 451 m thick. Lithologically, Ajali formation has poorly consolidated sandstone typically cross-bedded with minor clay layers (Reyment 1965). Nsukka Formation (upper coal measures) conformably overlies the Ajali Sandstone Formation. The lithology of Nsukka is mainly sandstones intercalating with clay, interbedded shales, siltstones, sands and thin coal seams (Reyment 1965), but have become lateritised in many places where they characteristically form resistant capping on mesas and buttes. Nsukka Formation is described as cap rock previously known as upper coal measures (Simpson 1954; Reyment 1965). Nsukka Formation is physiographically dotted by numerous cone-shaped hills which are separated by low lands and broad valleys and are laterite capped (Ogbukagu 1976). Nsukka Formation with oImo Shale marks the onset of another transgression in Anambra Basin during the Palaeocene (Obaje 2009). The most prominent topographical features in the study area are the North–South trending cuesta over Ajali sandstone.

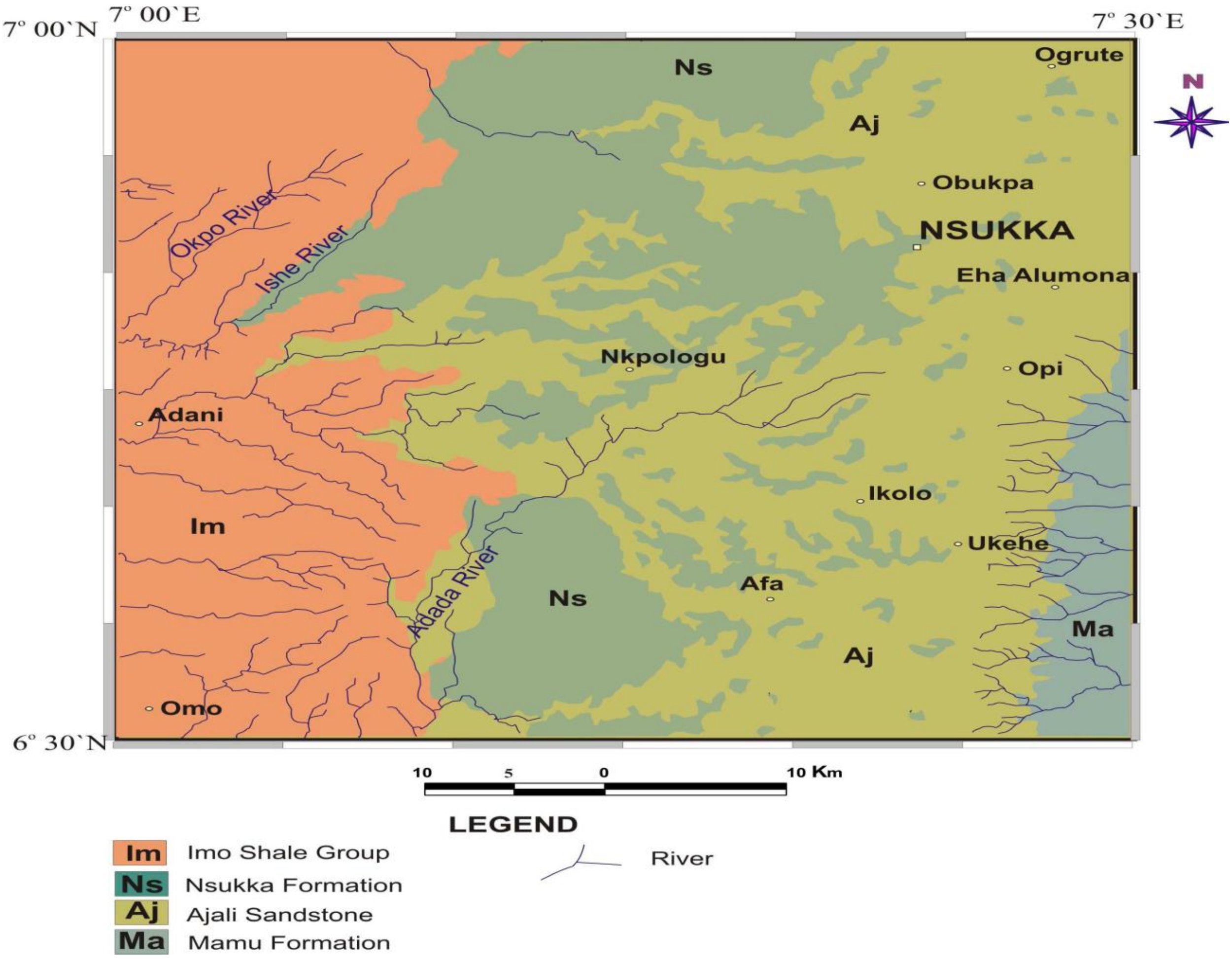


**Fig 1: The geology of the study area (Igwe, et. al, 2017)**

## II. METHOD OF DATA ANALYSIS

### Theory of Electrical Resistivity Method

Electrical resistivity tomography (ERT) is one of the most popular geophysical tools for near-surface characterization. This is perhaps based on its speed of data acquisition, cost effectiveness and proxy to the spatial and temporal variability of many other subsurface physio-chemical properties such as soil types, porosity, moisture content, clay content and mineralogy, soil water content, organic matter, and bulk density. Clay content for instance can affect the soil strength, porosity and ultimately the conductivity (or resistivity) of the soil matrix in various degrees (Neil and Ahmed, 2006). Generally, electrical resistivity tomography technique is non-destructive, minimally invasive and has been applied to various subsurface characterization problems involving groundwater exploration, engineering site investigations, landfill and solute transport delineation, determination of compaction and soil horizon thickness, archaeological prospecting, and assessment of both soil hydrological properties and foundation instability. The property that describes a material's ability to transmit electrical current that is independent of the geometrical factors is called resistivity. Consider a conducting cylinder of resistance dR, length dr. and cross-sectional area dA, the resistivity (ρ measured in ohm-meter (Ωm)) is given by:

$$\rho = \frac{\mathrm{dRdA}}{\mathrm{dr}}. \qquad 1$$

The reciprocal of resistivity is called conductivity. The unit is Seimens (1/Ωm). Rearranging equation 1, the resistance of a material can be written as:

