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# Geoelectrical and Geotechnical Evaluation of Foundation Beds at Naze, Owerri Southeastern Nigeria

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## Abstract

A foundation study has been undertaken at a proposed building site located at about 3km east of Owerri, along Aba-Owerri road, between the Nekede Mechanic village and the Naze/Nekede road junction. The aim of this study is to examine the Geoelectrical and Geotechnical parameters that can be used to evaluate the stratigraphy, nature, structural disposition/integrity and competence of the shallow section of the subsurface for construction purposes and building development. The Vertical Electrical Sounding (VES), using schlumberger configuration and soil analysis techniques were adopted. A total of six (6) Vertical Electrical Sounding (VES) stations were occupied and this was complemented with geotechnical analysis of six soil samples collected at all the VES points down to a depth of 2m within the study area. Quantitative interpretations of the VES curves were carried out using partial curve matching technique and computer iteration technique. The investigation delineated four geologic layers which include the Sandy and Organic-rich top soil, Iron-stained sand, Medium-grained sand and Gravely sand. The topsoil composed mostly of sand and laterite with resistivity generally greater than 350Ωm. The layer (topsoil) with thickness that varies from 1.4–5.8m constitutes the layers within which normal civil engineering foundation is founded. There are no indications of any major structures such as faults, fractures and lineaments down to a depth of 40m that could be deleterious to engineering construction in the area. All the determined geotechnical parameters of the subsoil fall within the specification recommended for foundation material by FMWH, 1972 and are generally increasing towards the southern part of the area. From the results, we conclude that soil units between 0.0-2.0 meters (0-6.6 feet) are characterized by very high bearing capacity of values ranging from 381 to 524 $KN/M^2$. The deduction from the above is that, the topsoil formation may be rated as relatively good as a foundation material. The foundation of the proposed civil structure can be hosted by this formation.

**Keywords:** Bearing Capacity, Foundation, Geoelectric, Lineament, Resistivity, Schlumberger.

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# 1 Introduction

Engineering structures are designed and constructed with long life expectancy [1]. Generally, most problems of structural failure are often associated with improper founding of foundations and poor quality of building materials. However, inadequate knowledge of the physical parameters governing the competency of the soil supporting engineering structures has also been identified [2]. Consequently, the primary consideration is the foundation and the capacity of the foundation bed to sustain both the dead and live load imposed by the overlying structure. Hence the stability of the foundation and the superstructure supported by the foundation depends on the bearing capacity of the geologic materials underlying the site [3]. Usually, civil and building engineers prefer drilling, cone penetrometer test and some other geo-technical methods in assessing the strength of materials for the support of infrastructures such as roads, buildings and dams [4]. However, it is believed that the integration of geophysical methods have become indispensable in general foundation studies, since they offer a fast, cheap and cost effective method of evaluating the geotechnical competence of sub-soils and rocks for building foundations as well as providing subsurface information at reasonable cost, locate critical areas for test drilling and thus eliminate less favorable sites [5]. Consequently, an efficient sequence of foundation investigation should therefore embrace surface geological survey, subsurface geophysical investigation and the traditional insitu engineering/laboratory tests, in order to design the most suitable foundation for the proposed structure. Therefore, it is imperative to complement these with cost effective geophysical method which are commonly applied in engineering site investigation ([6], [7]). Several works have established the relevance of application of geophysical methods in the investigation of geomaterials underlying engineering foundation sites ([8]; [9] and [10]), and the methods have been established to play complementary roles in geotechnical studies, besides the fact that they are less expensive and non-invasive. Dipole-dipole array has been used to investigate the causes of road failure along Ilesa-Akure-Benin federal highway [11]. It was reported that the road failure was due to the clay content of the topsoil and the heterogeneous nature of the sub-base and sub-grade material on which the road was constructed. Combined geophysical and geotechnical methods have been used to study the sub-soil conditions and the electrical properties of the soil which may have effect on the foundation of the proposed switch station facility for telecommunication site [12]. It was observed that areas with low resistivity have soil that can lead to severe corrosion and high concentration of dissolved salts in the soil. 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 ([13], [14]). In other to emphasis importance of predevelopment survey, Geoelectrical and geotechnical investigations were carried out in this project to examine those parameters that can be used to evaluate the stratigraphy, nature, structural disposition/integrity and competence of the shallow section of the subsurface for construction purposes and building development. Results of the study shall aid the structural engineer in his design of appropriate structures that command professional feat. This is informed by the spate of collapsed structures which necessarily are not due to material problems but due to improper design, stemming from lack of proper foundation elements; a condition that spurred this research.

## 2 Location and Accessibility

The Building site is located at about 3km east of Owerri, along Aba-Owerri road, between the Nekede Mechanic village and the Naze/Nekede road junction (figure 1). It is located approximately on the following co-ordinates Latitude 5$^{o}$ 27.430'N to 5$^{o}$ 27.446'N and Longitude 7$^{o}$ 02.760'E to 7$^{o}$ 02.790'E. The site is readily accessible along Owerri-Aba road, Egbu-Naze road and Nekede-Owerri new road.

