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Integration of Geoelectrical and Geotechnical Data for Evaluation of the Structural Disposition of the Foundation Beds within the University of Port Harcourt, Nigeria

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ABSTRACT

An integrated geophysical and geotechnical investigation was carried out in and around the Abuja Campus (Abuja Park) of the University of Port Harcourt to evaluate the competence of the near surface formation for foundation of engineering structures with the aim of predicting remedial measures for possible failures of link roads and engineering structure foundation. The study was carried out in two phases. In the first, six vertical electrical soundings (VES) were carried out within the University using the Schlumberger electrode configuration and electrode spread of 400m to determine the resistivity variation with depth. The ABEM Terrameter 1000C with a 2000C booster for better penetration was used to acquire the field data which were processed and interpreted using a Computer Model Software (P12WIN) Version 3.0 (2003). Six soil samples were collected in the second phase at each sounding point to the depth of 1 to 3 meters into the earth. The soil samples were subjected to laboratory test and analysis for determination of basic geotechnical parameters of the soil samples. The VES results showed various geoelectric layers with varying resistivity and thickness. The average resistivity values of the top soil which form the foundation bed ranged from 2.792 Ωm to 1185.2Ωm. The thickness of the topsoil ranged from 2.71m to 6.92m. The soil compaction test revealed the dry density variation with moisture content with Maximum Dry Density (MDD) of 1912kgm^{-3} and Optimum Moisture Content (OMC) of 20% determined for the area. The results of this study show that the structural disposition or competence of the subsurface is quite good for engineering structure foundation in most areas of the University. Recommendation of remedial measures to forestall possible failures is made.

INTRODUCTION

The resistivity technique of geophysical exploration is based on the response of the earth to the flow of electric current introduced ~~into~~ in it. The determination of the resistivity values of different formations within the subsurface helps to determine the strength of the soil and its contents. Electrical resistivity varies with depth and compaction of the soil. Compaction of soil samples results from increase in weight of overburden and pressure. It leads to increase in density and affects electrical resistivity, reducing porosity, rate of water saturation and soil content.

There have been worrisome cases of collapsed buildings and road failures experienced in the sedimentary areas of Nigeria, with the attendant disastrous effects. It has also been observed that some of the link roads within and outside the University of Port Harcourt are periodically being rehabilitated due to failure and this no doubt involves huge financial costs.

Some cracks have been noticed in some of the engineering structures which could be due to weak foundation and/or use of materials of poor quality or inadequacy of construction materials (Okechukwu and Okugbue, 2011). Also, poor design and specification, road usage and poor drainage have been identified as contributing factors to highway failures (Emujakporue, 2012). The case of the building under construction near the University gate close to Delta Park now undergoing demolition is a warning signal that calls for investigation. It is, therefore, imperative to carry out proper geophysical and geotechnical investigations before construction work commences to avoid the huge financial costs of reconstruction of buildings and rehabilitation of failed roads.

Precise determination of engineering properties of soil is essential for proper design and successful construction of any structure (Fahad and Syed, 2012). Although stability of natural engineering structures such as buildings, roads, tunnels and bridges is the most vital aspect of geotechnical engineering, geoelectrical approach has become increasingly practiced in engineering site characterization because of its non-evasive, non-destructive and cost-effective application (Fahad and Syed, 2012). A combination of both methods, therefore, provides a very reliable approach in this study.

This study, therefore, intends to determine the Geotechnical and Geoelectrical parameters that can be used to evaluate the structural disposition or competence of the shallow section of the subsurface within the University which will guide construction purposes and build development plan. By integrating geoelectrical survey results with geotechnical parameters of the top soil, prediction of possible failure of link roads and engineering structure foundation within the study area and remedial measures against possible failure can be possible. This will provide the works unit and university management useful information for formulation of policies guiding the award of contracts for projects sited in the University.

Several literature materials are available in Geoelectrical and Geotechnical studies on road failures. Emujakporue used resistivity survey to assess the causes of Highway failures and identified the factors responsible for road failures in Nigeria to include poor construction materials, poor design and specification, road usage and poor drainage (Emujakporue, 2012). Ibeneme combined geoelectrical and geotechnical studies to evaluate the foundation beds at Naze in Owerri (Ibeneme et al., 2014). They observed 4 to 5 geoelectric layers with the topsoil having reasonable thickness and resistivity values for civil engineering structures to be founded. Ngah and Nwankwoala evaluated subsoil geotechnical properties for shallow foundation design in Onne, Rivers State Nigeria (Ngah and Nwankwoala, 2013). Adejumo also applied integrated geophysical and geotechnical technique for subsoil evaluation for pre-foundation study of proposed site of Vocational Skill and Entrepreneurship Centre at the Polytechnic Ibadan, Southwest Nigeria (Adejumo et al., 2015).

