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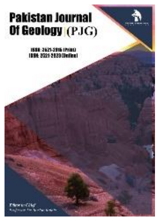

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RESEARCH ARTICLE

SUBSURFACE COMPETENCE EVALUATION USING ELECTRICAL RESISTIVITY METHOD AT A PROPOSED BUILDING SITE ALONG FUTA STAFF QUARTERS, OBA NLA, AKURE SOUTHWESTERN NIGERIA

Mudashiru Soliu Ademola[a]., Olatunji Anuoluwa Olamide[a*]., Oke Paul Adetayo[a]., Adeyanju Olumide Lateef[a]., Orowale Triumph Prosper[b]

[a] Department of Applied Geophysics, Federal University of Technology, Akure
[b] École Doctorale Informatique et Changement Climatique, Université Joseph Ki-Zerbo, Ouagadougou, Burkina Faso
**Corresponding Author's email: olatunjiao@futa.edu.ng*

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ABSTRACT

A detailed geophysical investigation has been undertaken to evaluate the subsurface/subsoil competence of a proposed building site in Federal University of Technology, Akure. The study utilized electrical method involving the use of horizontal profiling, vertical electrical sounding and the combined vertical electrical sounding and horizontal profiling at the site of investigation. Four traverses were occupied in order to have a detailed understanding of the area. Twenty (20) Vertical Electrical Sounding (VES) locations were occupied using Schlumberger electrode configuration with AB/2 varying from 1 to 100 m. This was quantitatively interpreted using manual partial curve matching and computer iteration. The results were used to generate geoelectric sections and maps. Three to five subsurface geologic layers were delineated across the study area comprising; the topsoil, clay, weathered layer, laterite and fresh bedrock. The topsoil exhibits fairly high resistivity with resistivity ranging from 31 to 451 Ωm with thickness in excess of 1.5 m. Based on this, the upper layer can host the foundation of less heavy weight buildings using strip foundation. However, the top layer is underlain by the weathered layer which is predominantly composed of a sandy clay formation, with resistivity values ranging from 85 to 190 Ωm and thickness between 0.5 and 12 m. The last layer, with resistivity values ranging from 383 to 2491 Ωm, is considered to be the competent layer capable of supporting heavy engineering structures with deeper foundations.

KEYWORDS

Subsurface, Electrical resistivity, Geophysical investigation, Competent

1. Introduction

Overtime, it has been observed that areas where civil engineering projects have been carried out without prior knowledge of the subsurface soil and other factors such as geomorphologic and groundwater conditions often experience significant structural failures, increased maintenance costs, and safety hazards (Toll et al., 2012; Hasan and Shang, 2022). This lack of due diligence can lead to unforeseen complications, including foundation instability, and compromised infrastructure integrity, thereby undermining the long term sustainability of the projects. However, engineering design and construction of foundation especially of high rise buildings, dams, highways routes and bridges requires a sound knowledge of the subsurface on which these structures will be erected (Capozzoli et al., 2020). Such information includes the configuration of the subsurface layers, the nature/competence of the subsoil, the bedrock topography and its structural disposition (Ojo et al., 2015; Olayanju et al., 2017; Ademola and Ojo, 2015). This understanding enables engineers to design and locate structures that suits variable character of the bedrock to ensure stability, safety, longevity and integrity of the structures.

In some cases, civil engineers prefer geotechnical methods, such as drilling, cone penetrometer tests, soil analysis etc. to determine the strength of materials for the support of civil engineering projects (Niazi and Mayne, 2018). Although these techniques are viable and valuable, the major drawback is that they are often not cost effective, and they frequently do not provide adequate information about the entire area. Additionally, the depth of investigation is typically shallow, which can lead to incomplete assessments of subsurface conditions. This limitation can result in unforeseen challenges during construction, such as encountering unexpected soil types or groundwater conditions that were not identified during initial assessments (Shrestha and Neupane, 2020). Therefore, it is important to complement these geotechnical methods with geophysical methods in order to have a proper knowledge of what is lying beneath at a deeper depth without the need of opening trenches.

Recently, in Federal University of Technology, Akure, there has been a rapid development in physical infrastructures most especially building construction which includes lecture halls, hostel, staff quarters etc. This surge in development requires detailed geophysical evaluation before construction on the proposed sites to find out the quality, and the competence of the subsurface/subsoil materials as well as the period to monitor the construction to ensure its integrity. In lieu of this, engineering geophysics offers wide methods that can be used in evaluating the subsurface for foundation designs (Romero-Ruiz et al., 2018; Akinotinwa and Adesoji, 2009; Akintorinwa and Adeusi, 2009). The electrical resistivity method is one of frequently used geophysical method in site investigation because the electrical resistivity of earth materials is dependent on several factors which includes: the amount of concentration of saturating fluid, degree of fracturing, rock texture, degree of grain cementation, degree of cementation and the extent of weathering that significantly determine the competence of such earth materials (PO, 2020; Ayolabi et al., 2012; Cai et al., 2017). This study aimed to evaluate the

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subsurface sequence structure disposition which is necessary for foundation design in the study area.

2. Site Description

The study area (figure 1) is situated on the Precambrian Basement Complex of Southwestern Nigeria, characterized by crystalline rocks such as porphyritic granite, biotite granite, quartzite, and migmatite gneiss (Rahaman, 1976). Additionally, Charnokite rocks are found as isolated formations in various locations throughout the study area. The geological features and boundaries of the lithological units have been deduced in areas where they are concealed by overlying residual soil.

