

## Application of Electrical Resistivity Method to Site Characterisation for Construction Purposes at Institute of Agriculture Research and Training Moor Plantation Ibadan

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**Abstract:** This research was carried out within the Institute of Agriculture Research and Training Moor Plantation Ibadan, Southwestern Nigeria, to ascertain the suitability of the proposed site for building construction and usage. The geophysical investigation involved three electrical resistivity techniques; Vertical Electrical Sounding (VES) using the Schlumberger configuration, 2D ERT, and 2-D electrical imaging using Dipole-dipole electrode configuration. Two traverses were established E–W direction cutting across geologic strike with a distance of 80 m and of varying inter-traverse spacing. Eight (8) VES stations were occupied covering the entire study area for layer stratification and geoelectric parameters. The results were qualitatively and quantitatively interpreted and are presented as sounding curves and geoelectric sections. The 2-D imaging gave information on the subsurface characteristic in the area with generally low apparent resistivity indicating low competence material. The results obtained from the VES delineate three geoelectric units which comprise the topsoil, weathered layer, and fresh basement. The results from the VES were used to determine the second-order parameters. The entire results correlate well with one another showing that all the techniques used were complemented. This study has further justified the need for geophysical site investigation as a pre-condition before any construction to avoid problems of differential settlement. In determining foundation material, topography elevation, clay content, and the depth of weak zones should be put into consideration, since the depth of the weak zone is appreciably high.

**Keywords:** Dipole-dipole, ERT, VES, Geoelectric section, Foundation integrity

### INTRODUCTION

Geophysics is the application of physical parameters to determine subsurface geological properties. The Earth is comprised of subsurface lithologies that have different physical variations. Geophysical equipments are made to map spatial variations in the physical properties of the Earth. Geophysicists interpret these measured variations and use them to develop geologic models of different complexity (Ozegin et al., 2019a). If the subsurface depth of interest can be differentiated from the basis of contrasting physical properties, the output geologic model can be of great utility to an engineering design (Ilugbo et al., 2018a, Aigbedion et al., 2021). A direct consequence of global warming occasioned by the depletion of the ozone layer may be induced as a result of human negligence (Bawallah et al., 2019a, Aigbedion et al., 2019a). However, many researchers have attempted to determine the major factors that often account for most subsequent failures of structures/foundations (Adelusi et al., 2013, Adelusi et al., 2014, Akintorinwa & Adeusi, 2009, Oyedele et al., 2011, Ozegin et al., 2019b).

The problem of buildings failure, bridges, or any form of erected structures on the earth can be sometimes attached with inadequate pre-construction subsurface investigation or due to geotechnical inadequacies of the soil at the proposed site (Ilugbo et al., 2018b, Bawallah et al., 2019b, Bawallah et al., 2020). Thus, it is essential to determine the local bearing capacity of the underlying site (Magawata et al., 2020).

The causes of foundation failure may be as a result of differential settlement within a weak subsurface layer or the presence of geologic fissures such as faults, fractures, and shear zones beneath the construction site (Oyedele et al., 2020). Despite this clear reason, site engineers sometimes fail to incorporate pre-construction investigation (Geophysical survey) in their job schedule due to cost, and the findings are not taken into consideration in the design, and construction phase (Ilugbo et al., 2018a, Adebisi et al., 2018, Bawallah et al., 2019a). Designing a stable structure that is safe, durable, and has low maintenance costs depends upon an adequate understanding of the geologic properties on which such a building is sited (Adebo et al., 2019). Less occasionally mentioned is the subsurface geologic properties of the ground on which the buildings are sited.

The geology properties of the proposed site play a significant role in the sub/supper construction of buildings (Aigbedion et al., 2019b). Therefore, an Electrical resistivity survey is increasingly being used in engineering investigations, where detailed knowledge of the subsurface is sought. It is based on the fact that the subsurface geological structures possess varying resistivities and it provides subsurface information regarding subsurface resistivity distribution, thickness, and depth of various layers.

Hence, this research work becomes necessary using Electrical Resistivity Method to bring an enduring solution to the problem of building failures, which has been mostly attributed to poor building materials or poor engineering design without taking into cognizance the subsurface geological properties.

## METHOD

### Site Description and Geology of the Study Area

The investigation was carried within the Institute of Agriculture Research and Training Moor Plantation Ibadan which is located at Ibadan, Southwestern Nigeria. It falls within latitude  $7^{\circ} 32'20''$  to  $7^{\circ} 38'20''$  North and longitude  $4^{\circ} 36'20''$  to  $4^{\circ} 44'20''$  East (Figure 1). That is, (833572 to 844687 Northings and 677150 to 691821 Eastings) using the Universal Traverse Mercator (UTM). This area falls within the 1:50,000 Topographic maps of Oyo sheet 234 SW. Major and minor road linkages characterize the study area.

The study area is concealed with the Southwestern Nigeria basement complex composing migmatite-gneiss complex, metaigneous rock such as granite, pelitic schist, quartzite, amphibolites, charnockitic rocks, older granite, and unmetamorphosed dolerite dykes (Odeyemi, 1981, Obaje, 2009). The rock sequence consists of basically weathered quartzite older granite. The basement complex rocks of Nigeria are made up of heterogeneous assemblages (Rahaman, 1989).

### Research Method

In this Research, three electrical resistivity techniques were used such as Vertical Electrical Sounding (VES), 2-D Electrical Resistivity Tomography (ERT), and Combine Horizontal Profiling (HP) and Vertical Electrical Sounding (VES) with the corresponding configurations including Schlumberger, Wenner, and Dipole-Dipole electrode configurations (Figure 2). Eight (8) sounding stations were occupied within the two traverses, and the current electrode spacing (AB/2) varies from 1 to 40 m. The VES apparent resistivity values obtained were plotted against the electrode distance (AB/2) and subsequently interpreted quantitatively using the partial curve matching method and computer-assisted 1-D forward modeling with WinResist 1.0 version software. The results from the VES interpretation were used to model geoelectric sections and maps.