LOCATION AND GEOLOGICAL SETTING OF THE STUDY AREA.

The study area is the Abuja Park of the University of Port Harcourt adjacent to East-West express road in Choba Community of Rivers State, Nigeria (Fig.1). The geological setting of the area is shown in Figure 2. The underlying sediments form part of the stratigraphic sequence in the Niger Delta.

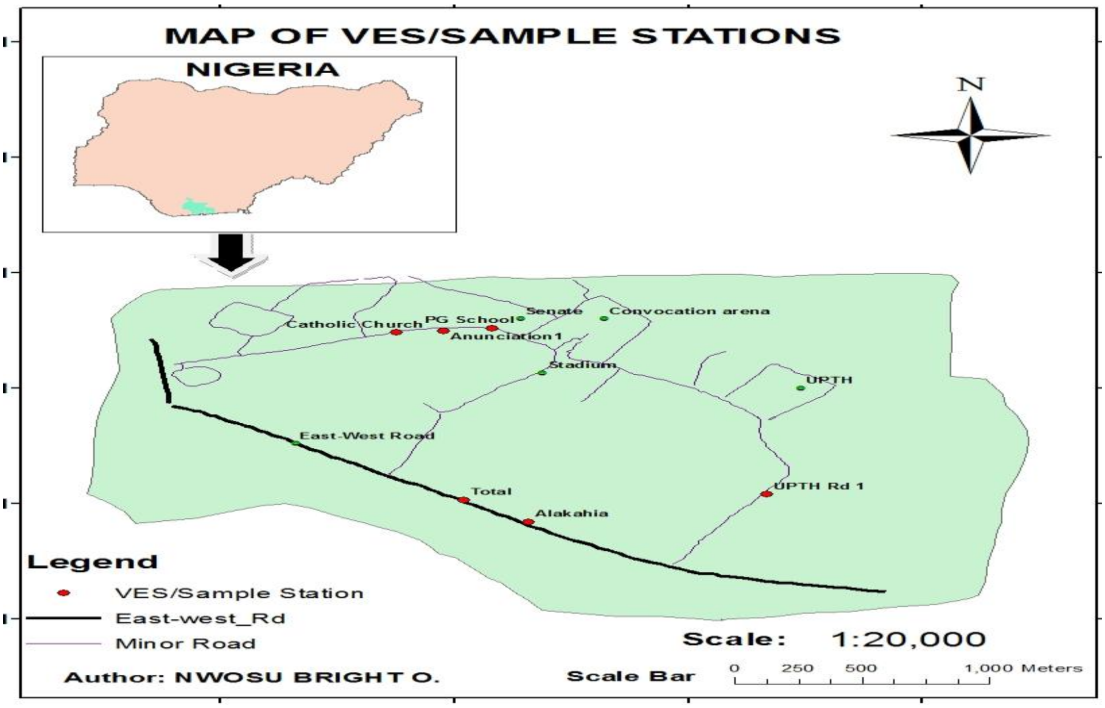


Fig. 1: Map of the Study area showing VES/Sample Stations

The study area is located in the Niger Delta Complex described by Ofodile as a sedimentary basin with complex regressive off lay sequence of clastic sediments ranging in thickness from 9000 – 12000meters (Ofodile, 1992). Three major stratigraphic units that make up the Niger Delta are the Benin Formation, the Agbada Formation and the Akata Formation.

The study area is underlain by the Benin Formation or Coastal Plain Sands laid down during the end of the Tertiary and early Quaternary period (Fig. 2). The formation consists of lenticular, unconsolidated coarse to medium fine sand/clayey shale (Nwankwo et al., 2013; Nwosu et al., 2013; Nwachukwu et al., 2013; Emujakporue, 2012). The formation is overlain by a considerable thickness of lateritic red earth formed by weathering and subsequent ferruginization of the weathered older sequences (Nwankwo et al., 2013).

