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GEOPHYSICAL AND GEOTECHNICAL INVESTIGATIONS OF THE SITE OF A COLLAPSED TWO-STOREY BUILDING IN MODOMO, ILE-IFE, SOUTHWESTERN NIGERIA

Afolabi, O.*, **Salami, B. M., Olapade, T. M. and Alao, O. A.**
Department of Geology, Obafemi Awolowo University, Ile Ife, Nigeria.
*Corresponding Author's Email: toltobi@yahoo.co.uk
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ABSTRACT

Geophysical and the geotechnical methods were used to study the site of a collapsed two-storey building in order to determine the sequence and competence of the subsurface layers and determine the cause of the collapse of the building. The geophysical method employed the electrical resistivity method involving one dimensional (1D) Vertical Electrical Sounding (VES) and the two dimensional (2D) imaging techniques. Three VES stations were occupied using Schlumberger electrode configuration. 2D imaging data were acquired along four traverses using dipole-dipole electrode configuration. The geotechnical method involved Cone Penetration Test (CPT). CPT data was acquired at two points with the aid of 2.5 ton Dutch CPT machine. The results showed four subsurface layers based on the 1D VES results and 2D imaging results namely: topsoil, weathered layer, fractured basement rock and fresh basement rock. The topsoil resistivity varied from 116 Ωm to 191 Ωm and has thickness of about 1.5 m. It was classified as moderately competent. The second layer is weathered rock with resistivity varying between 92 Ωm and 327 Ωm and of about 8 m to 13 m thickness. This layer is also moderately competent. The third layer is fractured basement rock. It underlies the weathered rock and have resistivity varying from 391 Ωm to 405 Ωm. Its thickness varied from about 2 m to 20 m. This layer is competent. The fourth layer is the fresh basement rock having resistivity varying from 1365 Ωm to 12348 Ωm and is highly competent. The subsurface materials in the area are competent and can sustain the foundation of the building. Hence, the study concluded that the building collapse did not result from incompetent subsurface materials. Factors other than incompetent subsoil material that is human factors are believed to be responsible. This study has demonstrated the effectiveness of geophysical and geotechnical investigations in determining the competence of subsurface materials at engineering sites.

Keywords: Collapse, Foundation, Geophysical, Geotechnical, Penetrometer.

INTRODUCTION

A building or edifice is a structure with a roof and walls standing permanently more or less in one place such as a house or factory (Wikipedia, 2021). Nigeria is rarely faced with natural disaster such as earthquakes, flood or hurricane when compared to some other countries of the world where such disaster portends great risks to buildings and other infrastructures. Boateng (2020) and Awoyera *et al* (2021) asserted that in spite of significant advancement both in architectural design and structural engineering in this century, incidences of building failure still abound around the globe and is more rampant in developing countries. In developing countries, most of the cases of building collapse are mainly due to human factors such as errors in design, foundation/soil issues, absent institutional mechanisms and capacity to prevent the collapse of buildings, Fernandez (2014) and Asante and Sasu (2018).

The recent increase in the rate of structural deficiencies or collapse of buildings in Nigeria have reached worrisome proportions as many lives are lost and huge investments wasted. For instance, ten building collapse cases in Nigeria were listed by Chendo and Obi (2015) from 1974 to 2013 of which 60% were already complete and in use while 40% were uncompleted or under construction. Major cities such as Abuja, Port Harcourt, and Ibadan are not spared of these avoidable, distasteful and terrible phenomena partly caused by ineptitude, carelessness and lack of adherence to the recommendations of the local and international codes of practice and poor knowledge of the subsurface geology (Ayinuola and Olalusi, 2004). The losses arising from building collapse in monetary terms may be more than N500 Billion since independence in 1960 (Ali, 2015). The recent sharp increase in the incidences has brought to the fore, the issue of building collapse in Nigeria. Hence, this study was undertaken to investigate of the sub-surface of a two-storey building collapse site in order to determine the sequence and competence of the subsurface layers and ascertain whether the subsoil was responsible for collapse of the building.

The importance of site characterization before the construction of any engineering structure cannot be over emphasized as this will provide baseline data for appropriate foundation design among other uses. Although, geophysical investigations are non-invasive and cost effective, geotechnical investigation of the subsurface is discrete, invasive and expensive. Both delineate geological features; determine subsurface lithologic sequence and competence. Geotechnical method goes a step further by providing information on the engineering characteristics of earth materials.

LOCATION, GEOLOGY, GEOMORPHOLOGY, CLIMATE AND VEGETATION OF THE SITE

The investigated site is located in Modomo, Ile Ife, Southwestern Nigeria (Figure 1). It lies between Latitudes 730'N and 731'N and Longitudes 429'55"E and 429'57"E. Geologically, Ile-Ife lies within the crystalline Basement Complex rocks of Southwestern Nigeria (Figure 2). The two main petrological units in the study area are; grey gneiss and granite gneiss. Grey gneiss occurs widely in Southwestern Nigeria Basement Complex and usually occurs very close to the granite gneiss, often separated by a narrow strip of muscovite quartzite schist (Rahaman, 1988).