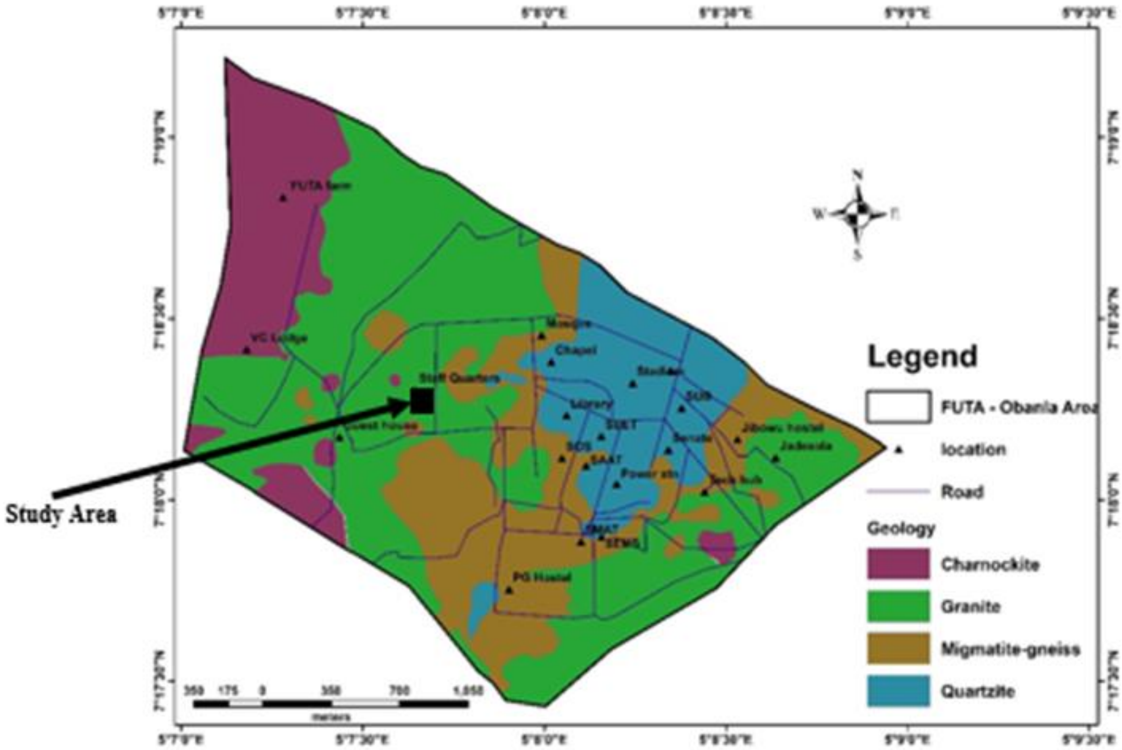


Figure 1: Geological map of FUTA showing the study area (modified after Olayanju and Ojo, 2015)

The study area is a site located at FUTA staff quarters not too far from the academic building within the Federal University of Technology, Akure. The area lie within the latitudes 735520E and 0735540E and the longitudes 0807835N and 0807855N. The area is characterized by the absence of outcrops with small and not too tall vegetation covering some extent of the area. The area is accessible through FUTA North gate with a good network of tarred road. The area extent of the study area is about 648m^2.

3. Materials and Methods of Study

The Horizontal Profiling (HP), Vertical Electrical Sounding (VES) and Combined Horizontal profiling techniques using Wenner, Schlumberger and Dipole-Dipole configurations respectively were adopted for investigation in this study. The data were acquired using Ohmega resisitivity meter. The method involves sending current into the subsurface through two pairs of current electrodes and the potential difference is measure through two pairs of potential electrodes. Four (4) traverses were established within the study area with each profile trending West-East (W-E) direction respectively (figure 2). The four traverses were about 100 m long with station spacing of 10 m each for wenner and dipole-dipole array measurement. The Horizontal Profiling was carried out on all the four traverses with a constant electrode separation of 10 m. Twenty (20) Vertical Electrical Soundings (VES) stations were occupied with at least 20 m apart from each other on the traverses within the study area with half-electrode spacing (AB/2) ranging between 1 and 100 m depending on accessibility.

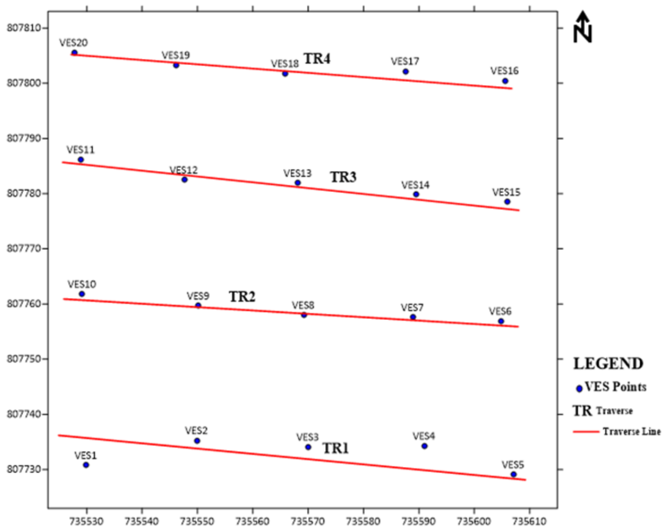


Figure 2: Data acquisition map showing the distribution of VES points within the study area

Accordingly, 2D resistivity imaging (Dipole-Dipole) was carried out along the four (4) traverses established using the electrode spacing of 5 m with electrode expansion factor varying between 1 and 5. The horizontal profile data involving the apparent resistivity was plotted against measuring position which is the mid-point of the two potential electrodes. Additionally, The VES resistivity data were plotted against their respective half-current electrode spacing (AB/2) on a log-log graph and presented as depth sounding curves. The curves were interpreted quantitatively by the method of partial curve matching and 1D computer assisted forward modeling using WINRESIST version 1.0 software. The interpreted VES results (layer resistivities and thicknesses) were used to prepare the lithology of the underlying formation. Also, the dipole-dipole data were inverted using DIPRO for windows version 4.3 software into 2D subsurface imaging displaying the lateral and vertical variation in apparent resistivity with depth. The co-ordinate of each sounding station was recorded using GERMIN 12 channel personnel navigation geographic position system (GPR) unit in Universal Traverse Mercator (UTM).