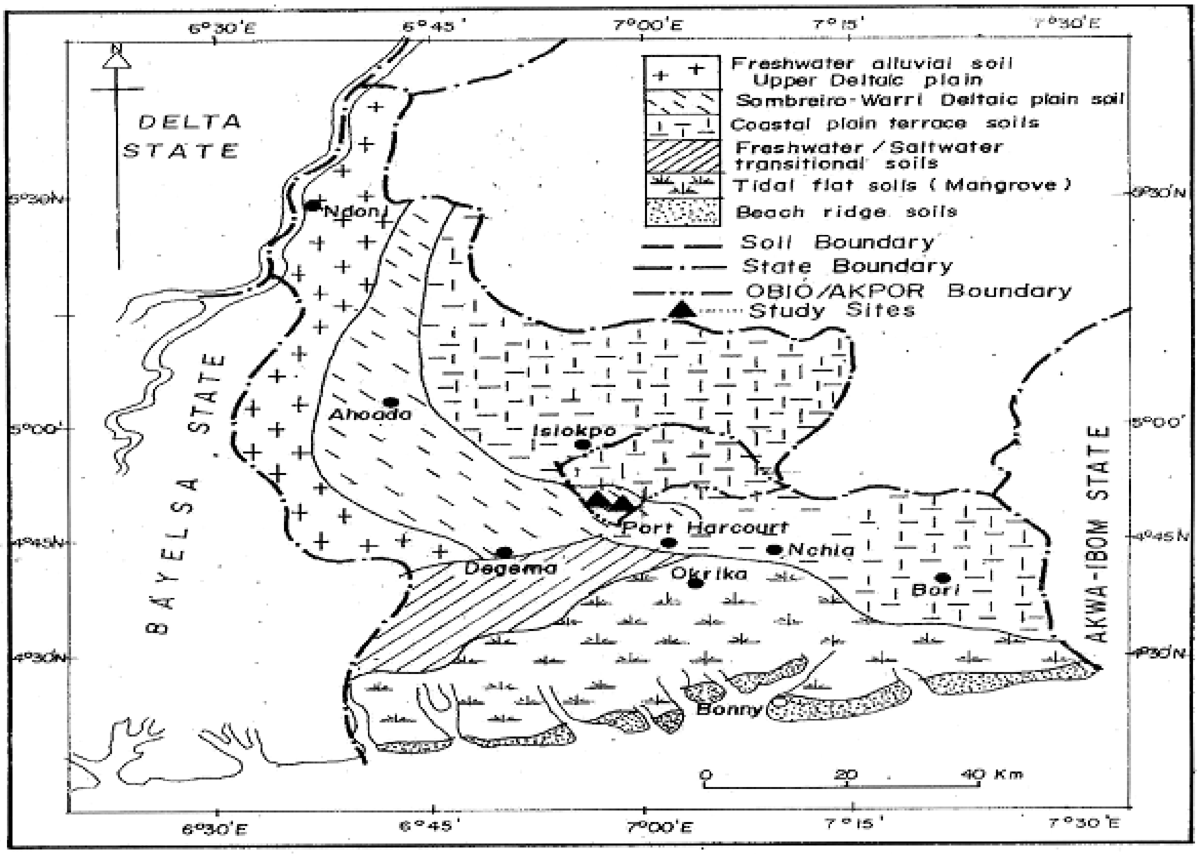


Figure 2: Geological Map of Niger Delta (Adapted from Ehirim et al., 2009).

METHOD OF STUDY

At each station for data acquisition, the elevation and coordinates were measured using the Global Positioning System (GPS) which enabled the development of the project map. A combination of geoelectrical and geotechnical methods was used. Six vertical electrical soundings (VES) were carried out in different locations along the link roads and engineering structures within and around the Abuja campus of the University including the University Teaching Hospital and Alakahia areas. The VES and soil sampling stations were located at the Stadium opposite the Powerhouse and adjacent to the Convocation arena; the area behind Volleyball and basketball pitch opposite United Bank for Africa (UBA); the area around the school of Graduate Studies and the Catholic Church; the area within the university of Port Harcourt Teaching Hospital (UPTH) Roads, Alakahia and the area between chapel of Annunciation and University gate opposite Delta Park, along the road experiencing failure and where one of the buildings under construction is being demolished, perhaps due to weak foundation resulting in crack.

Geoelectrical Method

The Schlumberger electrode array was adopted and the ABEM Terrameter 1000c aided with a 2000c booster for better penetration was used to measure the field data. A 12V DC supply was used with four stainless non-polarizable electrodes. Current electrode spread of 400m was used to determine the resistivity variation with depth.

The field data were subjected to quantitative interpretation first by computing the field resistance using equation 1

$$R = \frac{\Delta v}{I} \qquad 1$$

Where, Δv = potential difference

I = electric current

Details of field procedure and quantitative interpretation can be obtained in Dobrin and Savit (1988) and Telford et al. (1990). The current electrode spacing was increased symmetrically about the center while the potential electrodes were kept constant until it became necessary to increase it when the strength of the measured signal diminished.

The field data were then subjected to further quantitative interpretation by computing the apparent resistivity using equation 2.

$$\rho_a = KR \qquad 2$$

Where, K is the geometric factor defined by the expression in equation 3

$$K = \pi\left(\frac{(AB/2)^2 - (MN/2)^2}{MN}\right) \qquad 3$$

Where, AB/2 = Half current electrode spacing

MN/2 = Half potential electrode spacing

R = the field resistance

The apparent resistivity values were then plotted against half of the current electrode spacing AB/2 on a log – log graph. The sounding curves were then subjected to conventional partial curve matching to obtain the initial model parameters (resistivities and thicknesses) used for computer aided interpretation. This was accomplished using a computer model software (IPI2WIN) version 3.0 (2003). The model curves, true resistivities and depths were then obtained (Fig.3).

