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SUBSOIL CHARACTERIZATION FOR SHALLOW FOUNDATION CONSTRUCTION USING INTEGRATED GEOPHYSICAL AND GEOTECHNICAL METHODS IN NORTH-CENTRAL NIGERIA

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ABSTRACT

An integrated geophysical and geotechnical study was conducted within the Prince Abubakar Audu University (Formerly Known as Kogi State University), North Central Nigeria in order to delineate subsurface lithologies and evaluate their suitability as foundation for building constructions. The geophysical study carried out involved both electrical resistivity tomography (ERT) resulting in 2-D resistivity imaging along 5 profiles and Vertical electrical sounding on the 2D profile lines. The geotechnical studies involved five cone penetration tests to determine the insitu bearing capacity of the soils and their characteristic nature The ERT were processed using DIPROfWIN software, while the VES data were subjected to qualitative and quantitative interpretation. Winresist software for 1D forward modelling was used. Both geophysical and geotechnical methods reveal that the subsoil is underlain by loose sand, medium and dense sand at variable depths. The resistivity values of the medium to dense sand ranged from 500 – 12000 Ohms-m with bearing capacity values ranging from 53 kN/m^2 – 180 kN/m^2 and can support light (1-2 storey) to medium (2-5 storey) building structures at shallow depths (1.5 – 2 m) except the college of Health where a depth of $\geq 2.75 \leq 4$ m is recommended. This study suggests that integrated geophysical and geotechnical investigations be used for subsoil evaluation for foundation purposes in other regions of Nigeria for sustainability.

Keywords: Bearing capacity, Foundation, Resistivity, Cone penetration test, Electrical resistivity tomography

INTRODUCTION

One basic need of humans is shelter and other life support infrastructure such as roads, bridges dams and others. These structures are supported by foundation rocks (Banso *et al*., 2022). A very important parameter that is sacrosanct to safety of the infrastructures is the bearing capacity of the foundation soils. Soil investigation plays a crucial role in the determination of this property (Setiawan *et al*., 2021).

The demand for shelter as well as the need for basic infrastructure is continuously on the rise due to the constant increase in population of Prince Abubakar Audu University, Anyigba (KSU) and environs. This trend has necessitated the growing number of construction works undertaken in and around the campus and demand for optimized space utilization. Developmental activities must however be preceded by adequate subsoil investigation in order to mitigate failure and collapse of the built structures (Fagbenle *et al.* 2010 and Oyedele *et al*. 2011).

In a developing country like Nigeria, the review of literature and anecdotal evidence reveal that between 1974 and 2019, over 221 incidences of collapsed buildings have been reported in major towns and cities leading to several fatalities. In fact, within the last four years, Nigeria has recorded over 56 cases of building collapse (Yaqub, 2019). There is no state in Nigeria, without at least one incidence of building collapse in the past ten years (Oyedele, 2018). Available records also show that between 1971 and 2016, 1,455 fatalities were recorded in 175 collapse cases (Omenihu *et al*., 2016). The Nigeria Construction and Infrastructure Summit Group estimates that the country loses between 2.03trn and 3.05trn annually to infrastructure deficit from building failure because the magnitude of overall damage to the initial cause is usually out of proportion due to progressive collapse. As a result, research efforts have been focused on identifying the various factors that contribute to the cases of collapsed buildings in this country through physical observations and or sample collection of debris from building collapse sites and oral interviews of eye witnesses or residents within the vicinities.

Among the factors identified by the existing studies include the lack of soil test investigation, poor design, dysfunctional construction, lack of adherence to established building standards, lack of enforcement of building codes/regulations/bye-laws. Also, the use of substandard construction materials, engagement of non-professionals and poorly trained workmen, poor supervision, excessive loading of buildings, poor maintenance practices, heavy downpour, greed and corrupt practices and others (Adenuga, 2012; Adeyemi, 2002; Chendo and Obi, 2015; Oloyede *et al*., 2010; Oyediran and Famakinwa, 2015).

Specifically, Oyewande (1992) noted that around 50% of the factors leading to building collapse in Nigeria can be linked to faulty design, 40% to fault on construction sites and 10% to product failure. According to Ellingwood *et al*., (2007), most structural failures and damages in buildings may result from errors in the planning, designing, erecting, and using the buildings rather than statistical prediction of differences in the load bearing capacity of buildings and the load on them.

A number of authors (e.g. Oyedele and Olorode, 2010) have shown the effectiveness of a combined geophysical and geotechnical investigation in foundation studies. Geotechnical investigations are usually point tests and become very expensive and time consuming to conduct in several places within an area. To enhance, efficiency and overcome this limitation, the integration of electrical resistivity tomography to geotechnical investigation can aid in imaging and characterizing the subsurface rapidly both laterally and vertically. This study therefore aims to utilize integrated geophysical and geotechnical methods to assess the suitability of subsoil conditions for shallow foundation constructions at Prince Abubakar Audu University.

The study area is delineated within N7^{0}28’, E7^{0}11’ – N7^{0}30’, E7^{0}12 (Fig.1). It is geologically situated within the Northern Anambra Basin (Fig. 2). The Northern Anambra Basin consists of four main litho-stratigraphic units characterised by sediments of Cretaceous and younger ages (Odumoso *et al*., 2013). From the oldest to the youngest, they are Nkporo, Mamu Formation, the Ajali Sandstone and Nsukka Formation consisting of gravels and coarse sandstone within the upper horizon and grades into medium fine grained sandstone at greater depth (Fatoye *et al*., 2013). The study area is directly underlain by the Ajali Formation.

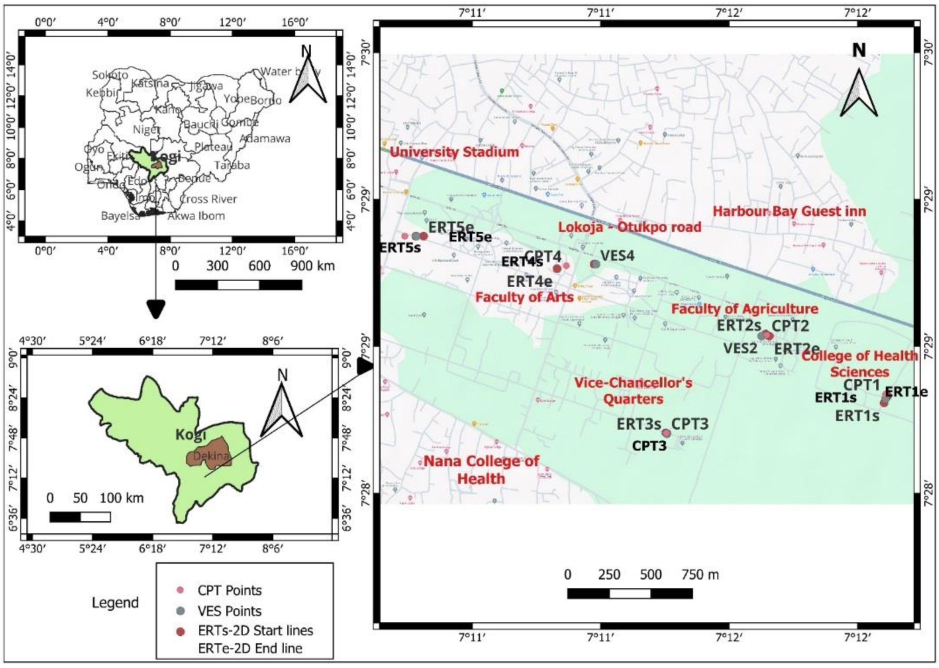


Figure 1: Location map of the study area. Inset: Kogi State Local Government and Dekina Local Government Area

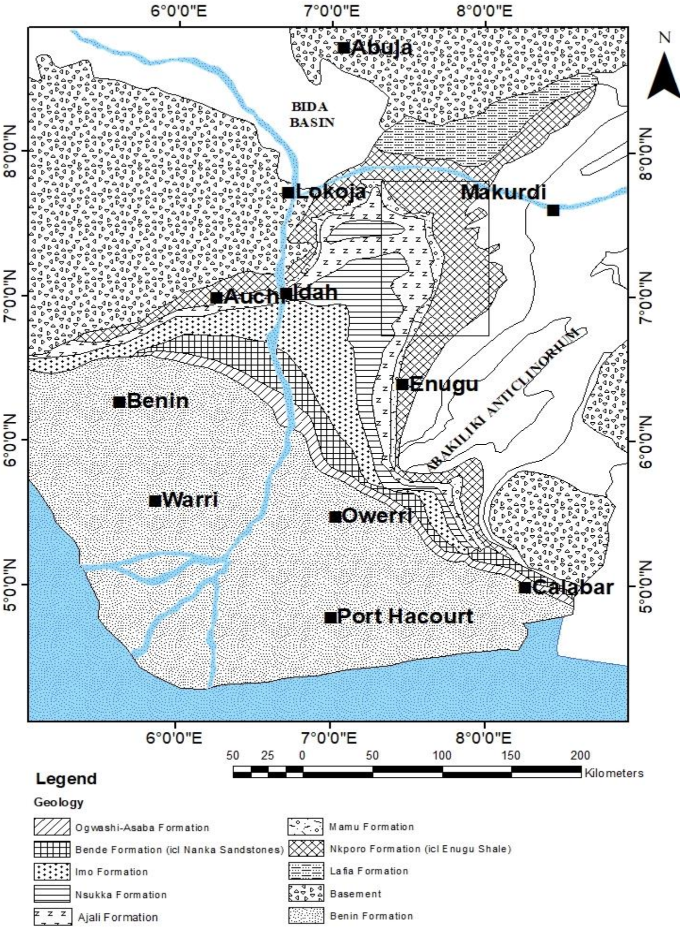


Figure 2: Regional Geology and stratigraphy of the southern Nigeria showing location of study site (modified from Obaje, 2009).