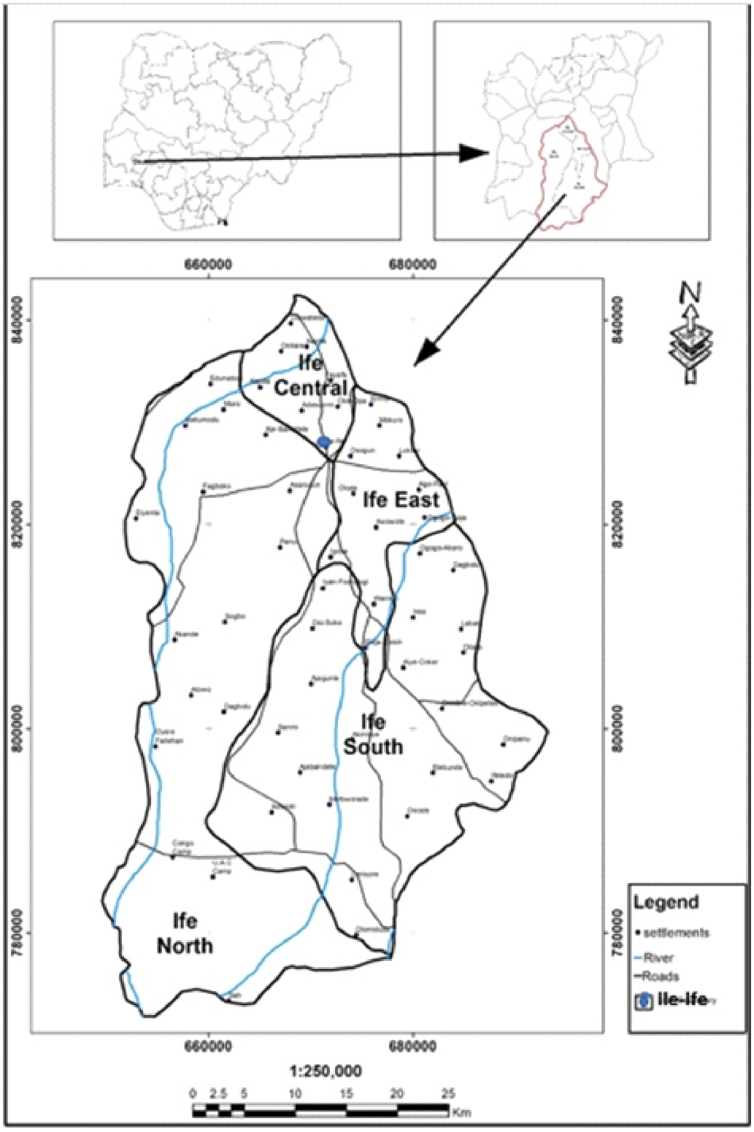


Figure 1. Map of Ife Central Local Government and environs (Nwosu *et al*., 2017).

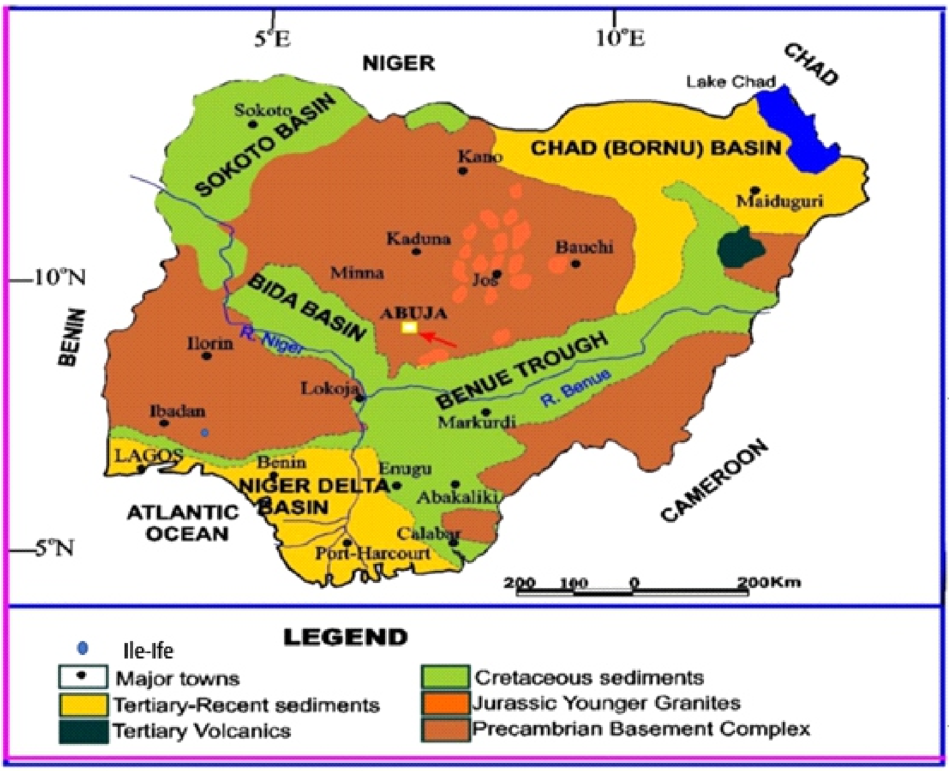


Figure 2: Geologic map of Nigeria showing Basement Complex regions and the sedimentary basins (modified from Obaje, 2009).