$$\mathrm{dR} = \frac{\rho dr}{dA}\ . \qquad 2$$

If current (I) is passed through the cylindrical conductors, causing a potential drop (dV) between the ends of the element, then ohm's law which governs the flow of current in a conducting material relates the current (I), potential drop (dV) and resistance (R) mathematically by:

$$\mathrm{dV = RI.} \qquad 3$$

Arranging a pair of current electrodes and a pair of potential electrodes as shown in Figure 2, the potential (ΔV) at the centre will be the algebraic sum of the potentials due to current source electrode at point A and the current sink electrode at point B. This gives the summary equation of apparent resistivity.

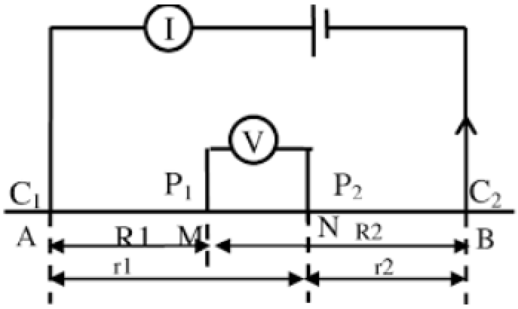


**Figure 2:** The generalized form of electrode configuration

$$\rho = \frac{2\pi\Delta v}{I} = \left\{\left[\frac{1}{r_A} - \frac{1}{r_A}\right] - \left[\frac{1}{R_A} - \frac{1}{R_B}\right]\right\}, \qquad 4$$

where $\frac{\Delta v}{I}$ is the resistance of the ground measured in ohms. When the ground is homogenous the resistivity calculated from equation 4 should be constant and independent of both electrode spacing and surface location. But when the surface inhomogeneity exits, the resistivity will vary with the relative positions of the electrodes. Once this variation is noticed, any computed resistivity value is known as apparent resistivity (Keary and Brooks, 1991).

**Electrode configuration**

The value of the apparent resistivity depends on the geometry of electrodes array used in inhomogeneous earth. The choice of the array for a field survey depends on the type of structure to be mapped, the sensitivity of the meter and the background noise level (Loke, 1997 & 2000). The most commonly used configurations are the Werner, Schlumberger, and Double dipole arrays. Among the characteristics of an array that should be considered are: the depth of investigation, sensitivity of the array to vertical and horizontal changes in the subsurface resistivity, horizontal data coverage and speed in field operations and convenience.

**Werner Electrode Configuration**

The current and potential electrode pairs have a common midpoint and the distance between adjacent electrodes are equal. The four electrodes are equally space and the whole set-up is moved to successive sounding points. Werner array is very useful in studying the lateral variation in subsurface strata since information is coming from a particular layer. The geometric factor G for Werner is:

$$\mathbf{G=2\pi a,} \qquad \mathbf{5}$$

and the apparent resistivity is given by

$$\boldsymbol{\rho_a = 2\pi \frac{\Delta v}{I} a,} \qquad \mathbf{6}$$

where 'a', is the electrode spacing, $\frac{\Delta v}{I} = R\ (Ohms)$ is the field resistance.

