Geophysical Evaluation of Foundation Soils in a Basement Complex Terrain: A Case Study of LAUTECH Campus, Ogbomoso, Southwestern Nigeria

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ABSTRACT

Electrical resistivity surveys were carried out at the eastern part of LAUTECH campus, Ogbomoso, southwestern Nigeria in order to investigate the subsoil foundation characteristics and thus provide subsurface information that will guide the design of foundation of engineering structures at the location.

Forty-one (41) VES stations were occupied at the study area using the Schlumberger electrode configuration with electrode spacing varied from 1m to 100m. Interpretation of data was done by initial partial curve matching followed by computer-aided iterative technique. The layer parameters were used to generate geoelectric sections while the geographic coordinates and resistivity values were used to produce the isopach map of the overburden and the bedrock relief map.

The interpretation of the geoelectrical data revealed that the study area consists of three to four layers defined as the topsoil, clay/sandy clay layer, and weathered/fresh bedrock. The resistivity and thickness of the topsoil range from 51 to 1887.1Ωm and 0.3 to 3.2m respectively. The resistivity of the weathered layer varies between 13.4 and 415Ωm and is 2.0 to 17.2m thick. The layer comprises a mixture of clay and sandy clay. Bedrock varies between 109 and 70380Ωm while depth to the bedrock ranges from 2.1 to 19.6m. The isopach map of the overburden and the bedrock relief map show that the study area is underlain by relatively thin (<10m) and relatively thick overburden (>10m) as well as bedrock ridges and depressions. Areas with thin overburden are associated with high bedrock relief (>350m) while those with thick overburden are associated with bedrock depression (<350m).

The subsurface of the study area can support deep foundations, except at VES 28 where the overburden thickness is less than 3m. The areas underlain by sandy clay and bedrock ridges are expected to be more competent for safe foundation. The clay layer will be good foundation materials if the clay has activity less than 0.75 indicative of low swell-shrink potential. The results of this study will serve as useful guide in the choice of sites for engineering structures and also reduce the number of geotechnical probes for foundation studies and hence reduce the overall cost of investigation.

(Keywords: geoelectric parameters, subsoil characteristics, foundation integrity, engineering structures, overburden thickness, bedrock relief)

INTRODUCTION

Proper design of engineering structures requires adequate and thorough understanding of the subsurface conditions of the earth materials within which the structures will be erected. Many engineering structures such as roads, buildings and bridges have failed because the subsurface geology of the site was not considered in the design of their foundation prior to construction.

The existence of geological features and/or deficient engineering characteristics of subsurface soils and rocks are capable of undermining the integrity of the foundation of engineering structures and may lead to their collapse. The non-recognition of this fact has led to loss of integrity and eventual collapse of many engineering structures across the country (Olorunfemi et al., 2000; Olorunfemi et al., 2005).

It is therefore vital for engineers to carry out foundation investigations of proposed engineering sites prior to the design and construction of engineering structures. Foundation investigation provides subsurface information which include depth to the bedrock, geotechnical integrity of the subsoils and bedrock, and groundwater conditions (Peck et al., 1973, Bowles, 1984, Sharma, 1997)

Application of geophysical methods has been shown to be efficient and cost-effective in providing the required geotechnical information in engineering site investigation (Gokhale and Dasari, 1984; Adeduro et. al., 1987; Ojo et. al., 1990; Olorunfemi et. al., 2000). Geophysics is able to provide a broad, composite picture of the subsurface over large area with speed and economy not attainable by other means (Sharma, 1997).

Since the ongoing physical development on Ladoke Akintola University of Technology (LAUTECH) campus, Ogbomoso, Nigeria involves the construction of infrastructure such as roads, lecture theaters, office complexes and laboratories, it is important that the characteristics of the subsoils be understood so as to ensure that foundations of structures are safely sited. Geophysics can be applied to provide useful information regarding the early detection of potentially dangerous subsurface conditions. The sources of hazards in civil engineering works are essentially undetected near-surface structures such as cavities and/or inhomogeneities in foundation geomaterials (Olorunfemi and Mesida, 1987; Soupios et al., 2007).

This study was therefore aimed at providing subsurface information meant to guide in the choice of the parts of the campus for the foundations of various proposed structures by delineating the geoelectric sequences using the layer parameters (layer resistivities and thicknesses), determining the nature and thickness of the overburden, depth to the bedrock, bedrock relief and possible presence of geological features which may cause structural failure. The information above would enable the construction engineers to take appropriate decisions in the design and siting of adequately safe foundations for future physical development projects on the university campus.

The study area is located between Latitude between 080 10'N to 080 12'N and Longitudes 04015'E to 040 17'E. The topographic elevation varies from about 322m to 388m at its highest points. It lies within the basement complex terrain of southwestern Nigeria with migmatite gneiss and granite gneiss occurring as the major rock types. The location and geology of the study area are presented in Figure 1.

METHODOLOGY

Schlumberger Vertical electrical sounding technique was conducted at 41 VES stations occupied within the study area (Figure 2). The field procedure involved introducing artificially generated current into the ground through two current electrodes and measuring the resulting potential difference at the surface, across two potential electrodes. Deviation from the pattern of potential difference expected from homogenous ground provides information on the form and properties of subsurface inhomogeneities.