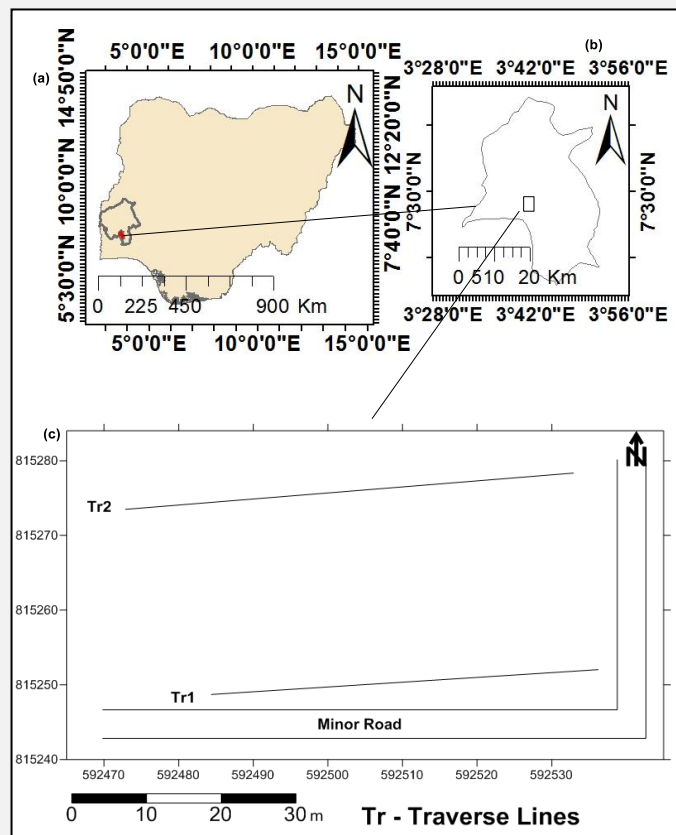


Figure 1. (a) Map of Nigeria, Oyo State Showing Ido Local Govt. (b) Map of the Ido Local Govt. Showing the Study Area (c) Map of the Study Location

The dipole-dipole data were inverted using 2-D subsurface images using the DIPPRO™ 4.0 inversion software. The inter-electrode spacing of 5 m was adopted while inter-dipole expansion factor (n) varied from 1 to 5. Lateral Resistivity Profiling (LRP) techniques were taken at a = 5, 10, 15, and 20 m which give useful information on the nature, trends of the sub-surface, and structural trends. The data obtained were inverted using 2-D subsurface images using the Resis2D software (Figure 2). Resistivity values were obtained by taking readings using the R50 resistivity meter. The results from the three techniques were integrated to delineate the suitability of the proposed site for building construction.

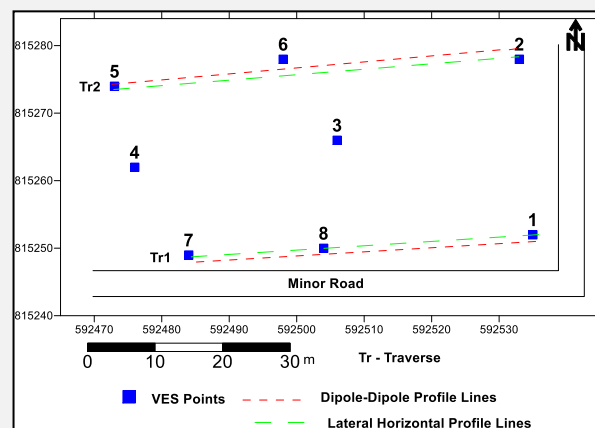


Figure 2. Data Acquisition Map of the Study Area

## RESULT AND DISCUSSION

### Characteristic Depth Sounding Curve Types

The H curve type was obtained, while the curve types are characteristic of the basement complex area. The H curve type was predominated (Figure 3).