Ile-Ife falls within the tropical humid climate that is characterized by wet and dry seasons. The pattern of rainfall is characterized by the double maxima regime, the two periods of maximum rainfall being June/July and September/October (Orewole *et al*, 2017). The average annual temperature in Ile-Ife is 26.2 °C and the average precipitation is 1340 mm.The Ile-Ife area lies in the dry deciduous forest zone (Onochie, 1979). White (1983) described the vegetation as Guineo-Congolian dried forest type. The vegetation varies with its microclimate, soil, elevation and human impact.

METHOD OF STUDY

The study employed geophysical and geotechnical methods involving Electrical Resistivity (ER) and Cone Penetration Test (CPT) measurements. Geophysical data acquisition was conducted along four traverses out of which two run N-S and spaced 45 m apart. The other two run E-W and spaced 25 m apart (Figure 3). The length of the traverses varied from 50 m to 110 m. Electrical resistivity measurements were conducted using ABEM SAS 300C Terrameter. The techniques of the electrical resistivity method were profiling and Vertical Electrical Sounding (VES) using dipole-dipole and the Schlumberger electrode arrays respectively. The electrode spacing (a) were 10 m and 5 m on Traverses 1 and 2, and Traverses 3 and 4, respectively while AB/2 was varied from 1 m to 150 m in the VES data acquisition conducted at three points. The VES data were interpreted quantitatively by partial curve matching followed by computer assisted 1D forward modelling using WinResist software. The profiling data were also interpreted quantitatively using Diprowin software.

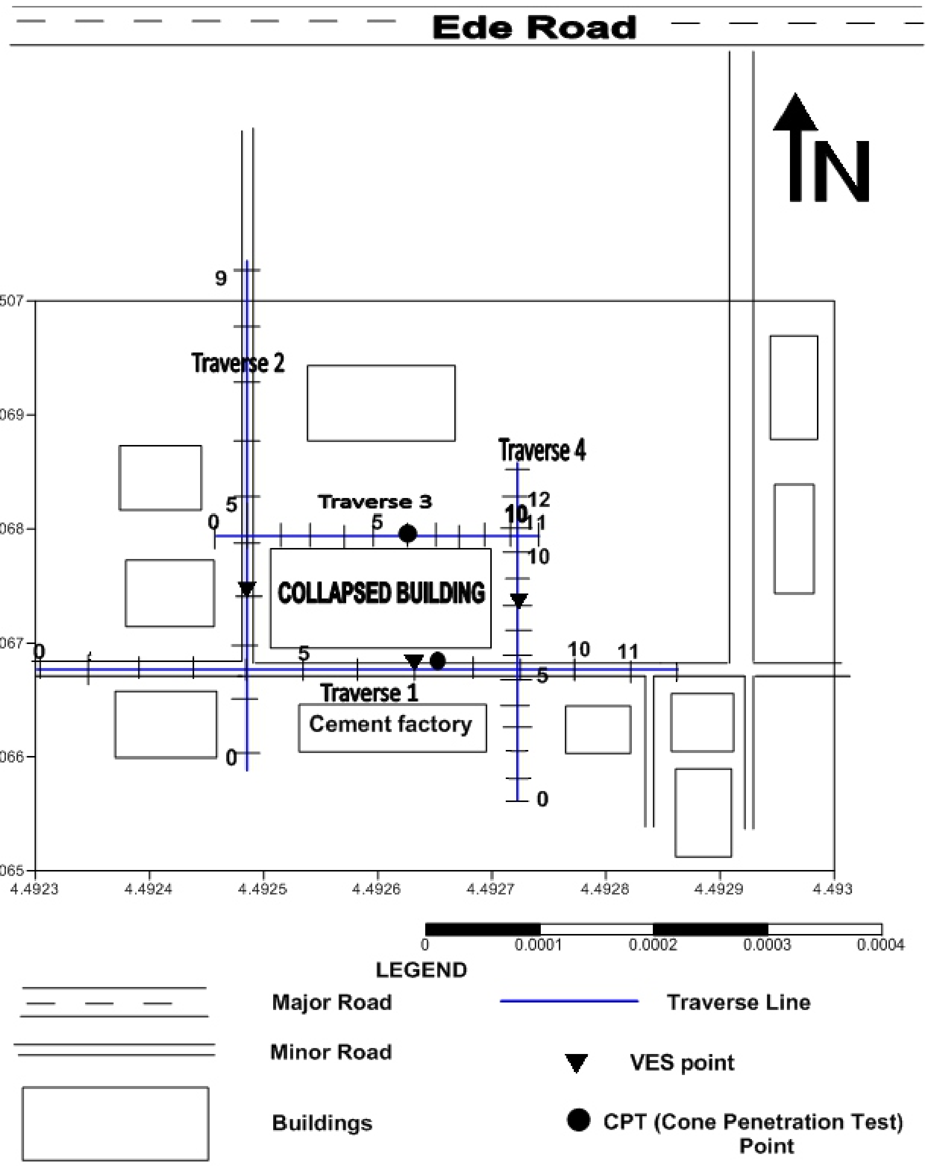


Figure 3: Base map of study area showing the VES stations, traverses, and the CPT points.