Geotechnical Method

Six borings were accomplished using a precursor rig with the aid of augers. The soil samples corresponding to the VES stations were taken to the laboratory for test in order to determine the soil characteristics. Compaction test parameters determined are shown in Table 2a and 2b. The boring was done by opening the surface of the earth with the auger by rotating in clockwise direction, the T-handle of the auger extension (Nwankwoala and Oborie, 2014). Additional extension was attached until the required depth up to 3m was probed. Samples were collected at intervals down the depth.

Laboratory tests carried out include moisture content which was achieved by oven drying of wet/moist soil samples for at least 12 hrs to a constant mass at temperature up to 110^{0}C and the difference in mass before and after drying recorded as the mass of water in the sample while the mass of the sample remaining was taken as the mass of the solid particles. The ratio of the mass of water to the mass of the solid gave the water content of the material (Nwankwoala and Oborie, 2014).

Some of the geotechnical parameters were computed using the following relations:

$$\text{Moisture content} \quad M = \frac{Ww}{Ws} \; x \; 100\% \qquad 4$$

$$\text{Bulk density} \quad Y = \frac{W}{V} \qquad 5$$

$$\text{Dry density} \quad Y_d = \frac{Ws}{V} \qquad 6$$

$$= \frac{Y}{1+M}$$

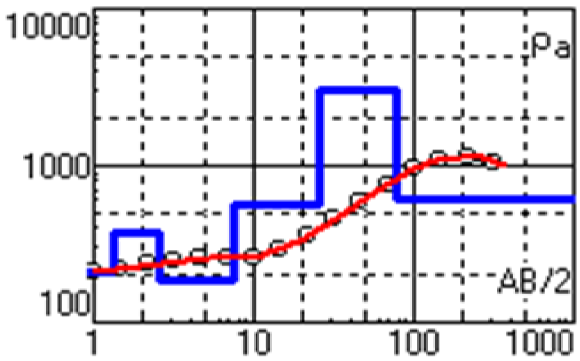
Where, w_w = weight of water

w_s = weight of solid

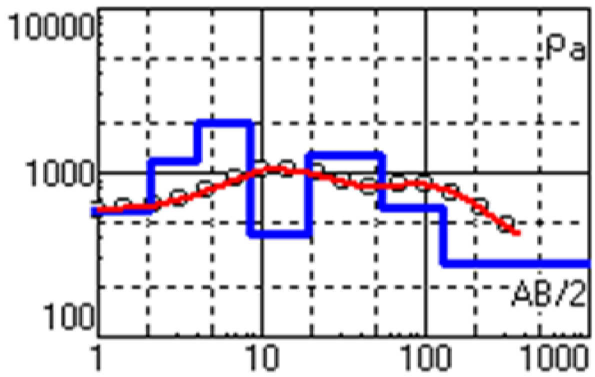
V = volume of solid

RESULTS AND DISCUSSION

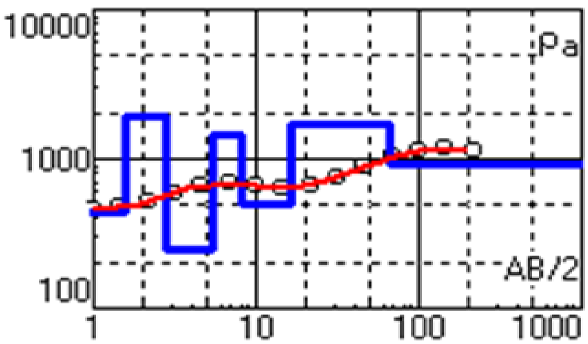
The curves of the VES modeling results are shown in Figure 3 for the 6 VES points while Table 1 is the summary of the modeling results. The VES results



