



Geoelectrical and Geotechnical based-assessment of Subsurface Soil Electrical Earthing Property and Corrosive Vulnerability along Coker Village Road, Osogbo, Nigeria

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Abstract

This study integrates a geophysical and geotechnical approach to the subsurface soil along Coker Village Road located about 200 meters from the Osun State University, Main Campus gate in Osogbo, Southwestern Nigeria. This is with the aim of assessing the subsurface electrical earthing properties and the corrosivity of the soils within the study area. Twelve vertical electrical sounding (VES) surveys, one 2D Wenner profiling were collected, with four located 100 m apart from another four, while three cone penetration test measurements were collected at the midpoint of each of the four VES points to determine the in-situ shear strength properties. The VES data were interpreted using partial curve matching and later iterated using the DCInversion software, while the 2D Wenner profiling data were interpreted using the DiprofWin software. The corrosivity of the subsurface soil was inferred from appropriate classification ranges of resistivity values, while the cone penetrometer data were interpreted using the Microsoft Excel spreadsheet. The results of the investigation reveal that there exist four to five geoelectric layers that alternate between lateritic topsoil with a resistivity ranging from 424.7 Ωm to 819.9 Ωm , lateritic layer with a resistivity ranging from 290.5 Ωm to 512.3 Ωm , and sandy bedrock with resistivity ranging from 265.9 Ωm to 1205.5 Ωm . All the first three geoelectric layers occur to a depth of more than 5 meters, possess a high shear stress to support the hosting of the mast, do not possess reliable earthing properties due to the high resistivity of lateritic subsurface materials and are practically non-corrosive with resistivity values above 180 Ωm . The result of 2D Wenner profiling showed that the topmost part of the study area is composed of high resistance materials, that extend from a minimum depth of 4-5 meters to a maximum depth of up to 12

meters. This study demonstrates the efficacy of integrating geophysical, geological, and geotechnical approaches in obtaining more information about the subsurface condition of the soil in the studied area as opposed to using only one technique. The study recommends that a conductive earth medium be created by using clay or salt (brine) chambers within the study area so as to make electrical conduction continuous.

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1.0 Introduction

Earthing materials are critical in the generation, transmission, and distribution of electricity in order to ensure the safe and proper operation of any electric installation. These devices create a low-resistance channel for lightning discharges, preventing them from traveling through infrastructure. There are a variety of compelling reasons for earthing, but the fundamental one is to assure worker safety (Rhett, 2001; Akintorinwa and Adesoji, 2009). The electrical properties of earthing depend essentially on two parameters: the configuration of earthing electrodes and soil resistivity. Earthing electrodes maintain ground potential on all the connected conductors. This was used to dissipate excess charges into the ground. Geophysical techniques have been proven to be effective in resolving the resistivity of the subsurface of the earth, and so, they have found application in a wide variety of human development programs, including infrastructure development, electrical earthenings, hydrogeology, engineering, fundamental research, and environmental studies and planning (Barker, 1990; Pfeiffer, 2001; Ofomola *et al.*, 2009).

Geophysical applications of electrical resistivity methods are much more suitable when it comes to finding conductive media through which

earthing installations can be buried. The resistivity of the soil in which an earth electrode is driven has a significant impact on the resistance of the electrode, and as a result, soil resistivity measurements are an important element for planning earthing systems. The principle behind the use of the geophysical method to study the earthing properties of soil is based on the fact that subsurface soils have low resistivity portions as well as high resistivity portions. When lightning occurs in the atmosphere, excess electrical charges are released into the atmosphere. These charges pass through the atmosphere and also through any metallic or conducting medium into the earth. When inside the earth, the charges are supposed to meet a high conductive soils, through which the conduction of charges is continued. If the conduction of the charges is not made continuous into the earth surface, the charges are trapped in the low conductive (i.e., high resistivity medium) soils. As a result, the charges accumulate on infrastructure such as electrical masts, electric poles, and other electrical gadgets placed on highly resistive soils. This poses a lot of threat to lives moving on the surface around the electrical material. To ensure that lightning discharges don't pass through infrastructure, earthing devices must be installed in a low-resistance

path. To ensure that these devices are installed in a safe conductive medium, electrical safety regulations as regards the conductive medium, must be adhered to throughout strictly throughout their installation. Geophysical investigation also helps to understudy the subsurface soil's ability to undergo corrosion when planted. Geotechnical investigation, on the other hand, finds use in the determination of the soil strength to support the electrical gadget when planted.

A number of workers have discussed the significance of investigating the subsurface electrical and corrosive properties of rocks (Beackmann and Schweak (1976), LEM (2005), Megger (2005) and AEMC (2012). In Nigeria, Olayanju and Onaolapo (2015), Oladele *et al.* (2015), Akintorinwa and Adesoji (2009), Adejumo *et al.* (2015) and Oyedele and Olorode (2010) have also discussed the effects of clay on the electrical earthing properties of soil. The geotechnical properties of such soils are of great importance, especially in understanding the bearing strength of the soil when infrastructure is sited on them. Therefore, there is a need to understand the penetrating capability of infrastructure and the depth of a competent layer in such soils. Penetration devices cause minimal disturbance to the soil as a whole. The cone penetration test (CPT) for light soils and the standard penetration test (SPT) for reasonably hard soils are the most extensively used static and dynamic penetration tests (Baldi *et al.*, 1995). Cone resistance can be calculated as Q_c is the cone resistance of the soil at a certain depth, and it serves as a direct measure of the strength of the soil. A number of major factors contributing to the increasing popularity of CPT include its low cost, high efficiency, rapidity, simplicity, dependability, and ability to provide nearly continuous information on soil parameters with depth. q_c is of major importance because it

represents a small driven pile or foundation in soil; as a result, it may be used to directly estimate pile bearing capacity (the pressure between a foundation and the soil that will cause shear failure in the soil). As a result, the CPT provides essential restrictions for all settlement and stability calculations that are performed. Despite the fact that CPT gives significant information about the strength of the soil, the information is only available at the CPT site itself (Eslaamizaad *et al.*, 1998). CPTs are frequently conducted at intervals of tens or hundreds of meters. Soil models based on lateral interpolation of CPT data gathered at a few places at a specific site are bound to have substantial errors, which increases the risk associated with engineering design in the first place.

Most times, subsurface earthing property have been conducted using geophysical methods without taking into consideration the ability of the subsurface soil to hold the mast place and the vulnerability of the materials used to build the mast to corrosion. This has resulted in the loss of electrical mast to soil creep and rusting of the mast material. For a sustainable management of the electrical mast, a comprehensive study of all these properties is essential towards achieving a safe mast completion.

It is against this backdrop that this project is designed to employ geophysical methods and geotechnical methods to access the subsurface conditions along Coker Road, Oke-Baale, Osogbo where electrical mast infrastructure is to be sited. Geophysical method is able to provide information about the conductive ability of the subsurface rock as well as the Corrosivity vulnerability for a suitable down conductor grounding systems (Beackmann and Schweak, 1976; LEM, 2005; Megger, 2005; AEMC, 2012) while geotechnical method provides information about the ability of the subsurface material to

hold the mast within the shallow subsurface. In this study, vertical electrical sounding (VES) and cone penetration test (CPT) were employed to investigate the subsurface earthing and corrosive property of the study area by delineating the subsurface geological sequence, determining the geo-electric parameters, determining the geotechnical penetrative potential, bearing capability of the soil in the study area, the depth to competency and assessing the suitability of the subsurface soil within the study area for installation of earthing.

2.0 Location of the Study Area

The study area is located at Coker Village, Osun State University Main Campus, Oshogbo, southwestern Nigeria. It is situated within latitudes $07^{\circ} 46' 025''\text{N}$ and $07^{\circ} 47' 03''\text{N}$ and longitudes $E004^{\circ}36'005'$ and $E004^{\circ} 37' 435''\text{E}$. Coker Village is within Oke Baale District,

Osogbo Local Government Area, Osun State, Nigeria (Figure 1). The study area is generally accessible using minor roads and footpaths, and can be characterised by a dispersed type of settlements with several hundred houses. Coker Village has a population of 860, with farming and cattle rearing being the major occupations of the inhabitants. The study area is characterized by a relatively low to moderate relief. Most of the rocks in the study area are slightly exposed. The study area is drained by a major river. The River Osun and its tributaries, which flow into many smaller streams that are dry for many months, especially from November to May. The drainage pattern typical of the study area is mostly dendritic, which is controlled by the structures and local geology of the study area.