All the procedures adopted for the tests were in accordance/conformity with the British Standard 1377. The specific gravity of the samples was measured/determined using the pycnometer method, while the sieve analysis and hydrometer methods were used to study the particle size distribution of the samples. Consistency limits, which include a liquid limit (LL), plastic limit (PL) and shrinkage limit (SL) were all determined using the Atterberg tests. The consistency/reliability limits were performed on air-dried soil samples passing through the British standard sieve no. 40 (slot size of 0.425 mm). The Casagrande method was used for LL tests, and shear strength parameters/values (cohesion (Cu) and angle of shearing resistance ($Ø^0$) were obtained using the direct shear test. The direct shear test begins with compacted samples positioned inside the shear box under loading blocks weighing 5kg, 10kg, 15kg and 20 kg respectively. Readings were measured/determined using the deformation dial gauges. The mineralogy of the samples was determined at the University of Pretoria using the X-Ray diffraction (XRD) method. Powdered samples were illuminated with X-rays of a fixed wavelength and the intensity of the reflected radiation was recorded using a goniometer.

4. RESULTS AND DISCUSSION

The results of this study is presented in form of histogram, sounding curves, profiles, geoelectric section, pseudosections, table and maps.

4.1 Characteristics of Vertical Electrical Sounding curves

The qualitative interpretation of resistivity sounding data obtained in the study area from the computer modeled curves is characterized by typical H, A, QH, HA and KH varying between three to four geoelectric layers (Figure 3). This explains the alternate high and low resistivity values found in all the sounding points. Figures 4a and 4b show typical curve types, resistivity values and layer thicknesses obtained in the study area. These distinct geoelectric layers represent alternation of topsoil, clay, laterite, weathered later and fresh basement in the study area.

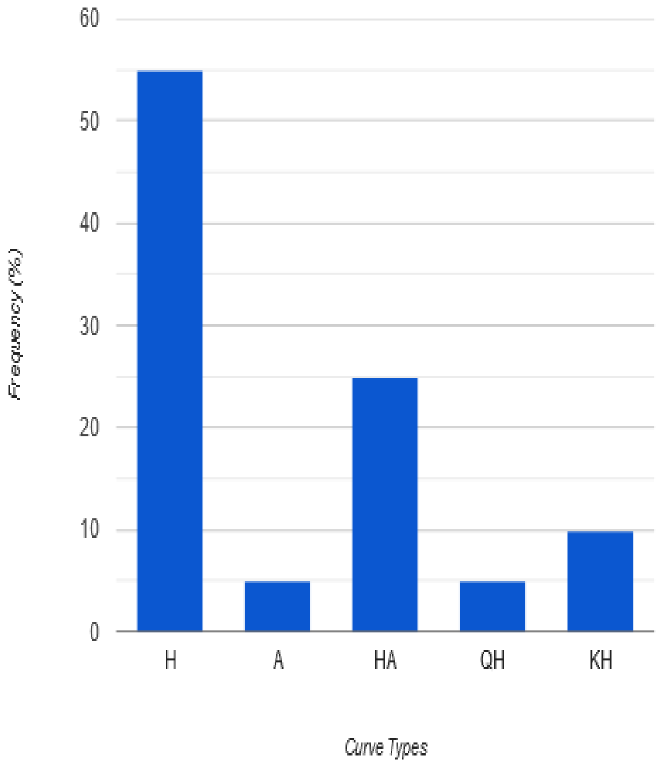


Figure 3: Histogram showing the distribution of the VES curve types in the study are

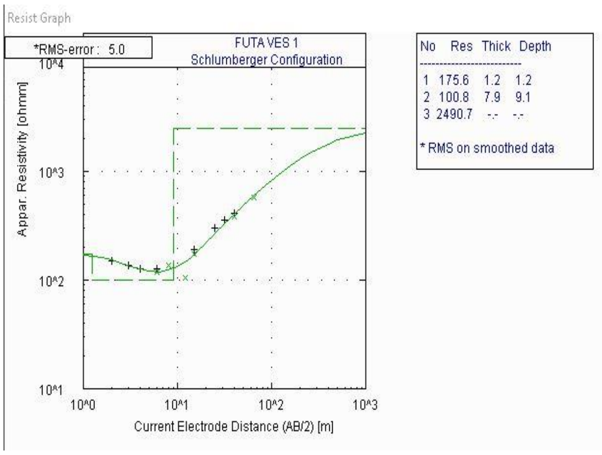


Figure 4(a): Typical H curve

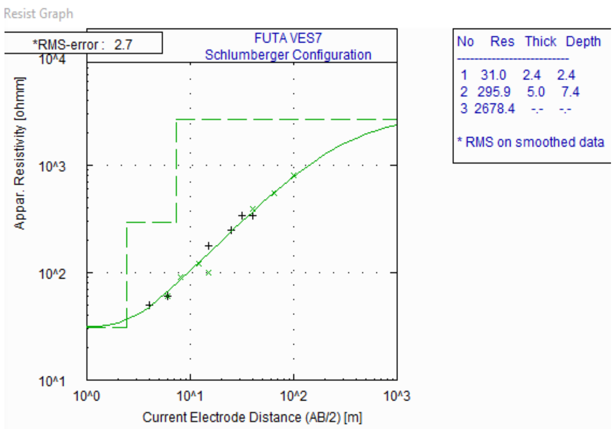
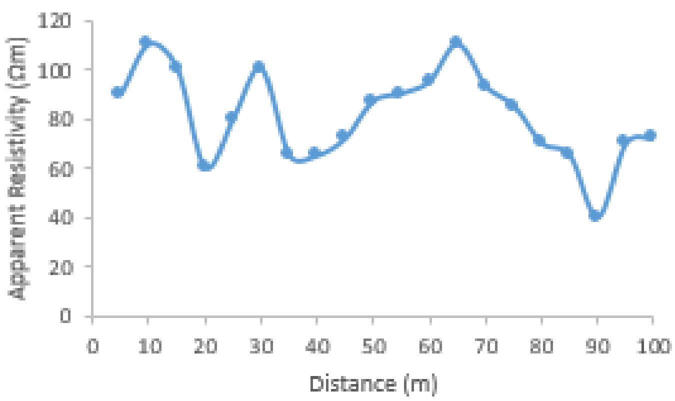