The Campus Omega resistivity meter was used with its accessories to acquire the resistivity data while the Global Positioning System (GPS) was used to determine the geographic coordinates and elevation of the VES stations. The resistivity data acquired were interpreted by partial curve matching (Orellana and Mooney, 1968) and computer-aided iterative inversion (Zohdy, 1989). The geoelctric parameters (layer resistivities and thicknesses) obtained were then used to produce geoelectric sections along established profile lines. The Isopach map of the overburden and Bedrock relief map were also produced.

RESULTS AND DISCUSSION

The interpretation of the geoelectrical data revealed that the study area consists of three layers defined as the topsoil, clay/sandy clay layer, and weathered/fresh bedrock. The results are presented in Table 1.

The sounding curves are predominantly the H-type (Figure 3, Table 2) which show steeply rising terminal branch, characteristic of the basement crystalline bedrock (Olayinka and Oyedele, 2001). The resistivity and thickness of the topsoil range from 107 to 1887Ωm and 0.3 to 3.2m respectively. The resistivity of the weathered layer varies between 13 and 415Ωm.and is 2.0 to 17.2m thick. The layer comprises a mixture of clay and sandy clay. Bedrock resistivity varies between 109Ωm and 70380Ωm while depth to the bedrock ranges from 2.1 to 19.6m. The geoelectric sections along four profiles within the study area are presented in Figures 4-7.

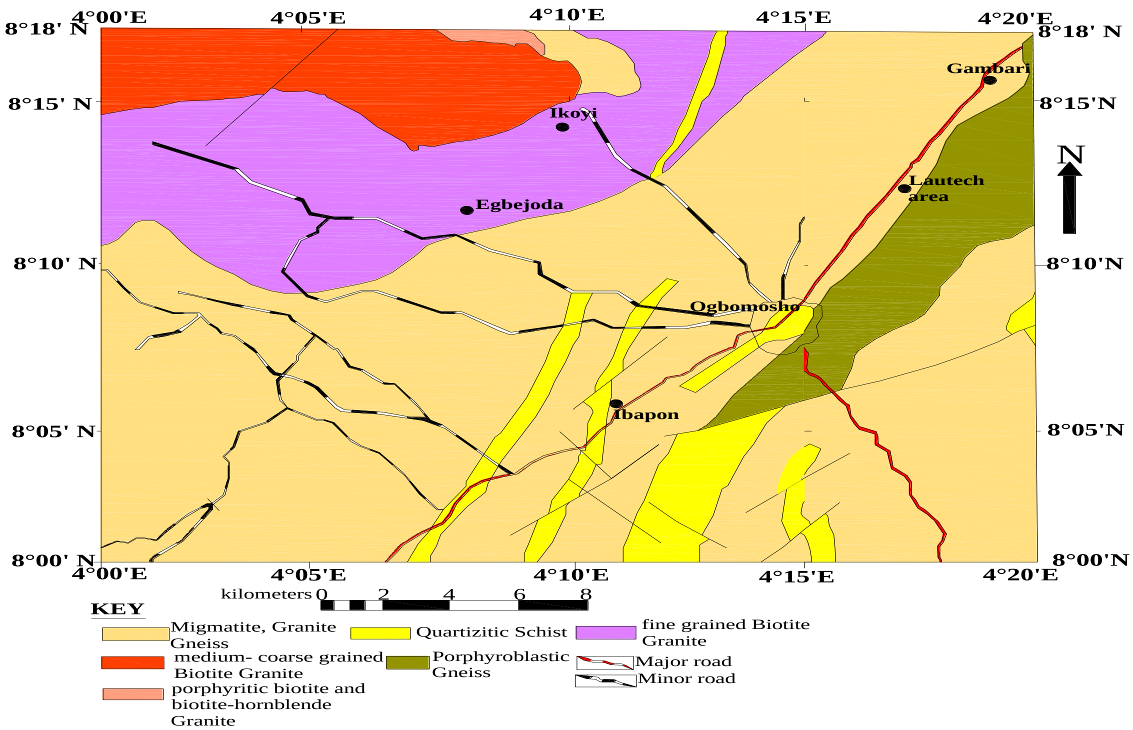


Figure 1: Geological Map of Ogbomoso showing LAUTECH Campus.