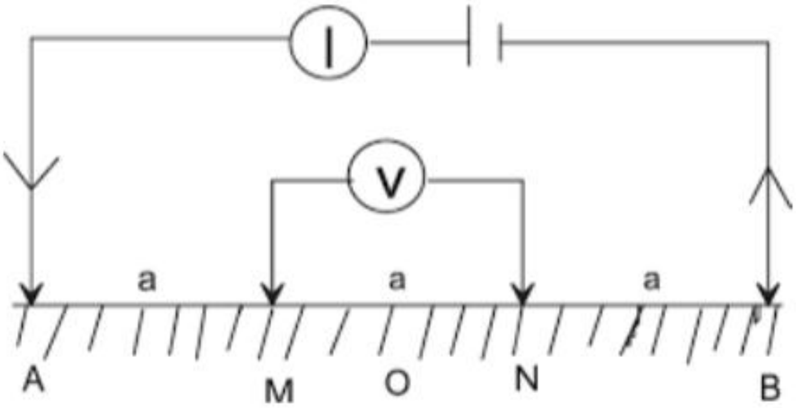


**Figure 3:** Werner electrode configuration

**Schlumberger Electrode Configuration:**
In this configuration, the current and potential pairs of electrode have a common mid-point, but the distances between adjacent electrodes differ. The Schlumberger array is often used to determine the depth from top to bottom and thickness of layers as well as resistivity values (Evans, 2006). The apparent resistivity, $\boldsymbol{\rho_a}$ for this configuration is given by:

$$\boldsymbol{\rho_a = \pi \left[\frac{\frac{(AB)^2}{2} - \frac{(MN)^2}{2}}{MN}\right] R_a}. \qquad \mathbf{7}$$

The equation can be simplified to

$$\rho_a = ZR_a, \qquad 8$$

where Z is the geometric factor: $\boldsymbol{\pi \left[\frac{\frac{(AB)^2}{2} - \frac{(MN)^2}{2}}{MN}\right]}, \boldsymbol{R_a}$ is the apparent resistance, AB is the distance between the two current electrodes and MN is the distance between potential electrodes.

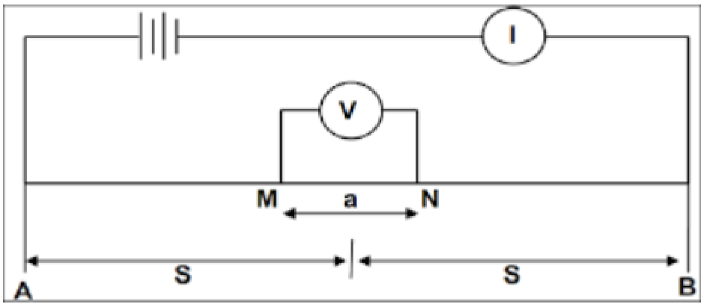


**Figure 4:** Schlumberger electrode configuration

**Resistivity Survey instrument and procedure**
Resistivity Meter (Model SSR-MP-ATS), Two current transmission cables, Two potential transmission cables, Five metal electrodes, Global positioning system (GPS), Five Hammers, Two calibrated tapes, Three batteries, Cutlass, Pen and paper.

The resistivity meter when properly connected through the connecting cables to the current and potential electrode firmly earthed, injects current into the ground and also receives the signal sent back from the ground.

**Survey Procedure**

One (1) data point was acquired with a maximum electrode spacing of 800 m and maximum potential electrode spacing of 40 m for the VES data while 3 data points were acquired for each ERT data with a 4 m interval and 200 m spread. A pair of current electrodes and a pair of potential electrode were connected to the resistivity meter with the aid of connecting cables. The current and potential electrodes were driven into the ground with the aid of the hammers to about a two-third length of the electrode in order to make good electrical contact with the earth. The resistivity meter was connected to the ground through the connecting cable and the electrodes. The current electrodes spacing in straight part was gradually increased and measured up to 400 m half electrode spacing using measuring tape. At each spacing, the current was driven into the ground through the current electrode and the potential difference determined by resistivity meter through the potential electrode.

**Data Processing**

The VES data was processed with the aid of Winresist software. The data was read into the software which plotted a log-log graph of apparent resistivity $(\rho_a)$against half electrode spacing $\left(\frac{AB}{2}\right)$. The results showed the resistivity, depth and thickness of each layer. The ERT was processed using Res2dinv which showed 2D model of the subsurface. The model showed the calculated, measured and the inverted resistivity of the study area with depth.

**Geohydraulic Parameters**
These are essential elements in groundwater resource management and conservation. Most of these parameters especially the hydraulic conductivity and transmissivity are usually indicative of subsurface ability to hold or transmit fluid.

**Hydraulic conductivity (K)**

According to Heigold et al. (1979), the hydraulic conductivity (K) values was estimated using equation 9;

$K=386.40\rho_a{}^{-0.93283}$, **9**

where K is the hydraulic conductivity and $\rho_a$ is the layer resistivity.

**Porosity (Φ)**

It is a measure of the fraction of the volume of void spaces in soil or rock over the total volume. As a fractional porosity it is always expressed between 0 and 1 or a percentage between 0 % and 100 % and can be estimated by equation 10;

$\Phi = 25.5 + 4.5 \text{In } K$ , **10**

where K is the hydraulic conductivity and Φ is the porosity.