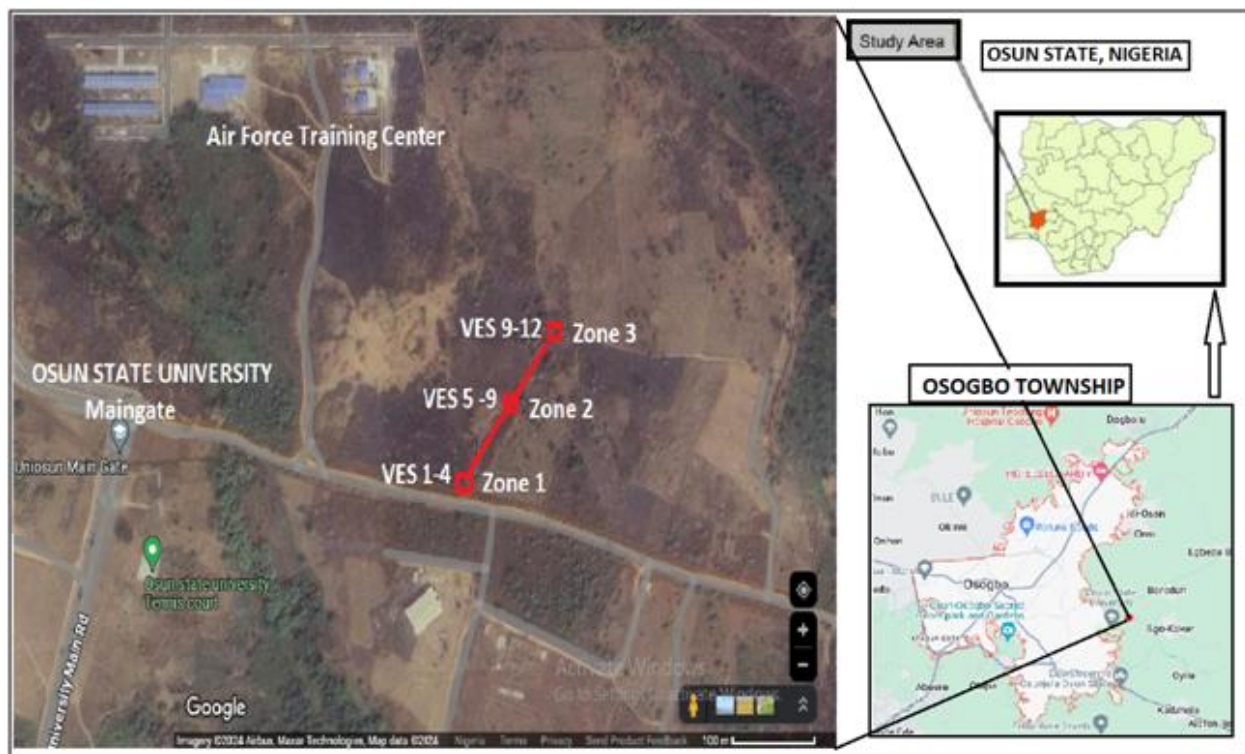


Figure 1: Location Map of the Study Area showing the positions of the VES point within the Basement Complex of Osogbo, Nigeria (adopted from Obaje, 2009)

2.1 Geology and tectonic setting of South western Nigeria

Geologically, the study area belongs to the migmatite-gneiss of the quartzite zone that falls within the Basement Complex of Southwestern Nigeria and was formed during the Pan African reactivation event of 600 ± 150 mya (Alabi *et al.*, 2016). Tectonically, the origin of the basement complex has been linked with three geologic events, which include, one, the commencement of processes that led to the formation of the crust in the Early Proterozoic (2000 Ma) typically noticed in Ibadan (Southwestern Nigeria) and the formation of grey gneisses (Woakes *et al.*, 1987) directly derived (Figure 2). It also resulted in the emplacement of granites during the Early Proterozoic (2000 Ma) and finally the Pan African orogenic event between 450 Ma and 750 Ma (Rahaman and Ocan, 1978). These were concluded based on geological field mapping reports over ten evolutionary events within the basement complex, with the emplacement of dolerite dykes as the youngest. However, Oyinloye (1998 and 2011) has been able to review and modify the work of Burke *et al.* (1976), which borders sequence of evolutionary events in the Southwestern Nigeria basement complex. A greater proportion of the top soil in the study area is lateritic soils, which is usually formed as a result of the weathering of parent sedimentary rocks (limestone), metamorphic rocks (schists, gneisses, migmatites), and igneous rocks (granites, basalts, gabbros, and peridotite). In this case, the lateritic soils are formed as a result of the weathering of metamorphic rocks (schists, gneisses, and migmatites), leaving the more insoluble ions, which are predominantly iron and aluminium. Hence, lateritic soils are rich in aluminium and iron and they are commonly associated with tropical environments, especially in the complex basement terrains of Nigeria. The

predominant major local rock type in the vicinity of the study area is composed of schist and banded-gneiss. Most of the rocks in the study area are slightly exposed. The study area is drained by a major river, the River Osun and its tributaries, which flow into many smaller streams, that are dry for many months, especially from November to May. The drainage pattern typical of the study area is mostly dendritic and is controlled by the structures and local geology of the study area.

The average yearly relative humidity is about 80%. There is rainfall for about eight months of the year, and the annual rainfall figure ranges from 1200 to 1500 mm per year, peaking in the month of September. The mean annual rainfall is about 1300 mm. Rainfall is mainly cyclonic, with double maxima in June/July and September/October. Due to the high intensity of solar radiation and high humidity conditions, convectional rainfall is also common. The temperature is generally high all through the year, ranging from 27°C to 32°C with the maximum temperature recorded around April (United Nations Human Settlements Programme, 2014). The vegetation is typical of the tropical rain forest in Nigeria, with vegetation of many varieties of hardwood timber, climbers, heterogeneous trees of the hardwood genre and bamboo thickets. This research work was carried out off the road leading to Coker community, Osogbo, which is situated about one kilometers away from the main campus gate of Osun State University, Osogbo, Southwestern Nigeria.

3.0 Materials and Methods

The investigation involved the division of the study area into three zones with four (4) VES soundings each, arranged in the form of 5 x 5 meter squares, with one zone separated from the other by 100 meters. Twelve (12) vertical electrical soundings, four at each VES location,

were collected using the ABEM SAS 1000 resistivity meter. The Schlumberger technique of the electrical resistivity method was employed over a total electrode spacing of 100 and 120 meters. A single 2D Wenner profiling survey was carried out on the traverse to pass through the entire length of the traverse. The objective is to be able to geoelectrically image a shallow subsurface depth of not up to 30 meters, upon which the electrical mast would be implanted. A plot of $AB/2$ (m) versus apparent resistivity (ρ) was made, and the result was first interpreted by partial curve matching and later iterated using the DC Inversion software. Twelve resistivity curves were obtained after a number of iterations until the model generated for all the VES curves was totally resolved with a minimum root mean square (RMS) error ($\leq 1\%$). The iterative curves were used to deduce the geo-electric parameters such as the true resistivity and true thickness of the geoelectric layers. These were employed to infer the lithology based on average lithology resistivity obtained from Southern part of Nigeria (Table 1). Three (3) cone penetrative tests (CPT)

were carried out at the intersection of the two diagonals that bisect the four VES points using the cone Penetrometer instrument. The use of the cone penetration test in this study is due to the presence of soft unconsolidated materials in the shallow subsurface in the investigated site. CPTs were performed at three the centre of the diagonal that bisects the four VES points at each zone. They are chosen so as to have geotechnical information that would serve to constrain the interpretation of geophysical data, especially since there is no borehole data within the study area to determine the strength of subsurface materials. Several blows of the hammer were applied at the rates of $0-20 \text{ kg/cm}^3$, $0-40 \text{ kg/cm}^3$, $0-100 \text{ kg/cm}^3$ and $0-120 \text{ kg/cm}^3$. A plot of the penetrative blows against the depth of penetration was generated, and this plot is correlated with the geoelectric layers of each zone. The resistivity of the first geoelectric layers was also used to predict the degree of corrosivity of each zone and the effect of the overall corrosivity on the electrical gadget installed.