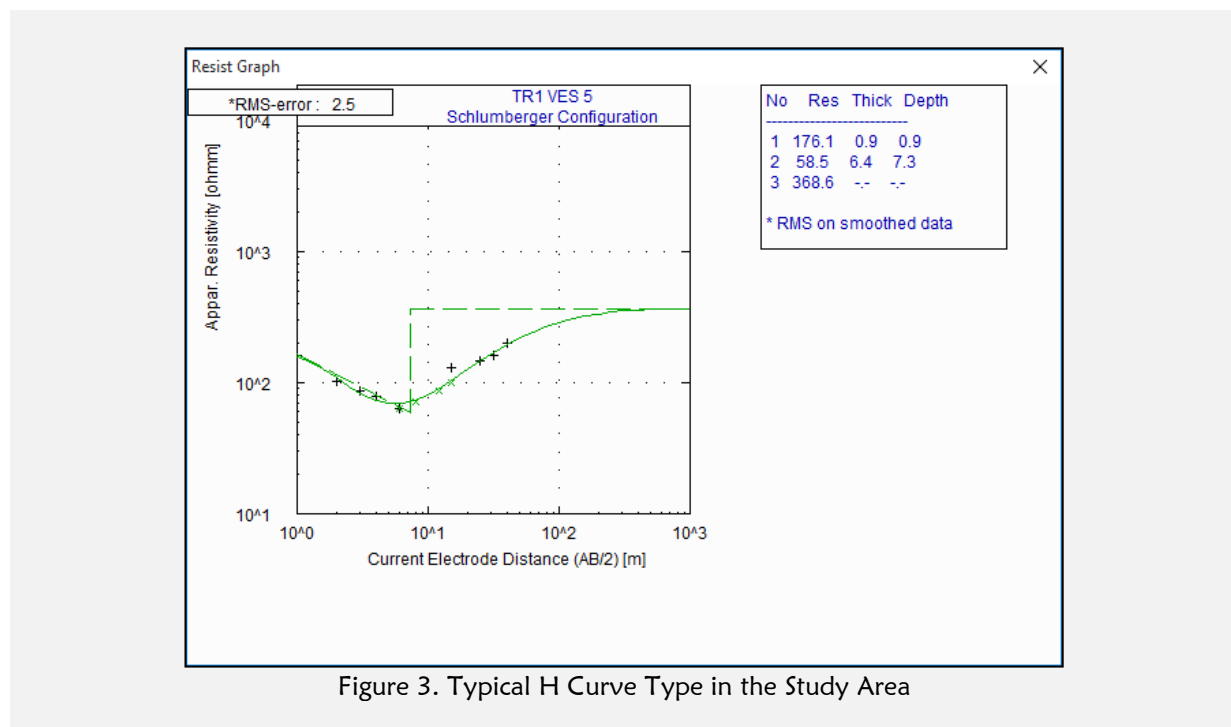


Figure 3. Typical H Curve Type in the Study Area

### Goelectric Sections along Traverse One and Two

The quantitative interpretation of the VES curves resulted in a determination of goelectric layer parameters for the subsurface characterization. Two (2) goelectric sections were generated within the study area, and a maximum of three geologic layers were mapped, these were the topsoil, weathered layer, and the fresh basement or bedrock. The goelectric section shows two dimensional or cross-sectional impression of the subsurface. The topography of the bedrock along the profile can be seen from the sections.

The goelectric section along traverse one was oriented from Southwestern to Northeastern and three (3) goelectric layers were delineated (Figure 4). The topsoil has resistivity distribution of 131 – 204 ohm-m and thickness of 0.8 – 2.0 m which comprises sandy clay, sand, and lateritic formation. The weathered layer has resistivity value ranging from 40 – 388 ohm-m and thickness of 4.3– 7.0 m which comprises clay contents which are generally weak in terms of foundation stability. The last layer has resistivity value ranges from 819 – 1019 ohm-m depicts fresh basement.

Three subsurface geologic layers (topsoil, weathered layer, and fresh basement) were delineated along traverse two (Figure 5). The topsoil comprising of clay, clayey sand, sandy clay, sand, and hardpan with the resistivity values ranges from 157 to 229  $\Omega$ -m with its thickness varies from 0.9 to 2.0 m, while the weathered layer resistivity varies from 23 to 369  $\Omega$ -m and thickness ranges from 2.6 to 9.5 m which is generally weak in term of foundation stability. The last layer has resistivity value ranges from 450 – 2127 ohm-m depicts fresh basement. The resistivity values of the topsoil are indicative of clay, sandy clay, and clayey sand. This layer may not be of any special interest since topsoil is normally excavated. Hence, the foundation of the proposed structures cannot be found on this layer.

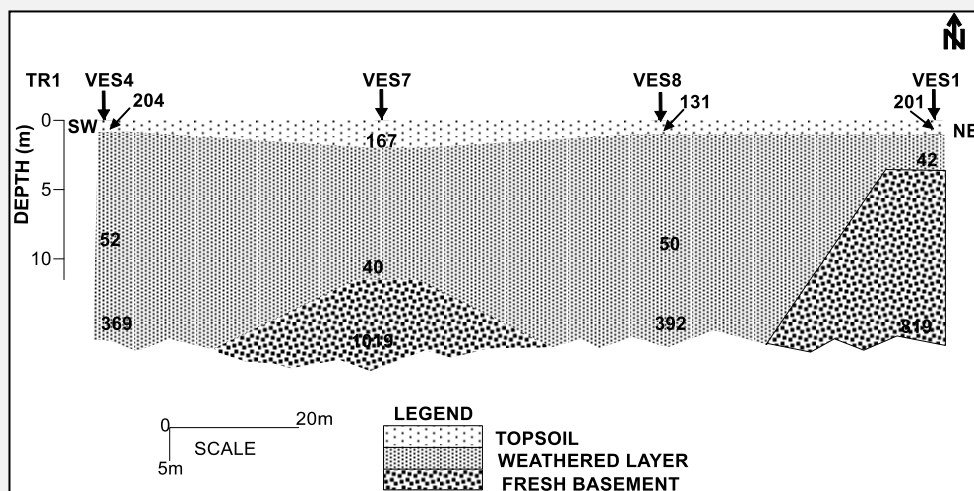


Figure 4. Goelectric section along Traverse one

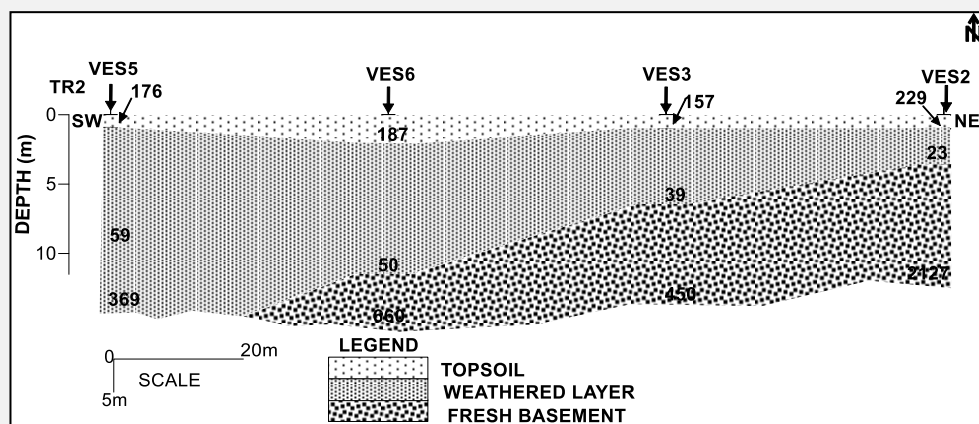


Figure 5. Goelectric section along Traverse Two

## Geoelectric Maps

### *Isoresistivity Map of Topsoil*

This map shows important information on the topsoil resistivity of the study area (Figure 6). The topsoil comprises clay, clayey sand, sandy clay, sand, and hardpan. The Northeastern, southeastern, western, and southwestern parts of the study area have the highest resistivity value ranging from 185 to 235  $\Omega\text{m}$ . Northeastern, northwestern, southeastern, western, and southwestern parts of the study showed moderate resistivity value ranging from 150 to 185  $\Omega\text{m}$ , which exhibits the presence of weak geologic materials that may affect the building. The southern part of the investigated area displays low resistivity which exhibits low weak geological material that may pose threat to any structure built on it due to the presence of clay. Any proposed building on this investigated area should put into cognizance the area of low resistivity to prevent differential settlement.