Cone Penetration Test (CPT) was performed at two locations within the study area using a 2.5 ton Dutch cone penetration machine. The test was carried out by securing the winch frame to the ground by means of anchors. The cone and the rod (1 m) were pushed into the ground at a uniform rate of about 2 cm/s. The resistance of the penetration of the cone registered on the pressure gauge was recorded. All the tests reached refusal before the anchors were pulled out from the subsurface. The layer sequences were interpreted from the variation of the values of the cone resistance with depth. On the basis of the expected resistance contrast between the various layers, inflection points of the penetrometer curves were interpreted as the interface between the different lithologies.

RESULTS AND DISCUSSION

The geoelectric characteristics of the subsurface, i.e., layer resistivities and thicknesses as well as the strength of the subsurface materials were determined from the 1D, 2D and CPT data, respectively.

The 1-D VES Results

The VES curves of VES 1, VES 2 and VES 3 were HA and HKH types (Figure 4). The result of the VES interpretation, i.e., layer resistivity and thickness, presented in Table 1 was used to generate the geoelectric section (Figure 5) along VES 1 to VES 3.

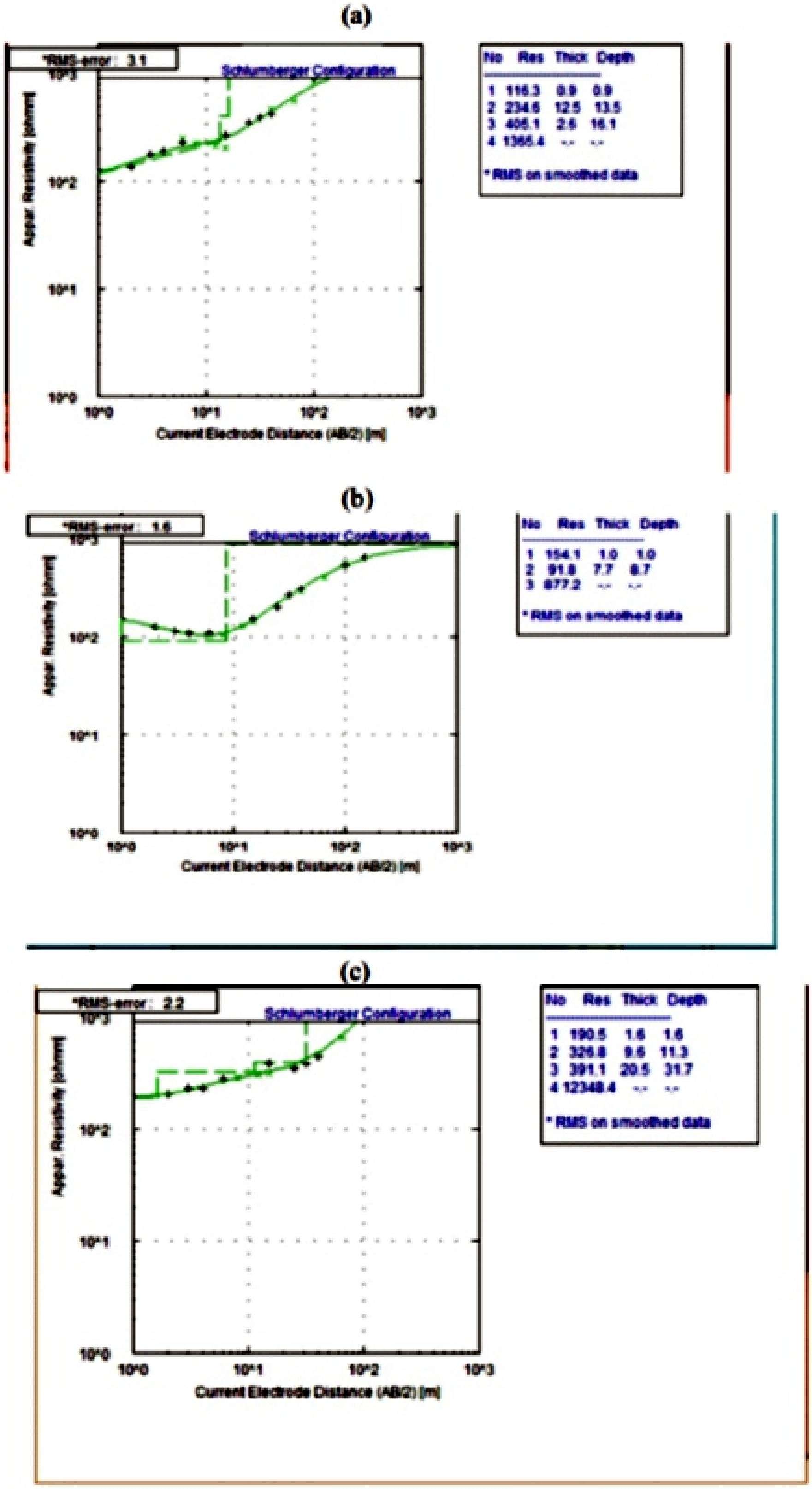


Figure 4: Curves and model parameters of (a) VES 1, (b), VES 2 and (c) VES 3.