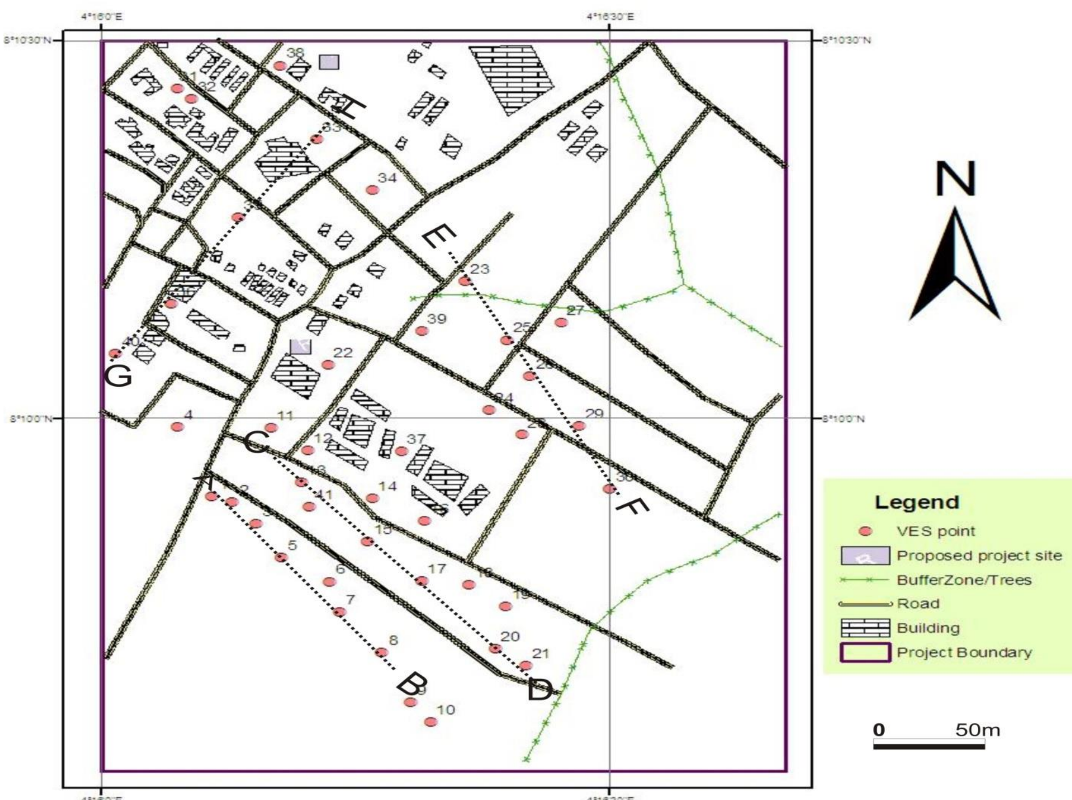


Figure 2: VES Stations Occupied in the Study Area.

Table 1: Summary of VES Interpretation.

VES No.	Location	Layer Resistivity $\rho_1/\rho_2/\rho_3(\Omega m)$	Thickness h_1/h_2(m)	Depth H_1/H_2(m)	Inferred Lithology
1	Pre-Degree Complex	354/57/7603	5.4/9.8	5.4/14.8	Topsoil/Clay/Fresh Bedrock
2	LICO	1259/104/7231	2.0/6.5	2.0/8.5	Topsoil/Sandy Clay/Fresh Bedrock
3	Staff School 1	1538/154/645	1.0/5.1	1.0/6.1	Topsoil/Sandy Clay/Weathered Bedrock
4	Staff School 2	575/115/5175	1.1/7.4	1.1/8.5	Topsoil/Sandy Clay/Fresh Bedrock
5	School Field	834/64/12672	2.1/3.9	2.1/6.0	Topsoil/Clay/Fresh Bedrock
6	Staff School Extension.	306/36/9561	1.9/8.5	1.9/10.4	Topsoil/Clay/Fresh Bedrock
7	Staff School Extension 2	266/23/1283	3.0/1.7	3.0/4.7	Topsoil/Clay/Fresh Bedrock
8	1500LT	622/92/675	1.0/6.9	1.0/7.9	Topsoil/Clay/Weathered Bedrock
9	1500LT 2	410/127/60104	1.6/7.4	1.6/9.0	Topsoil/Sandy Clay/Fresh Bedrock
10	1500 Extension	832/59/2247	1.4/7.6	1.4/9.0	Topsoil/Clay/Fresh Bedrock
11	1500 Extension 2	1098/51/2205	1.9/13.8	1.9/15.7	Topsoil/Clay/Fresh Bedrock
12	Man'O War Base	51/36/3114	1.1/15.8	1.1/16.9	Topsoil/Clay/Fresh Bedrock
13	Man'O War Base Extension	1887/46/3112	1.9/7.0	1.9/8.9	Topsoil/Clay/Fresh Bedrock
14	Sport Complex	1792/29/1033	1.9/4.0	1.9/5.9	Topsoil/Clay/Fresh Bedrock
15	Sport Complex 2	302/82/435	0.9/15.6	0.9/16.5	Topsoil/Clay/Weathered Bedrock
16	Lawn Tennis	417/83/432	0.7/10.1	0.7/10.8	Topsoil/Clay/Weathered Bedrock
17	Lawn Tennis Extension	1218/39/850	1.2/3.9	1.2/5.1	Topsoil/Clay/Weathered Bedrock
18	Lawn Tennis 2	1233/113/575	0.6/5.1	0.6/5.7	Topsoil/Sandy Clay/Weathered Bedrock
19	Bukateria	663/14/178	1.0/3.5	1.0/4.5	Topsoil/Clay/Weathered Bedrock
20	Bukateria Extension	574/25/122	1.3/5.3	1.3/6.6	Topsoil/Clay/Weathered Bedrock
21	University Boundary	652/13/605	1.3/6.2	1.3/7.5	Topsoil/Clay/Weathered Bedrock
22	1200LT	771/61/70380	1.8/6.8	1.8/8.6	Topsoil/Clay/Fresh Bedrock
23	1200LT Extension	942/143/312	1.0/7.2	1.0/8.2	Topsoil/Clay/Weathered Bedrock
24	1200LT Extension 2	837/54/4144	1.3/8.5	1.3/9.8	Topsoil/Clay/Fresh Bedrock
25	Management Science	1040/33/1051	1.2/5.0	1.2/6.2	Topsoil/Clay/Fresh Bedrock
26	Motion Ground	1143/60/644	0.8/5.6	0.8/6.4	Topsoil/Sandy Cay/Weathered Bedrock
27	University Farm	1115/221/4803	0.7/4.8	0.7/5.5	Topsoil/Sandy Clay/Fresh Bedrock
28	Sport Complex 3	140/65/2431	0.4/1.8	0.4/2.2	Topsoil/Clay/Fresh Bedrock
29	Sport Complex 4	1317/176/1044	0.9/6.6	0.9/7.5	Topsoil/Sandy Clay/Fresh Bedrock
30	Stream	445/28/329	1.0/11.6	1.0/12.6	Topsoil/Clay/Weathered Bedrock
31	Livestock Farm	107/71/2689	1.6/4.7	1.6/6.3	Topsoil/Clay/Weathered Bedrock
32	LH	747/123/584	1.4/6.9	1.4/8.3	Topsoil/Sandy Clay/Weathered Bedrock
33	100L Laboratory Complex	382/415/109	1.2/19.9	1.2/21.1	Topsoil/Sandy Clay/Weathered Bedrock
34	ICT New Site	877/51/3314	0.5/18.2	0.5/18.7	Topsoil/Clay/Fresh Bedrock
35	FET	839/79/859	1.2/14.5	1.2/15.7	Topsoil/Clay/Weathered Bedrock
36	Senate Building	1113/133/11869	3.2/5.6	3.2/8.8	Topsoil/Sandy Clay/Fresh Bedrock
37	Staff School 3	1550/314/12178	1.3/6.5	1.3/7.8	Topsoil/Sandy Clay/Fresh Bedrock
38	FAGS	526/166/14885	2.4/4.8	2.4/7.2	Topsoil/Sandy Clay/FreshBedrock
39	FET Central Lab	623/53/3884	1.7/17.3	1.7/19.0	Topsoil/Clay/Fresh Bedrock
40	Old Archi. Studio	527/282/1977	0.8/4.4	0.8/5.2	Topsoil/Sandy Clay/Fresh Bedrock
41	CVE Shed	248/47/3846	3.9/7.3	3.9/11.2	Topsoil/Clay/Fresh Bedrock