### *Isopach map of topsoil*

This map gives relevant information on layer thickness on the topsoil thickness of the study area (Figure 7). The northwestern, northeastern, eastern, southeastern, and southwestern parts of the study area have a thickness ranging from 0.8 to 1.2 m and the region was a major point of interest with a high presence of clay at the southern part. The thickness of the topsoil may not be of any interest since topsoil is generally excavated.

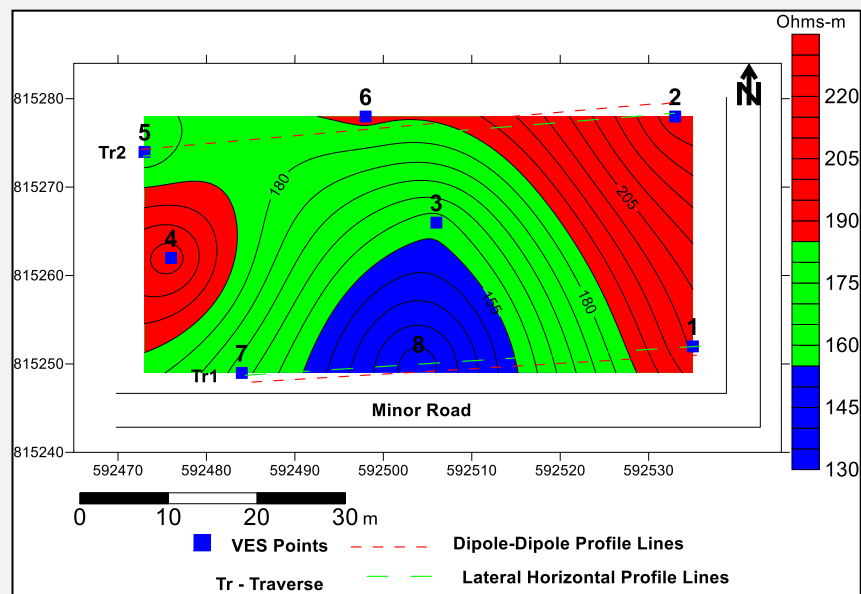


Figure 6. Isoresistivity map of topsoil

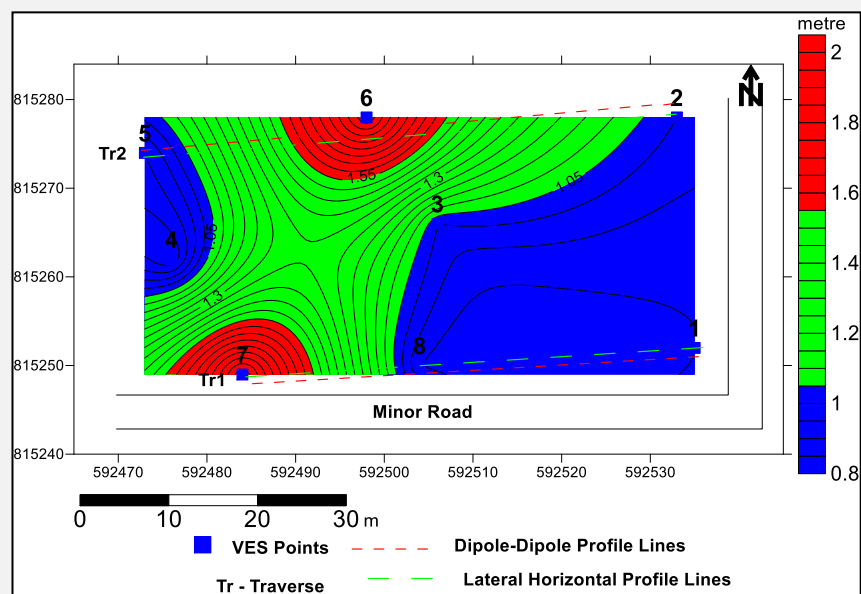


Figure 7. Isopach map of topsoil

#### *Isoresistivity Map of Weathered layer*

The map showed the isoresistivity of the weathered layer which comprises clay, clayey sand, sandy clay, sand, and lateritic formation (Figure 8). The Northwestern, western, and southern parts of the study area have the highest resistivity value ranging from 220 to 420  $\Omega$ m. Northwestern, southeastern, and southwestern parts of the study exhibited moderately resistivity values from 120 to 220  $\Omega$ m, which indicates moderately weak zones that may cause structural failure.

The northern, northeastern, southeastern, and small closure at southwestern parts of the investigated area displays low resistivity which comprises of clay, sandy clay, and clayey sand with value ranges from 20 to 140  $\Omega$ m which exhibits weak geological material that may cause differential settlement on any structure build on it.

Any structure erected on this study area should put into cognizance the area of low resistivity to prevent differential settlement.