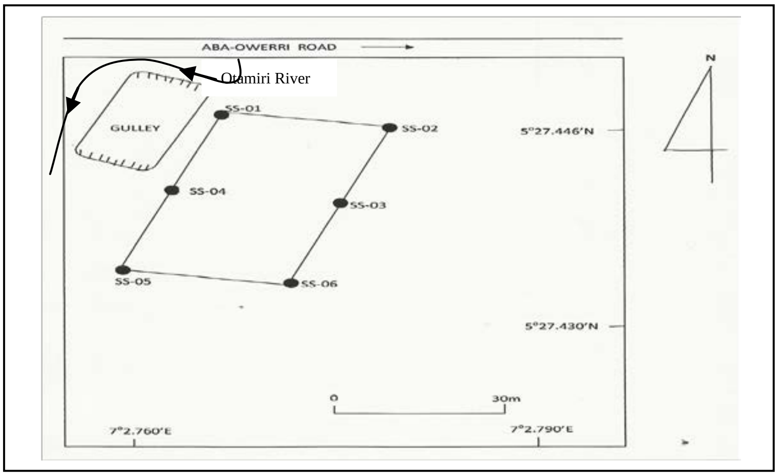


Figure 1: Location Map of Building Site (owerri-Aba Road)

## 3 Geology of the Study Area

Naze area is located in an area underlain by Benin Formation. The units are made up of sandy to gravelly sands without any shale or swelling clays. In general, Benin Formation spans from Miocene to Recent. It is the youngest of Niger Delta sediments. Its thickness is about 6,000ft, and very little hydrocarbon accumulation has been associated with the Benin Formation. The Benin Formation comprises the top part of the Niger Delta clastic wedge, from the Benin-Onitsha area in the north to beyond the present coastline [15]. The Benin formation consists of massive continental sands and gravels, it underlain gradationally by the delta front paralic lithofacies. The top of the formation is the recent sub aerially - exposed delta top surface and its base extend to a depth of 4600 feet. The base is defined by the youngest marine shale. Shallow parts of the formation are composed entirely of non-marine sand deposited in alluvial or upper coastal plain environments during progradation of the delta [16]. Although lack of preserved fauna inhibits accurate age dating, the age of the formation is estimated to range from Oligocene to Recent [15]. Benin Formation covers the following areas: Benin City, Warri, Rivers State, Cross River State, Abia state (Part of Umuahia, and Aba), Imo State ( some part of Anara, Amaimo, Ikeduru, Atta Village) it covers the entire owerri area with its outcrops at Ihiagwa behind Federal University of Technology Owerri.

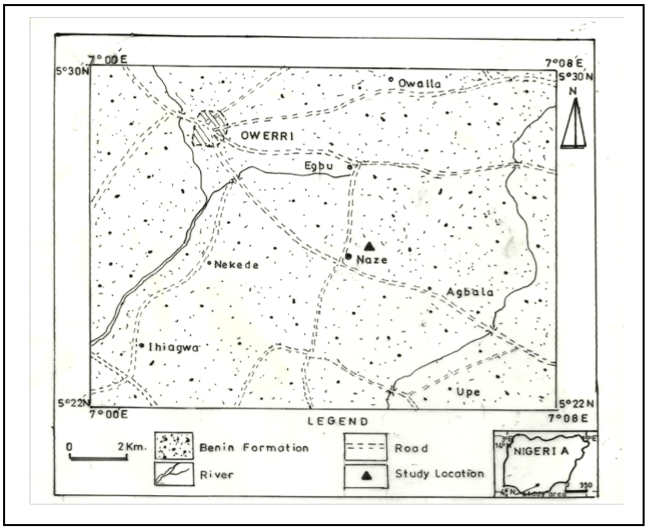


Figure 2: Topographic map of the study area showing the sampling points

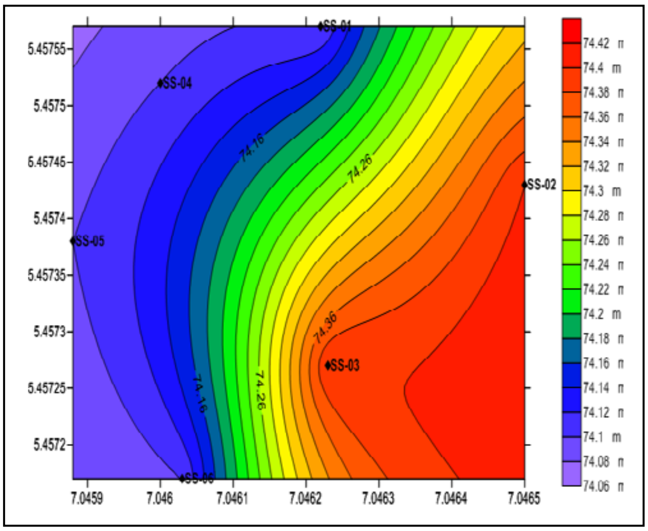


Figure 3: Geological map of the study area

## 4 Materials and Methods

The ABEM Terrameter model SAS 4000 with an in-built digital display and recording system was used in the field reading operation. It has three operating modes (Resistivity, IP, SP) in one complete unit. It is expandable to 2D/3D imaging and borehole tomography for a broad range of near surface geophysical applications. Scopes of applications, data acquisition speed, and accuracy have defined the architecture of the ABEM Terrameter SAS 4000 model. Core electronics, such as the Signal Averaging System (a.k.a Signal Stacking) from which the ABEM Terrameter SAS derives its name, deliver accurate and dependable results at maximized speed thereby reducing field time. It has inbuilt productivity software, incorporates a sophisticated signal-averaging (or signal stacking) algorithm where consecutive readings are taken automatically and the results are averaged continuously to improve the accuracy of the measurements. Rechargeable 12-volt batteries coupled to the equipment provide the energy for the equipment operation. Three (3) traverses were established across the study area (Figure. 1). Two (2) Vertical Electrical Sounding (VES) stations were occupied along each of the traverses. A total of 6 soundings were carried out using the Schlumberger configuration. The electrode spacing (AB/2) was varied from 1.5m to 95.0m, ensuring approximately 63 meters depth of investigation. The cross over distance is encountered at 10.5m, 14m, and 42m. The cross over position is the position of the potential electrode where voltage readings become so small that they make very significant change in the resistance reading to be recorded [17]. They are done by keeping the current electrodes fixed and the potential electrodes are moved at a specific distance in logarithmic steps in a progressive manner away from the reference point in order of 1.5m, 2.0m, 3.4m, 4.5m, 6.0m, 8.0m, 14.0m, 18.0m, 34.0m, 42.0m, 55.0m, 72.0m, and 95.0m. Field readings in Ohms were reduced to apparent resistivity values using the Schlumberger Equation:

$$\ell a = \pi(a^2/b - b/4)\,R \qquad (1)$$

where

$\ell a$ = apparent resistivity in Ohm-m
a = AB/2, the Half Current Electrode Separation in meters
b = Potential electrode separation in meters
R = Meter Reading in Ohms