**Transmissivity (Tr)**

Transmissivity is the rate at which water passes through a unit width of the aquifer under a unit hydraulic gradient. It is also the rate at which groundwater flows horizontally through an aquifer. Transmissivity provides a general idea of the water- producing capabilities of aquifer. An increase Transmissivity implies an aquifer with enough sustainable water. Transmissivity values were estimated following Todd et al. (1980);

$Tr = Kh$ , 11

where K **i**s the hydraulic conductivity and h is aquifer thickness.

## III. Results and Discussion

### Results

The data was interpreted qualitatively and quantitatively. Qualitative interpretation was done by inspecting the maps and graphs generated by the software. The layer resistivity, depth and thickness of the VES points were observed and recorded from the graph while the ERT showed color aggregate corresponding to the resistivity of the area.

The vertical electrical sounding was interpreted using Winresist software while the ERT data was interpreted using the Res2dinx software. The qualitative interpretations of Electrical Resistivity Tomography data are presented in Tables 1, 2 and 3 which give a detailed result of their resistivity, depth, hydraulic conductivity, transmissivity and porosity, while Table 4 shows the interpretation of the results of the vertical electrical sounding resistivity, depth, hydraulic conductivity, transmissivity and porosity of five layers observed in the study area.

**TABLE 1: Estimated subsurface parameters for ERT 1**

| INDICATORS | Resistivity $\rho_a$ (Ωm) | Depth h (m) | Hydraulic conductivity K (m/day) | Transmissivity ($m^2$/day) | Porosity Φ (%) |
|---|---|---|---|---|---|
| A | 3.31 | 10.70 | 42.3455 | 453.0969 | 42.3564 |
| B | 5507.00 | 10.20 | 44.2786 | 451.6417 | 42.5573 |
| C | 135.00 | 3.40 | 123.3852 | 419.5097 | 47.1689 |
| D | 1600.00 | 5.29 | 81.6926 | 432.1539 | 45.3133 |
| E | 1500.00 | 4.41 | 0.4210 | 1.8568 | 21.6069 |

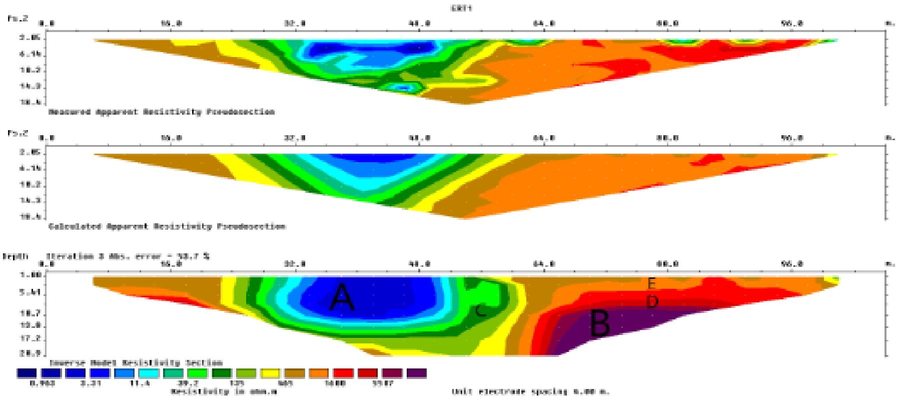


Fig 5: 2D resistivity model of ERT 1

**TABLE 2: Estimated subsurface parameters for ERT 2**

| INDICATORS | Resistivity $\rho_a$ (Ωm) | Depth h (m) | Hydraulic Conductivity K (m/day) | Transmissivity $T_r$ ($m^2$/day) | Pororsity Φ (%) |
|---|---|---|---|---|---|
| B | 1030.00 | 9.70 | 0.5979 | 5.7993 | 23.1855 |
| D | 10607.00 | 10.20 | 0.0679 | 0.6926 | 13.3962 |
| A | 339.00 | 12.20 | 1.6858 | 20.5668 | 36.7565 |
| E | 3667.00 | 13.49 | 0.1829 | 2.4673 | 37.2088 |
| C | 1069.00 | 15.49 | 0.5775 | 8.9455 | 23.0293 |