Figure 4(b): Typical A curve

4.2 Horizontal Profile

Figures 5(a)-(d) shows the plot of apparent resistivity against station locations, covering a lateral extent of about 110 m. The profile shows the resistivity distribution across the four established traverses, with values ranging from 40 to 110 Ωm. The resistivity distribution along the traverses is nearly sinusoidal, with very low resistivity values, presumably indicative of clay or sandy clay formations. However, anomalously high resistivity values are observed at distances of 10 m, 30 m, and 65 m in Figure 5a; at 20 m in Figures 5b and 5c; and at 40 m in Figure 5d, with resistivity values ranging from 95 Ωm to 110 Ωm. These anomalous zones are likely attributed to soil compaction in the area.



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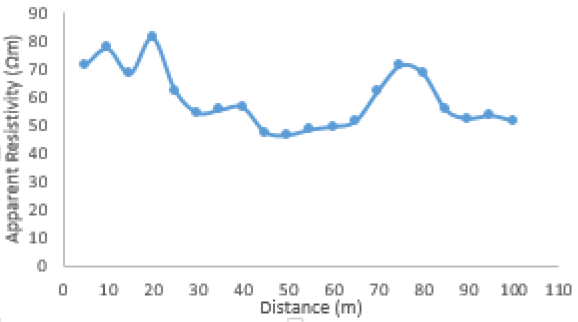

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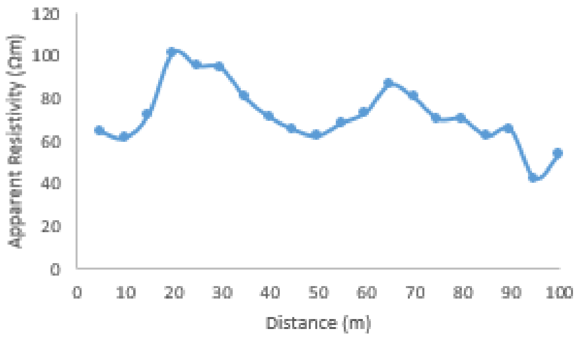

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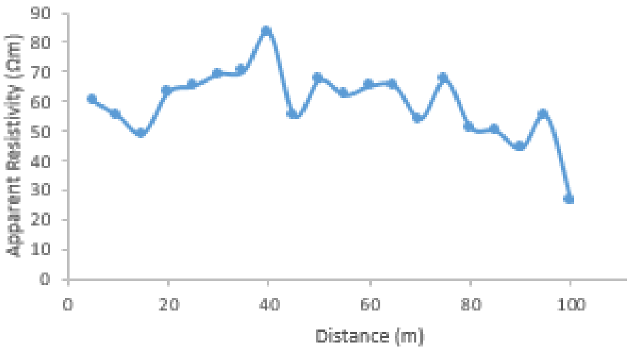
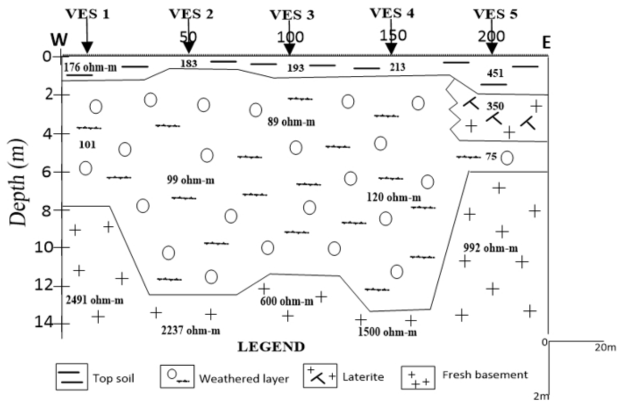


(d)

Figure 5(a-d): Horizontal Profiling along Traverse 1 to 4

4.3 Geoelectric Section

The 2-D view of the geo-electric parameters (resistivity and depth) obtained from the inversion of the electrical resistivity sounding data are presented as geo-electric sections. The geo-electric section along the four traverses (Figure 6(a)-(d)) attempts to correlate the geo-electric sequence across the traverses. Three to five subsurface geologic layers were delineated across the study area; the topsoil, clay, weathered layer, laterite and fresh bedrock. The topsoil (resistivity varies from 31 to 451 Ωm and thickness ranges from 0.6 to 2.1 m); clayey layer (resistivity varies from 15 to 66 Ωm and thickness ranges from 0.6 to 10 m); weathered layer with resistivity values varying from 85 to 190 Ωm and thickness ranges from 0.5 to 12 m; lateritic layer (resistivity varies from 190 to 350 Ωm and thickness ranges from 3.2 to 15 m) The last identified layer is fresh basement/bedrock with resistivity values ranging from 383 to 2491 Ωm, the thickness of this layer could not be determined due to the termination of current in this region. Generally, the geoelectric section shows that the topsoil based on the resistivity values is considered competent to host pavement of strip foundation of light weight buildings, but due to the relatively thin thickness of this layer, it may not provide adequate stability or support for deeper structures. However, the depth to competent layer is about an average of 16 m. This suggests that the layer overlying the competent layer is presumably diagnostic of clay/sandy clay formation. The geoelectric section confirms the interpretation derived from the resistivity profiling indicating that the area is underlain by conductive materials indicative of clayey formation in the near surface which is inimical to engineering structures.