MATERIALS AND METHODS

Geophysical Methods

2-D Electrical resistivity (Electrical Resistivity Tomography) and Vertical Electrical Sounding

Electrical resistivity tomography (ERT) involving 2-D Electrical resistivity survey using Dipole-Dipole Array and Vertical Electrical Sounding (VES) using Schlumberger array were employed. Dipole-Dipole was adopted for the 2-D survey because it has good horizontal data coverage and is able to map vertical structures such as cavities (Loke, 2001). Five (5) 2-D profiles, each approximately 50 m long were carried out at the College of Health (ERT1), Faculty of Agriculture (ERT2), Vice Chancellor's (VC) Quarters (ERT3), Faculty of Arts (ERT4) and Behind the University Stadium (ERT5).

The 2-D measurements were made using the ABEM SAS1000, potential and current electrodes, Global Positioning System (GPS), hammers and measuring tapes. The configuration used for the 2-D dipole-dipole array is shown in Figure 2. C2 and C1 are current electrodes which are separated by a distance, known as spacing, denoted by 'a'. This spacing is also kept constant for P1 and P2 which are the potential electrodes. A spacing of 5 m was adopted for the 2-D survey for optimum resolution of the subsurface at shallow depth. The depth of investigation is a product of the spacing, 'a' and 'n' which is the distance between C1 and P1. In order to increase the depth of investigation, n is progressively increased by a constant factor. For this study, n was increased in 3 steps. This yielded 'na' values of 5, 10, and 15, making the depth range of current penetration between 0 – 15 m. The geometric factor was obtained for each value of n and multiplied by the corresponding resistance value for each station along the entire profile length to calculate the electrical resistivity values. This is illustrated by Equation 1 below

$$\rho_a = \pi R a\ (n+1)\ (n+2) \qquad (1)$$

Where ρ_a is the apparent electrical resistivity

π is pie, taken as 3.142

"R" is resistance, "a" is spacing; n is distance between current electrode (C1) and potential electrode (P1)

Diprof software which is a simple and user friendly 2D resistivity data imaging was used to perform the iteration process and to generate the 2-D electrical resistivity structure of the subsurface. A VES was conducted on each 2-D profile, resulting in five (5) soundings being acquired. Namely VES 1, VES 2, VES 3, VES 4 and VES 5 on ERT1, ERT2, ERT3, ERT4 and ERT5 respectively. The maximum half-current electrode spacing (AB/2) of 50 m was adjudged adequate to probe the near-surface depth of interest. For the VES measurement, Current (I) was injected into the earth through two outer current electrodes (A and B) and the resultant potential difference (ΔV) was measured from the two inner electrodes (M and N). Deeper penetration of current was achieved by the stepwise continuous increase of the outer electrodes and occasional increase of the inner electrodes. The configuration (as shown in Figure 4), was done such that the distance between the two inner electrodes was not less than a fourth of the distance between the outer electrodes. The terrameter displayed the resistance (R = ΔV/I), which was converted into the apparent electrical resistivity (ρa) by multiplying it with the appropriate geometric factor (K) using the relationship in equation (2):

$$\rho_a = \frac{-\pi R\left(\frac{AB}{2}\right)^2}{MN} \qquad (2)$$

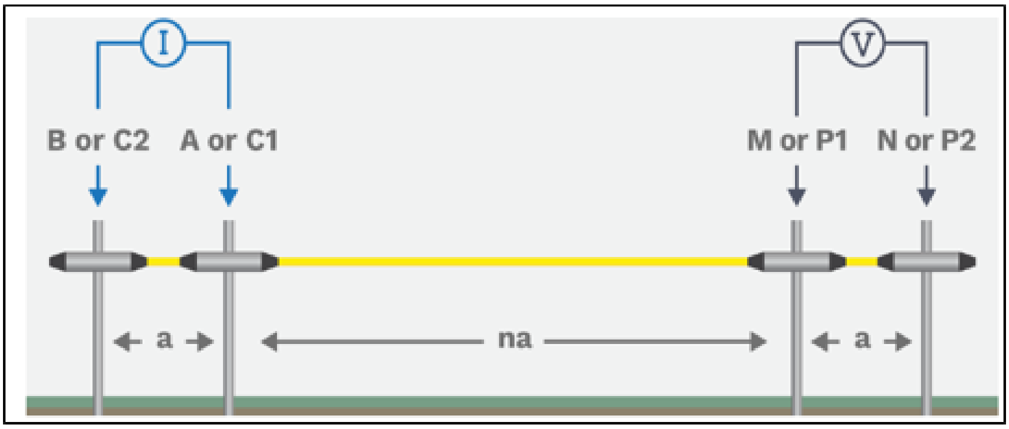


Figure 3: Dipole-Dipole Array (Ohaegbuchua, Anyadiegwua, Odoha, and Orjia, 2019)

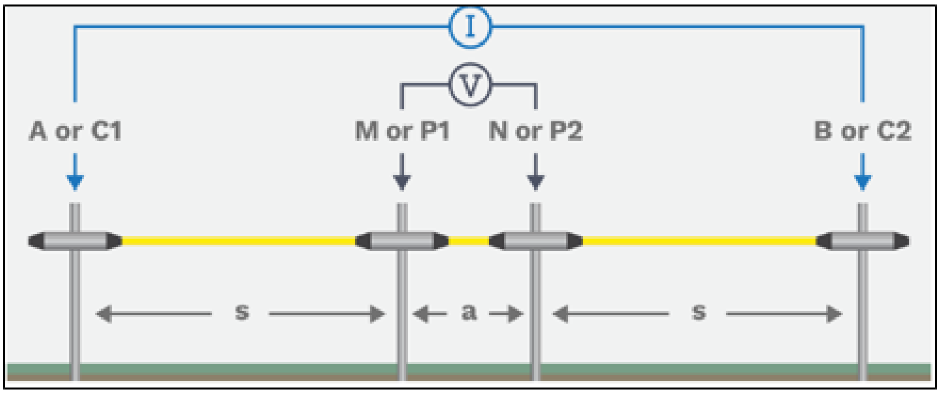


Figure 4: Schlumberger Array Configuration (Ohaegbuchua *et al.*, 2019)

Cone Penetration tests were performed at a total of five (5) locations where ERT and VES were conducted to aid integrated studies. These include CPT1 (College of Health Sciences), CPT2 (Faculty of Agriculture), CPT3 (Vice-Chancellor's Quarters), CPT4 (Faculty of Arts) and CPT5 (Behind University Stadium). The tests were carried out to a depth of refusal of the cone by the subsurface. The Dutch static penetration measures the resistance of penetration into soils using a 60^{o} steel cone with an area of 10.2 cm^2. The resistance to the penetration of the cone was read every 0.25 m. The result of the cone resistance is plotted against depth.

The cone penetration test is measured in Kg/Cm^2. To obtain the bearing capacity of the foundation soil, Meyerof equation follow shallow foundation was used as shown in equation 3.

$$\frac{qa}{qc} = (1 + D/B)\frac{B}{40} \qquad (3)$$

Where qa is the allowable bearing capacity (kN/m^2), qc is the cone resistance (kg/cm^2), D is the depth (m) and B is width (m).

In this study, a shallow square footing with a width of 2 m and variable depths were used for the calculation of the bearing capacity. The obtained results were compared to Terzaghi (1943) and Hansen (1970) minimum bearing capacity standards required for light building (1-2 storeys) and medium building (2-5 storeys).

RESULTS AND DISCUSSION

Vertical Electrical Sounding and 2-D (Electrical resistivity Tomography)

2D resistivity measurement (ERT) was combined with VES for complimentary purposes and to help provide a rapid imaging of the subsurface both laterally and vertically. The results of Electrical Resistivity Tomography (ERT) and VES are presented in the form of figures. The table for the Interpretation of the VES models were based on the knowledge of local geology of the study area, trial pits and literature.

The electrical resistivity of the foundation soils can be used to predict their competence. This is because the electrical resistivity of a material is largely dependent on the fluid content and matrix or mechanical properties (Obasaju *et al*. 2022). Studies by Idornegie *et al*. (2006) proposed foundation soils' competency rating based on resistivity values while Baeckmann and Schweak, (1975) with Agunloye, (1984) classified soils into varying degree of corrosivity based on their electrical resistivity range as shown in Table 1. These were used to infer the competence and how corrosive the soils are. According to Akintorinwa and Adesoji (2009), soils with low resistivities (<100 Ohms-m) could be corrosive to metal or steel and lead to corrosion failure. Albeit such soils have good electrical conductivity property which is desirable for earthing. Table 2 presents summary of the VES results.