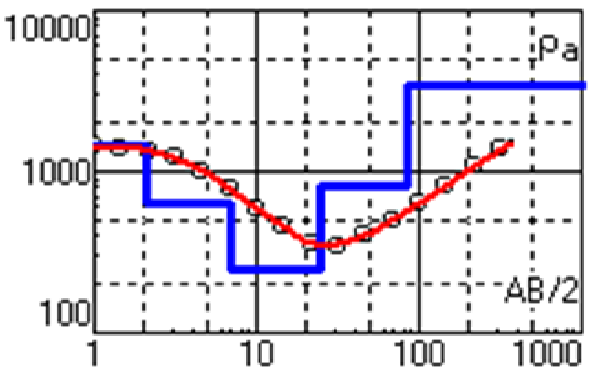
VES 1 Alakahia



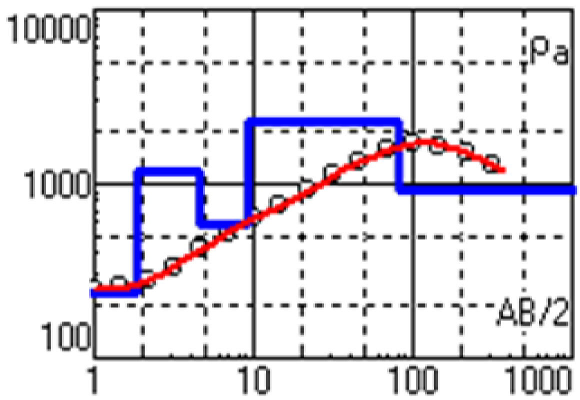
VES 2 Catholic Church premises



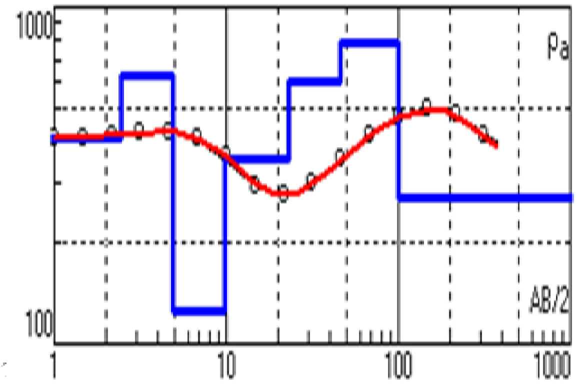
VES 3 Annunciation Church



VES 4 School of Graduate Studies



VES 5 Total Petrol Station



VES 6 UPTH Road 1

Figure 3: Figure showing 6 VES points

This revealed that the University Campus is underlain by multi geoelectric layers ranging from 5 to 7 layers with varying resistivity and thickness (Table 1). The resistivity value ranges from 125.1 Ωm recorded in the 3rd geoelectric layer around UPTH Road 1 (VES 6) to 3433.0 Ωm recorded in the 6th geoelectric layer around the School of Graduate Studies (VES 4). The average resistivity values of the top soil which form the foundation bed of the engineering structures and link roads are shown in Table 3. The resistivity values range from 279.2 Ωm observed at Alakahia (VES 1) to 1185.2 Ωm recorded at Annunciation Church (VES 3). Figure 4 shows the isoresistivity map of the overburden in the study area. The map shows the variation of resistivity of the top soil. More than half of the overburden in the study area has relatively high value of electrical resistivity indicating high degree of consolidation which is favorable for founding engineering structures.

The variation of electrical resistivity with moisture content of the top soil is shown in Fig.7. The amount of moisture present in the soil is the most important parameter in geotechnical evaluation of subsoil. Several studies including that of Fahad and Syed have shown that the moisture content is the most dominant factor that influences electrical resistivity of soil (Fahad and Syed, 2012). Relating moisture content to electrical resistivity of top soil (Table 3) in the study area gives a graph that shows inverse relationship between the parameters (Fig. 7).

Electrical conductivity occurs due to displacement of ions in the pore water. As moisture content increases adsorbed ions in the soil particles are released leading to increase in mobility of electrical charges. Electrical resistivity of soil, therefore, decreases with increase of moisture content. Increase in soil water content results in a decrease in electrical resistivity (Bhatt and John, 2014).

In the Isopach map of the study area (Fig. 5), the variation in thickness of the overburden is shown. The thickness ranges from 1.82m to 3.46m. Thus the top soil holds appreciable thickness to host foundation of engineering structures

Table 1: Summary of the Modeling results of VES

VES No	Resistivity of Layers (Ωm)							Thickness of layers (m)					
	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	ρ_7	h_1	h_2	h_3	h_4	h_5	h_6
1	209.6	372.8	185.3	562.3	3035.0	610.0	-	1.33	1.24	4.92	18.26	52.39	-
2	586.0	1179.0	3012.0	421.7	1280.0	610.5	279.5	2.09	1.95	4.44	11.20	34.29	24.03
3	439.4	1931.0	247.1	1448.0	497.1	1707.0	921.1	1.59	1.22	2.60	6.75	8.24	49.91
4	1448.0	636.2	744.1	247.1	814.2	3433.0	-	2.09	4.87	17.81	60.13	-	-
5	237.1	1179.0	586.0	2276.0	921.1	-	-	1.85	2.72	4.64	72.36	-	-
6	408.0	625.8	125.1	353.7	600.9	283.1	271.4	2.45	2.43	4.89	13.29	23.04	53.70