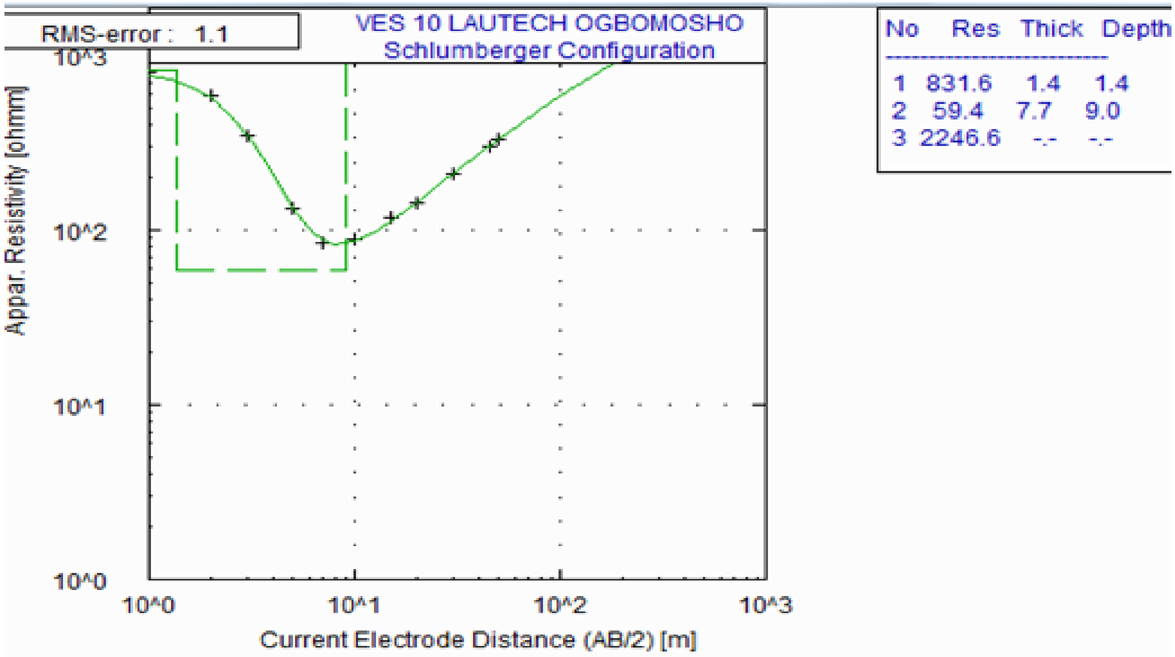


Figure 3: Typical Sounding Curve from the Study Area.

Table 2: Classification of Sounding Curves.