Table 1: Competence and Corrosivity rating using resistivity values (Idornigie *et al*., 2006; Baeckmann and Schweak, 1975; Agunloye, 1984)

Electrical resistivity range (Ω-m)	Rating (Idornigie *et al.*, 2006)	Corrosivity (Ohms-m)	Interpretation (Baeckmann and Schweak, 1975; Agunloye, 1984)
< 100	Incompetent	<10	Very strongly corrosive (VSC)
100 - 1000	Moderately Competent	10 - 60	Moderate Corrosive (MC)
> 2000	Competent	60 – 180	Slightly Corrosive (SC)
		>180	Practically Non-Corrosive (PNC)

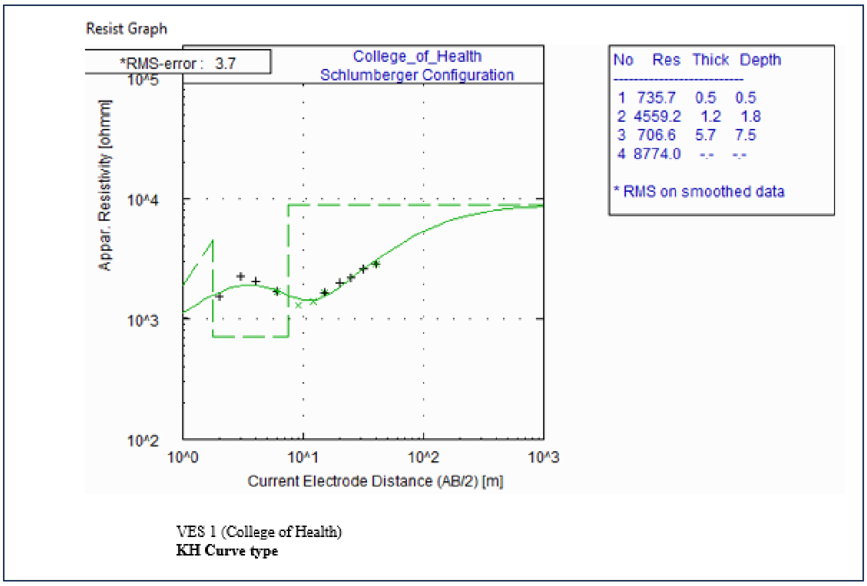
Table 2: Summary of VES results of the study area

VES no.	Layers	2D line no.	Resistivity (Ohm-m)	Thickness (m)	Depth (m)	Curve type	Inferred Lithology
College of Health (VES 1)	1 2 3 4	ERT 1	73 5 4559 706 877 4	0 . 5 1 . 2 5 . 7 -	0. 5 1. 8 7. 5 -	K H	lateritic top soil sand clayey/silty sand clean sand
Fac. Of Agric (VES 2)	1 2 3	ERT 2	923 2595 12033	1.4 8 . 2 -	1.4 9.6 -	A	lateritic top soil clayey/silty sand clean sand
VC's Qtrs (VES 3)	1 2 3 4	ERT 3	1612 573.2 1419.1 5250.2	0.5 2.5 16.2 -	0.5 3.0 19.2 -	H A	lateritic top soil sandy clay/silt clayey/silty sand clean sand
Fac. of Arts (VES 4)	1 2 3 4	ERT 4	685 555 747 5770	1 1 9.1 -	1 2 11. 1	H A	lateritic top soil sandy clay/silt clayey/silty sand clean sand

Behind Uni Stadium (VES5)	1	ERT5	230	0.6	0.6	K	lateritic top soil
	2		1502	8.7	9.3	H	clayey/silty sand
	3		902	21.5	30.8		sandy clay/silt
	4		10003				clean sand

ERT 1 and VES 1 (College of Health)

The 1D model, ERT model and combined models for ER1 and VES1 are presented in Figs. 5-7. The 2-D structure of ERT 1 and 1D model of VES 1 revealed thin top soil (<0.5 m) with a high resistivity > 700 Ohms-m. The trial pit confirmed that this layer is lateritic in nature. Beneath the top soil is a layer of high resistivity (> 4000 Ohms-m) extending up to an approximate depth of 4 m as shown by the 2D structure (Fig. 6). This layer is inferred as sand unit. This is supported by the soil sample recovered from the trial pit within this depth. Using the Idornegie's *et al*., (2006) competence rating of soil based on resistivity, the soil at this layer classifies as competent soil for raising a building structure. The soil is practically non corrosive to steal and metal and may not pose any danger of corrosivity failure, based on rating proposed in Table 1 by Baeckmann and Schweak, (1975); Agunloye, (1984). This substratum may however not be suitable to place earthing material because of the higher conductivity required. An introduction of a material of high conductivity such as clay is recommended for earthing purposes. Beneath this sand layer is a sandy-clay/clayey-sand layer with resistivity of 700 Ohms-m, extending up to a depth of 7 m. And this is further underlain by a clean sand unit of very high resistivity with unknown thickness and depth due to termination of electric current at this depth. Thus, 4 geoelectric layers can be identified, corresponding to lateritic top soil, clean sand, sandy layer (sandy-clay/silt) and clean sand with resistivity values (Ω-m) 735.7, 4559.2, 706.6 and 8774 respectively. The curve type is a 4-layer KH type represented by ρ1< ρ2> ρ3< ρ4 (Table 2). This implies a layer of higher resistivity beneath the top soil, which can be considered suitable for foundation depth. Below this is a lower resistive material and lastly a layer of higher resistivity. Except for the need for introduction of a conductive material (e.g. clay) at the point and depth (typically less than 4 m) where earthen material is required, the preponderance of sand at this depth and location, suggests a layer of high bearing capacity (Oloruntola *et al*., 2018), low compressibility (Oloruntola *et al*., 2020), practically non-corrosive (Akintorinwa and Adesoji, 2009), low moisture and no swelling potential (Oloruntola *et al*., 2020) which are all desirable properties for a good foundation soil.



No	Res	Thick	Depth
1	735.7	0.5	0.5
2	4559.2	1.2	1.8
3	706.6	5.7	7.5
4	8774.0	-.-	-.-

* RMS on smoothed data

VES 1 (College of Health)
KH Curve type

Figure 5: VES1 Resistivity model Structure of subsoil within the College of Health Sciences, Prince Abubakar Audu University Campus

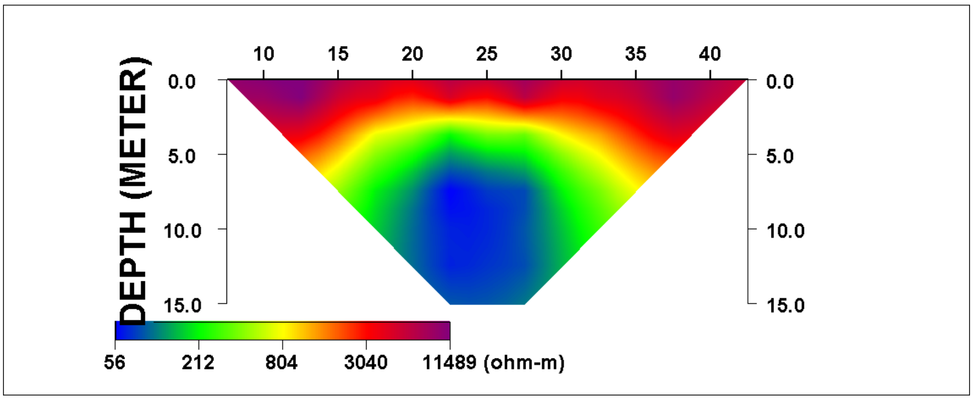


Figure 6: ERT 1, 2D – Resistivity Structure of subsoil within the College of Health Sciences, Prince Abubakar Audu University Campus