Table 2a: Water Content Determination

Sample No.	1		2		3		4		5		6	
Moisture can No.	M1	E1	M2	E2	M3	E3	M4	E4	M5	E5	M6	E6
Mass of cup+wet soil	28.60	32.90	30.00	34.50	41.70	42.40	35.30	41.90	94.80	40.70	34.30	36.30
Mass of wet soi	9.10	12.20	15.70	13.80	19.70	15.30	14.20	20.10	17.00	13.80	16.60	16.80
Mass of cup+dry soil	27.50	31.60	28.60	32.30	38.40	39.70	32.70	38.20	41.20	37.60	31.10	31.10
Mass of dry soil	8.00	10.90	14.30	11.60	16.40	12.60	12.60	16.40	15.80	14.60	13.40	13.50
Mass of cup	19.50	20.70	14.30	20.70	22.00	27.10	27.10	21.80	25.40	23.00	17.70	19.60
Mass of water	1.10	1.30	1.40	2.20	3.30	2.70	2.70	3.70	3.60	3.10	3.80	3.30
Water content w%	13.75	11.93	9.74	18.97	20.12	21.43	21.43	22.58	22.78	21.23	28.36	24.44

Table 2b: Density Determination

Test No	1	2	3	4	5	6
Water content W%	12.85	14.38	20.78	22.00	22.01	26.40
Mass of mold+ base plate (kg)	4.39	4.39	4.39	4.39	4.39	4.39
Mass of mold + base plate + wet soil (kg)	6.14	6.23	6.35	6.87	6.28	6.29
Mass of wet soil (kg)	1.75	1.85	1.96	1.98	1.89	1.90
Volume of mould (cm^3)	848.57	848.57	148.57	848.57	848.57	848.57
Wet density (kgm^3)	2062	2180	2310	2334	2337	2339
Moisture content from above	12.85	14.38	20.78	22.00	22.00	26.40
Dry density (kgm^3)	1828	1906	1912	1905	1826	1803

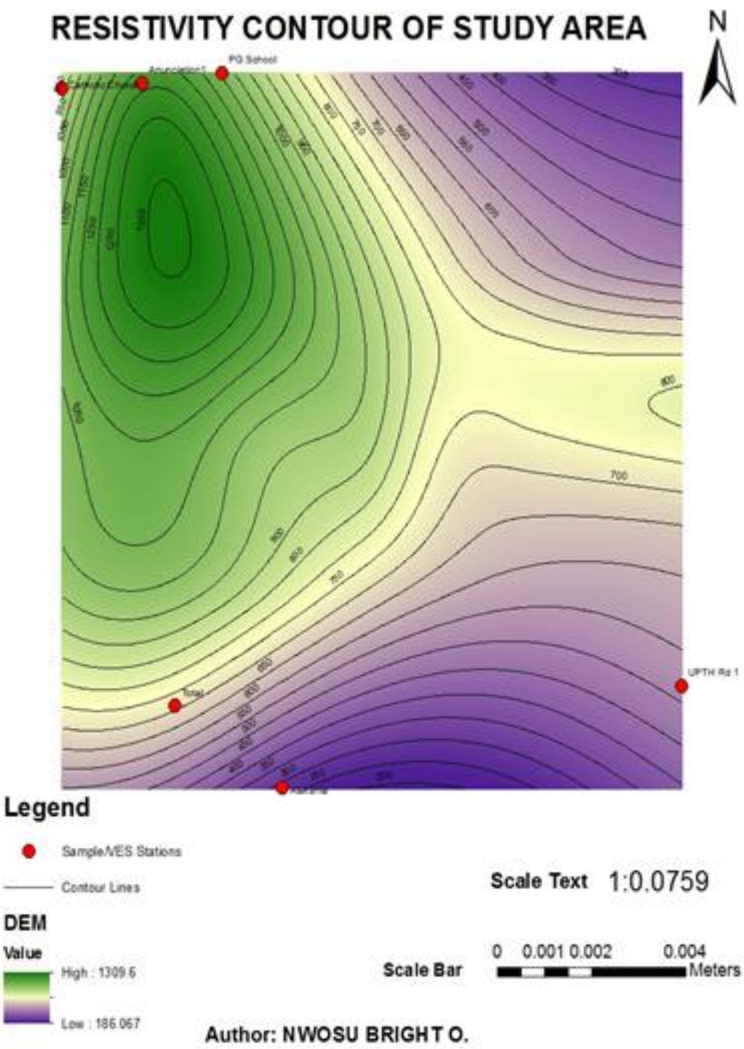


Figure 4: Top Soil Resistivity Contour Map of the study area.