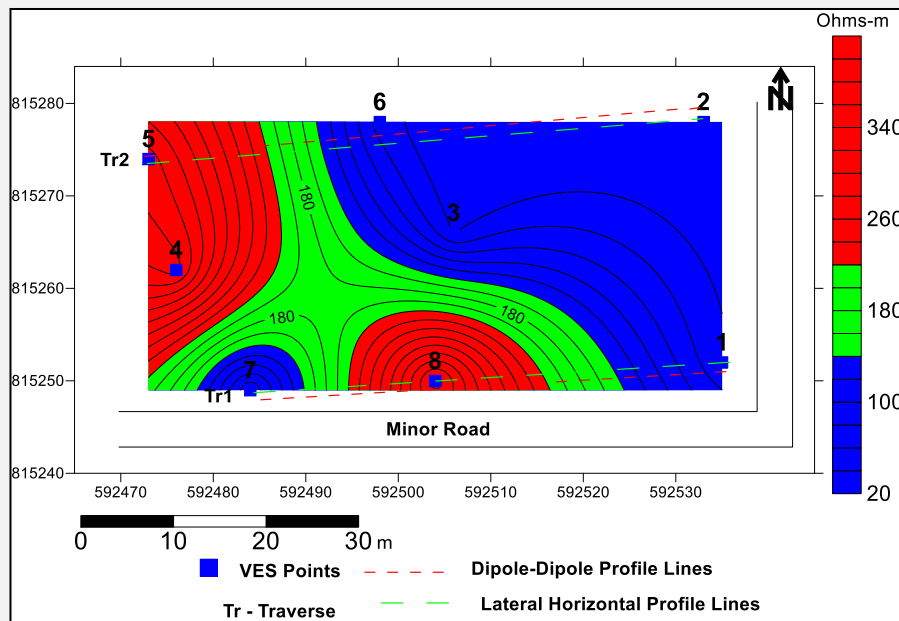


Figure 8. Isoresistivity map of Weathered layer

*Isopach map of Weathered layer*

Figure 9 showed an isopach map of weathered layer with thickness ranging from 6 to 10 m at the northwestern, southwestern, and southern parts of the investigated area and the region is moderately thick in terms of building construction. The northeastern, southeastern, and eastern parts have a thickness ranging from 2.5 to 4.5 m which correlated with an area of low resistivity. This area of low thickness must be put into cognizance before erecting any structure on it, due to the presence of clay which may lead to differential settlement if any structure is built on it.

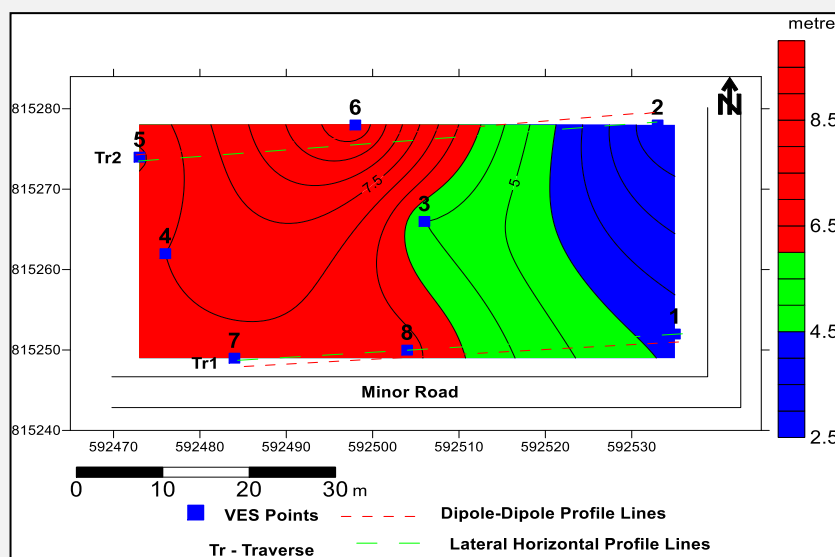


Figure 9. Isopach map of Weathered Layer

### Isopach map of Overburden Thickness

Figure 10 showed an overburden thickness map of the study area which includes the topsoil, the weathered layer, and the fractured basement. Hence, the established depths to the bedrock beneath all the VES stations were contoured to produce the overburden thickness map with thickness varies from 3.5 to 12 m. The map displays a relatively thick overburden in the southwestern, western, and northwestern parts of the study area while southern, central northeastern parts show moderate overburden thickness.

The relatively low overburden (less than 6.5 m) was found at the northeastern, eastern, and southeastern parts of the investigated area.

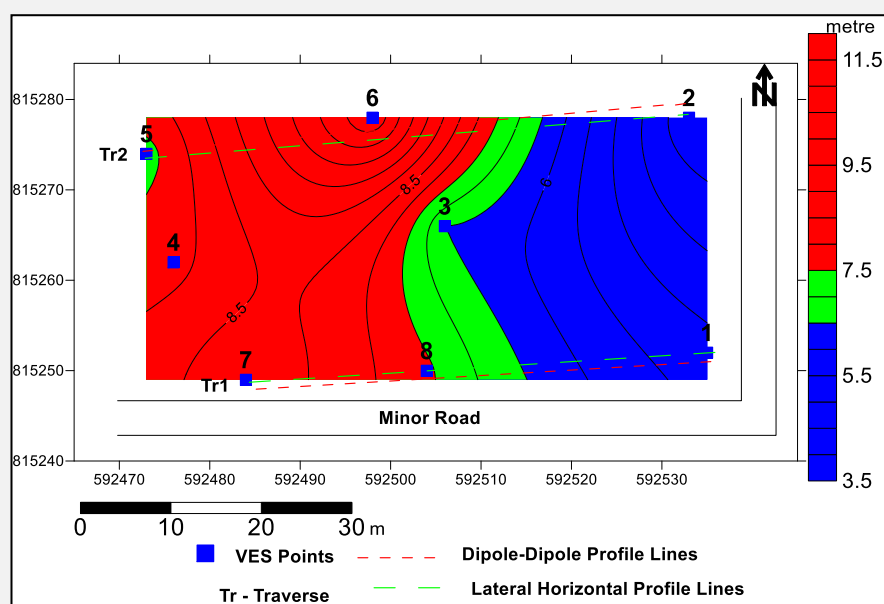


Figure 10. Overburden Thickness Map of the Study Area

### Total longitudinal conductance map

Figure 11 showed the total longitudinal conductance map of the investigated area. The northeastern, eastern, southeastern, and northwestern regions have low total longitudinal conductance values ranging from  $0.105$  to  $0.135 \Omega^{-1}$ , which indicates low presence of clayey and high resistive geological properties characterizing the presence of foundation stability. The central part was characterized by moderate total longitudinal conductance with value ranging from  $0.135$  to  $0.170 \Omega^{-1}$ , which is a reflection of moderately foundation stability.

The northwestern and small closure at southwestern parts has the highest total longitudinal conductance values ranging from  $0.170$  to  $0.205 \Omega^{-1}$ . This indicates major weak zone that may lead to differential settlement for any structure built on it.

### Total Transverse Resistance

The total transverse resistance in terms of foundation stability illustrates the ability of the soil to withstand the load, as well as an indicator of the load bearing capacity of any study location for foundation and structural parameters within the subsurface (Aigbedion et al., 2021). The eastern, northeastern, and southeastern parts of the study area were characterized by low total transverse resistance values ranging from  $280$  to  $420 \Omega\text{m}^2$  showing areas that are most susceptible to failure due to underlying weak geologic materials.