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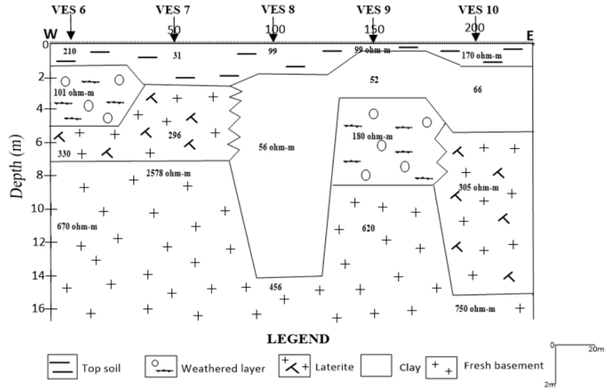

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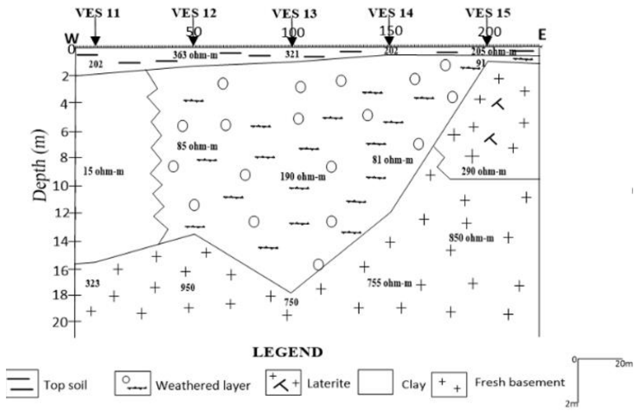

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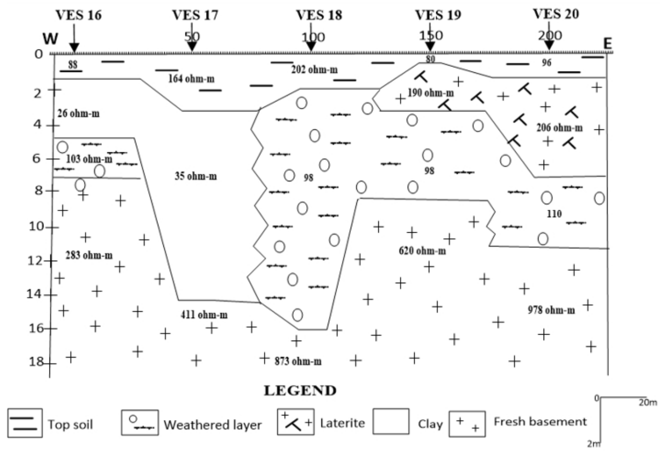


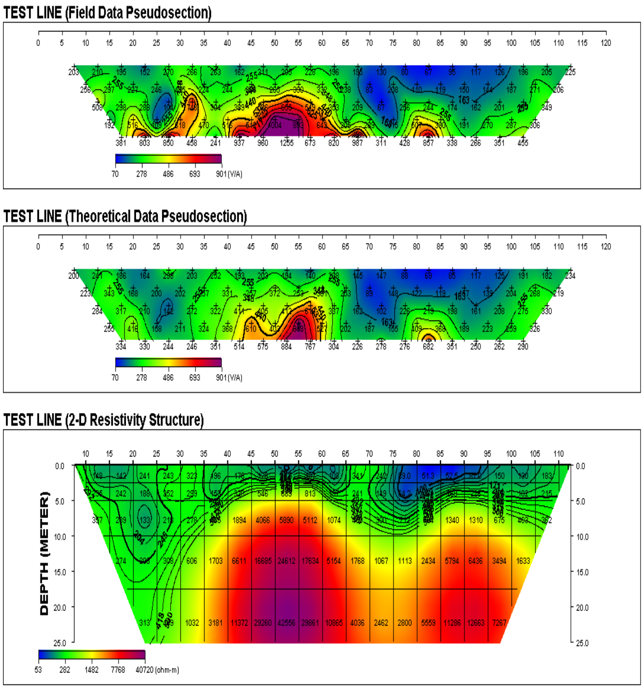
(d)

Figure 6(a) – (d): Geoelectric section along Traverse 1 to 4

4.4 2-D Imaging (Dipole-Dipole)

Figure 7(a)-(d) shows the 2D resistivity model that was produced from the dipole dipole data taken along the established four traverses. It was set up to have a 2-Dimensional clear view of the subsurface because it shows the interpretation of unilateral data and its contours. The pseudosections delineated four distinct layers that represent the subsurface conditions: topsoil, weathered layer, partly weathered layer, and fresh basement.

The resistive parts are seen at the lower part of the sections represented by red colour band which is the fresh basement while the green and blue colour band occurring at the upper part of the section representing a conductive layer. It is observed that that the top soil is generally underlain by conductive materials with resistivity values ranging between 25 and 55 Ωm. The fresh basement is observed to be closer to the surface at the close end of the traverse line in figures 7b and 7d. Also a vertical discontinuity indicative of fracture or fault is observed in figure 7c between stations 25 and 40. This discontinuity may pose serious problem on any civil structure within that vicinity.