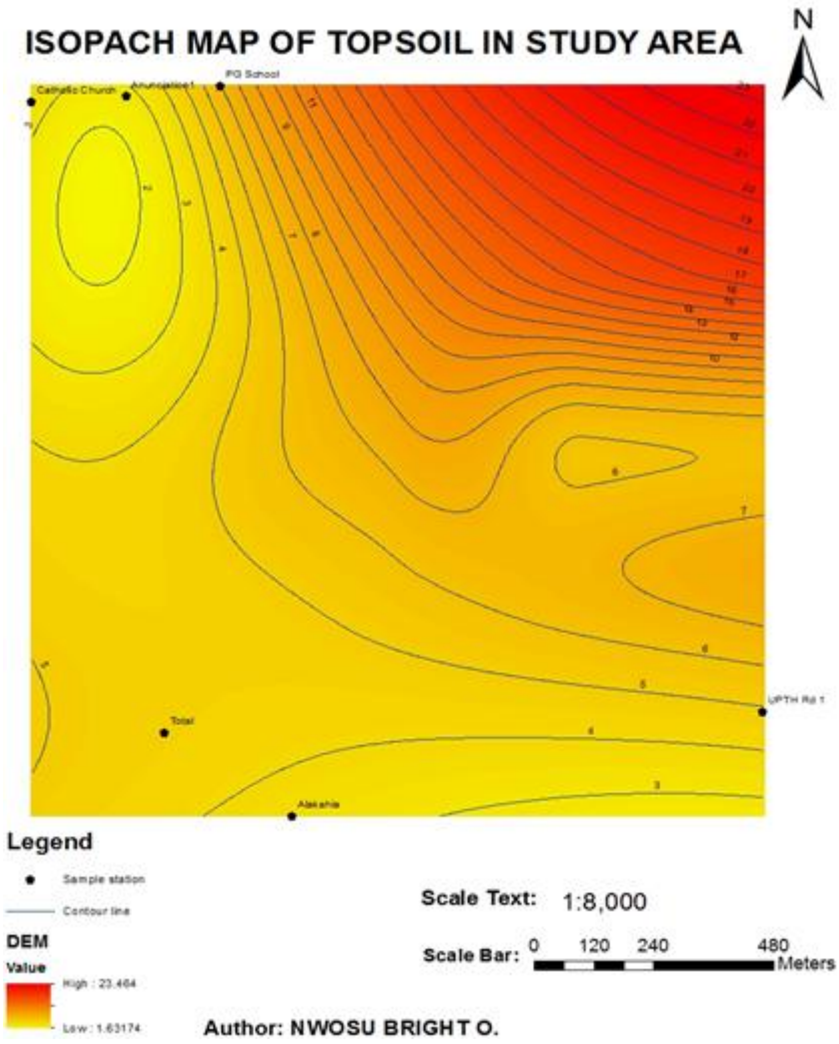


Fig 5: Isopach Map of the top Soil of the study area

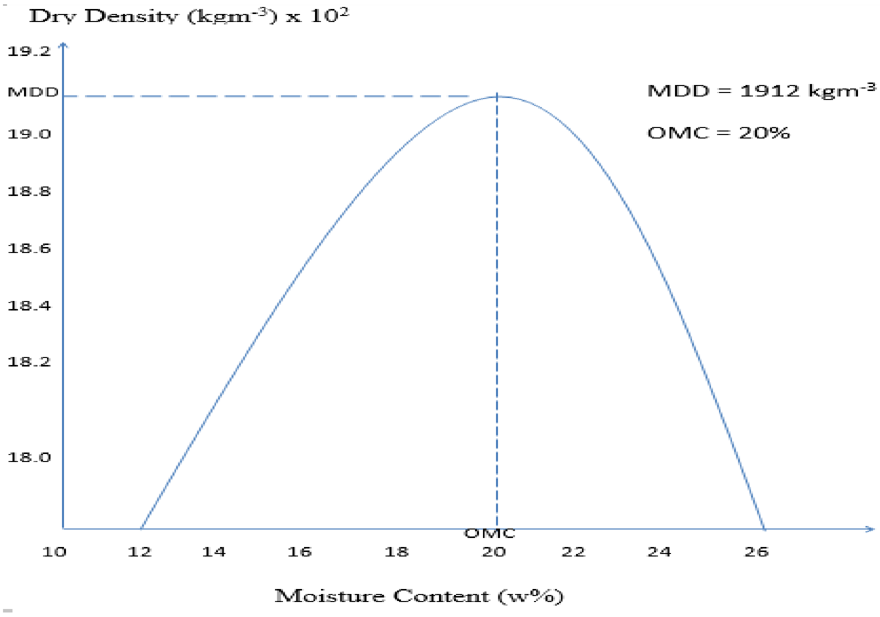


Fig. 6: Graph of dry density versus moisture content

The results of the laboratory test (compaction test) on soil samples show the relevant geotechnical parameters displayed in Tables 2a and 2b. Table 3 summarizes the parameters for integrating geoelectrical and geotechnical techniques in the study.