Table 1: Range of Resistivity Values of Soil Samples in South Western Nigeria

Soils	Resistivity Values (Ωm)
0 - 50	Clay
60 - 150	Sandy clay or Unconsolidated laterite
160 – 220(240)	Clayey sand or Consolidated Laterite
250 – 450 (500)	Compacted Laterite
500 - 700	High density laterite
800 above	Basement Rock

4.0 Results and Discussion

The summary of the percentages of resistivity curve types delineated in the study area is as shown in Table 2, while the summary of the geoelectric parameters and inferred lithology interpreted from the field data is as shown in Table 3. Figure 2 represents the iterative curve of the VES 1 to VES 4 resistivity data, while Figure 3 is the geoelectric section of VES 1 to 4 in Zone

1. In the same vein, Figure 4 represents the iterative curve of VES 5 to VES 8 interpreted data while Figure 5 represents the geoelectric section of VES 5 to VES 8 in Zone 2. Similarly, Figure 6 shows the combined iterative curves for all the VES 9 to VES 12 in Zone 3 while the geoelectric section generated for the same VES points in this zone is as shown in Figure 7. The plot of the number of blows versus the subsurface

strength using the cone penetrative test correlated with the geoelectric column (in red) in each of the zones 1 to 3 is as shown in Figures 8 to 10. Figures 8 to 10 also describe the correlation between the geoelectric and lithological sequence of the shallowest region in each of the three zones. Table 3 represents the classification table for the degree of corrosivity of subsurface rocks with regards to resistivity values.

4.1 Geoelectric Section of VES Points in Zone 1

The root mean square (RMS) errors for the analysis were found to be very low, with an average of 0.3 % in all VES points. This underscores the reliability of the analysis and interpretation tools used for this study. Six different types of resistivity curves were observed to predominate in the study area. These include HK, HA, QHA, QH, and AK. The curve types obtained during electrical soundings over a horizontally stratified earth are indicative of the number of layers as well as the electrode configuration adopted (Zohdy *et al.*, 1974).

Table 2: Frequency and percentage of resistivity curves delineated in the study area

S/N	Curve types	Frequency	VES points	Percentage (%)
1	HK	4	1,2,3,4	33.3
2	HA	2	5,8	16.6
3	QHA	3	9,10,12	25.0
4	QH	2	7,11	16.6
5	AK	1	6	8.33

Generally, high resistivity materials overlie the VES stations. The implication of this is that these rocks may not serve as good electrical earthing materials as they would not conduct electrical charges within the soil. Most times, subsurface layers up to $> 180 \Omega\text{m}$ are considered to possess moderate resistivity, while resistivity $> 300 \Omega\text{m}$ is considered high. These two extremes may not serve as good electric earthing materials (Akintorinwa and Adesoji, 2009). The iterative curves of VES 1 to 4 are as shown in Figures 2, while the geosection through VES 1 to VES 4 is as shown in Figure 3.

The VES curves observed in Zone 1 were observed to be HK in VES points 1- 4, all having four (4) geo-electric layers delineated. The topmost layer is the topsoil, with a resistivity value of $474.5 \Omega\text{m}$ and a thickness and depth of 2.59 meters. The second geo-electric layer has resistivity, thickness and depth of $290.5 \Omega\text{m}$, 0.46 m, and 3.28 m respectively. Lithologically, the

topsoil is interpreted to be a lateritic deposit sitting conformably on top of a clayey sand interval. The clayey sand interval is sitting on a basement rock about 16.35 m thick with an in-situ resistivity value of $1202.4 \Omega\text{m}$. However, below the basement rock is a sandy layer, probably constituting the weathered layer with a resistivity of $268.1 \Omega\text{m}$, which continues downward. (Figure 3). The resistivity values observed within the topmost layer in Zone 1 vary from as low as $474.5 \Omega\text{m}$ in VES 1 to as high as $819.9 \Omega\text{m}$ in VES 4. These values were assumed to be made of highly resistive concretionary lateritic topsoil with thickness values as thick as 7.91m. This implies that since the mast's installation depth is usually between 2 to 4 m deep, the lower bottom of the mast would be buried within the high resistive lateritic layers. The layer underlying this lateritic topsoil is composed of lateritic sand in some places (VES 1-3), while in VES 4, it is interpreted to be a

laterite layer with no sand intercalation. This layer is sitting conformably on top of a basement rock of very high resistivity that is all far above 1000 Ωm . Although, the subsurface condition at this point is strong and competent enough to support the siting of an electrical mast to a depth of 2.59 meters thick in the lateritic first layer and continue to about 3.28 meters, a depth that represents the top of the competent basement rock, it is not advisable to site a mast because of the high resistivity of topsoil; as it would retain electric charges.

4.2 Geoelectric Section of VES Points in Zone 2

The resistivity curves observed in this zone are HA-type, AK-type, and QH-type curve, most of which are iterated with RMS error of 0.07%. Four (4) geo-electric layers were also delineated, with the first layer constituting the lateritic topsoil with concretionary evidence in VES 5, 7 and 8. The resistivity values of these topmost layers were observed to be 622.1 Ωm in VES 5,

424.7 Ωm in VES 6, 715.8 Ωm in VES 7 and 655.0 in VES 8. The first layer has thicknesses that range from 1.96 meters in VES 6 to 11.49 meters in VES 8, 11.36 meters in VES 5 to 15.10 meters in VES 7.

The resistivity values observed in the second and third geo-electric layers of VES 5 were 240.1 Ωm , and 418.7 Ωm , respectively. However, the second layer is very thin and of an average of about 0.42 meters thick while the third layer is continuous into the subsurface (Figure 4(a)). In VES 6, second and third layer resistivity values are about 278.8 Ωm and 399.2 Ωm respectively. These two were interpreted to be composed of sandy material with small amount of laterite. This implies that the entire VES 5 is underlain by lateritic materials of high resistivity. Hence, the point is competent enough to support the electrical mast but would not be suitable for electrical earthing.