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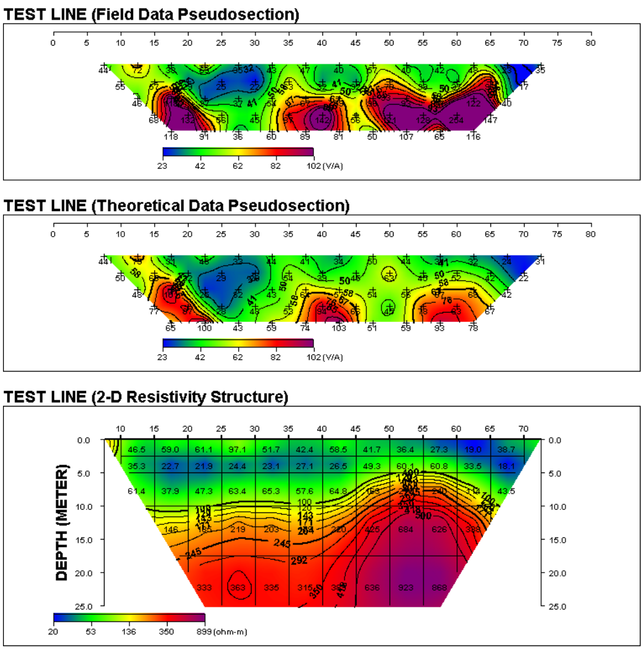

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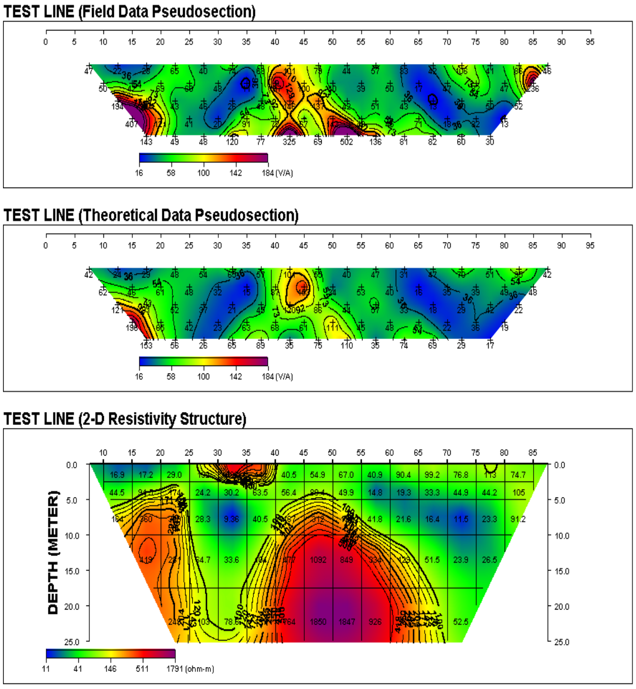

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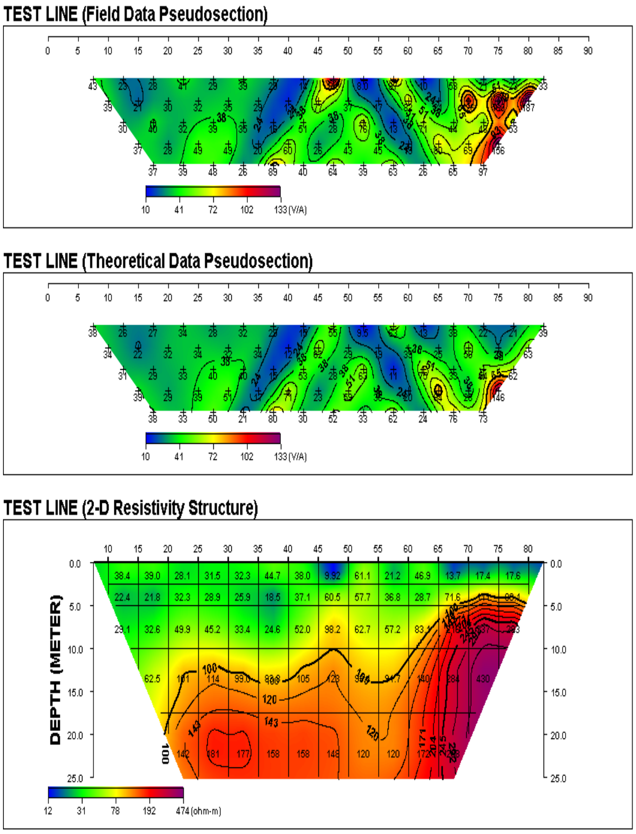

(d)

Figure 7(a) – (d): Pseudosection from Dipole-dipole data along Traverse 1 to 4

4.5 Subsurface Lithology characteristics

The interpreted VES results were used to prepare the subsurface lithology characterizing the study area (Table 1) according to the classification by a group researchers of resistivity values of common rock types (Keary et al., 2002). The subsurface lithology identified three to five geoelectric/geologic layers comprising the topsoil, clay, weathered layer, lateritic layer and fresh basement.

Table 1: Summary of the VES geologic/geoelectric parameters and lithological interpretation