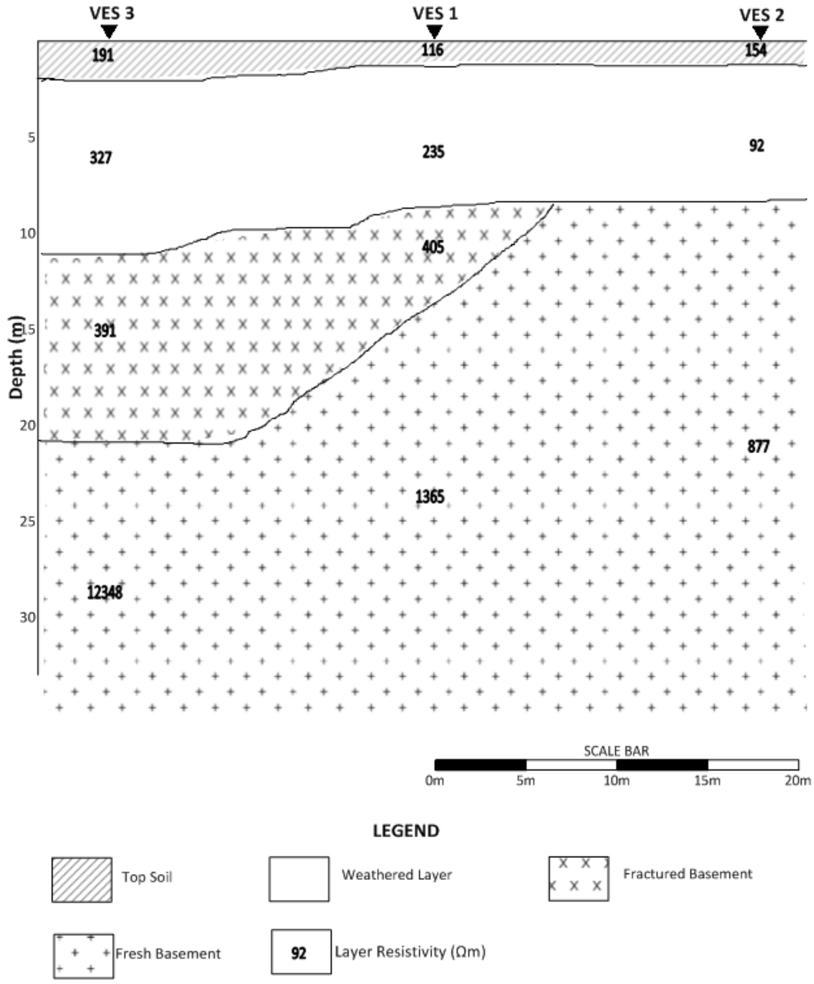


Figure 5: Geo-electric section along VES 1, VES 2 and VES 3 stations.

Table 1: VES Interpretation Results

VES NUMBER	TYPE CURVE	NUMBERS OF LAYERS	COMPUTER ITERATION PARAMETERS		LITHOLOGY
			Resistivity values	Thickness	
1	KH	5	116.1	0.9	Topsoil
			234.6	13.5	Weathered layer
			405.1	16.1	Fractured basement
			1365.4	-	Fresh basement
2	HA	4	154.1	1.0	Topsoil
			91.8	7.7	Weathered layer
			877.2	-	Fresh basement
3	HKH	3	190.5	1.6	Topsoil
			326.8	9.6	Weathered layer
			391.1	20.5	Fractured basement
			12348.4	-	Fresh basement

The Geo-electric Section

Three main geoelectric layers were delineated on the geoelectric section (Figure 5) namely; topsoil, weathered layer and fresh basement. The first layer, the topsoil, has resistivity varying from 115 Ωm to 156 Ωm and thickness of about 1 m. The second layer, the weathered layer, has resistivity varying from 88 Ωm to 252 Ωm and thickness varying from about 8.7 m to 9.3 m. The third layer is the fresh basement having resistivity varying from 900 Ωm to 1024 Ωm.

The 2-D Dipole-Dipole Results

The 2D resistivity structure along Traverses 1 and 3, and Traverses 2 and 4 are presented in Figures 6 and 7 respectively. The 2D resistivity structures show resistivity varying from about 100 Ωm to about 4000 Ωm, in blue to purple. The resistivity was classified into two i.e., 100 Ωm to 400 Ωm and >400 Ωm representing the overburden and the crystalline rock respectively in blue to green and yellow to purple. The thickness of the overburden varied from about 10 m to 20 m, 5 m to > 20 m, 0 to 15 m and 3 m to >25 m on Traverses 1 to 4, respectively.