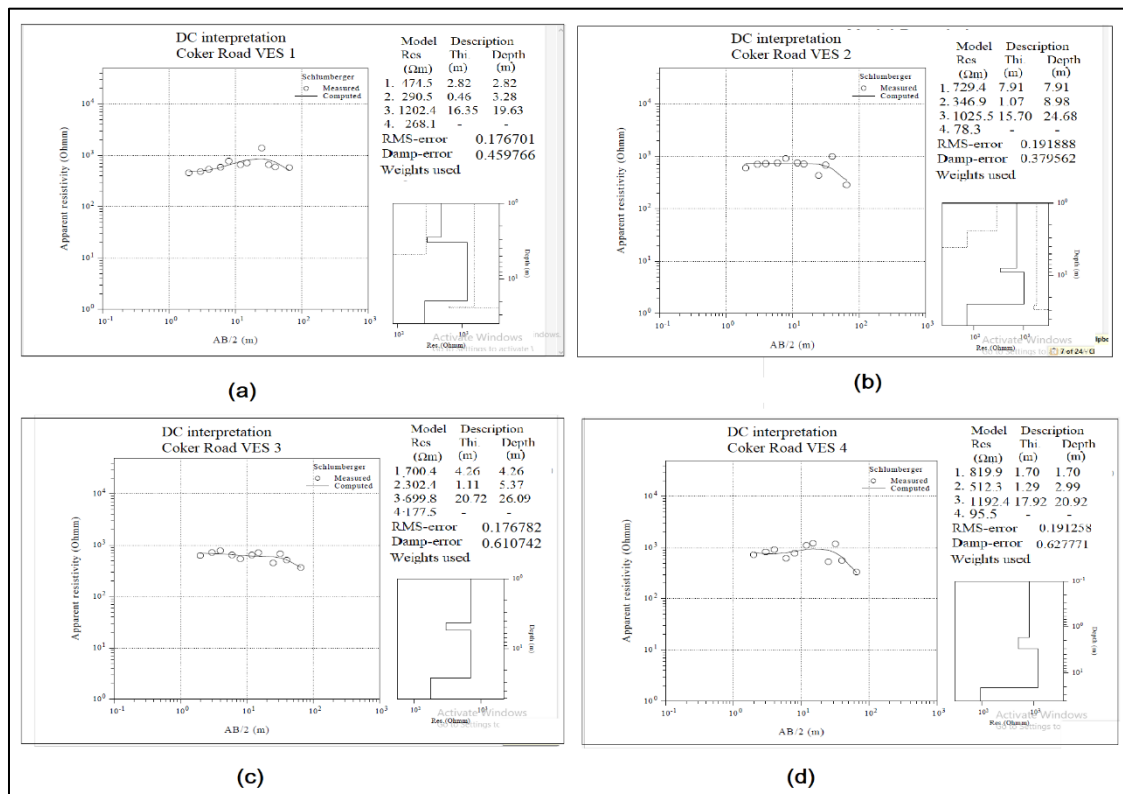


Figure 2: Iterative curves of VES 1- 4are as shown in a – d, respectively

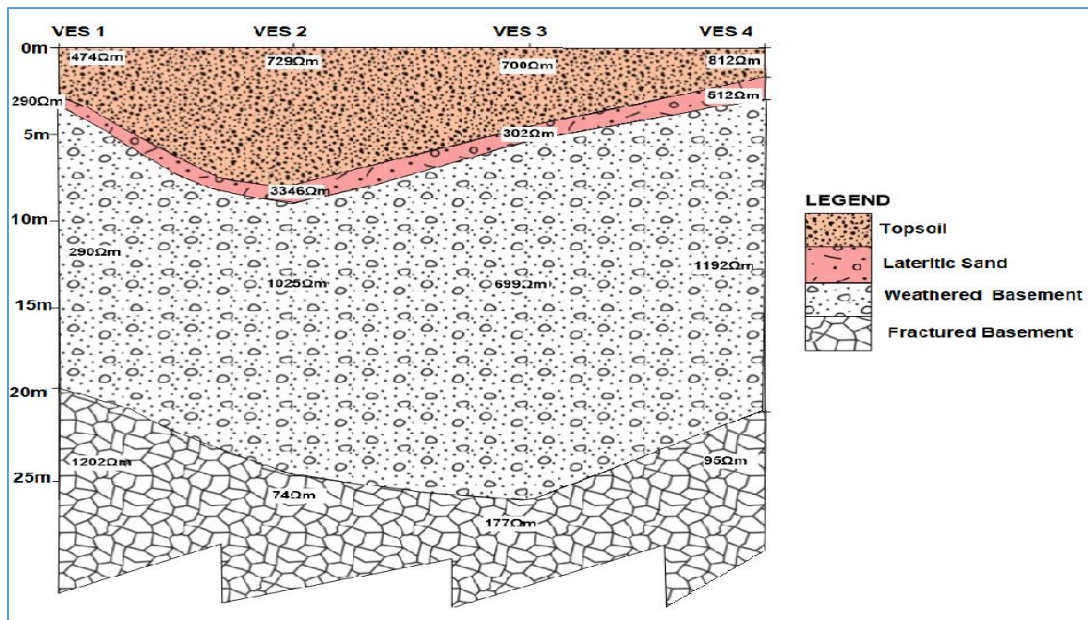


Figure 3: Geoelectric Section through VES 1- 4

However, the last geo-electric layer has a resistivity of $418.7\Omega\text{m}$ with an undefined thickness and depth. Lithologically, the entire three geo-electric layers was inferred to be composed of lateritic material. The high resistivity of these lateritic layers are high enough to hold the mast in place at the required depth, but the resistivity values are so high that they do not possess good earthening property. In VES point 7, the resistivity curve delineated revealed a QH-type with RMS error of 0.04%. Four (4) geo-electric layers were delineated showed that the topsoil is underlain by concretionary topsoil with a resistivity value of $715.8\Omega\text{m}$, thickness, and depth of 15.78 m while the second geo-electric layer has resistivity, thickness and depth of $345.4\Omega\text{m}$, 1.67 m, and 16.77 m, respectively. The third geo-electric layer has resistivity, thickness and depth of $265.9\Omega\text{m}$, 19.85 m and 36.62 m respectively. The third layer is inferred to be a sandy layer with little lateritic content. The last layer is also a lateritic layer of about $653.0\Omega\text{m}$ with an undefined thickness and depth (Figure 4(c)). The high resistivity of the first two geo-electric layer upon

which the feet of the mast would be emplaced possess high enough resistivity value to hold the mast in place but the resistivity values are so high that they do not possess good earthening property. In VES 8, the resistivity curve showed an HA-type with RMS error of 0.21%. The first of the three geoelectric layers is the topsoil with resistivity value of $655.0\Omega\text{m}$, thickness and depth of 11.49 m while the second geo-electric layer has resistivity, thickness and depth of $319.3\Omega\text{m}$, 1.85 m, and 13.34 m respectively. However, the third and the last geo-electric layer has resistivity value of $415.2\Omega\text{m}$ and an undefined thickness and depth (Figure 4(d)). The thickness of the first layer occurs at a depth of 11.49 meters, hence, mast emplacement would be possible at a reasonable depth within the first layer, but the resistivity values are so high that they do not possess good earthening properties. Hence, it would not conduct excess electric charges within the soil matrix, which may pose a potential source of hazards. Low resistivity topsoil is needed to maintain a continuous, unhindered flow of electrical charges. The

geosection of VES soundings in the second zone is as shown in Figure 5.

4.3 Geoelectric section of VES Points in Zone 3

The resistivity curves delineated at VES point 9, 10, 11 and 12 are QHA-type, QHA-type, QH-type and QHA type curve, all with RMS error of 0.25%, 0.21%, 0.21% and 0.21%. respectively. Five (5) geo-electric layers were delineated with VES point 9, 10 and 12 but VES 11 had four geoelectric layers. The first layer constitute the lateritic topsoil with resistivity value that vary from 535.9 Ωm to 601.0 Ωm . (See Figure 6 a,b,c and d). This layer is underlain by a laterite layer of resistivity value that range from as low as 443.1 Ωm in VES 1 and 441.1 Ωm in VES 2; this resistivity values correspond to the average value of strongly consolidated lateritic material. This layer continues into the subsurface. This geoelectric layer is generally thick across the VES points, as the thickness vary between 6.63 meters in VES 9 and 12.62 meters in VES 12. Below this layer is the clayey sand layer of average thickness of 13.18 meters and resistivity value of 128.4 Ωm in VES 9, 187.8 Ωm in VES 10, 131.9 Ωm in VES 11 and 153.0 Ωm in VES 12. A weathered layer overlie the basement in this zone 3 and also constitute the aquitard having negligible groundwater due to its high resistivity. The basement rock underlain this interval and continues downward into the subsurface as the oldest strata. The geoelectric section of VES sounding in Zone 3 is as shown in Figure 7.

Lithologically, the entire five geoelectric layers in all the VES points are inferred to be composed of lateritic top soil, lateritic layer, clayey sand layer, weathered layer and basement rock respectively. The high resistivity values of these lateritic layers are high enough to hold the mast in place but the

resistivity values are so high that they do not possess good earthing property. Hence, the geoelectric layers would retain excess charges within their matrices. As a result, it may pose a potential source of hazard. Low resistivity topsoil is needed to maintain a continuous unhindered flow of electrical charges. The geosection of VES soundings in the second zone is as shown in Figure 5.

4.4 Results of Cone Penetration Tests

The CPT curves obtained in the study area are shown in Figure 8 to 10. Cone penetration tests were performed at three (3) locations at the intersection of the diagonal that divide alternate corners of the four VES points at each zone. The tests were carried out to a depth of 2.0 m, a depth that is assumed to be reasonable for the emplacement of the feet of the electrical mast. Usually, the subsurface material upon which any electrical mast must be emplaced must be strong enough to support the superstructure. As a result, cone penetration test (CPT) carried out is with a view to determine the depth to which the equipment could penetrate before encountering the very competent layer.

At the middle of the first four VES points, the first cone penetrating test (CPT 1) has penetrative resistance from 0 - 10 kg/cm^2 first at a minimum penetration depth of 0.2 m but increased to 50 kg/cm^2 at a depth of 0.3 m (Figure 8). Later, it increased to a penetrative resistance of 0 - 45 kg/cm^2 at a depth of 0.4 m and finally a penetrative resistance from 0 - 100 kg/cm^2 , a depth of 1.3 meters. This indicates the presence of materials of high penetrative resistance a depth of 1.3 meters. The maximum penetrative resistance of 0-100 kg/cm^2 was observed continuously to a depth of 1.4 meters deep.