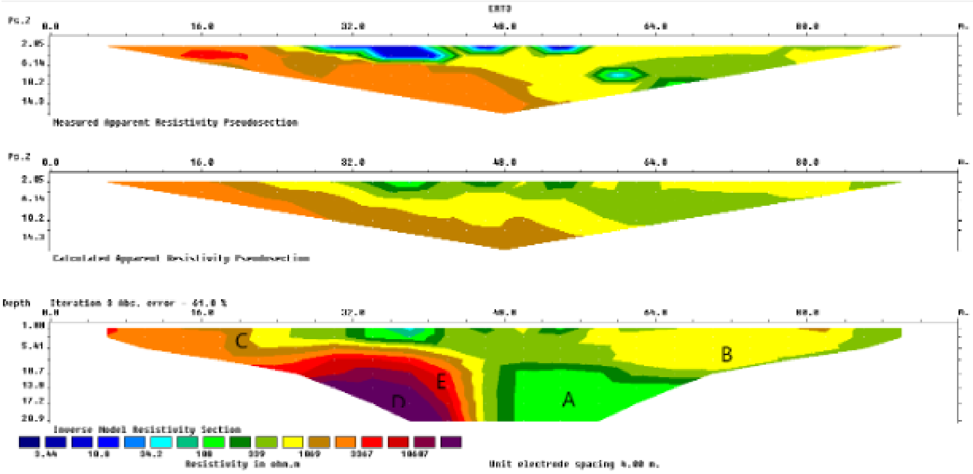


**Fig 6: 2D resistivity model of ERT 2**

**TABL 3: Estimated subsurface parameters for ERT 3**

| INDICATORS | Resistivity (Ωm) | Depth h (m) | Hydraulic conductivity K (m/day) | Transmissivity $T_r$ ($m^2$/day) | Porosity Φ (%) |
|---|---|---|---|---|---|
| A | 193.00 | 5.41 | 2.8512 | 1044.13 | 30.2148 |
| B | 520.00 | 7.41 | 1.1311 | 3853.20 | 34.5127 |
| C | 533.00 | 2.00 | 1.1053 | 1066.00 | 25.9505 |
| D | 4600.00 | 13.49 | 0.1480 | 62054.00 | 37.2088 |
| E | 1471.00 | 6.41 | 0.4288 | 9429.11 | 33.8604 |

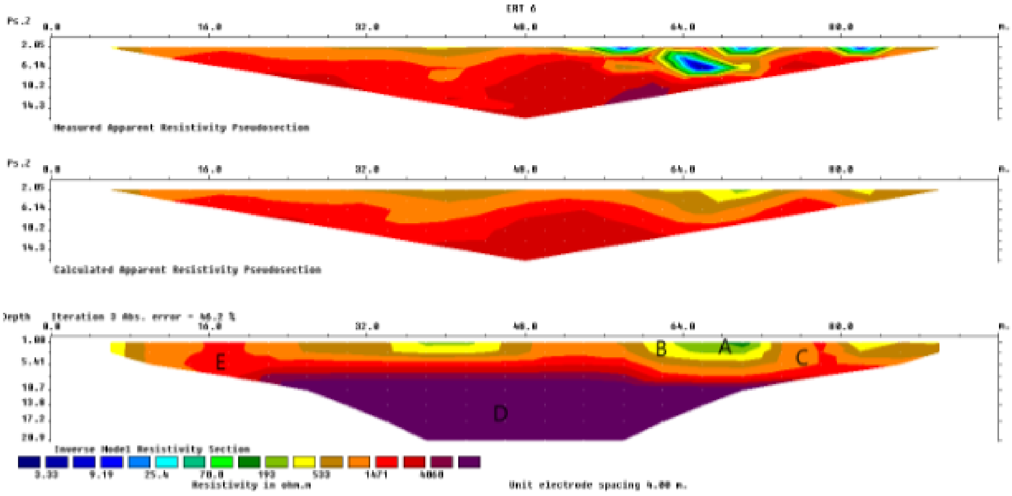
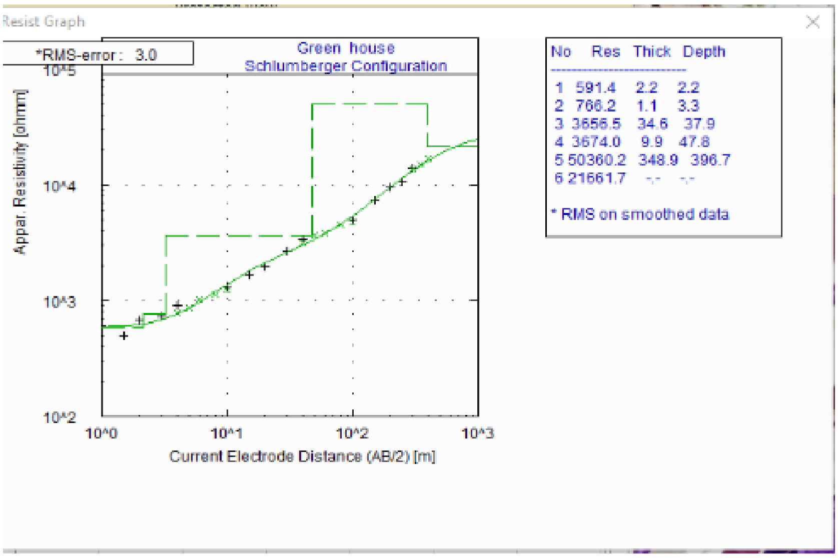