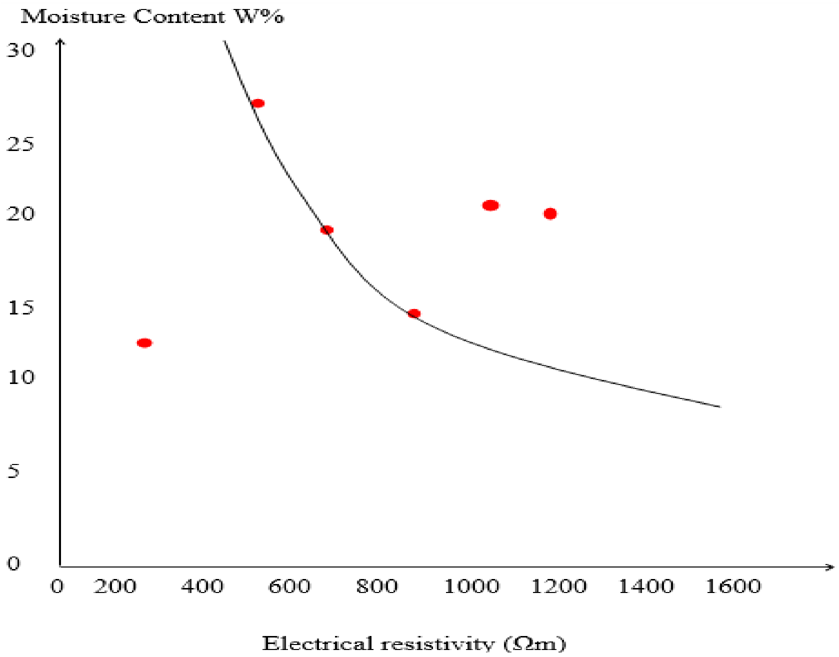


Fig. 7 Graph of moisture content versus electrical resistivity of top soil in the study area.

Table 3: Summary of Parameters for Integrating Geophysical and Geotechnical Techniques for the Study

VES No	Elevation (ft)	Thickness of Topsoil (m)	Average Resistivity of Topsoil Ωm	Moisture Content W%	Dry Density (kgm^{-3})
1	47	3.57	279.2	12.85	1828
2	47	3.54	882.5	14.38	1906
3	47	2.71	1185.2	20.78	1912
4	43	6.96	1042.1	22.00	1905
5	47	4.57	708.1	22.01	1826
6	47	4.88	516.9	26.40	1803

Integrating geoelectrical and geotechnical results of this study shows that resistivity and compaction of soil are related. Compaction of soil sample is a result of increase in weight and pressure acting directly on the soil properties. This affects the electrical parameters, such as soil resistivity, soil porosity, soil permeability, water saturation and salinity. Highly compacted soil exhibits high resistivity and low conductivity. Variation of the parameters is due to the type of soil sample, its electrical properties available and the depth it is situated. Higher average resistivity of top soil ranging from 708.1Ωm to 1185.2Ωm was recorded in areas around Annunciation Catholic Church, Graduate School and Total Petrol Station indicating more compacted top soil. Table 3 shows parameters for integrating geoelectric and geotechnical methods for evaluation of the structural disposition of the foundation beds of the study area. The graph of dry density versus moisture content (Fig. 6) gave a parabolic curve. The coordinates of the turning point yielded result of Maximum Dry Density (MDD) of 1912 kg m^{-3} and Optimum Moisture Content (OMC) of 20%.

From the results of this study, the Abuja Park of the University of Port Harcourt is underlain by top soil whose resistivity and thickness indicate that the structural disposition or competence is quite good for engineering structure foundation especially around School of Graduate Studies, Total Petrol Station and the Annunciation Church. The periodic rehabilitation of link roads and crack of the building cited in this study could be as a result of some of the following conclusions drawn from the study with remedial measures recommended to forestall possible failures:

(1) Flooding experienced within the Campus during rainy seasons could be a factor and require proper drainage analysis and construction of well designed drainage system to channel the flood.

(2) Proper geophysical and geotechnical survey should be carried out before construction work commences.

(3) Thorough supervision of work should be done by the Works Unit of the University to ensure that proper construction materials are used and to the specification prescribed by survey team.

CONCLUSION

This study has integrated Geoelectric and Geotechnical techniques to evaluate the structural disposition of the foundation beds of the study area. The result is very reliable and the recommendations, if implemented by the University authority, will forestall possible failures of engineering structures and reduce the cost of periodically rehabilitating the link roads.

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