VES Station	No. of Layers	Apparent Resistivity (Ωm)	Layer Thickness	Layer Depth (m)	Lithology	Curve Type
VES 1	3	175.6 100.8 2490.7	1.2 7.9 --	1.2 9.1 --	Topsoil Weathered Layer Basement	H
VES 2	3	183.0 98.6 2237.1	0.6 12.5 --	0.6 13.1 --	Topsoil Weathered Layer Basement	H
VES 3	3	192.5 89.1 600.2	1.1 11.5 --	1.1 12.6 --	Topsoil Weathered Layer Basement	H
VES 4	3	212.6 120.0 1500.6	0.9 13.3 --	0.9 14.1 --	Topsoil Weathered Layer Basement	H
VES 5	4	450.5 350.3 75.2 992.3	1.9 4.5 6.0 --	1.9 6.4 12.4 --	Topsoil Laterite Weathered Layer Basement	QH
VES 6	4	210.2 101.1 330.2 670.2	1.4 4.9 7.1 --	1.4 6.3 13.4 --	Topsoil Weathered Layer Laterite Basement	HA
VES 7	3	31.0 295.9 2578.4	2.4 5.0 --	2.4 7.4 --	Topsoil Laterite Basement	A
VES 8	3	98.8 55.8 455.9	1.9 14.2 --	1.9 16.1 --	Topsoil Clay Basement	H
VES 9	4	99.1 52.3 180.2 620.1	0.5 3.3 8.6 -	0.5 3.9 12.5 -	Topsoil Clay Weathered Layer Basement	HA
VES 10	4	170.4 65.8 305.0 750.4	1.3 5.2 15.2 -	1.3 6.5 21.7 -	Topsoil Clay Laterite Basement	HA
VES 11	3	202.1 14.9 323.1	2.0 15.6 --	2.0 17.6 --	Topsoil Clay Basement	H
VES 12	3	362.5 85.2 950.1	1.4 13.6 --	1.4 15.0 --	Topsoil Weathered Layer Basement	H
VES 13	3	320.5 190.1 750.2	1.1 17.8 --	1.1 18.9 --	Topsoil Weathered Layer Basement	H
VES 14	3	202.1 80.5 755.2	0.6 12.1 --	0.6 12.7 --	Topsoil Weathered Layer Basement	H
VES 15	4	205.3 91.2 290.3 850.3	0.6 1.1 9.6 --	0.6 1.7 11.3 --	Topsoil Weathered Layer Laterite Basement	HA
VES 16	4	88.2 26.4 102.6 282.8	1.4 4.9 7.1 --	1.4 6.3 13.4 --	Topsoil Clay Weathered Layer Basement	HA
VES 17	3	164.3 34.9 411.4	3.2 14.4 --	3.2 17.6 --	Topsoil Clay Basement	H

Table 1 (Conts) : Summary of the VES geologic/geoelectric parameters and lithological interpretation

VES 18	3	201.8 97..8	2.0 16.2	2.0 18.2	Topsoil Weathered Layer	H
		872.9	--	--	Basement	
VES 19	4	80.1 190.3 98.2 620.1	0.5 3.3 8.6 -	0.5 3.9 12.5 -	Topsoil Laterite Weathered Layer Basement	KH
VES 20	4	96.4 205.8 110.0 978.4	1.3 7.2 11. 2 -	1.3 8.5 19.7 -	Topsoil Laterite Weathered Layer Basement	KH

4.6 Isoresistivity and Isopatch Map of the Topsoil

Figures 8 and 9 shows the distribution of resistivity and thickness of the topsoil across the study area. The topsoil resistivity ranges from 20 to 460 Ωm, which indicate that the topsoil is fairly conductive and presumably made up of clayey sand formation. However, the resistivity value ranging from 120 to 200 Ωm is predominant in the central part of the study area. The thickness of the topsoil is relatively thin across the study area with values in the range of 0.5 to 1.5 m. Due to the fair conductivity of the soil and relatively thin thickness, the layer can only withstand light engineering structures without deep foundation to avoid the compromise of the structure with time.