**Fig 7: 2D resistivity model of ERT 3**

TABLE 4: Estimated subsurface parameters for VES

| Layers | Resistivity $\rho_a$ ($\Omega$m) | Depth h (m) | Hydraulic conductivity K (m/day) | Transmissivity $T_r$ (m$^2$/day) | Porosity $\Phi$ (%) |
|---|---|---|---|---|---|
| 1 | 591.40 | 2.20 | 1.0032 | 2.2070 | 25.5144 |
| 2 | 766.20 | 1.10 | 0.7879 | 0.8667 | 24.4273 |
| 3 | 3656.50 | 34.60 | 0.1834 | 6.3456 | 41.4473 |
| 4 | 3574.00 | 9.90 | 0.1873 | 1.8543 | 35.8164 |
| 5 | 50360.20 | 348.90 | 0.0159 | 0.0555 | 31.5652 |
| 6 | 21661.70 | ∞ | | | |



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No   Res     Thick  Depth
---------------------------
1  591.4     2.2    2.2
2  766.2     1.1    3.3
3  3656.5    34.6   37.9
4  3674.0    9.9    47.8
5 50360.2   348.9  396.7
6 21661.7    -.-    -.-

* RMS on smoothed data
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**Fig 8: Resistivity Model of VES**

# IV. DISCUSSIONS

## RESISTIVITY

The resistivity values (Table 1 and Figure 5) ranges from 3.31 Ωm to 5507 Ωm for ERT 1. The region A (Blue area) has a resistivity value of 3.31 Ωm which shows that the area is highly conductive. The area levelled B (Purple) has a resistivity value of 5507 Ωm which shows that the area has a very low conductivity. The Green area labelled C has a resistivity value of 135 Ωm which shows also that it is conductive. The area labelled D (red) has a resistivity value of 1600 Ωm which shows that the area has low-to-moderate conductivity. The region E (orange) has a resistivity value of 1500 Ωm which shows that the area has low-to-moderate conductivity. The resistivity values for ERT 2 (Table 2 and Figure 6) ranges from 3.44 Ωm to10607 Ωm. The region A (Green area) has a resistivity value of 1030 Ωm which shows that the area is conductive. The area labelled B (yellow) has a resistivity value of 10607 Ωm which shows that area has a very low conductivity. The area labelled C (orange) has a resistivity value of 339 Ωm which shows that the conductivity of the area is high. The area labelled D (purple) has a resistivity value of 3667 Ωm which shows that the area has low conductivity. The area labelled E (Red) has a resistivity value of 1069 Ωm which shows that the area has high conductivity. The resistivity values for ERT 3 (Table 3 and Figure 7) ranges from 3.33 Ωm to 4660 Ωm**.** The region A (Green area) has a resistivity value of 193 Ωm which shows that the area is conductive. The area labelled B (Yellow) has a resistivity value of 520 Ωm which shows that area is conductive. The area labelled C (Orange) has a resistivity value of 533 Ωm which shows that the area is conductive. The area labelled D (Purple) has a resistivity value of 4600 Ωm which shows that the area has low conductivity. The area labelled E (Red) has a resistivity value of 1471 Ωm which shows that the area has low conductivity. Generally, the study area is heterogeneous and unstable with regards to conductivity (resistivity) of the subsurface material. The top-layer, although heterogeneous, is very conductive up to the depth of about 10 to 20 m in most places. This makes the top-soil unsuitable for engineering work especially large complex siting.

## Geo-Hydraulic Results

The subsurface around the building has geomaterials like sandstone, siltstone and claystone labeled A, B, C and D while the portion labeled E has sandstone and siltstone respectively for ERT 1. The subsurface around the building has shale, sandstone and siltstone at the portion labeled B. The portion labeled D has shalely-limestone material. The portion labeled A has gravel, siltstone, sandstone, limestone. The portion labeled has gravel, dolomite, siltstone, sandstone and limestone for ERT 2 while ERT 3 results show that portion labeled A has shale, sandstone, siltstone and limestone and dolomite. The portion labeled B has shale, sandstone, siltstone, limestone and dolomite. Portion C has shale, sandstone, siltstone, dolomite and limestone. D has shale, sandstone, siltstone, dolomite and limestone and E has shale, sandstone, siltstone, dolomite, clay-stone and limestone. Most of the geomaterials found in the area are suitable for building/construction purposes, but the impact of the heterogeneity of the area supersedes the engineering strength of the individual materials.

The analysis of the VES data points (Table 4), showed that layer 1 has shale, sandstone, limestone, siltstone and limestone. Layer 2 has shale, sandstone, dolomite, siltstone, and limestone. Layer 3 has shale, sandstone, dolomite, siltstone and claystone. Layer 4 has sandstone, siltstone, clay stone, shale and limestone. Layer 5 has sandstone, siltstone, limestone and dolomite. These geomaterials are in such a heterogeneous mixture that their engineering properties are not suitable for such a structure (the complex). Also, the presence of faults running through the site is another major factor that affected the structure.

## V. Conclusion

This field work was conducted to examine the cause of abandonment of a Complex in the University of Nigeria, Nsukka and also to identify the type of structural defects responsible for the abandonment.