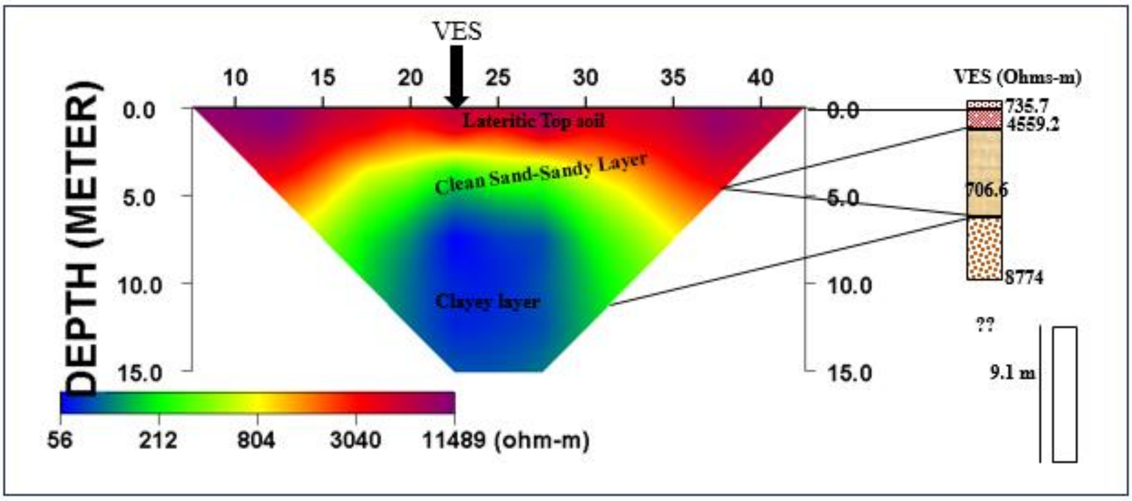
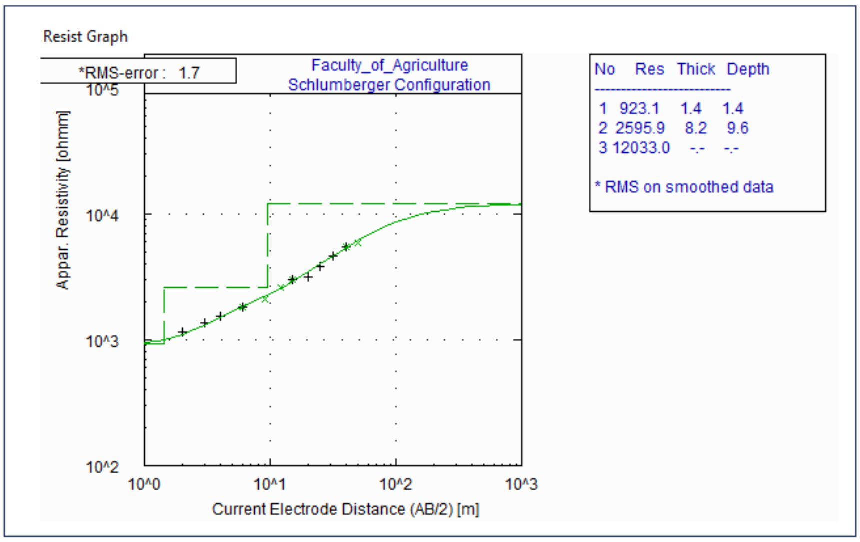


Figure 7: Integrated 2D – Resistivity Structure and geo-electric log of subsoil within the College of Health Sciences, Prince Abubakar Audu University Campus (ERT1, VES1)

ERT 2 and VES 2 (Faculty of Agriculture)

The 1D model, ERT model and combined models for ER2 and VES2 are presented in Figs. 8-10. The 2-D structure of ERT 2 and 1D model of VES 2 revealed a lateritic top soil of thickness of around 1 m with a resistivity > 900 m. This is also confirmed by the sample recovered sample from the trial pit. Beneath the top soil is a layer of high resistivity (> 1000 Ohms-m) extending up to an approximate depth of 10 m as shown by the 2D structure and VES model. This is interpreted as a sandy unit (clayey/silty sand). This layer is recommended to be the foundation depth for proposed buildings/structures. Although the tomography (2D) revealed that at about a depth of 15 m, there is a lens of clay unit, it is unlikely to pose any threat to the overlying foundation material because it is quite deeper than the possible depth of influence. The soil at the suggested foundation depth (2≥depth<10 m) classifies as competent for foundation and practically non corrosive as shown in Table 1. This substratum may however not be suitable to place earthen material because of the higher conductivity required. An introduction of a material of high conductivity such as clay is recommended for earthing purposes. Three, (3) geoelectric layers from the VES can be identified, corresponding to lateritic top soil, sandy layer (silty/clayey sand) and clean sand with resistivity values (Ω-m) 923.1, 2595.9, and 12033 respectively. The curve type is a 3-layer A type represented by ρ1< ρ2< ρ3 (Table 2). This implies a layer of higher resistivity beneath the top soil, which can be considered suitable for foundation depth. Below this is a layer of higher resistivity.



No	Res	Thick	Depth
1	923.1	1.4	1.4
2	2595.9	8.2	9.6
3	12033.0	-.-	-.-

* RMS on smoothed data

Figure 8: VES2, Resistivity model Structure of subsoil within the Faculty of Agriculture, Prince Abubakar Audu University Campus

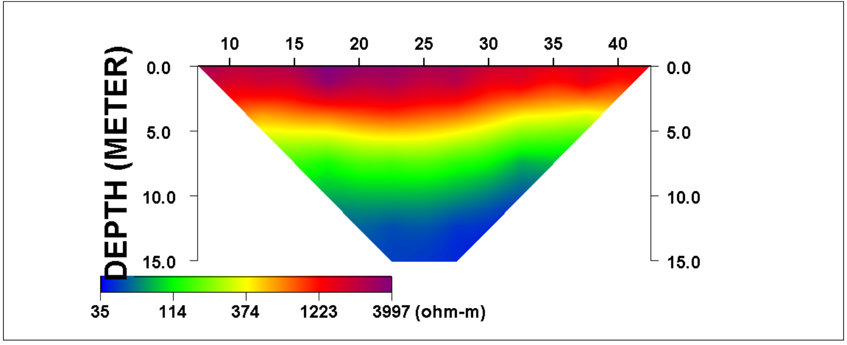


Figure 9: ERT 2, 2D – Resistivity Structure of subsoil within the Faculty of Agriculture, Prince Abubakar Audu University Campus

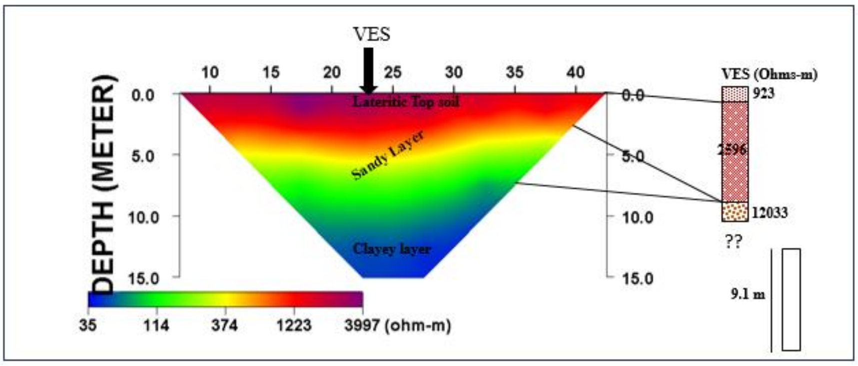
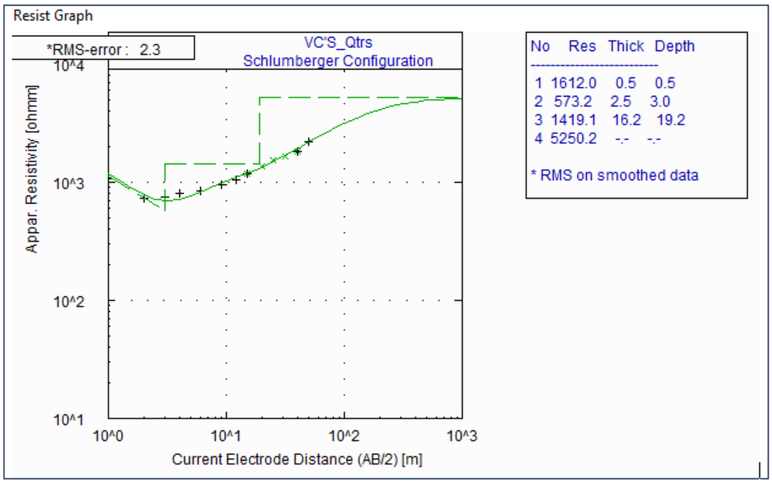


Figure 10: Integrated 2D – Resistivity Structure and geo-electric log of subsoil within the Faculty of Agriculture, Prince Abubakar Audu University Campus (ERT 2, VES 2)

ERT 3 and VES 3 (Vice-Chancellor's Quarters)
The 1D model, ERT model and combined models for ER3 and VES3 are presented in Figs. 9-11. The 2-D structure of ERT 3 and 1D model of VES 3 revealed a lateritic top soil of thickness of around 0.5 m with a resistivity > 1000 m. This is also confirmed by the sample recovered sample from the trial pit. Beneath the top soil are layers soils of resistivity values ranging from 500 – 1500 Ohms-m interpreted as sandy soils with varying amounts of fines (clays/silts), inferred as sandy silts/clay and silty/clayey sands at depths of 0.5 – 3 and 3 – 10 m respectively. This layer is recommended to be the foundation depth for proposed buildings/structures following Idornegie *et al.* (2006) classification. The tomography (2D) revealed pockets of clays between 5 and 10 m depth. This shows the feasibility of installing earthing materials at this depth due to lower resistivity (less than 100 Ohms-m) but higher conductivity (Akintorinwa and Adesoji, 2009). Interestingly, the VES could not reveal this layer possibly due to its small thickness and it's subsumed into the preponderant sandy unit. Also, because the VES is only showing the vertical variation in resistivity of the point sounded. Thus, it is a point test. By contrast, this limitation was overcome by the tomography as it reveals both vertical and horizontal variation in lithology. Four, (4) geoelectric layers from the VES can be identified, corresponding to lateritic top soil, sandy silt/clay, silty/clayey sand and clean sand with resistivity values (Ω-m) 1612, 573, 1419 and 5250 respectively. The curve type is a 4-layer HA type represented by ρ1 >ρ2< ρ3< ρ4. This implies a layer of lower resistivity beneath the lateritic top soil, due to admixture of clays and below this, are layers of sand with continuous increase in resistivity.