The layout is shown in figure 4

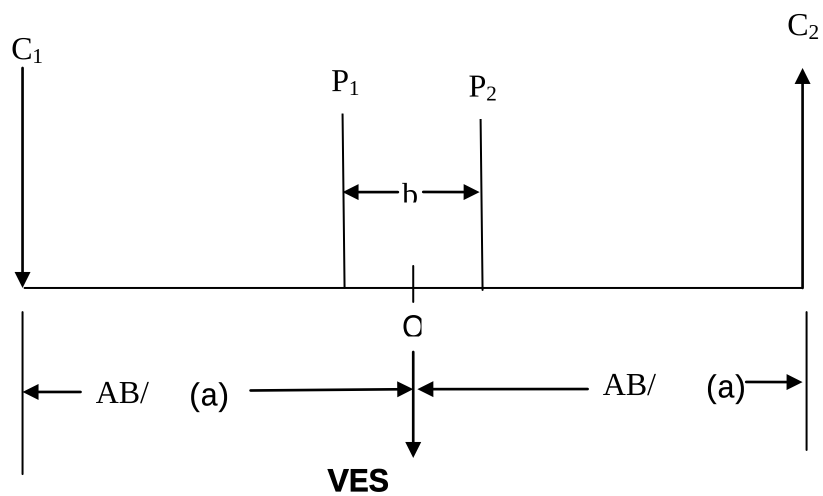


Figure 4: The Schlumberger Electrode Configuration Used.

The apparent resistivity values were plotted against electrode spacing (AB/2) on a bi-logarithmic graph sheet to generate depth sounding curves. The field curves were then inspected visually for identification of the curve type. Partial curve matching was carried out on the field curves. The interpretation results (layer resistivity and thicknesses) were fed into computer for 1-D computer assisted interpretation involving Zohdy software [18]. The final interpreted results were used for the preparation of geoelectric sections and maps. The co-ordinate of each of the sounding stations in Universal Traversal Mercator (UTM) was recorded with the aid of the “GARMIN 76CSx” personnel navigation geographic position system (GPS) unit. Geotechnical measurement of insitu soil materials were carried out to ascertain their engineering properties. Six (6) disturbed soil samples were collected at different locations. The exercise involved opening of pits to about 1m in each of the six (6) locations studied and collecting samples with auger at between 1.5 and 2.2m (). It is suggested that at this depth range, the organic-rich top soil may have been by-passed and the virgin soil studied. The six locations are shown in fig. 1. These samples were preserved in polythene bags and transported to the laboratory. The natural moisture content of the samples collected from the field was determined in the laboratory within a period of 24 hours after collection. This was followed by air drying of the samples by spreading them out on trays in a fairly warm room for four days. Large soil particles (clods) in the samples were broken with a wooden mallet. Care was taken not to crush the individual particles. Methods of testing soils for engineering parameters were conducted in accordance with [19] for all the soil samples collected. The tests include Natural moisture content, Bulk Density, Triaxial compressive strength, and California Bearing Ratio (CBR) test. Several softwares with different analytical modules were used in the interpretations. These include Geosoft Strata 3 version, Surfer 11 and EQS Geostatistical software version 6.1.

Plate 1: One of the researchers collecting soil samples at intervals of 1.5-2.2m

## 5 Results and Discussion

### 5.1 Geoelectric Results

The electrical resistivity method of geophysical prospecting using Vertical Electrical Sounding (VES) technique was utilized to map the subsurface layers to a maximum depth of about 40m. The VES curves generated are shown in figure 5 below. From the geoelectric section, the four major geoelectric layers were Sandy and Organic-rich top soil, Iron-stained sand, Medium-grained sand and Gravely sand, as obtained from the result of the partial curve matching which was refined by computer iteration. These are tabulated in the table 1 below. The results of interpreted results of electrical resistivity survey have made it possible to map the area from the ground surface to depth of about 40m. The major geoelectric sequences delineated were: Sandy and Organic-rich top soil, Iron-stained sand, Medium-grained sand and Gravely sand. The first layer is made up of topsoil (Sandy and Organic-rich) which has resistivity values ranging from 369 to 16300 ohm – meter. The thickness of the layer is between 1.4 and 5.8m. Beneath the topsoil lies the Iron-stained sands which are mainly wet with resistivity values varying from 19700 to 21300 ohm-meter. The thickness ranges from 2.2 to 4.1m. The third layer is made up of the Medium-grained sand that has resistivity values ranging from 5650 to 121000 ohm-meter with thickness of 4 to 18m. The fourth layer (gravely sand occupies the remaining column with its shallowest top observed at 13m in VES3 (figures 6 and 7). Table 1 below shows the summary of the results. Within the first layer down to a depth of approximately 5.8m, the northern part of the study area has the lowest resistivity values (< 1000 ohm-meter) which is an indication of a silty environment. Towards the southern part of the study area, we have a very high resistivity value reaching more than 16000 ohm-meter within this first layer (figure 8).