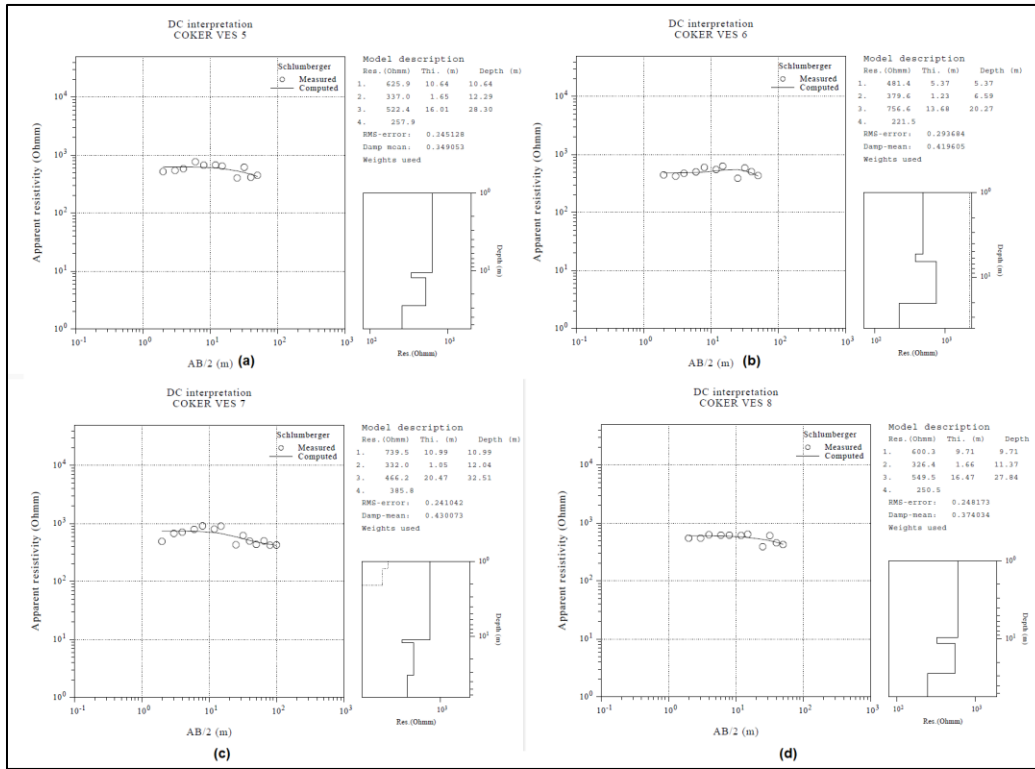


Figure 4: Iterative curves for VES 5 - 8 are as shown in a – d respectively

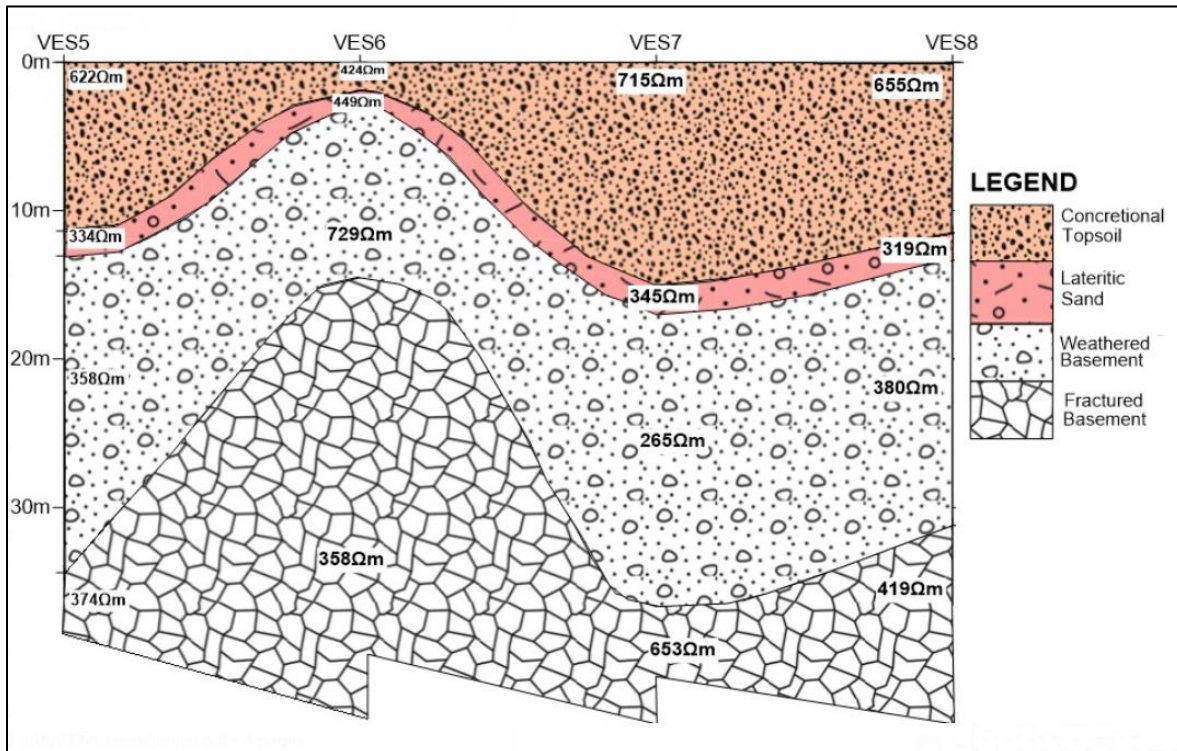


Figure 5: Goelectric Section through VES 5, 6, 7 and 8

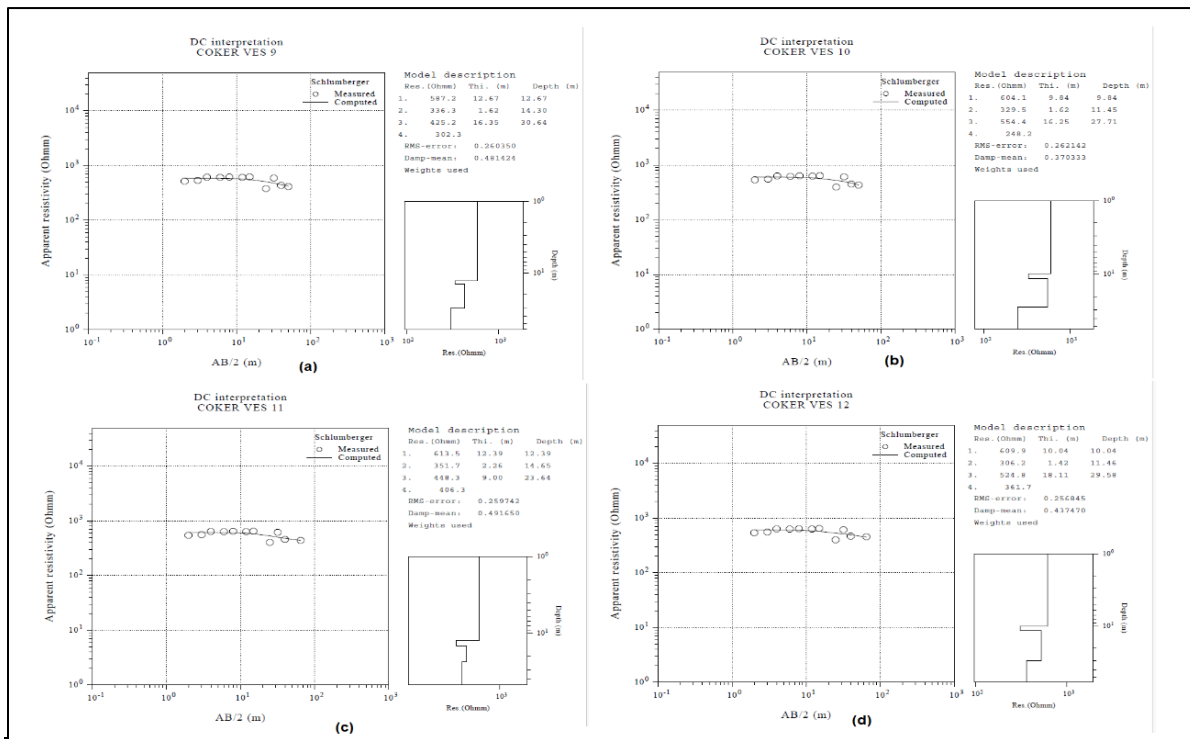


Figure 6: Iterative curves of VES 9 –12 are as shown in a – d respectively

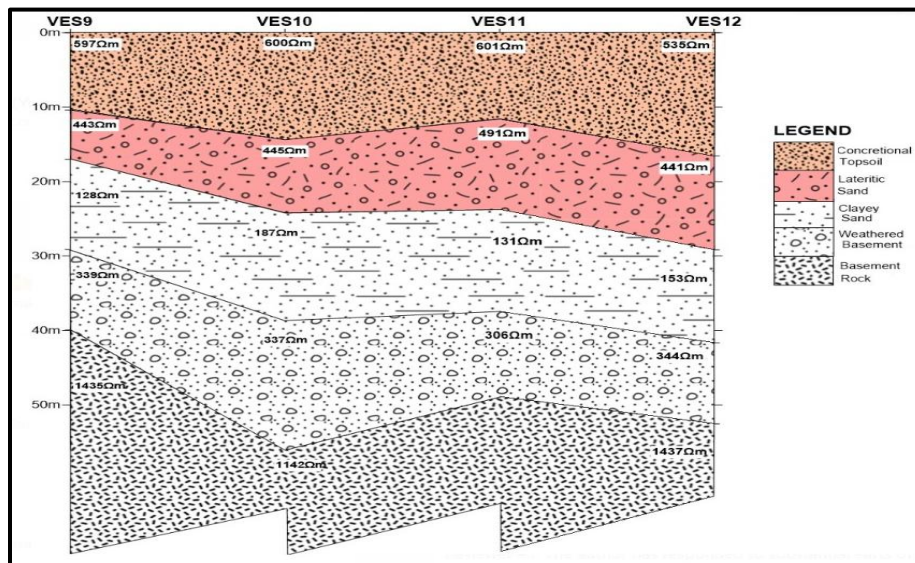


Figure 7: Goelectric Section through VES 9 – 12

Oyedele *et al.*, (2018) observed that this behavior of soils is suggestive of sub-soils with good geotechnical properties and it is capable of causing minimizing differential sinking of foundation soils with consequent damage to the any superstructure erected on it. A correlation of this result with the VES sounding reveals that

resistivity values of between 474.5 Ω m to 819.9 Ω m which correspond to resistivity value of laterite to concretionary laterite occur at shallow depths in this zone 1. Hence, the subsurface underlying zone 1 should be dug to a depth of 1.4 m and beyond (Figure 8).

Table 3: Table showing the summary of all VES interpretation and lithologic inference

VES	Resistivity (Ω m)	Thickness (m)	Depth (m)	Lithologic Inference
1	474.5	2.82	2.82	Lateritic topsoil
	290.5	0.46	3.28	Weathered layer
	1202.4	16.35	19.63	Basement rock
	268.1	-	-	Weathered layer
2	729.4	7.91	7.91	Concretional laterite topsoil
	3346.9	1.07	8.98	High resistivity laterite
	1025.5	15.70	24.68	High resistivity laterite
	74.3	-	-	Weathered layer
3	700.4	4.26	4.26	Concretional laterite topsoil
	302.4	1.11	5.37	Lateritized sand
	699.8	20.72	26.09	Lateritic layer
	177.5	-	-	Weathered layer
4	819.9	1.70	1.70	Concretional laterite topsoil
	512.3	1.29	2.99	Lateritic layer
	1192.4	17.92	20.92	Basement rock
	95.5	-	-	Weathered layer
5	631.1	10.60	10.60	Lateritic Topsoil
	240.1	0.42	11.02	Lateritized sand
	418.7	-	-	Lateritized sand
6	707.5	13.52	13.52	Concre. Lateritic Topsoil
	278.8	0.27	13.78	Lateritized sand
	399.2	-	-	Lateritized sand
7	715.8	15.10	15.10	Concretional laterite Topsoil
	345.4	1.67	16.77	Lateritized sand
	265.9	19.85	36.62	Lateritized sand
	653.0	-	-	Weathered layer
8	655.0	11.49	11.49	Concre. laterite Topsoil
	319.6	1.85	13.34	Lateritized sand
	415.2	-	-	Weathered layer
9	597.2	10.40	10.40	Concretional laterite Topsoil
	443.0	6.63	17.03	Lateritic layer
	128.4	12.09	29.12	Clayey Sand
	339.4	10.83	39.95	Weathered layer
	1435.3	-	-	Basement rock
10	600.2	14.40	14.40	Concretional laterite Topsoil
	445.7	9.83	24.23	Lateritic layer