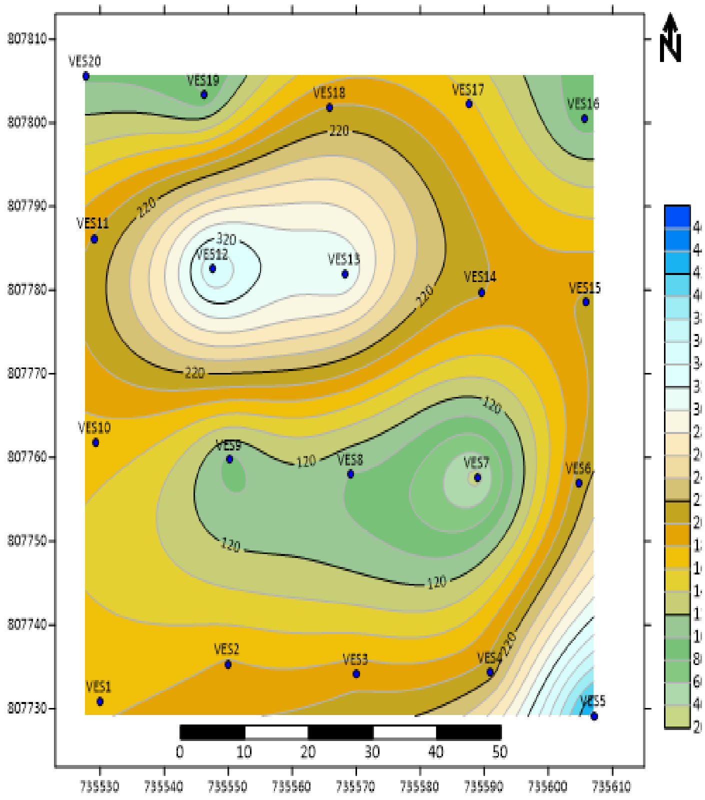

Figure 8: Isoresistivity map of the topsoil

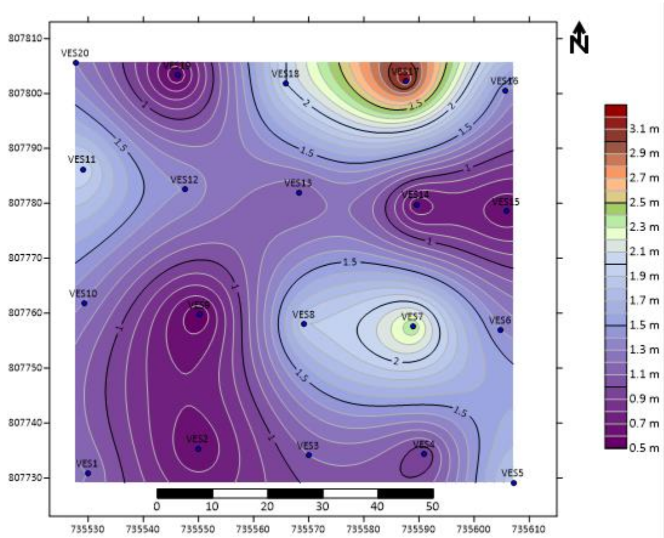

Figure 9: Isopach map of the topsoil

4.7 Isoresistivity and Isopatch Map of the Second Layer

Figures 10 and 11 show the resistivity and thickness distribution of the second layer respectively. The resistivity values range from 20 to 180 Ωm, indicating a weathered layer which cannot host foundation of fairly large civil structures. This layer (figure 10) is predominantly composed of clay/sandy clay formation and its thickness (figure 11) ranges from 1 to 19 m. Generally, the second layer has low resistivity values (<400 Ωm), suggesting that it may be incompetent for supporting substantial engineering structure.

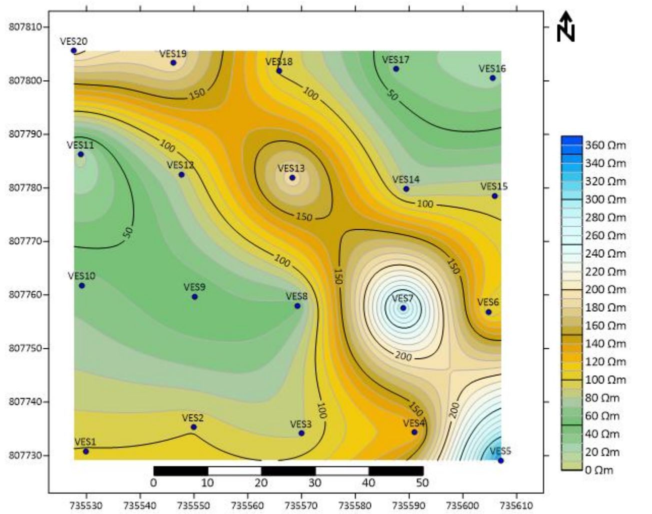

Figure 10: Isoresistivity map of the second layer

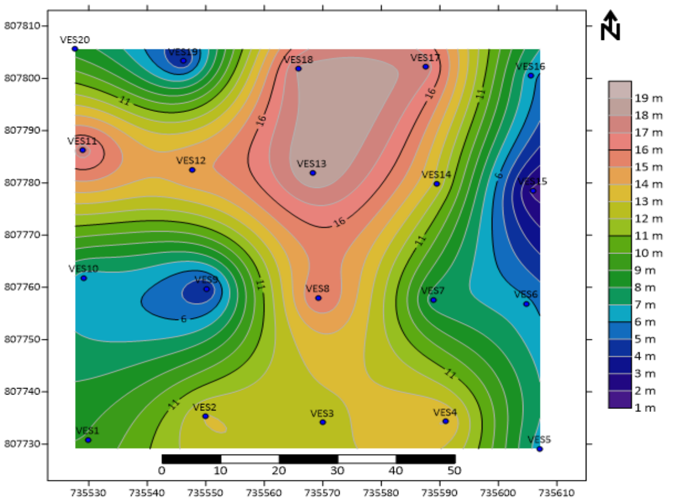

Figure 11: Isopach map of the second layer

4.8 Engineering Evaluation of the Subsoil in the study area

According to a study, the higher the resistivity value of a layer, the higher the competence of the layer (Akintorinwa and Adeusi, 2009). The geoelectric sections, 2D imaging (dipole-dipole), and isoresistivity map of the topsoil showed relatively fair high resistivity topsoil. Based on the resistivity values of the topsoil, it is considered suitable for supporting light to moderate civil structures with pavement of strip foundations and thickness less than 2 m. Table 2 shows the relationship of the competence of earth materials with respect to their resistivity values.

Table 2: Rating of subsoil competence using resistivity value (Ojo et al., 2015)

Resistivity (ohm-m)	Lithology	Competence Rating
< 100	Clay	Incompetent
100 – 350	Sandy clay	Moderately Competent
350 – 750	Clayey sand	Competent
> 750	Sand/Laterites/Crystalline Rock	Highly Competent

5. Conclusion

The study has been able to show the application of geophysics in the evaluation of a proposed building site. The electrical method involving horizontal profiling, vertical electrical sounding and the combined vertical electrical sounding and horizontal profiling was utilized at the site of investigation. The geophysical evaluation was necessary for the comprehensive assessment of the subsurface/subsoil materials, ensuring their suitability for engineering structures designs. The data from the investigation were interpreted quantitatively using manual partial curve matching and computer iteration. From this, geoelectric sections, subsurface lithology and maps were generated in relation to the objectives of the study.

The geoelectric sections identified three to five geoeleteric/geologic subsurface layers comprising of topsoil, clay, weathered layer, laterite and fresh bedrock. The topsoil resistivity ranges from 31 to 451 Ωm with thickness range between 0.6 and 2.1 m. This layer is made up of clayey sand formation. The second layer constitutes the weathered layer, which presumably connotes sandy clay formation with resistivity values ranging from 85 to 190 Ωm and thickness ranging from 0.5 to 12 m. The clay formation which occurs beneath VES 8, 9, 10, 11, 16 and 17 has resistivity less than 60 Ωm. However, areas with vertical discontinuity suggesting the presence of fault as shown by the dipole-dipole especially in figure 7c should be avoided.

The study concluded that the fairly high resistivity value of the topsoil is considered to be competent for only less heavy buildings with strip foundations. However, the site is not suitable for heavy buildings unless piling is done to an average depth of about 15 m.

Declaration of Competing Interest

The authors declare that there are no known conflicts of interest.

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