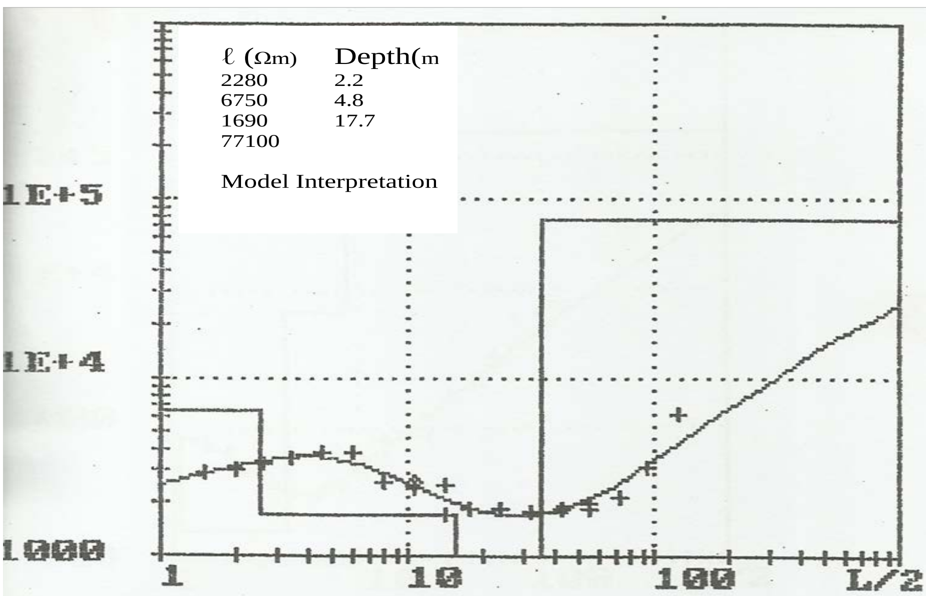


Figure 5: Typical Modeled curve of the Study Area

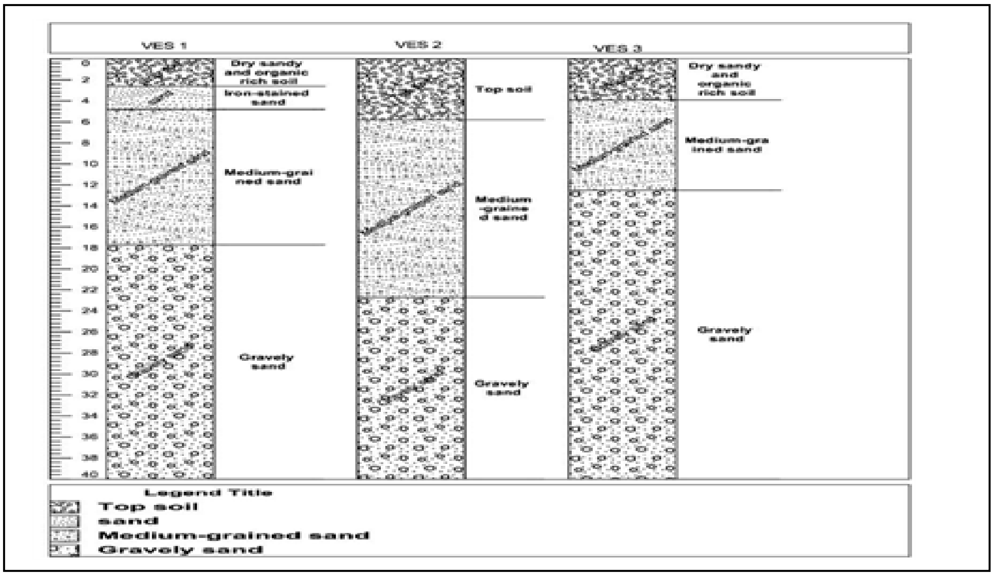


Figure 6: Geoelectric Sections of VES 1, 2 and 3 of the Study Area

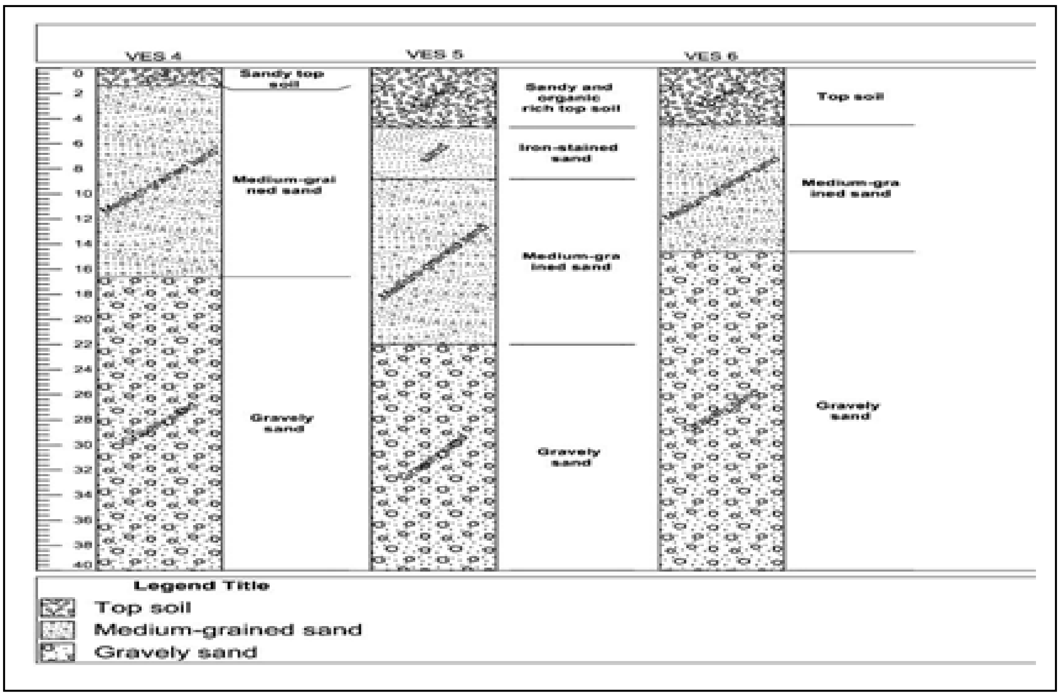


Figure 7: Geoelectric Sections of VES 4, 5 and 6 of the Study Area

Map of resistivity variations with depth at the study area is shown in figure 8 above. Within the top soil down to a depth of about 5.8m (Layer 1), high resistivity values were observed within the southern part of the study area. This indicates lack of clay bearing rocks within these localities and as such depicts competence for load bearing. The deeper one goes to a depth of about 25m, resistivity increases towards the east and further down to a depth of approximately 40m and below, resistivity increases towards the north (figure 8). These spatial variations in resistivity with depth could be ascribed to the thick deposition of gravely sands within these localities and along the river bed which the Otamiri river incised.

Table 1: Summary of the Geoelectrical Interpretation along the Dam axis

| VES NO | LAYER PARAMETERS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Layer 1 | | | Layer 2 | | | Layer 3 | | | Layer 4 | | |
| | Depth (m) | ρ(Ohm-m) | Lithology | Depth(m) | ρ(Ohm-m) | Lithology | Depth(m) | ρ(Ohm-m) | Lithology | Depth(m) | ρ(Ohm-m) | Lithology |
| VES 1 | 2.6 | 2280 | Dry sandy and organic rich soil | 4.8 | 6750 | Iron-stained sand | 17.7 | 1690 | Medium-grained sand | 40.0 | 77100 | Gravely sand |
| VES 2 | 5.8 | 3280 | Sandy top soil | 22.7 | 121000 | Medium-grained sand | 40.0 | 9000 | Gravely sand | - | - | - |
| VES 3 | 3.9 | 16300 | Dry sandy and organic rich soil | 12.5 | 13400 | Medium-grained sand | 40.0 | 1190 | Gravely sand | - | - | - |
| VES 4 | 1.4 | 1690 | Sandy top soil | 16.6 | 14600 | Medium-grained sand | 40.0 | 12700 | Gravely sand | - | - | - |
| VES 5 | 4.7 | 1140 | Sandy and organic rich top soil | 8.8 | 19700 | Iron-stained sand | 22.0 | 7840 | Medium-grained sand | 40.0 | 12000 | Gravely sand |
| VES 6 | 4.5 | 369 | Sandy top soil | 14.6 | 5650 | Medium-grained sand | 40.0 | 548 | Gravely sand | - | - | - |