CLASS	CURVE TYPE	FREQUENCY
Class 1	H	38
Class 2	A	1
Class 3	HK	1
Class 4	HKH	1
TOTAL		41

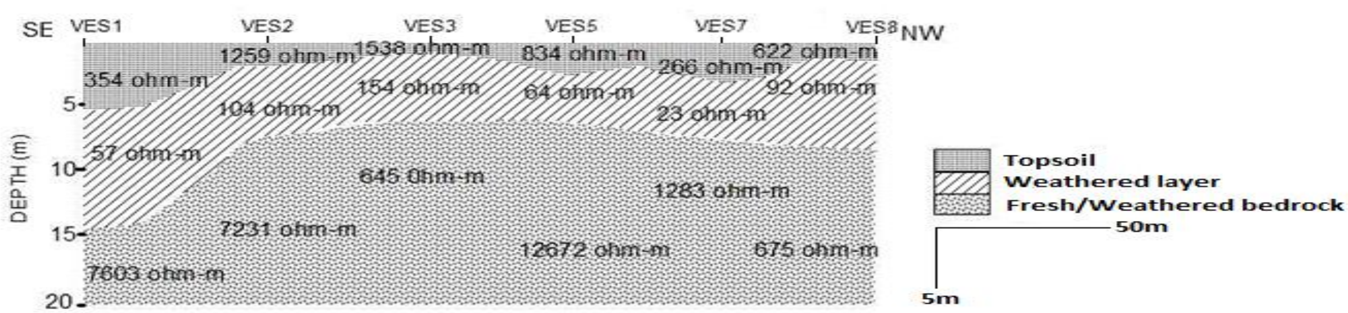


Figure 4: Geoelectric Section Beneath Profile AB.

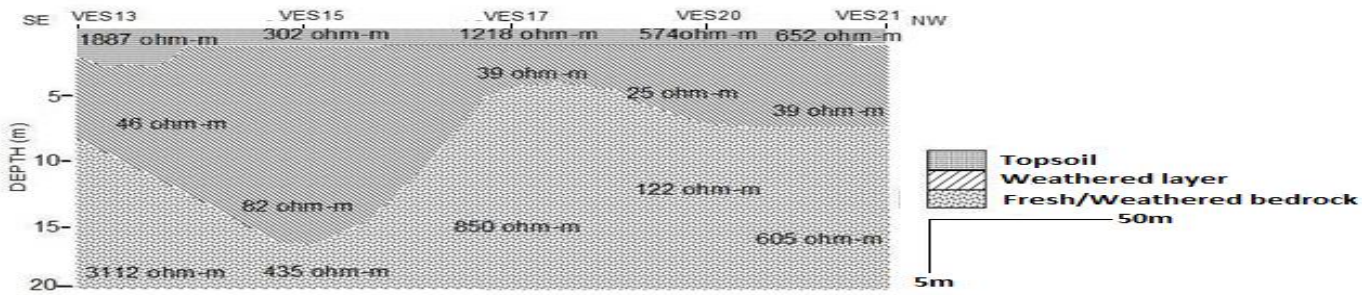


Figure 5: Geoelectric Section Beneath Profile CD.

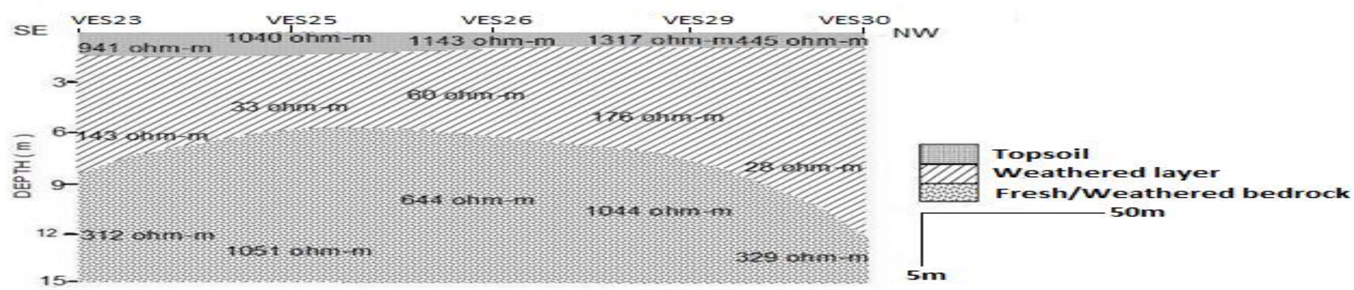


Figure 6: Geoelectric Section Beneath Profile EF.