*RMS-error : 2.3

No	Res	Thick	Depth
1	1612.0	0.5	0.5
2	573.2	2.5	3.0
3	1419.1	16.2	19.2
4	5250.2	-.-	-.-

* RMS on smoothed data

Figure 11: VES3, Resistivity model Structure of subsoil within the Vice-Chancellor's Qtrs., Prince Abubakar Audu University Campus

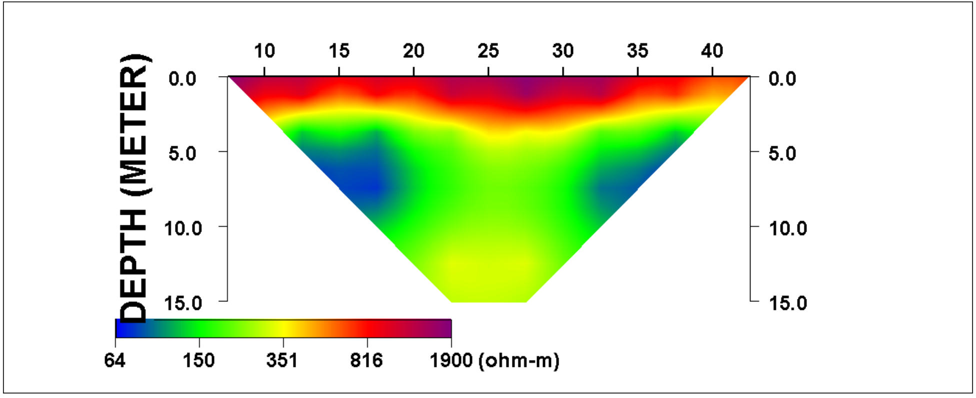


Figure 12: ERT 3, 2D – Resistivity Structure of subsoil within the Vice-Chancellor's Qtrs., Prince Abubakar Audu University Campus

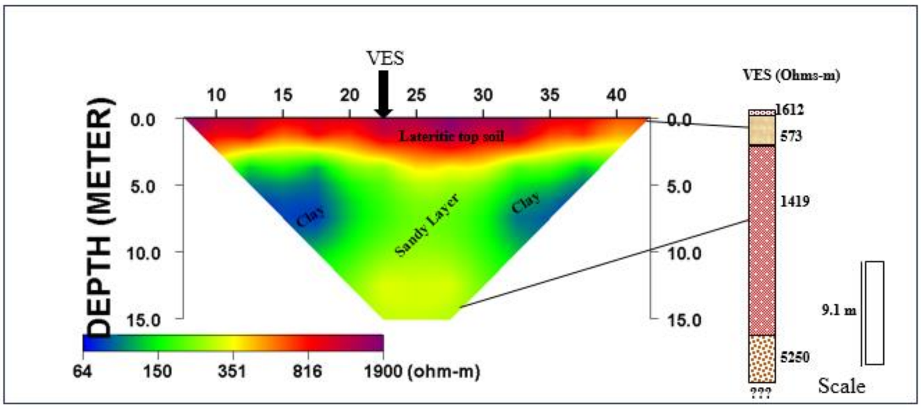
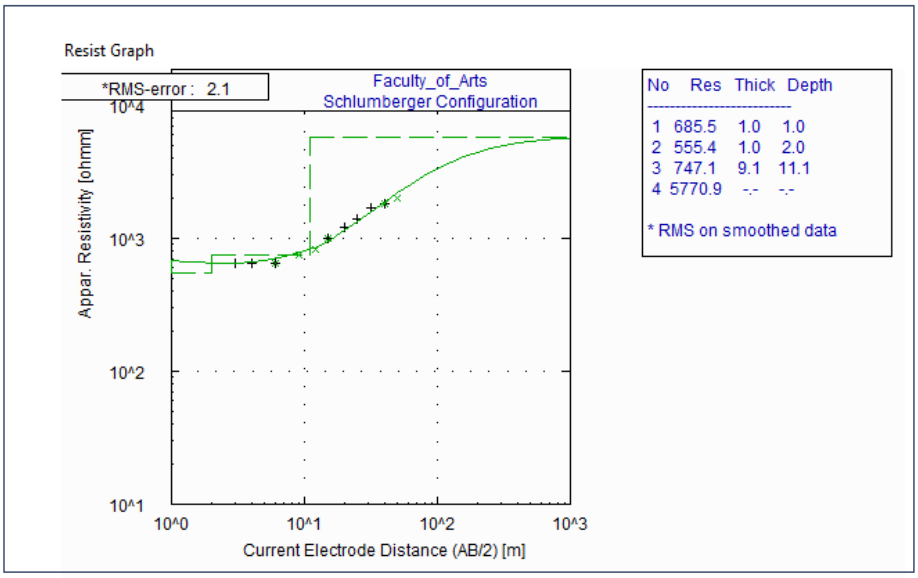


Figure 13: Integrated 2D – Resistivity Structure and geo-electric log of subsoil within the Vice-Chancellor's Qtrs., Prince Abubakar Audu University Campus (ERT 3, VES 3)

ERT 4 and VES 4 (Faculty of Arts)

The 1D model, ERT model and combined models for ER4 and VES4 are presented in Figs. 14-16. The 2-D structure of ERT 4 and 1D model of VES 4 show a very good agreement. The first layer is a lateritic top soil of 1 m thick with resistivity a resistivity > 600 Ohms-m. Varying resistivity values between 500 and 1000 Ohms-m characterised the sandy units that constitute the foundation soils extending up to a depth of 10 m. These layers are underlain by a clean sand zone of higher resistivity > 5000 Ohms-m. The VES reveals four, (4) geoelectric layers corresponding to lateritic top soil, sandy silt/clay, silty/clayey sand and clean sand with resistivity values (Ω-m) 685, 555, 747 and 5770 respectively. The curve type is a 4-layer HA type represented by ρ1 >ρ2< ρ3< ρ4 (Table 2). This implies a layer of lower resistivity beneath the lateritic top soil, due to admixture of clays and below this, are layers of sand with continuous increase in resistivity.



*RMS-error : 2.1

Faculty_of_Arts
Schlumberger Configuration

No	Res	Thick	Depth
1	685.5	1.0	1.0
2	555.4	1.0	2.0
3	747.1	9.1	11.1
4	5770.9	-.-	-.-

* RMS on smoothed data

Figure 14: VES4, Resistivity model Structure of subsoil within the Faculty of Arts, Prince Abubakar Audu University Campus

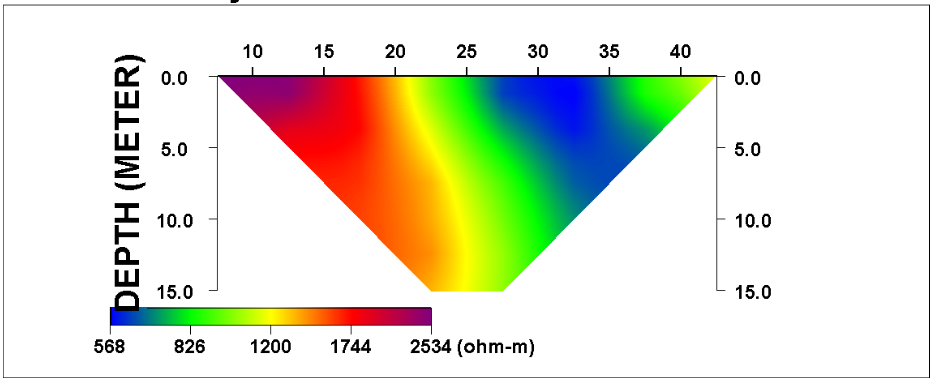


Figure 15: ERT 4, 2D – Resistivity Structure of subsoil within the Faculty of Arts, Prince Abubakar Audu University Campus