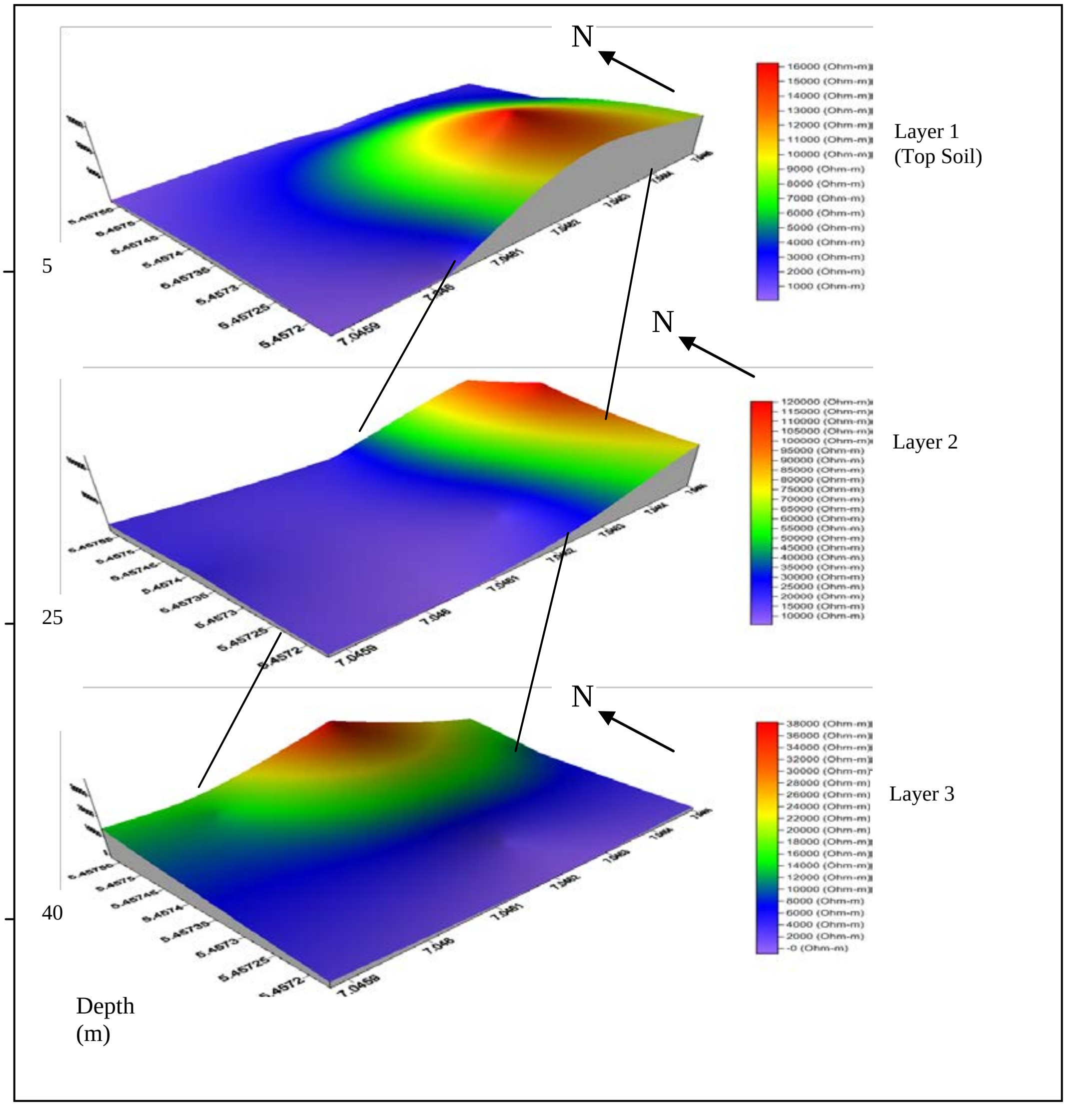


Figure 8: 3D Model of resistivity variations at 5, 25 and 40m depth in the study area

## 5.2 Geotechnical Results

Table 2 below shows the results of the geotechnical analysis carried out on the soil samples.

Table 2: Summary of Geotechnical Test Results

| Bore Hole No | Depth (m) | Natural Moisture Content (%) | Bulk Density ($Mg/m^3$) | Angle of Shearing Resistant ($^0$) | Cohesion ($KN/m^2$) | Bearing Capacity ($KN/m^2$) |
|---|---|---|---|---|---|---|
| SS-01 | 2.00 | 11.8 | 2.27 | 17 | 70 | 381 |
| SS-02 | 2.00 | 11.0 | 2.28 | 20 | 74 | 485 |
| SS-03 | 2.00 | 11.3 | 2.26 | 21 | 73 | 510 |
| SS-04 | 2.00 | 10.2 | 2.23 | 20 | 65 | 427 |
| SS-05 | 2.00 | 11.5 | 2.24 | 22 | 63 | 472 |
| SS-06 | 2.00 | 12.4 | 2.28 | 22 | 70 | 524 |

The natural moisture content of tested soil samples ranges from 10.2 - 12.4%. It increases from value of 11.8% in location SS-01 to an all high value of 12.4% in location SS-06, a-southward increase in the value. This shows that the moisture content of the soil in the area is relatively low at its natural state. Moisture variation is generally determined by intensity of rain, depth of collection of sample and texture of the soil [20]. The northwestern part of the study area shows the lowest moisture content value (figure 9). This could be as a result of increased porosity and permeability as the soils could not retain appreciable amount of water. This is because unconsolidated soils loose moisture very quickly on exposure to heat as a result of little or no matrix. Low water retaintivity, high porosity and permeability make the soil to be easily washed away; a condition that favours gully development as is the case within the northern and northwestern parts of the study area.