The purpose of this work was achieved, fault zone was observed within a depth range of 15 m to 25 m. Geologically, the areas with a conductive layer or fault zone have earth materials with low or poor engineering strength that could lead to collapse of building either by sinking or by fall and this is the case of the site we studied. We suggest that further work should be done using soil sampling technique (Geotechnical study) to a depth of between 15 m to 25 m in the study area especially at those areas with high conductivity. We recommend that the building be pulled down to avert further damages.

## REFERENCES

[1]. Adeoti, L., Ojo, A.O., Adegbola, R.B. and Fasakin, O.O. (2016). Geoelectric assessment as an aid to geotechnical investigation at a proposed residential development site in Ilibirin, Lagos, Southwestern Nigeria. Arabian Journal of Geosciences 9(5), 1-10

[2]. Adesunloye, M.O. (1987). Investigating the problem soil in Nigeria. Proceeding of the 9th regional conferences for Africa on soil mechanics and foundation engineering, Lagos.103-112.

[3]. Adewoyin, O. O., Joshua, E. O., Akinyemi, M. L., Omeje, M., & Akinwumi, S. (2019). Predicting dynamic geotechnical parameters in near-surface coastal environment. Cogent Engineering, 6, 1588081.

[4]. Agagu, O.A. (1985). A Geologic Evident Bituminous Sediment in Southwestern Nigeria, Dept. of Geology, University of Ibadan pp. 2 - 16.

[5]. Aizebeokhai, A. P., & Oyeyemi, K. D. (2014). The use of the multiple-gradient array for geoelectrical resistivity and induced polarization imaging. Journal of Applied Geophysics, 111, 364 –376. doi:10.1016/j. jappgeo.2014.10.023

[6]. Aizebeokhai, A. P., Ogungbade, O., & Oyeyemi, K. D. (2017). Integrating VES and 2D ERT for near-surface characterization in a crystalline basement terrain (pp. 5401–5406). SEG Technical Program Expanded Abstracts. Society of Exploration Geophysics (SEG) International Exposition and 87th Annual Meeting, 2017, Houston, Texas.

[7]. Aizebeokhai, A. P., Oyeyemi, K. D., & Kayode, O. T. (2015). Assessment of soil petrophysical parameters using electrical resistivity tomography (ERT) and induced polarization techniques. Research Journal of Applied Sciences, 10(9), 479–485.

[8]. Aizebeokhai, A.P., Oyeyemi, K.D., & Joel, E.S. (2016). Groundwater potential assessment in a sedimentary terrain, southwestern Nigeria. Arabian Journal of Geoscience, 9(7), 496–513. doi:10.1007/s12517-0162524-5.

[9]. Akintorinwa, O.J. and Adesoji, J. I. (2009). Application of Geophysical and Geotechnical Investigations in Engineering Site Evaluation, International Journal of Physical Sciences, Vol. 4 (8), pp 443-454

[10]. Akpabot, A. I., Ede, A. N., Olofinnade, O. M., & Bamigboye, G. O. (2019). Risks of seismic activities on built environment in Nigeria. International Journal of Environment and Sustainable Development, 18(3), 259–269. doi:10.1504/IJESD.2019.10022557

[11]. Ayolabi E.A., Enoh I.E., and Folorunsho A.F. (2013). Engineering Site Characterization Using 2-D and 3-D Electrical Resistivity Tomography. Earth Science Research 2(1) 133-142

[12]. Ede, A. N., Olofinnade, O. M., Bamigboye, G. O., Shittu, K. K., &Ugwu, E. I. (2017). Prediction of fresh and hardened properties of normal concrete via choice of aggregate sizes, concrete mix-ratios and cement. International Journal of Civil Engineering and Technology, 8(10), 288–301.

[13]. Evan, M. (2006). Groundwater Quality Regulation in Vermont: A Path Forward, 8 Vt. J . Envtl. L.1

[14]. Fouzan Al Fouzan and Muawia A Dafalla (2013). Predicting reliable soil profile using Electrical resistivity survey, Geotechnical and Geophysical Site Characterization: Proceeding of the 4th International Conference on Site Characterization, ISC-4 1, 971-976

[15]. Heigold, P.C., Gilkeson, R.H., Cartwright, K., and Reed, P.C. (1979). Aquifer Transmissivity from Surficial Electrical Methods, Groundwater, 17(4), p. 338 - 345. https://doi.org/10.1111/j.1745-6584.1979.tb03326.x

[16]. Igwe, Emmanuel Awucha, Yakubu, John Akor and Idike Julius Igboji (2018) Investigation of Nsukka Area, South-Eastern Nigeria for Mineral Exploration Using Gravity Method, Journal of Applied Physics (IOSR-JAP) e-ISSN: 2278-4861.Volume 10, Issue 2 Ver. I (Mar.– Apr. 2018), PP 22-32 www.iosrjournals.org

[17]. Keary, P and Brooks M (1991). An Introduction to Geophysical Exploration – 254 S. Blackwell, Oxford.