	187.8	14.46	38.69	Clayey Sand
	337.6	17.32	56.01	Weathered layer
	1142.8	-	-	Basement rock
11	601.1	11.60	11.60	Concretional laterite Topsoil
	491.6	12.23	23.83	Lateritic layer
	131.9	13.64	37.47	Clayey Sand
	306.6	-	-	Weathered layer
12	535.9	16.54	16.54	Concretional laterite Topsoil
	441.4	12.62	29.16	Lateritic layer
	153.0	12.48	41.64	Clayey Sand
	344.7	10.81	52.45	Weathered layer
	1437.1	-	--	Basement rock

CPT 2 also presents a similar scenario in that the penetration terminated in material of penetrative resistance of 0-20 kg/cm³ at 0.2 meter, 0-20 kg/cm³ at 0.75 m deep and 0 - 100 kg/cm² maximum penetration at a depth of 1.0 m and beyond except for certain interval where the their exist minimum penetration of 0 - 0.50 kg/cm³ between 1.3 and 1.4 meters deep. When correlated with the result of the VES sounding, this shows the occurrence of clayey sand, a relatively high competent engineering material, like in locations CPT 1 where competent geo-material was found throughout the penetration depth. The plot of the CPT curve in zone 2 is as shown in Figure 9. This might be an indication of competent zones of high resistive materials at this depth beyond 0.5 meters. This also imply that the competent layer was very close to the ground level since the maximum blow produces a resistance at a deeper depth (at 1.0 meters) than what was experienced in CPT 1. The result

showed that the penetrative blow exerted by the instrument was able to penetrate into the first layer up to about 0.5 meters deep but not beyond 10 meters. This steadily increases up to between 1.0 meters and 1.25 meters where the values peaks. From figure 9, it is clear that the first layer which consist of the high resistivity lateritic later (622.1 Ωm) lie within the first geoelectric layer having a total thickness of 11.36 meters, an indication that the first geoelectric layer exhibit very hard, high resistivity and competent earth materials at shallow depth that can support electrical mast. However, the high resistivity value of this topmost layer does not make it suitable as a good electrical earthing property since it would not maintain consistent current flow within the earth. Rather, it would store up electrical charges, the effect of which would not be desirable. However, considering the ability to support the superstructure, the soils would be suitable.

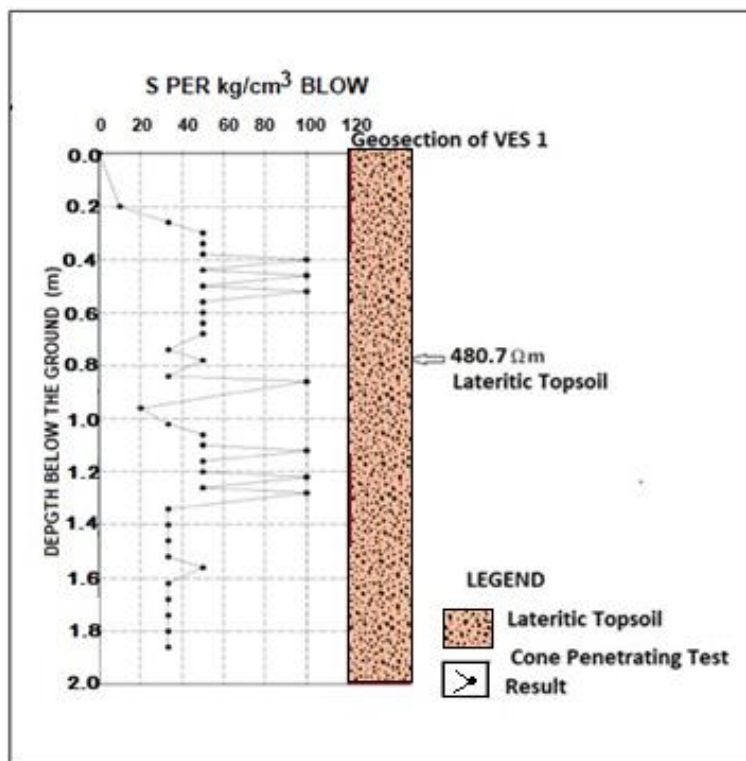


Figure 8: Typical CPT Plot correlated with Geo-electric and Lithological result in Zone 1