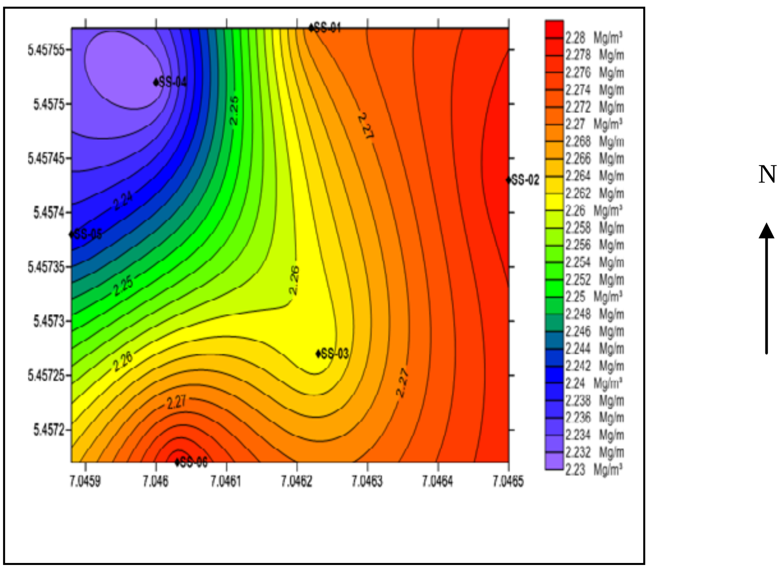


Figure 9: Natural Moisture Content variation in the Study Area

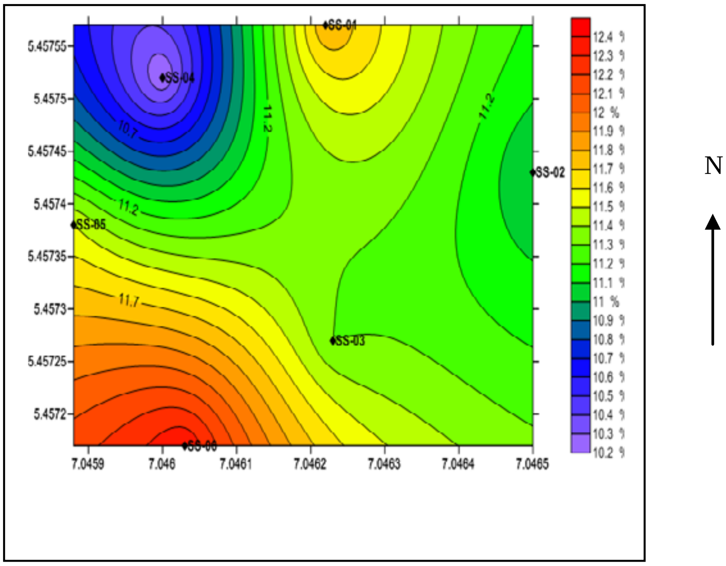


Figure 10: Bulk Density variation in the Study Area

Bulk density range from 2.23 X $10^3$kg/m$^2$ in location SS-04 to value of 2.28 X $10^3$kg/m$^3$ in location SS-06. Bulk density decreases towards the northwestern part and increases towards the eastern and southern parts of the area (figure 10). For shear angle, the value ranges from $17^0$ in location SS-01 to a maximum value of $22^0$ in locations SS-05 and SS-06 (figure 11). Cohesion is a function of silt or clay fraction. Cohesion values are lower in locations SS-04, SS-05 and SS-06. However, mean value of 69.1KN/M$^2$ was obtained. From cohesion values, the northern and northwestern parts of the study area can be said to contain low percentage of fines (figure 12). Fines content are known to contribute to the strength of a soil as their small sizes and mineralogy increase the bond between the grains. The fewer fines a soil has, the greater the ease with which moving water can detach the particles. Thus the low value observed within the northern part of the area indicates relative lack of strength; a condition that favours gully development as observed in the area.