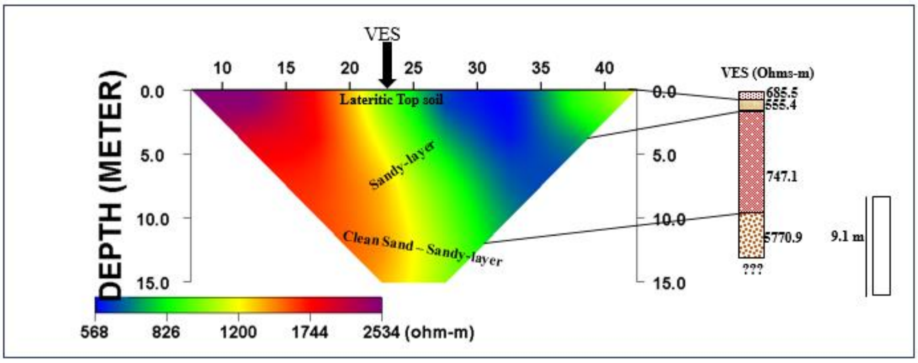
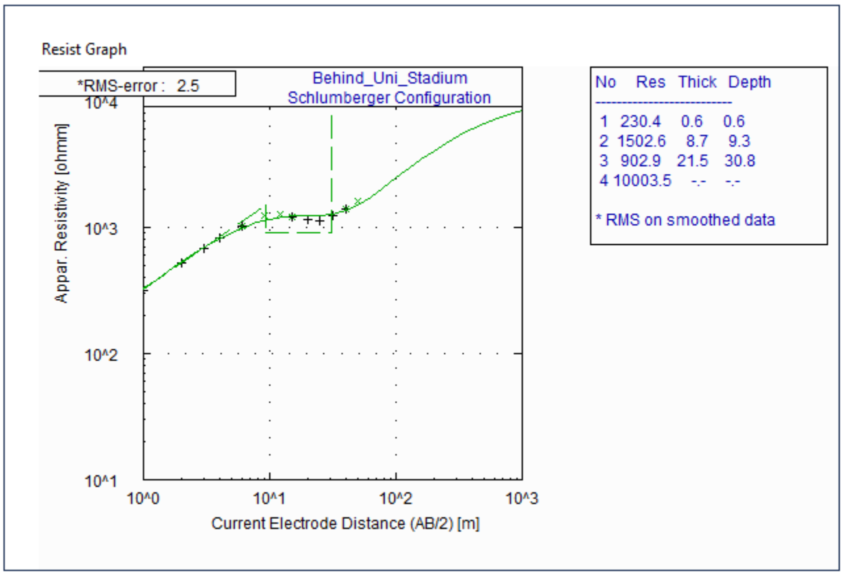


Figure 16: Integrated 2D – Resistivity Structure and geo-electric log of subsoil within the Faculty of Arts, Prince Abubakar Audu University Campus (ERT 4, VES 4)

ERT 5 and VES 5 (Behind University Stadium)

The 1D model, ERT model and combined models for ER3 and VES3 are presented in Figs. 17-19. The 2-D structure of ERT 5 and 1D model of VES 5 revealed a lateritic top soil of thickness of around 0.6 m with a resistivity > 230 Ohms-m. Beneath the top soil are layers soils of resistivity values ranging from 900 – 1500 Ohms-m interpreted as sandy soils with varying amounts of fines (clays/silts), inferred as silty/clayey sands and sandy silts/clay up to a depth of 15 m. These sandy units constitute the foundation soils. These layers are underlain by a clean sand zone of higher resistivity > 10000 Ohms-m. The VES reveals four, (4) geoelectric layers corresponding to lateritic top soil, silty/clayey sand, sandy silt/clay, and clean sand with resistivity values (Ω-m) 230, 1502, 902 and 10003 respectively. The curve type is a 4-layer KH type represented by ρ1 <ρ2> ρ3< ρ4 (Table 2). This implies a layer of higher resistivity beneath the lateritic top soil, followed by a lower resistivity substratum due to clay admixture and higher resistivity 4th layer.



```
No    Res   Thick  Depth
--------------------------
 1   230.4    0.6    0.6
 2  1502.6    8.7    9.3
 3   902.9   21.5   30.8
 4 10003.5    -.-    -.-

* RMS on smoothed data
```

Figure 17: VES5, Resistivity model Structure of subsoil behind the University Stadium, Prince Abubakar Audu University Campus

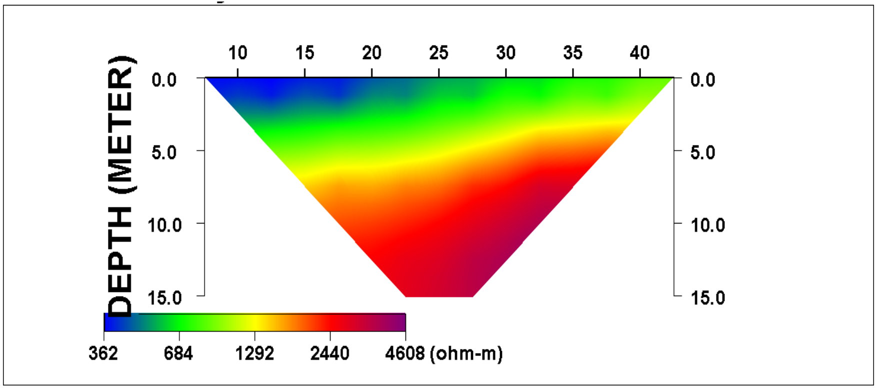


Figure 18: ERT 5: 2D – Resistivity Structure of subsoil behind the University Stadium, Prince Abubakar Audu University Campus

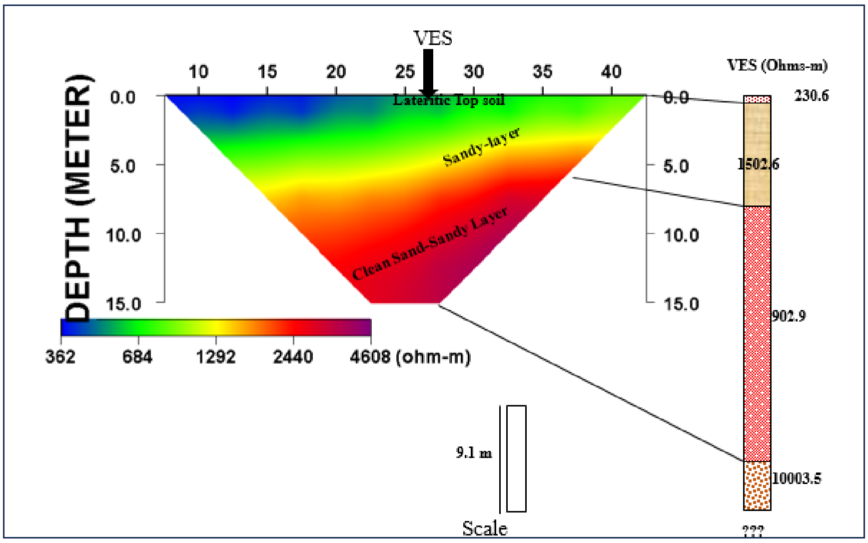


Figure 19. Integrated 2D – Resistivity Structure and geo-electric log of subsoil behind the University Stadium, Prince Abubakar Audu University Campus (ERT 5, VES 5)

Geotechnical Test

Cone Penetration Test (Bearing Capacity)

The cone penetration results are presented in Figures 20– 24. The results were used to obtain the bearing capacity of the subsoils at varying depth up to a maximum of 4 m. The bearing capacity represents the maximum stress which the soil can withstand beyond which it undergoes failure. Foundation soils were classified by standard codes (e.g., American Concrete Institute, 2019) based on their bearing capacity as high (≥ 200 kN/m²), medium (50 – 200 kN/m²), and low (< 50 kN/m²). The results were interpreted.to determine the category of building the soils can support in terms of light and medium load. The light and medium buildings represent 1-2 storey and 2-5 storey buildings respectively. Minimum bearing capacity values required for light (50 – 100 kN/m^2) and medium buildings (100 - 150 kN/m^2) were provided by Terzaghi, (1943) and Hansen (1970). The result of the calculation presented in this research work is applicable to a shallow foundation of a square footing, assuming a 2 meters width footing. Table 3 presents the results of the cone penetration test and bearing capacity of the soils at varying depths.