Whereas the western, northwestern, and southwestern parts illustrate moderate transverse resistance with values ranging from  $420$  to  $660 \Omega\text{m}^2$ , which indicates the moderate area of weak



geologic materials, furthermore, the northwestern part was dominated with the high value ranging from 660 to 860  $\Omega\text{m}^{-2}$  indicative of high foundation stability (Figure 12).

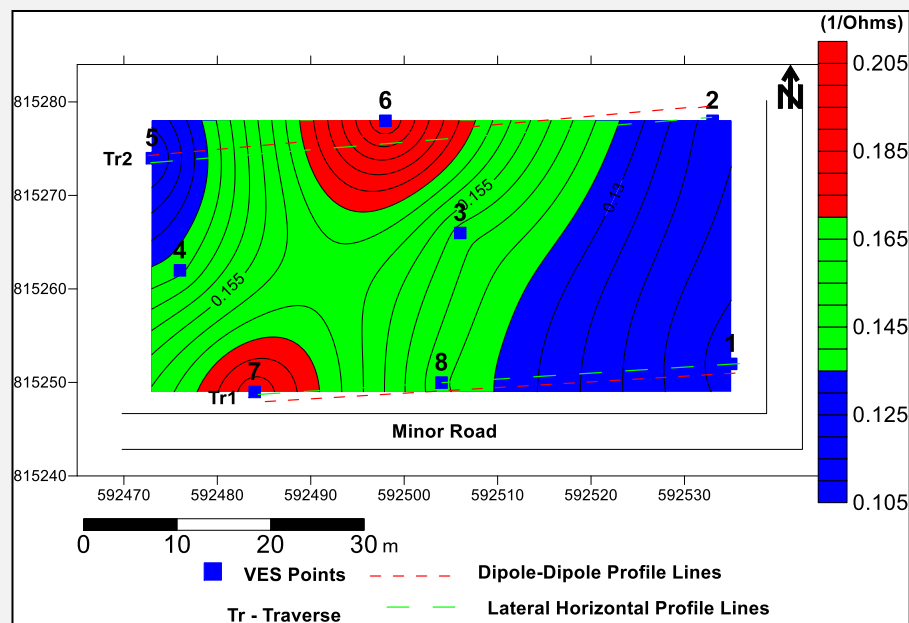


Figure 11. Total longitudinal conductance map

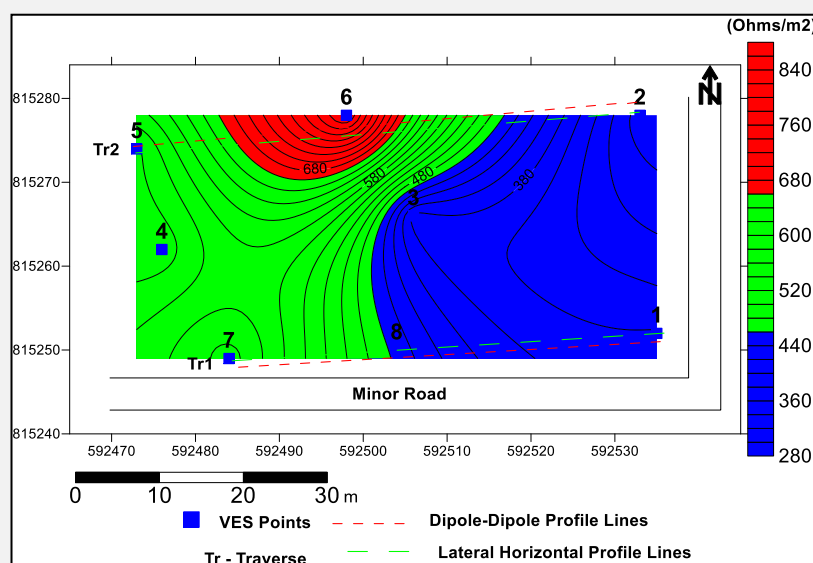


Figure 12. Total Transverse Resistance Map

### Dipole-Dipole Pseudo-Section along Traverse One and Two

Figure 13a displays 2D resistivity imaging along traverse one of the research area which covers a distance of 65 m. The results obtained from the pseudo-section revealed that the distance between 25 to 60 m to a depth of 2.5 m was characterized by weak zone due to the presence of clay contents, but beyond this region was indicative of competent layer which was directly underlain by fresh basement rock. While between the distances between 1 to 25 m to a depth of 17.5 m were generally weak due to the high presence of clay contents within this region.

Any structure builds between a distance of 1 and 25 m, the clayey contents must be into cognizance and a deep foundation is recommended. The dipole-dipole pseudo-section along traverse two showed that the entire traverse to a depth of 2.5 m is generally weak geological formations due to the presence of clay which may lead to building failure if not properly put into consideration (Figure 13b).

Beyond this region was indicative of competent layer which was directly underlain by fresh basement rock. Any proposed structure on this traverse must take cognizance of the upper 2.5 m which may pose threat to the foundation stability.