[18]. Keller GV, Frischknecht FC (1966): Electrical methods in geophysical prospecting. Pergamon Press, Oxford.

[19]. Klimis, N. S.; Papazachos, C.B. and Effremidis, C.F. (1999). Determination of the Behaviour of a Sedimentary Rock Mass: Comparison of Measured Static and the dynamic Properties. Proceeding of 9 International Conference on Rock Mechanics (Paris, France), .1-2.

[20]. Loke, M.H. (1997). Electrical imaging surveys for environmental and engineering studies: a practical guide to 2D and 3D surveys: Unpublished short training course lecture notes, University of Sains Malaysia, Penang, Malaysia.

[21]. Loke, M.H. (2000), Electric Imaging Surveys for Environmental and Engineering Studies— A Practical Guide for 2-D and 3-D Surveys, ABEM Instrument AB, Sunbyberg, Sweden.

[22]. Meyerhof, G.G. (1956). "The Ultimate Bearing Capacity of Foundations", Géotechnique, Vol. 2, 301-332.

[23]. Neil, A. and Ahmed, I. (2006). A generalized protocol for selecting appropriate geophysical techniques. In Workshop on Application of Geophysics. Department of Geology and Geophysics, University of Missouri- Rolla, Rolla, Missouri, 65401.

[24]. Obaje, N.G. (2009). Geology and Mineral Resources of Nigeria (221 p). Berlin: Springer. https://doi.org/10.1007/978-3-540-92685-6

[25]. Ogbukagu, K.N. (1976). Soil Erosion in the Northern Area of Awka-Orlu Upland, Nigeria Journal of Mining and Geology, 16 - 19

[26]. Oladunjoye, M.A., Salami, A.J., Aizbeokhai, A.P., Sanuade, O.A. and Kaka, S.I. (2017). Preliminary Geotechnical Characterization of a site in Southwest Nigeria using integrated electrical and seismic Methods, Journal of the Geological Society of India 89(2), 209-215.

[27]. Olorunfemi M. O. & E. A. Mesida, (1987), "Engineering Geophysics and its application in Engineering Site Investigation- (case study from Ile-Ife area)", The Nigerian Engineer, 22(2): 57-66.

[28]. Olorunfemi, M. O.; A. I. Idoringie, A. T. Coker, and G. E. Babadiya. (2004a). The application of the electrical resistivity method in foundation failure investigation. Global Journal of Geological Sciences, 2: 39 - 51.

[29]. Olorunfemi, M.O., Ojo, J.S. and Ojelabi, E.A. (2002). Geophysical Site Investigation of the premises of Idu Flow Station. Nigerian Agip Company (NAOC) Limited. (For multipurpose Oil Services Company Limited, Port Harcourt). Technical Report.

[30]. Olorunfemi, M.O.; Idonigie, A.I.; Coker A.T. and Babadiya, G.E. (2004b). The Application of the Electrical Resistivity Method in Foundation Failure Investigation. A Case Study of O.A.U. Ile-Ife, Dental Clinic. Global Journal of Geophysical Science, 2(1), 139-151.

[31]. Othman, A. A. (2005). Constructed Geotechnical Characteristics of Foundation Beds by Seismic Measurements. Journal of Geophysics, England, l.2, 126-38.

[32]. Oyedele, K.F., Oladele S. and Adedoyin O. (2011). Application of Geophysical and Geotechnical Method to Site Characterization for Construction Purposes at Ikoyi, Lagos, Nigeria. Journal of Earth Sciences and Geotechnical Engineering Vol.1(1) 87-100

[33]. Ozegin, K.O., Oseghale, A., Okolie, E.C., and Ujuanbi, O. (2011). Integration of very low-frequency electromagnetic (VLF-EM) and electrical resistivity Methods in mapping subsurface geologic structures favourable to road failures, International Journal of Water Resources and Environmental Engineering, 3(6), 126-131

[34]. Reyment, R.A. (1965). Aspect of Geology of Nigeria. Ibadan Univ. Press.

[35]. Soupios, P.M.; Georgakopoulos, P.; Papadopoulos, N.; Saltas, V.; Andreadakis, A.; Vallianatos, F.; Sarris, A. and Makris, J.P. (2007). Use of Engineering Geophysics to Investigate a Site for a Building Foundation. Journal of Geophysics Engineering, l.4, 1.

[36]. Todd, D.K. (1980). Groundwater Hydrology, Wiley India (P) Ltd, New Delhi

[37]. Ubido, E.O., Igwe, O, Ukah, B.U., and Idris, I.G. (2017). The Implications of Subsoil Geology in Foundation Failure Using Geotechnical Methods: A Case Study of Lagos Southwestern Nigeria. International Journal of Advance Research and Publications; 1(5), 165-174.