Table 3: Bearing Capacity of the foundation soils

<table>
<tr><th>Depth (m)</th><th colspan="4">CPT1</th><th colspan="5">CPT 2</th><th colspan="4">CPT3</th></tr>
<tr><th></th><th>Qc</th><th>Qa</th><th>Class</th><th>Building type</th><th>Qc</th><th>Qa</th><th>Class</th><th colspan="2">Building type</th><th>Qc</th><th>Qa</th><th>Class</th><th>Building type</th></tr>
<tr><td>0</td><td>0</td><td>0</td><td>Low</td><td>Unsuitable</td><td>0</td><td>0</td><td>Low</td><td colspan="2">Unsuitable</td><td>0</td><td>0</td><td>Low</td><td>Unsuitable</td></tr>
<tr><td>0.25</td><td>20</td><td>11</td><td>Low</td><td>Unsuitable</td><td>35</td><td>20</td><td>Low</td><td colspan="2">Unsuitable</td><td>25</td><td>14</td><td>Low</td><td>Unsuitable</td></tr>
<tr><td>0.5</td><td>20</td><td>13</td><td>Low</td><td>Unsuitable</td><td>40</td><td>25</td><td>Low</td><td colspan="2">Unsuitable</td><td>30</td><td>19</td><td>Low</td><td>Unsuitable</td></tr>
<tr><td>0.75</td><td>25</td><td>17</td><td>Low</td><td>Unsuitable</td><td>45</td><td>31</td><td>Low</td><td colspan="2">Unsuitable</td><td>45</td><td>31</td><td>Low</td><td>Unsuitable</td></tr>
<tr><td>1</td><td>35</td><td>26</td><td>Low</td><td>Unsuitable</td><td>50</td><td>38</td><td>Low</td><td colspan="2">Unsuitable</td><td>50</td><td>38</td><td>Low</td><td>Unsuitable</td></tr>
<tr><td>1.25</td><td>25</td><td>20</td><td>Low</td><td>Unsuitable</td><td>45</td><td>37</td><td>Low</td><td colspan="2">Unsuitable</td><td>45</td><td>37</td><td>Low</td><td>Unsuitable</td></tr>
<tr><td>1.5</td><td>30</td><td>26</td><td>Low</td><td>Unsuitable</td><td>70</td><td>61</td><td>Medium</td><td colspan="2">Light building</td><td>60</td><td>53</td><td>Medium</td><td>Light building</td></tr>
<tr><td>1.75</td><td>35</td><td>33</td><td>Low</td><td>Unsuitable</td><td>70</td><td>66</td><td>Medium</td><td colspan="2">Light building</td><td>75</td><td>70</td><td>Medium</td><td>Light building</td></tr>
<tr><td>2</td><td>45</td><td>45</td><td>Low</td><td>Unsuitable</td><td>120</td><td>120</td><td>Medium</td><td colspan="2">Medium building</td><td>110</td><td>110</td><td>Medium</td><td>Medium building</td></tr>
<tr><td rowspan="2">2.25</td><td rowspan="2">40</td><td rowspan="2">43</td><td rowspan="2">Low</td><td rowspan="2">Unsuitable</td><th colspan="5">CPT 4</th><th colspan="4">CPT5</th></tr>
<tr><th>Depth</th><th>Qc</th><th>Qa</th><th>Class</th><th>Building type</th><th>Qc</th><th>Qa</th><th>Class</th><th>Building type</th></tr>
<tr><td>2.5</td><td>40</td><td>45</td><td>Low</td><td>Unsuitable</td><td>0.25</td><td>15</td><td>Low</td><td>8</td><td>Unsuitable</td><td>15</td><td>8</td><td>Low</td><td>Unsuitable</td></tr>
<tr><td>2.75</td><td>45</td><td>53</td><td>Medium</td><td>Light building</td><td>0.5</td><td>20</td><td>Low</td><td>13</td><td>Unsuitable</td><td>15</td><td>9</td><td>Low</td><td>Unsuitable</td></tr>
<tr><td>3</td><td>50</td><td>63</td><td>Medium</td><td>Light building</td><td>0.75</td><td>25</td><td>Low</td><td>17</td><td>Unsuitable</td><td>25</td><td>17</td><td>Low</td><td>Unsuitable</td></tr>
<tr><td>3.25</td><td>75</td><td>98</td><td>Medium</td><td>Light building</td><td>1</td><td>25</td><td>Low</td><td>19</td><td>Unsuitable</td><td>40</td><td>30</td><td>Low</td><td>Unsuitable</td></tr>
<tr><td>3.5</td><td>80</td><td>110</td><td>Medium</td><td>Medium building</td><td>1.25</td><td>45</td><td>Low</td><td>37</td><td>Unsuitable</td><td>55</td><td>45</td><td>Low</td><td>Unsuitable</td></tr>
<tr><td>3.75</td><td>80</td><td>115</td><td>Medium</td><td>Medium building</td><td>1.5</td><td>50</td><td>Low</td><td>44</td><td>Unsuitable</td><td>60</td><td>53</td><td>Medium</td><td>Light building</td></tr>
<tr><td>4</td><td>120</td><td>180</td><td>Medium</td><td>Medium building</td><td>1.75</td><td>75</td><td>Medium</td><td>70</td><td>Light building</td><td>80</td><td>75</td><td>Medium</td><td>Light building</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>2</td><td>105</td><td>Medium</td><td>105</td><td>Medium building</td><td>110</td><td>110</td><td>Medium</td><td>Medium building</td></tr>
</table>

Qc = Cone penetrometer reading (kg/cm^2); Qa=Allowable bearing capacity (kN/m^2); Light building = 1-2 storey building; Medium = 3-5 storey building

CPT1 (Behind University Stadium)

The bearing capacity of subsoil at CPT1 within a depth of 0 – 2.5 m are less than < 50kN/m^2 (Table 3). These values are of low bearing capacity class and may not be suitable for any light or medium structure. However, the bearing capacity rose to a range of 50 – 100 kN/m^2 classified as medium and suitable for light building (1-2 storey) at a depth range of 2.75 – 3.25 m. A depth range of 3.5 – 4 m possess a higher bearing capacity within a range of 100 – 150 kN/m^2 and therefore able to support medium buildings such as 2-5 storeys. This depth range is composed of dense sand (Table 4 and Fig. 20). Foundation depth is recommended to be between 3 and 4 m for light and medium buildings using a 2 m width square footing. The CPT result is in agreement with the resistivity (ERT and VES) result.

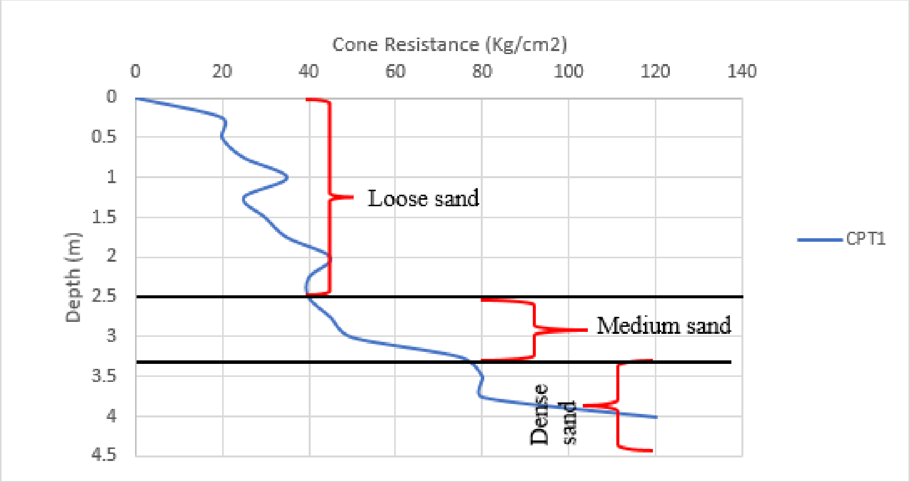


Figure 20: Cone resistance-Depth curve for College of Health Sciences

Table 4: Summary of CPT result and Inferred description

CPT	Location	Depth range (m)	Cone Resistance (Kg/cm^2)	Inferred description
CPT1	College of Health	0-2.5, 2.5-3.25, 3.25 - 4	0-45, 53-98, 110-180	Loose sand, Medium sand, Dense sand
CPT2	Faculty of Agriculture	0-1.25, 1.25-1.75, 1.7-2	0-37, 61-66, 100-120	Loose sand, Medium sand, Dense sand
CPT3	Vice Chancellor's Qtrs (VC's Qtrs)	0-1.25, 1.5-1.75, 1.75-2	0-37, 53-70,100-110	Loose sand, Medium sand, Dense sand
CPT4	Faculty of Arts	0-1.5,1.5-1.75, 1.75-2	0-44, 50-70, 100-105	Loose sand, Medium sand, Dense sand
CPT5	Behind University Stadium	0-1.5, 1.5-1.75, 1.75 - 2	0-45, 53-75, 100-110	Loose sand, Medium sand, Dense sand

CPT2 (Faculty of Arts)

The bearing capacity of subsoil at CPT2 within a depth of 0 – 1.25 m ranges between 0 - 37kN/m^2 (Table 3). These values are of low bearing capacity class (less than 50 kN/m^2) and may not be suitable for any light or medium structure. However, the bearing capacity rose to a range of 61 – 66 kN/m^2 classified as medium and suitable for light building (1-2 storey building; 50 – 100 kN/m^2) at a depth range of 1.5 – 1.75 m. A depth range of 1.75 – 2 m possess a higher bearing capacity within a range of 100 – 120 kN/m^2 and therefore able to support medium buildings (100 – 150 kN/m^2) such as 2-5 storeys. This depth range is composed of dense sand (Table 4 and Fig. 21). Foundation depth is recommended to be between 1.5 and 2 m for light and medium buildings using a 2 m width square footing.