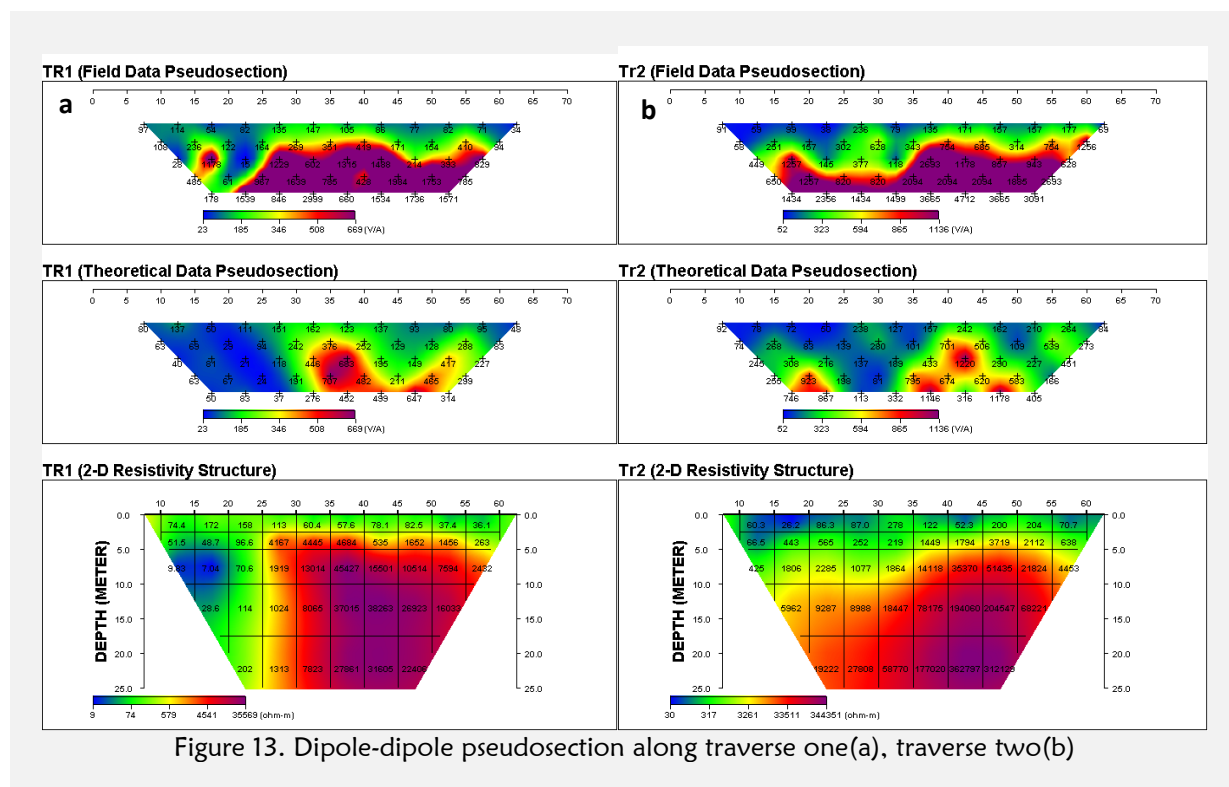


Figure 13. Dipole-dipole pseudosection along traverse one(a), traverse two(b)

### Electrical Resistivity Tomography (ERT) along Traverse One and Two

The imaging of the subsurface using Wenner resistivity parameters of  $a = 5, 10, 15,$  and  $20$  m gave important information about the subsurface geophysical parameters of the investigated area. Traverse one exhibits the existence of a major weak geological formation due to the presence of clay which may cause building failure if not properly put into consideration from the near-surface to a depth of 10 m between distances of 7.5 to 40 m (Figure 14a).

Whereas the imaging was characterized by weak geological material from the near-surface to a depth of 8 m between the distance 7.5 to 35 m along traverse two (Figure 14b). Beyond this region was indicative of competent layer which was directly underlain by fresh basement rock. Any proposed structure on this traverse must take cognizance of the upper 8 m which may pose threat to the foundation stability.

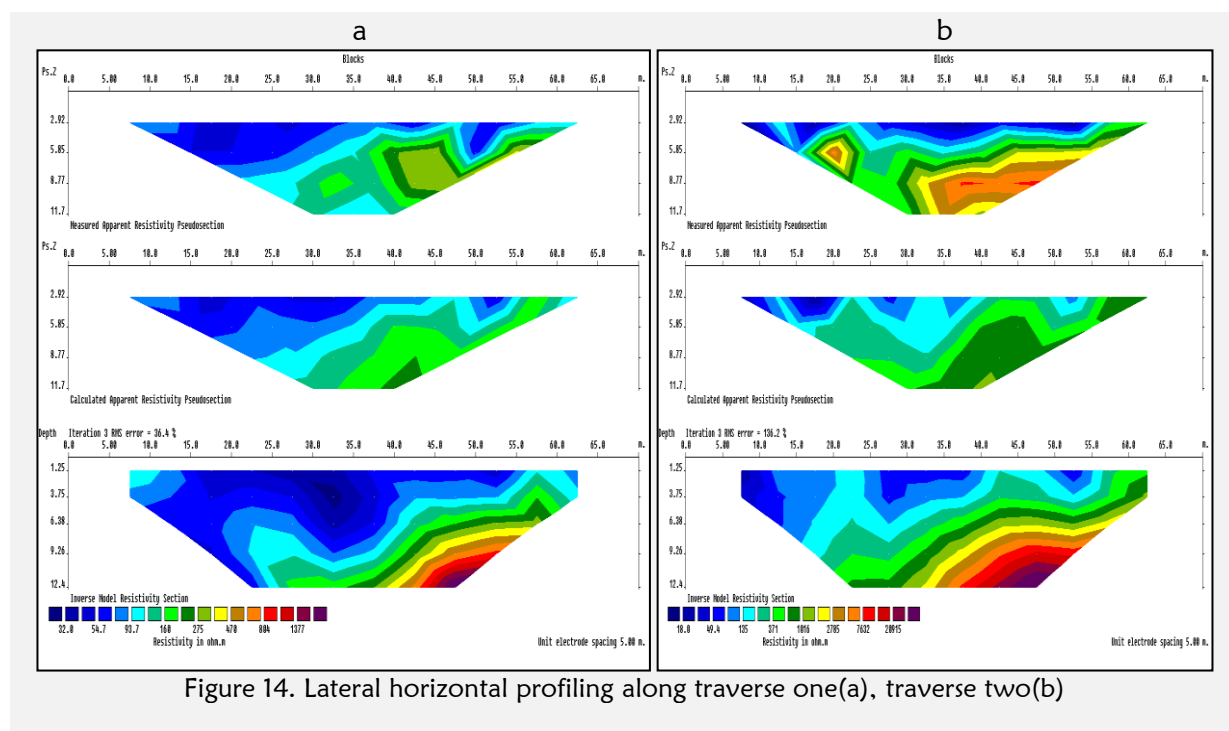
This is an indication that the presence of weak geologic materials in these traverses would subject any proposed structure into serious doubt and differential settlement if the clay contents are not properly put into consideration.