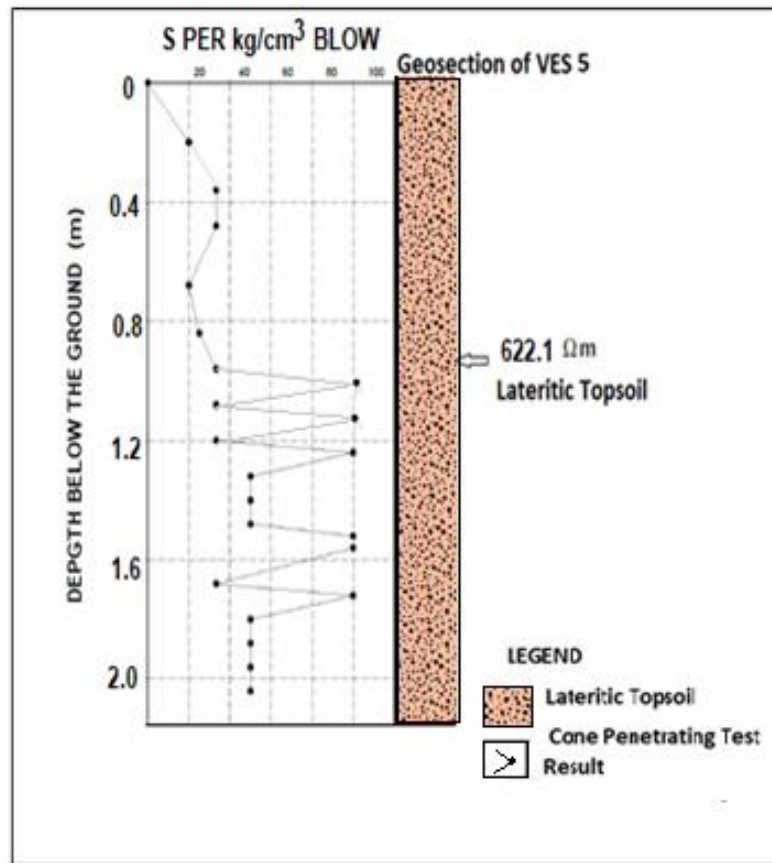


Figure 9: Typical CPT Plot correlated with Geo-electric and Lithological Result in Zone 2

The CPT curve in zone 3 is as shown in Figure 10 below. As usual, the minimum penetrative resistance of 0-20 kg/cm³ was first attained at 0.2 m and 0.55 m deep while maximum penetrative blow of 0-100 kg/cm³ blow was attained at a depth of 0.5 m deep and beyond. However, for 0 - 100 kg/cm² maximum penetration, the competent layer was first attained at a depth of 1.0 m and beyond except for certain interval where the their exist minimum penetration of 0 - 0.50 kg/cm³ between 1.3 and 1.4 meters deep as well. Although this is also an indication of a weak zone, the result was not found to be continuous into the subsurface. In this case, the competent layer was also discovered to be close to the ground level since the maximum blow produces a resistance at a deeper depth (at 1.0 meter) than what was experienced in CPT 1 also. The first layer which consist of the high

resistivity lateritic later (592.5 Ωm) is correlated with the first geoelectric layer having a total thickness of 8.92, an interval that can conveniently hold the electrical mast in place due to its high resistivity and competency (Figure 10). Integration of CPT results with the resistivity section shows that CPT 3 terminated in high resistivity materials interpreted as lateritic material from the surface to greater depth. This is unlike clayey materials which is viewed as being unsuitable for foundation health as a result of its low bearing capacity. In addition, some clay varieties expand when they absorb water. To make matters worst, some types of clay expand and contract through wet and dry periods. This is because water becomes bound to the clay particles and as such, structures sitting on top of such soils rise and fall with the soils. This tend to result is differential foundation movement or soil

creep which causes tilting of communication mast, electrical mast, foundation cracks as well as distress in the foundation completions (Oyedele et. al., 2018). The high resistivity value of this topmost layer in this case does not make this point suitable as a good electrical earthing property since it would not maintain consistent current flow within the earth only but also store up electrical charges, the effect of which would not be desirable. However, there may not be any

noticeable soil creep or tilting of electrical mast due to the high tensile strength of the subsurface material – laterite. In general, the maximum values recorded for the penetrative resistances of the CPTs in all these CPT points indicates that the soil resistance to penetration is less than or equal to 1 meter in zone 1 (0.4 meter) and zone 3 (0.5 meter) but slightly higher in VES 2 (1.0 meter).

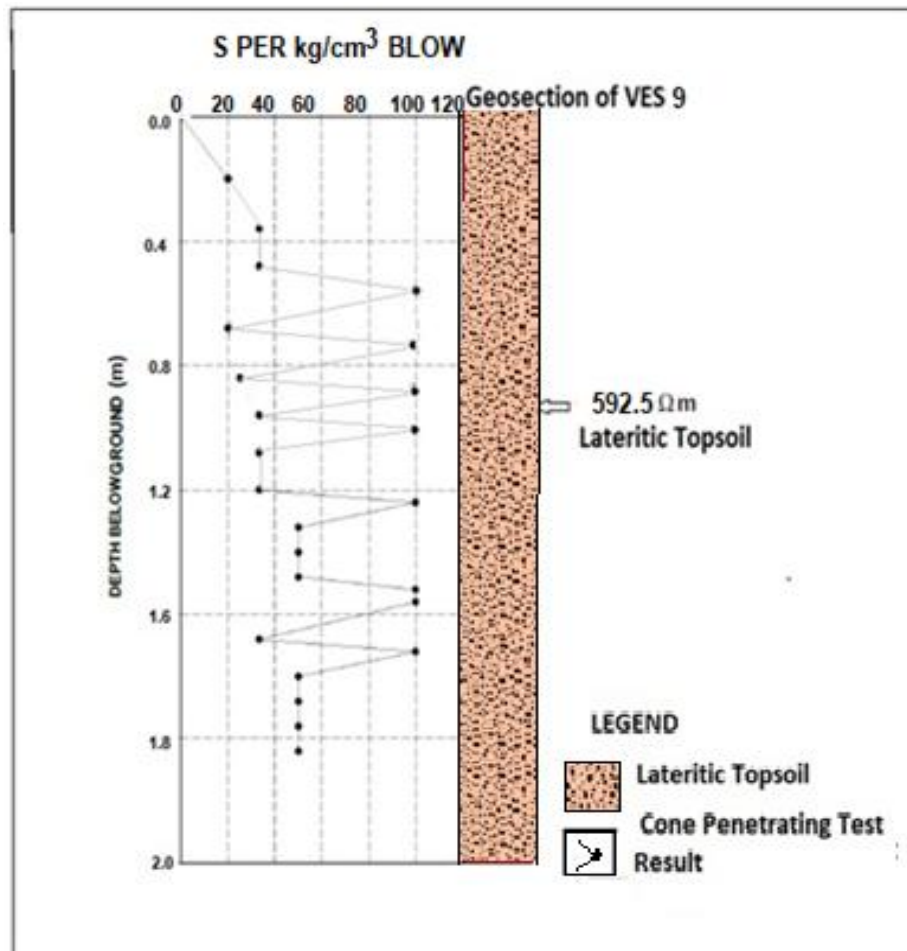


Figure 10: Typical CPT Plot correlated with Geo-electric and Lithological Result in Zone 3