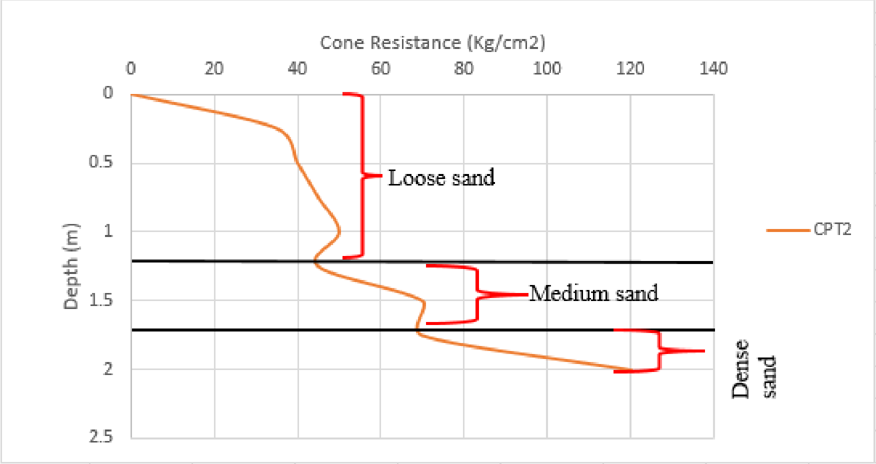


Figure 21: Cone resistance-Depth curve for Faculty of Agriculture

CPT3 (VC's Quarters)

The first 1.25 m of CPT3 have same range of bearing capacity (0 - 37kN/m^2) with and classified as low bearing capacity subsoils and thus unsuitable for any light or medium structure. However, the bearing capacity rose to a range of 53 – 70 kN/m^2 and hence to support light building (1-2 storey building; 50 – 100 kN/m^2) at a depth range of 1.5 – 1.75 m. A depth range of 1.75 – 2 m possess a higher bearing capacity within a range of 100 – 110 kN/m^2 and therefore able to support medium buildings (100 – 150 kN/m^2) such as 2-5 storeys. This depth range is composed of dense sand (Table 4 and Fig. 22). Foundation depth is recommended to be between 1.5 and 2 m for light and medium buildings using a 2 m width square footing.

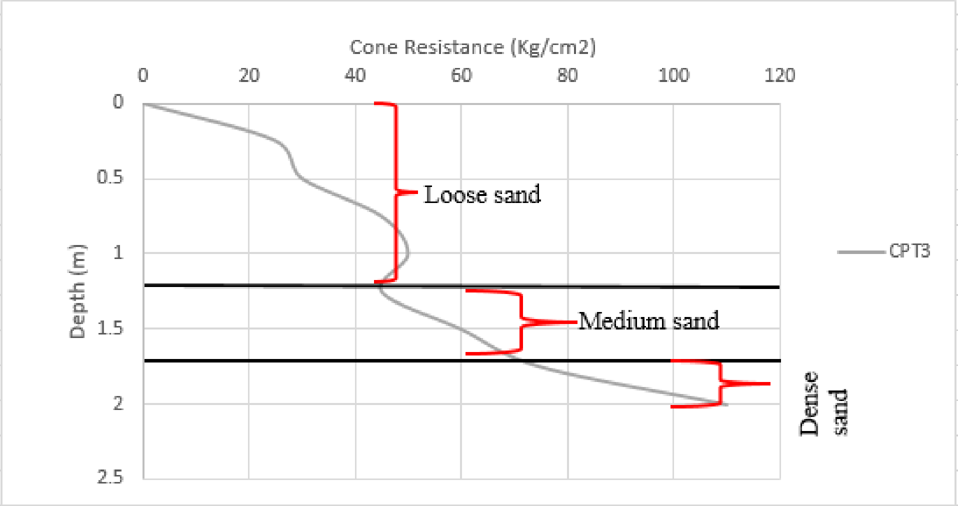


Figure 22: Cone resistance-Depth curve for Vice-Chancellor's Quarters

CPT 4 – Faculty of Arts

The subsoil within a depth of 0 – 1.5 m at CPT4 has a low bearing capacity of 0 – 44 kN/ m^2 and unsuitable for light and medium building foundation purposes at these depths. However, at a depth of 1.5 – 1.75 m. The bearing capacity increased to 70 kN/m^2 and can support light building (1-2 storey building). Medium size building (2 – 5 storey building) can be supported by the dense sand (Figure 23, Table 4) at the depth range of 1.75 – 2 m with a bearing capacity up to 105 kN/m^2. This foundation depth is recommended for light and medium buildings using a 2 m width square footing.

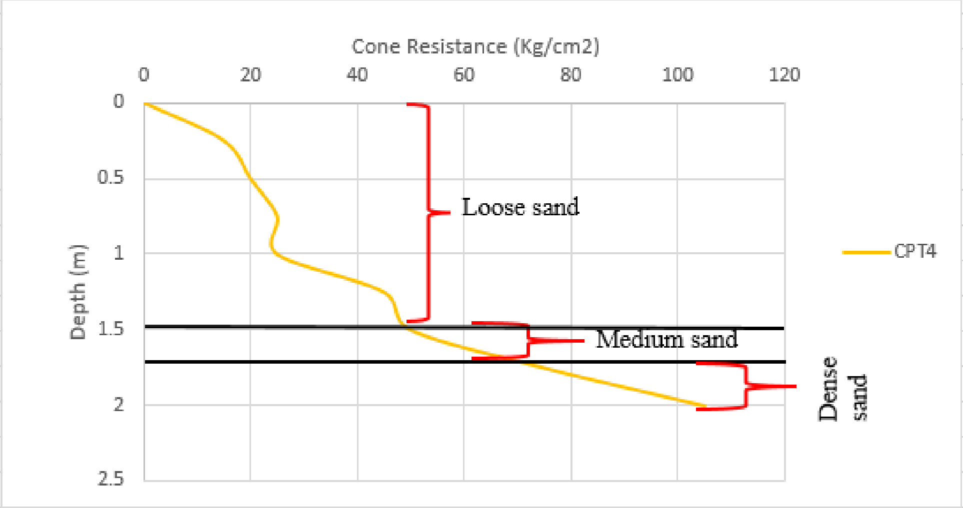


Figure 23: Cone resistance-Depth curve for Faculty of Arts

CPT5 (Behind University Stadium)

The bearing capacity of subsoil at CPT5 within a depth of 0 – 1.5 m ranges between 0 - 45kN/m^2. These values are of low bearing capacity class (less than 50 kN/m^2) and not suitable for light or medium structure. However, the bearing capacity rose to a range of 53 – 75 kN/m^2 classified as medium and suitable for light building (1-2 storey building; 50 – 100 kN/m^2) at a depth range of 1.5 – 1.75 m. A depth range of 1.75 – 2 m possess a higher bearing capacity within a range of 100 – 110 kN/m^2 and therefore able to support medium buildings (100 – 150 kN/m^2) such as 2-5 storeys. This depth range is composed of dense sand (Table 4 and Fig. 24). Foundation depth is recommended to be between 1.5 and 2 m for light and medium buildings using a 2 m width square footing.

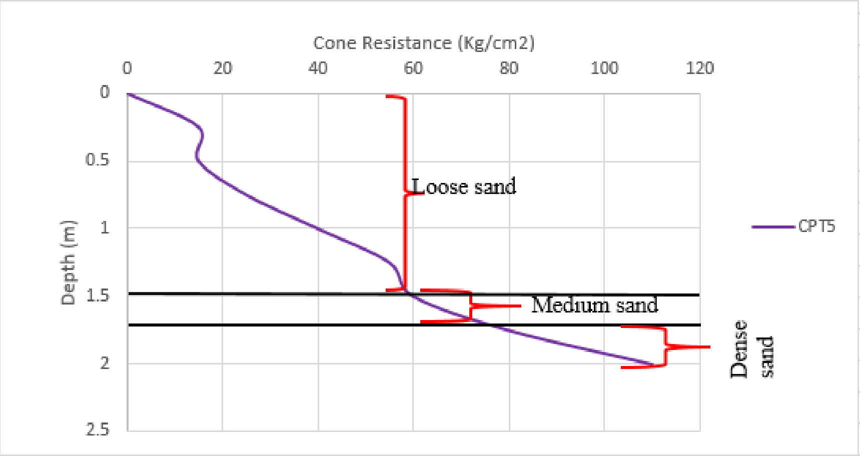


Figure 24: Cone resistance-Depth curve for location behind the University Stadium

CONCLUSION

This study has adopted the use of 2D resistivity (electrical resistivity tomography), vertical electrical sounding and cone penetration tests in order evaluate the subsoil suitability to hold light and medium buildings within the campus community of Prince Abubakar Audu University (formerly Kogi State University). This paper has presented the characteristic nature of the subsurface layers, depth to competent layer of the subsoils for university building expansion. The geophysical methods revealed that the area is made up of lateritic top soil, clayey/silty sand, sandy silt/clay and clean sand clay and sand units (competent) soils. The geotechnical tests further characterised the subsoils in to loose sand, medium sand and dense sand. The loose sand constitutes the problem soils in the area due to their low bearing capacity. They occur at depths 0 – 2.5 m at the college of health, 0 – 1.25 m at the Faculty of Agriculture, 0 – 1.25 m at the Vice Chancellor's quarters, 0 – 1.5 m at the Faculty of Arts and Behind University Stadium. Medium and dense sand occur at ≥ 2.75 m, ≥ 1.25 m, ≥ 1.25, ≥ 1.5 m and ≥ 1.5 m at the mentioned stations accordingly. And these depth ranges are recommended for installing foundation of a light (1-2 storey) to medium (2-5 storey) buildings using a 2 m width square footing.

Finally, it is suggested that depth of 2-4 m be used for the foundation of a light to medium building structure except at the college of health where a depth of ≥ 2.75 ≤ 4 m is recommended within the campus community.

The studies revealed that integrated geophysical and geotechnical investigations are effective in pre-foundation construction activities. The inclusion of Electrical Tomorgraphy (2D) particularly offered an advantage of rapidly imaging the subsurface laterally and vertically that aided decision making for geotechnical testing.

ACKNOWLEDGMENTS

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