### SYNTHESIS OF RESULTS

#### Traverse One

Figure 15a indicates the correlation of 2D dipole-dipole pseudosection, 2D ERT, and geoelectric section. The 2D dipole-dipole imaging indicates the presence of near-surface weak zone and clayey materials. A major weak zone was observed from the distance between 5 to 25 m

which is diagnostics of highly weathered material, except between distance of 25 to 60 m that exhibited the presence of fresh basement rock overlain by shallow/moderately thin overburden of 2.5 m.



2D ERT shows the existence of a major weak zone from the near-surface to a reasonable depth of 10 m from the distance between 7.5 to 40 m which also correlates with 2D dipole-dipole pseudosection.

The VES carried out along these traverses correlate effectively with the information obtained from both 2D imaging. Both exhibited effective correlations with the information obtained from both 2D imaging and the geoelectric section.

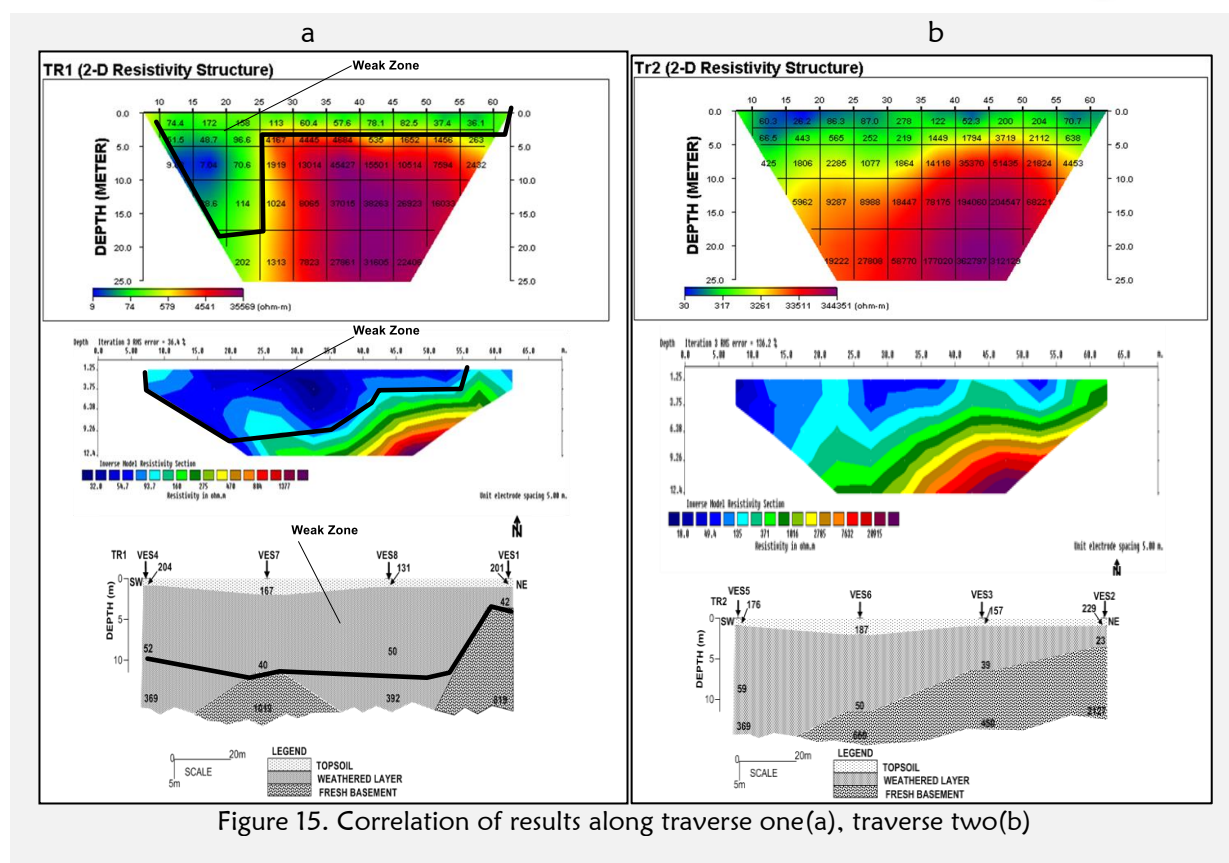
This is an indication that weak geological parameters in this traverse would subject any building into serious doubt and hence formation failure may lead to differential settlement of the building.

### Traverse Two

Figure 15b indicates the correlation of 2D dipole-dipole pseudosection, 2D ERT, and geoelectric section. This showed low resistivity values ranging from 26 to 219  $\Omega\text{m}$  indicating very weak geological formation that may pose threat to any proposed structure to a depth of 2.5 m. The 2D ERT shows weak zone from the near-surface to a depth of 8 m from distance between 7.5 to 40 m towards the eastern part which also correlates with 2D dipole-dipole pseudosection.

The geoelectric section carried out along this traverse correlates effectively with the information obtained from both 2D imaging. Both of these exhibited effective correlations with the information obtained from both 2D imaging and the geoelectric section.

This is an indication that weak geological parameters in this traverse would subject any building into serious doubt and hence formation failure may lead to differential settlement of the building.



## CONCLUSION

The study has shown the importance of geophysical site investigation for foundation design. Geophysics remains a very significant instrument that can be applied in civil engineering construction work. The results show the presence of fracturing, faulting, and a high degree of weathering processes coupled with the pressure of any proposed structure resting on the major weak zones would result in differential settlement.

Therefore, the major weak zones that cut across the entire investigated area may lead to the failure of any building within the study area. This study has further justified the need for geophysical site investigation as a pre-condition before any construction to avoid problems of differential settlement. From the study, the geophysical studies have a greater depth of penetration, and it also delineates a better layer stratification.

The choice of foundation material, clay, and topography elevation should be put into cognizance, due to the appreciable thickness of the clayey nature of the weathered layer. Geophysics remains a very cheap and viable approach to complement studies of this nature, especially where there is structural displacement.

## ACKNOWLEDGMENT

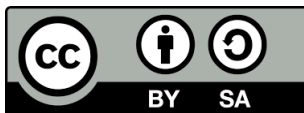
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