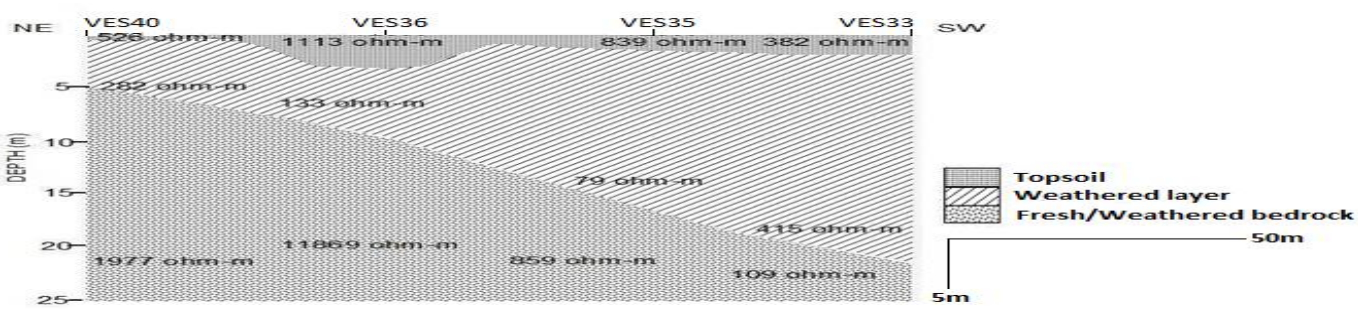


Figure 7: Geoelectric Section Beneath Profile GH.

Table 3: Overburden Thickness and Bedrock Relief in the Study Area.

VES NO	LOCATION	NORTHING (°)	EASTING (°)	ELEVATION (m)	OVERBURDEN THICKNESS (m)	BEDROCK RELIEF (m)
1	Pre-Degree Complex	8.16534	4.26832	358	19.5	338.5
2	LICO	8.16481	4.26881	363	7.7	355.3
3	Staff School	8.16433	4.26919	366	5.5	362.5
4	Staff School 2	8.16383	4.18628	347	8.5	338.5
5	School Field	8.16479	4.27236	346	6	340
6	Staff Sch. Ext.	8.16306	4.27039	350	10.4	339.6
7	Staff Sch. Extension 2	8.16239	4.27055	344	7.5	336.7
8	1500LT	8.1615	4.27125	339	7.9	331.1
9	1500LT 2	8.1604	4.27172	337	9	328
10	1500 Extension	8.15997	4.27205	335	9	326
11	1500 Extension 2	8.16647	4.26944	347	15.7	319.3
12	Man'O War Base	8.16542	4.27063	346	16.9	329.1
13	Man'O War Base Ext.	8.1655	4.2703	325	8.2	316.8
14	Sport Complex	8.1649	4.2711	329	9.2	319.8
15	Sport Complex 2	8.1643	4.2714	357	16.5	340.5
16	Lawn Tennis	8.1635	4.2717	343	9.8	333.2
17	Lawn Tennis Ext.	8.16308	4.2719	340	5.1	334.9
18	Lawn Tennis 2	8.1628	4.2724	352	5.7	346.3
19	Bukateria	8.1622	4.273	337	4.5	332.5
20	Bukateria Extension	8.1616	4.2734	334	6.6	327.4
21	University Boundary	8.1612	4.27361	327	7.5	321.5
22	1200LT	8.16770	4.27017	388	8.6	379.4
23	1200LT Extension	8.1651	4.2706	329	8.2	320.8
24	1200LT Ext. 2	8.165	4.2706	356	9.8	346.2
25	Management Science	8.16813	4.26956	356	6.2	349.8
26	Motion Ground	8.1676	4.27367	349	6.4	342.6
27	University Farm	8.169	4.274	341	5.6	335.4
28	Sport Complex 3	8.1662	4.2739	342	2.2	339.8
29	Sport Complex 4	8.1665	4.2745	340	7.5	332.5
30	Stream	8.1651	4.275	337	12.6	324.4
31	Livestock Farm	8.16881	4.27035	362	6.3	355.7
32	LH	8.1739	4.2681	369	8.3	360.7
33	100L Labs Complex	8.17112	4.26868	372	19.3	352.7
34	ICT New Site	8.1717	4.2711	351	18.7	332.3
35	FET	8.16737	4.26795	368	15.8	352.2
36	Senate Building	8.16622	4.26705	359	8.7	350.3
37	Staff School 3	8.1651	4.2706	353	7.8	345.2
38	FAGS	8.17111	4.26927	371	7	364
39	FET Labs	8.16730	4.26917	363	19	344
40	Archi. Studio	8.1681	4.2669	357	4.2	352.8
41	CVE Shed	8.165	4.2706	350	10.3	339.7