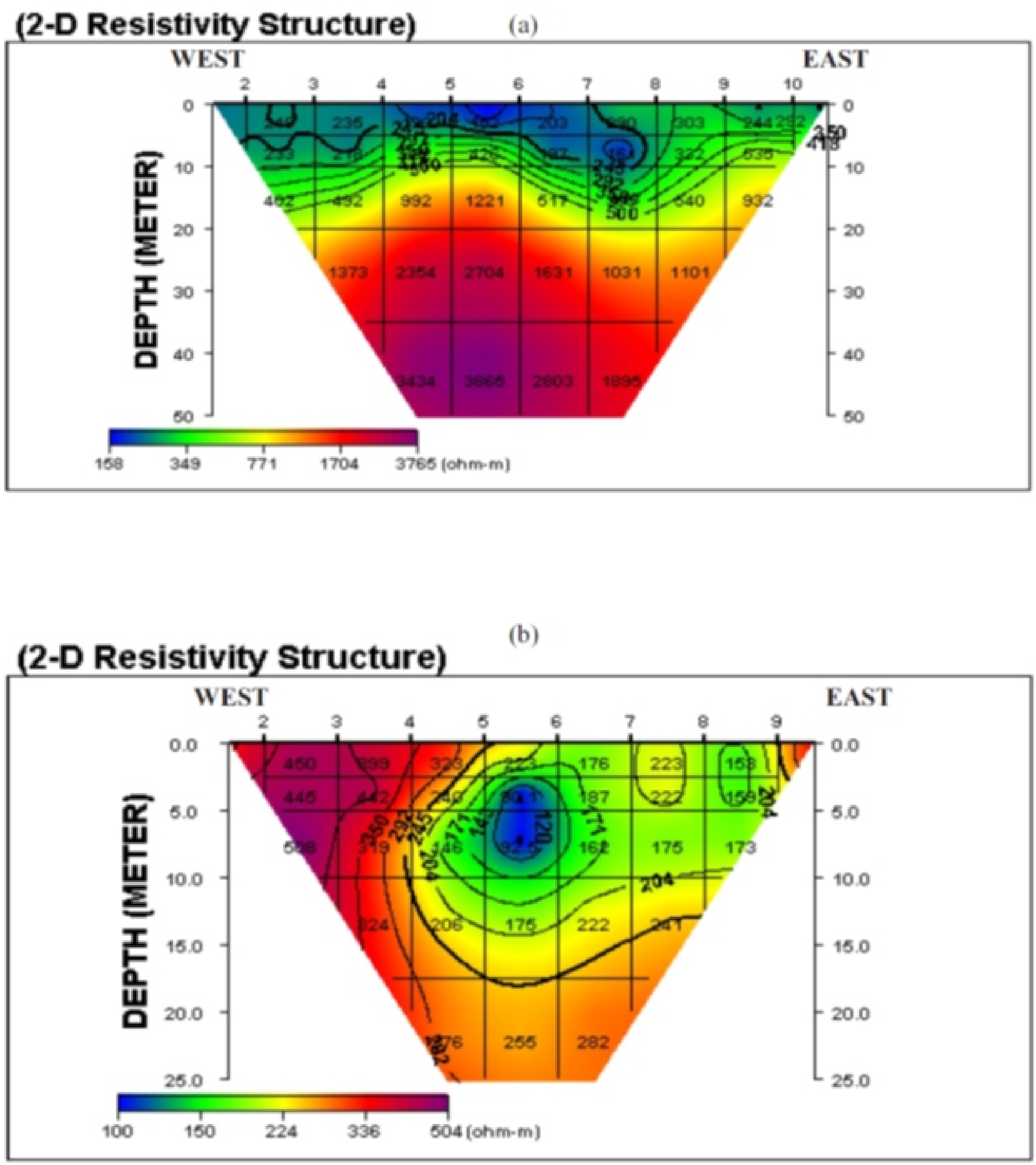


Figure 6: 2D resistivity structure along (a) Traverse 1, (b) Traverse 3.