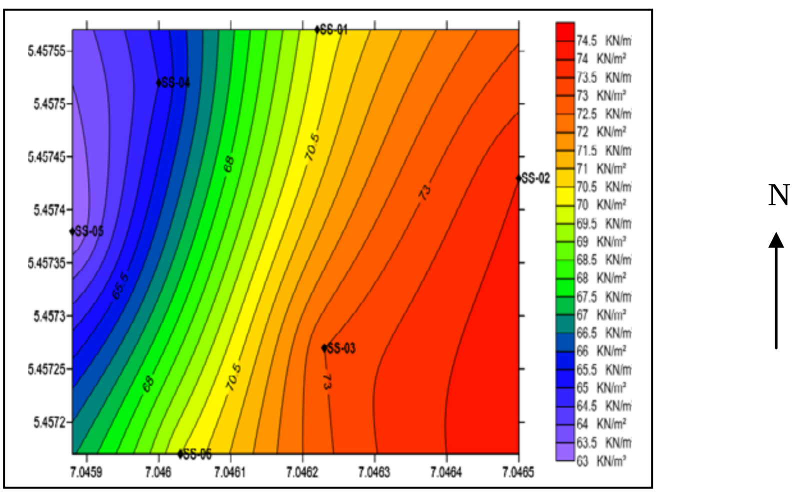


Figure 11: Angle of shearing Resistance variation in the Study Area

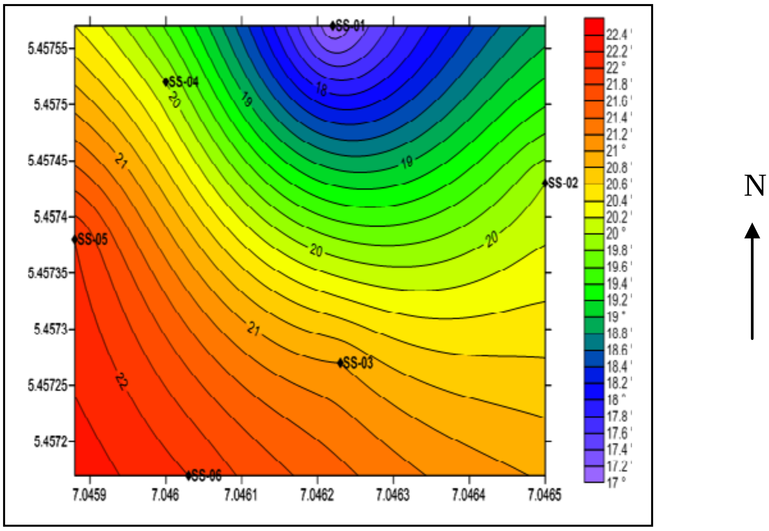


Figure 12: Cohession variation in the Study Area

From the result, no value of bearing capacity is less than 380KN/M$^2$. This implies greater sand fraction and competence of the soil at 2m depth. High values of 472, 485, 510 and 524 KN/M$^2$ are recorded for samples from locations SS-05, SS-02, SS-03 and SS-06. However, these values are typical of areas of overriding sandy fractions. From the contour map of bearing capacity values, it shows that to the north of the study area (west of Otamiri river), there is low bearing capacity and to the south of the study area (east of Otamiri river -Naze) there is a high bearing capacity (figures 13 and 14). There is a possibility of soft matter at the river bank to the west hence some treatment must be made to the soil at the northern and northwestern parts of the study area.

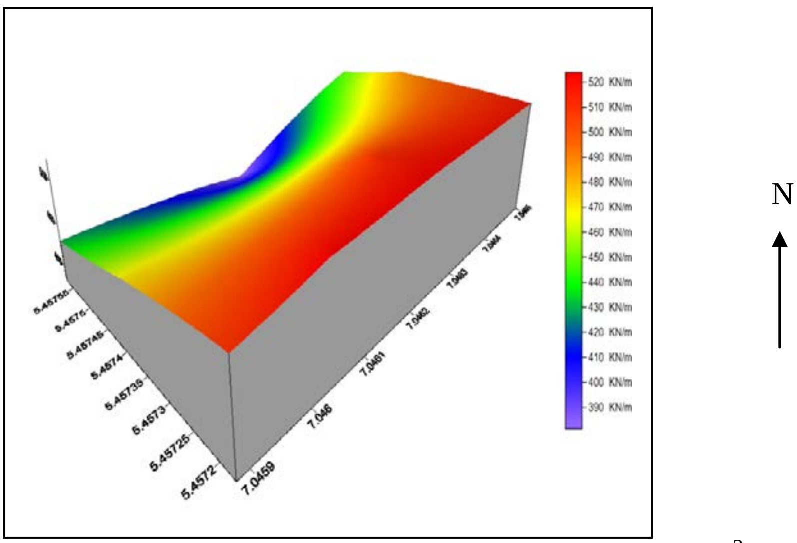


Figure 13: Contour image map of bearing capacity values (KN/m$^2$)