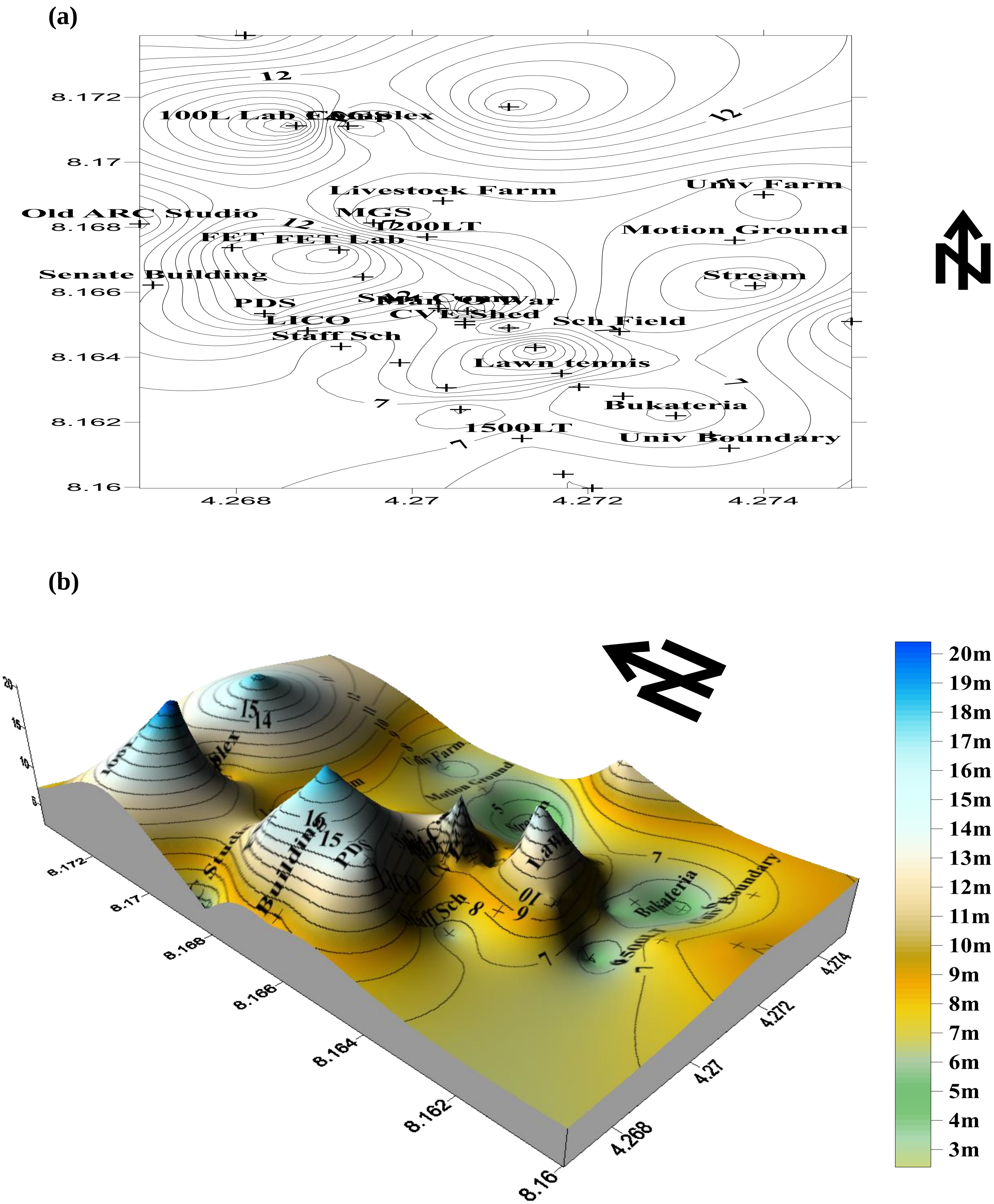
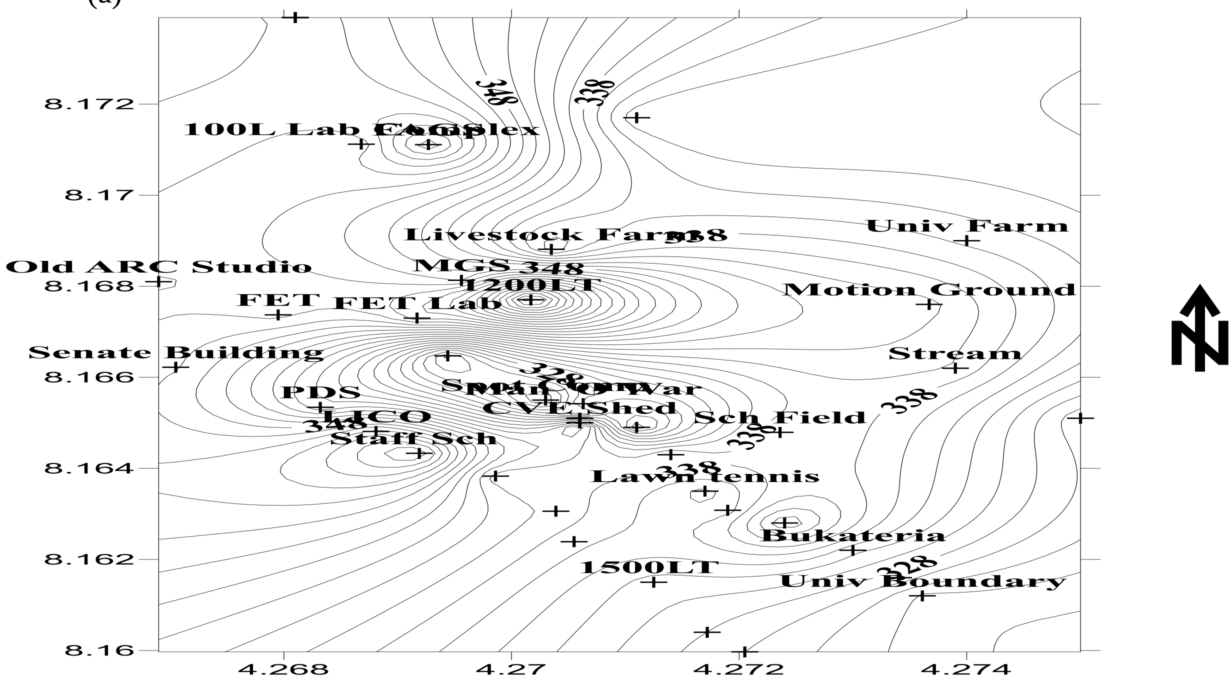


Figure 8: Isopach Maps of the Overburden (a) 2D (b) 3D.