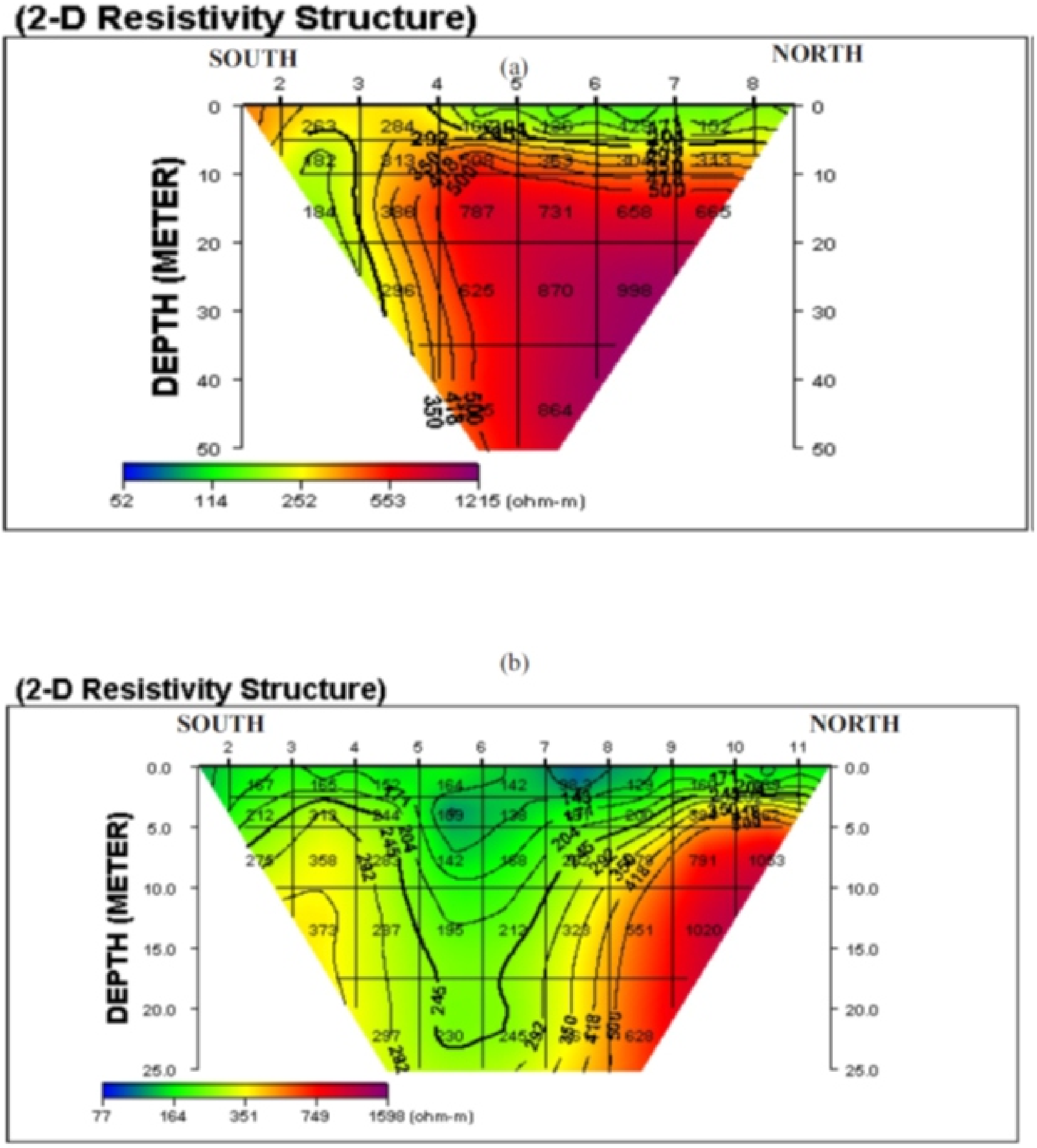


Figure 7: 2D resistivity structure along (a) Traverse 2, (b) Traverse 4.

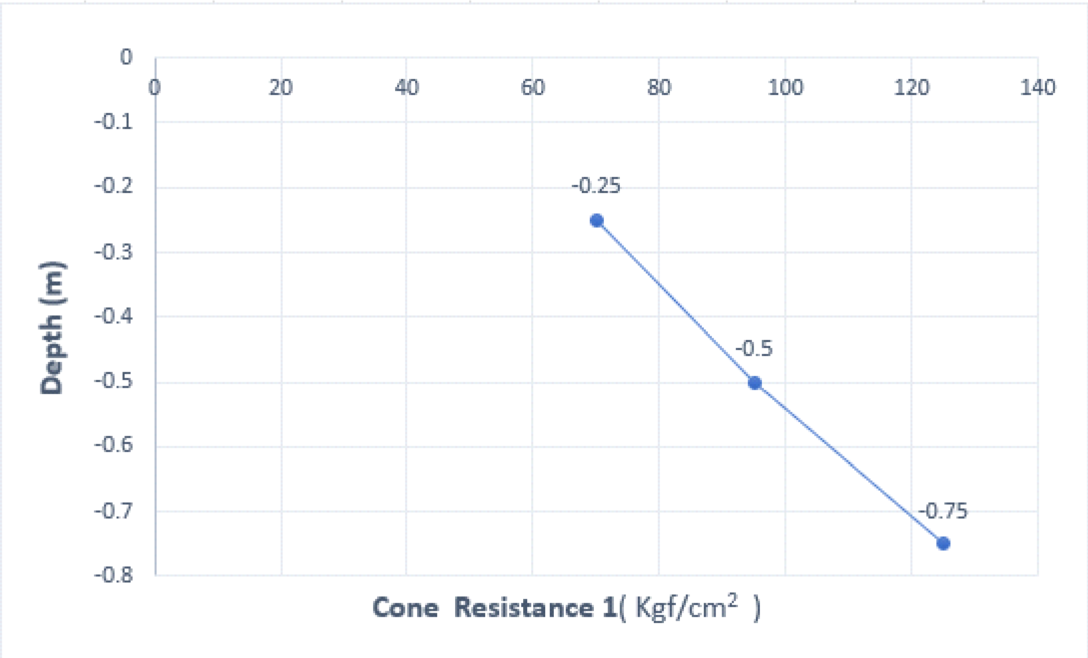
The Cone Penetrometer Results

The result obtained at CPT1 is presented in Table 2. The cone resistance was plotted against depth (Figure 8a). The cone resistance was recorded to a maximum depth of 0.75 m. The penetrative resistances 70 kgf/cm^2, 95 kgf/cm^2 and 125 kgf/cm^2 recorded at depths 0.25 m, 0.50 m, and 0.75 m respectively are indicative of compacted and competent materials. At the maximum depth of 0.75 m the cone penetrometer could not penetrate further due to the nature of materials present. The allowable bearing pressure at CPT1 point was generated from the cone resistances at the point.