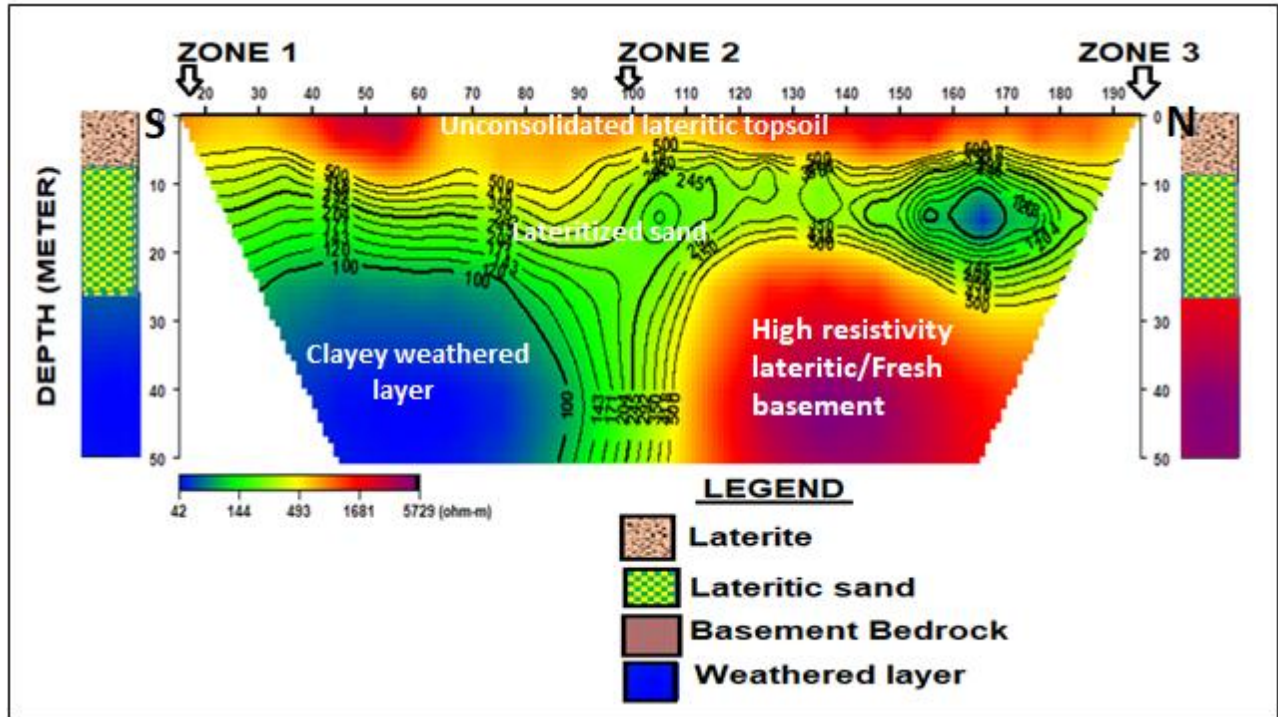


Figure 11: 2D Wenner Imaging of the Subsurface of the traverse

4.5 Soil Corrosivity Results

Soil corrosion that can lead to severe corrosion failure is known to be associated with low resistivity. A corrosive material is that which has the quality of eating away or consuming another material. In geotechnics, corrosivity may be defined in terms of a soil's ability to corrode a material that may be buried in it. It is necessary in a site testing exercise to evaluate soil corrosivity (also known as aggressivity) because soils at building sites would normally host engineering structures. The corrosivity of soils may be related to the electrical resistivity response of such soil. According to Baeckmann and Schwenk, (1975) and Agunloye, (1984), classification of soil corrosivity in terms of electrical resistivity is as shown in Table 3. Low resistivities ($<100 \Omega\text{m}$) are indicative of good electrical conductivity paths arising from reduced aeration, increased electrolyte saturating or high concentration of dissolved salts in soil. According to this classification, soils with

resistivity values of $10 \Omega\text{m}$ is very strongly corrosive, $10 - 60 \Omega\text{m}$ (moderately corrosive), $60 - 180 \Omega\text{m}$ (slightly corrosive) and $>180 \Omega\text{m}$ (practically non-corrosive).

In the present study, the resistivity of the topsoil layers varies from $424.7 \Omega\text{m} - 819.9 \Omega\text{m}$. This layer is practically non-corrosive. The second layer has resistivity which varies from $290.5 \Omega\text{m} - 512.3 \Omega\text{m}$, hence, it is also practically non-corrosive. The third layer has resistivity which varies from $265.9 \Omega\text{m}$ to $1205.5 \Omega\text{m}$; hence, it is also practically non-corrosive. These three layer which would host the mast are all non-corrosive since their resistivity values are all above $180 \Omega\text{m}$. Any metal or steel structures within these zones are practically not exposed to chemical corrosion.

4.6 2D Pseudosection

The diagram displayed in Figure 11 is a representation of 2 dimensional imaging of the subsurface of the study area.

Table 4: Classification of soil resistivity in terms of corrosivity (Baeckmann and Schwenk, 1975; Agunloye, 1984)

Soil resistivity (Ωm)	Soil Corrosivity
Up to 10	Very strongly corrosive (VSC)
10-60	Moderately corrosive (MC)
60 – 180	Slightly corrosive (SC)
180 and above	Practically non-corrosive (PNC)

The topmost layer of the study area display a high resistivity zone that vary from 424 Ωm to as high as 819 Ωm . This is composed of slightly laterite material to very strongly consolidated hard pan at certain intervals; and the thickness of this layer vary from as low as 4 meters towards the Southern part to as high as 10 to 12 meters near the central part part. The result generally showed that the topmost part of the study area is composed of high resistivity materials and it extend from a minimu depth of 4-5 meters to a máximum depth of up to 12 meters. Thus, it can hold the mast in place. There exists a región of weathered layer (probably composed of clayey materials around the southern part of the traverse at a depth of between 10 to 50 meters (having average resistivity of between 50 to 60 Ωm while around the northern part at the same depth, highly resistive interval probably consisting of high density laterite or basement exist having average resistivity of between 750 to 900 Ωm). These observation is in agreement to the results obtained using the VES sounding. Overlying the weathered layer and the basement is the región of lateritized sand material whose average resistivity value lie between 240 to 350 Ωm . The clayey layer and its low competence values can probably attributed to the high degree of saturation at that depth, which according to Oyedele et. al., (2018) do reduce the strength of the soil in-situ. However, its effect on the implantation of the mast may not be noticed since this clayey interval is located a greater depth

beyond the subsurface. The overlying lateritized sand layer when integrated with the resistivity of the topsoil is able to provide the needed support for the impantation of the mast and also show evidence of low corrosivity. However, the electrical neutrality of the study area is not guaranteed as these layers would retain electric charges within their matrix.

5.0 Conclusion and Recommendations

In this work, an intergrated geophysical and geotechnical investigation was carried along Coker Village road about 200 meters from the Osun State University, Main gate Campus, Osogbo, Southwestern Nigeria, with the aim to identify suitable area for earthing system within the study area. It was also aimed at investigating the corrosivity and shear strength of the sub-surface soil in the study area with aview to understand its ability to support any electrical mast installed on it. The study area were divided into three (3) zones with four VES points at each zone separated from another zone at a distance of 100 meters interval. The four VES points were arranged in a square shapes. The geophysical survey employed the vertical electrical sounding technique using Schlumberger configuration and the cone penetrometer test. A total of twelve (12) sounding were conducted in the study area while three (3) cone penetration (CPT) test points selected at the midpoint of four (4) VES points in each zone to determine the in-situ shear strength properties of the soil. The results of the

investigation reveal the following:

- (i) Six types of resistivity curves delineated in the study area include HK, AK, HA, QH, KHK and QHA- curve with HK predominating over other having about 33.3% of the total curves obtained in the study area. The rest include AK (8.33%), HA (8.33%), QH (16.66%), KHK (8.33%) and QHA (25%) respectively. The interpretation of the VES curves reveals four to five distinctive geo-electric layers that alternate between lateritic topsoil, lateritic and sandy bedrock. The resistivity of the topsoil layers varies from 424.7 Ωm – 819.9 Ωm . This layer is practically non-corrosive. The second layer has resistivity which varies from 290.5 Ωm – 512.3 Ωm , hence, it is also practically non-corrosive. The third layer has resistivity which varies from 265.9 Ωm to 1205.5 Ωm ; hence, it is also practically non-corrosive. These three layer which would host the mast are all non-corrosive since their resistivity values are all above 180 Ωm . Any metal or steel structures within these zones are practically not exposed to chemical corrosion. The topsoil and underlying layer are practically non-corrosive due to high resistivity. The zones of low resistivity that are considered suitable for electrical earthing systems in the study area are very strongly corrosive having resistivity from 1.514 Ωm to 10.1 Ωm .
- (ii) High resistive soils such as lateritized sand and laterite of varying resistivities are the predominant subsurface material in the study area and they possess high resistivity lateritic materials that extend from a minimum depth of 4-5 meters to a maximum depth of up to 12 meters. These soils are strong enough to support the high density mast to be sited on them, they are not

corrosive but they are poor medium to act as an earth material due to their high resistivity values up to the third layer.

Based on the results obtained from the investigations, the following recommendations were made: (i) due to the presence of high resistive soils in the area, it is recommended that a conductive earth medium could be created by using clay or salt (brine) chambers at the base of each foot of the masts if installation of earthing system is inevitable. This will create the needed conductive pathway to maintain a continuous flow of electric charges and also further prevent any eventualities. (ii) It is recommended that a thorough integrated investigations involving geophysical (electrical tomography imaging) and geotechnical studies be carried. A complex interpretation of such data allows for appropriate design and monitoring of earthing system.

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Conflict of Interest

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

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