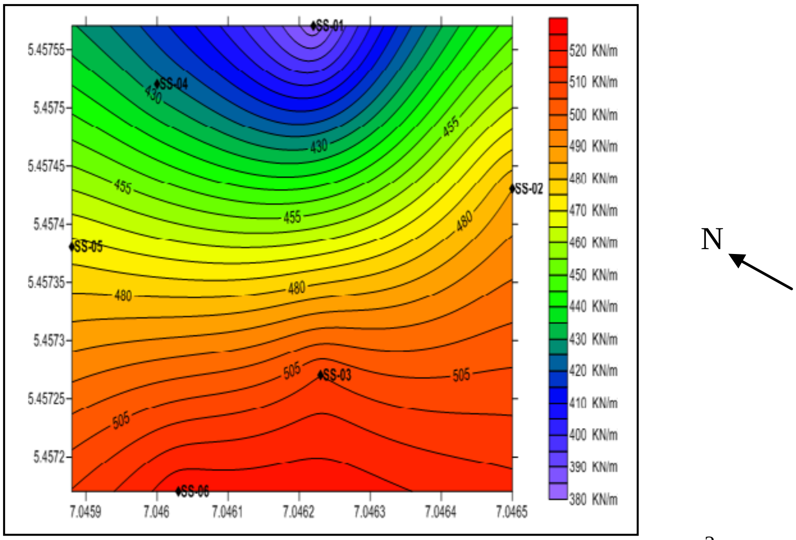


Figure 14: 3 D image map of bearing capacity values (KN/$m^2$)

The topsoil constitutes the layer within which normal Civil Engineering foundation is founded. The layer is composed of laterite and sandy materials. Foundation competence of the topsoil can be qualitatively evaluated from layer resistivity and geotechnical parameters [21]. According to [7], the higher the layer resistivity value, the higher the competence of the delineated topsoil units. The Federal Ministry of Works and Housing [22] says the higher the geotechnical parameters of a soil, the lesser the competence of the soil as a foundation material. In the study area, the values recorded are lower and falls within recommended value and thus accounts for the high competence of the soil as a good foundation material.

### 5.3 Comparison between Geological, Geoelectrical and Geotechnical Results

The site is located in an area underlain by the Benin Formation. The relatively high Bearing capacity of over 300 KN/$m^2$ is correlated with overriding pebbly samples from the borehole (figure 15) drilled and logged at the site by the researching team to provide water in the area. This is equally correlated with high resistivity values obtained in figure 8 down to a depth of about 5.8m (within the top soil zone). The units here are made up of sandy to gravely sands without any shale or swelling clays. From the log shown in figure 15, there is overriding sandy column. From 30 feet (10m) down to about 180 feet (60m), are all gravely sand. There is also positive correlation between the sand from the borehole and soil on top of the sandstone unit.

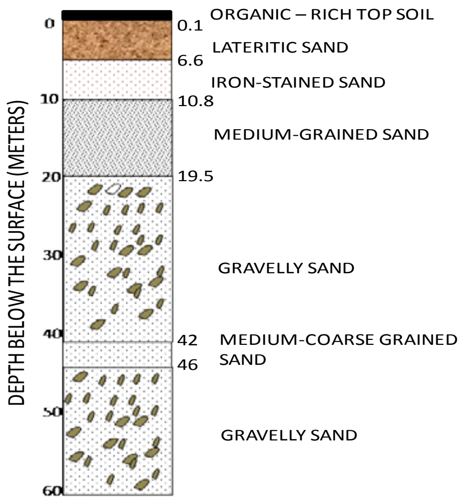


Figure 15: Geologic Log of the bore hole

## 6 Conclusion

Subsoil evaluation within a proposed site for civil engineering structure using geoelectrical and geotechnical methods of investigation were carried out in this research. The investigation was to provide information on the stratigraphy, nature, structural disposition and competence of the subsoil. Six (6) Vertical Electrical Sounding (VES) stations were occupied and this was complemented with geotechnical analysis of six soil samples collected at all the VES points down to a depth of 2m within the study area. Quantitative interpretations of the VES curves were carried out using partial curve matching technique and computer iteration technique. The investigation delineated four geologic layers which include the Sandy and Organic-rich top soil, Iron-stained sand, Medium-grained sand and Gravely sand. The topsoil composed mostly of sand and laterite with resistivity generally greater than 350Ωm. The layer (topsoil) with thickness varies from 1.4 – 5.8m constitutes the layers within which normal civil engineering foundation is founded. There are no indications of any major structures such as faults, fractures and lineaments down to a depth of 40m that could be deleterious to engineering construction in the area. All the determined geotechnical parameters of the subsoil fall within the specification recommended for foundation material [22]. From the results, we conclude that soil sample between 0.0-2.0 meter (0-6.6 feet) are characterized by very high bearing capacity of values ranging from 381 to 524 $KN/M^2$. The deduction from the above is that, the topsoil Formation may be rated as relatively good as a foundation material. The foundation of the proposed civil structure can be hosted by this formation.

## 7 Suggestion for further Work

In the light of the gulley northwest of the site, we suggest that high rising structures should not be sited within the northern and northwestern part of the area and filling of the gulley with materials of equally high bearing capacity such as sandstone or lime-bearing matter is recommended. Already sliding and slumping have commenced and gulleying may be advanced if not checked, irrespective of the relatively level topography.

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