(a)



(b)

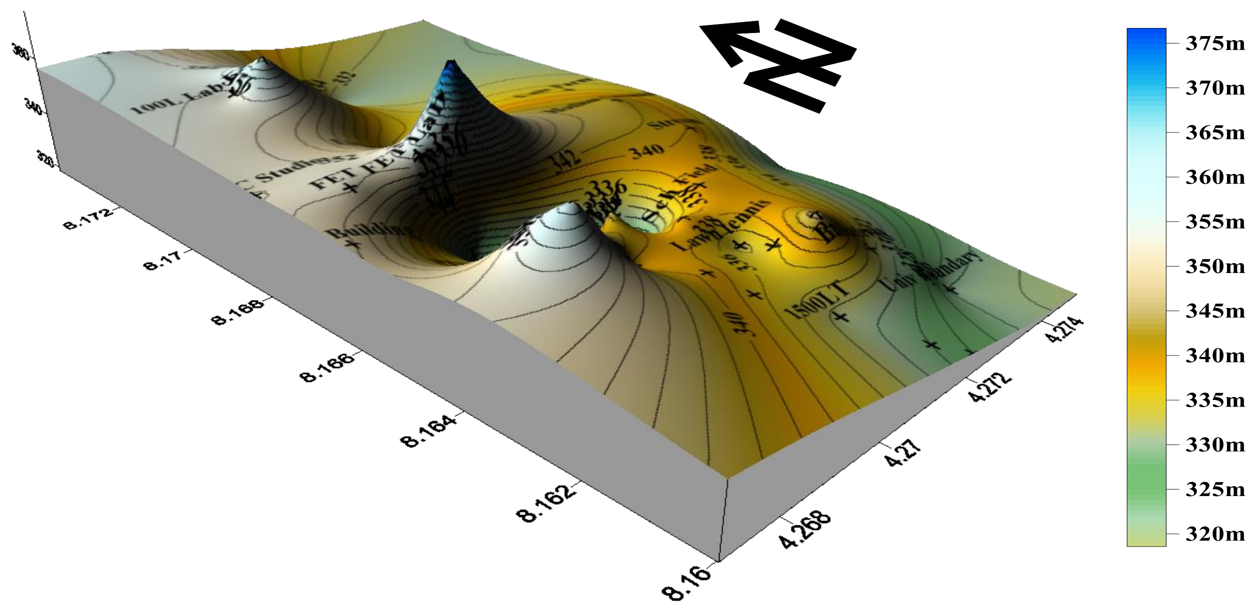


Figure 9: Bedrock Relief Maps (a) 2D (b) 3D map.

The general picture of variations in the overburden thickness in the study area is presented in Table 3 and Figure 8. Overburden thickness varies from 2.2m to 21.1m with the highest values obtained from the northwestern and western parts of the study area. The northeastern and southern parts have relatively thin overburden less than 10m. The thin and thick areas are presented as lows and highs respectively. Areas with thick overburden include those around the PDS Complex, Senate building, 100L Labs Complex, FAGS, LICO and Lawn Tennis Court.

The bedrock relief maps (Figure 9) show three major bedrock ridges with bedrock relief greater than 350m NW and SW of the study area. The significance of bedrock relief map is to reveal the bedrock head topography and structural disposition (Faleye and Omosuyi, 2011). Areas with bedrock ridges are suitable sites for foundations because they are groundwater discharge areas. There is a major bedrock depression in the central part of the study area. Adequate geotechnical information should be obtained about this area in considering them for sitting engineering structures since bedrock depressions are groundwater recharge areas.

The presence of clay in the weathered layer requires adequate consideration since clay has the ability to shrink and swell with seasonal changes in moisture content. The clay layer will be good foundation materials if the clay has activity less than 0.75 indicative of low swell-shrink potential.

CONCLUSION

The geoelectric sections along the profiles revealed an inhomogeneous subsurface consisting of three layers namely: topsoil, clay/sandy clay layer and the weathered/fresh bedrock. The study area is underlain by bedrock ridges and depressions. Overburden thickness varies between 2.2m and 21.1m. The areas underlain by bedrock ridges are expected to be more competent for safe foundation since they are groundwater discharge zones and cannot easily accumulate water. Adequate geotechnical information should be obtained about the areas underlain by bedrock depression to ascertain the soil strength and suitability as foundation materials.

The subsoil can support deep foundations, except at VES 28 where the overburden thickness is less than 3m. The presence of clay in the weathered layer requires adequate consideration since clay has the ability to shrink and swell with seasonal changes in moisture content. The clayey layers will be good foundation materials if the clay has activity less than 0.75 indicative of low swell-shrink potential. The results of this study will serve as useful guide in the choice of sites for engineering structures and also reduce the number of geotechnical probes required for foundation studies, and the overall cost of investigation.

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