Table 2: Cone Penetration Test 1

DEPTH (m)	CONE PENETRATION (Kg/cm^2)
0.25	70
0.50	95
0.75	125

(a)



(b)

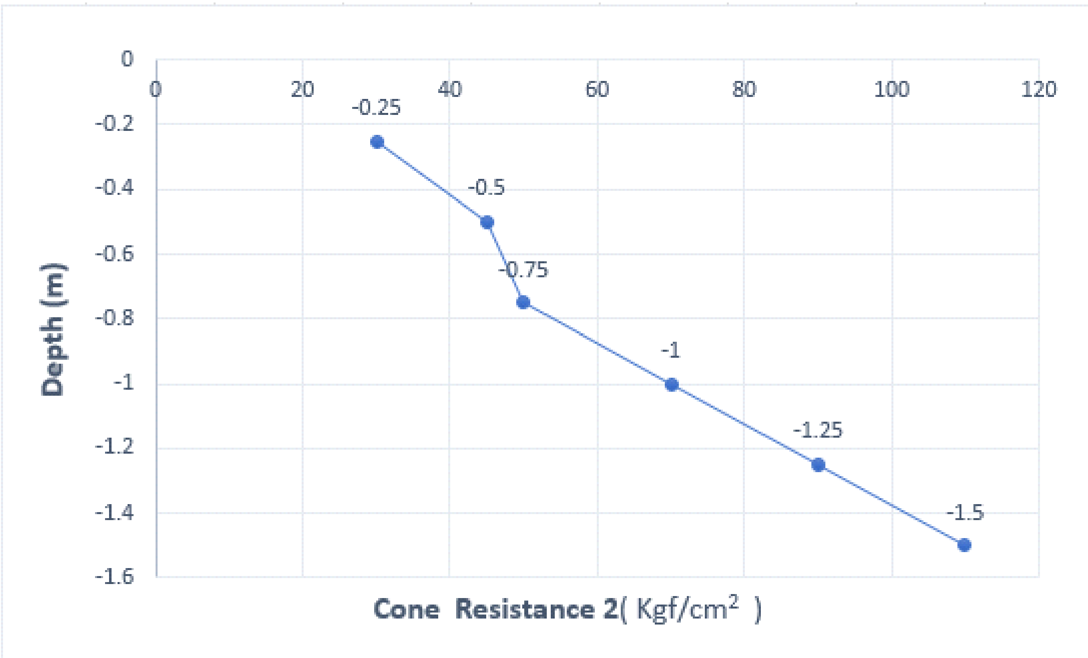


Figure 8: Cone resistance on (a) CPT 1 and (b) CPT 2.

The result obtained at CPT2 is presented in Table 3. The cone resistance was plotted against depth (Figure 8b). The cone resistance was recorded to a total depth of 1.5 m. The penetrative resistances 30 kgf/cm^2, 45 kgf/cm^2, 50 kgf/cm^2, 70 kgf/cm^2, 90 kgf/cm^2 and 110 kgf/cm^2 were recorded at depths 0.25, 0.50 m, 0.75 m, 1.0 m, 1.25 m and 1.5 m respectively. The penetrative resistances 30 kgf/cm^2-70 kgf/cm^2 is indicative of medium dense granular sand while 90 kgf/cm^2 to 110 kgf/cm^2 is indicative of dense/compacted sand. Increase in compaction prevented the cone penetrometer from penetrating further. The allowable bearing pressure at CPT2 point was generated from the cone resistances at the point.

Table 3: Cone Penetration Test 2.

DEPTH (m)	CONE PENETRATION (Kg/cm^2)
0.25	30
0.50	45
0.75	50
1.00	70
1.25	90
1.50	110

Synthesis of 1-D VES, 2-D Dipole-dipole Imaging and CPT Results

Three main geoelectric layers were delineated on the geoelectric section (Figure 4) namely; topsoil, weathered layer and fresh basement. The first layer, the topsoil, has resistivity varying from 115 Ωm to 156 Ωm and thickness of about 1m. The second layer, the weathered layer, has resistivity varying from 88 Ωm to 252 Ωm and thickness varying from about 8.7m to 9.3 m. the weathered later in lateritic on the west. The third layer is the fresh basement having resistivity varying from 900 Ωm to 1024 Ωm.

Table 4: Lithologic competence rating in terms of apparent resistivity values (Idornigie *et al,* 2006).

Apparent resistivity range (ohm-m)	Lithology	Competence rating
<100	Clay	Incompetent
100–350	Sandy clay	Moderately competent
350–750	Clayey sand	Competent
>750	Sand/laterite/bedrock	Highly competent

The 2D resistivity structure along the four traverses were interpreted in terms of overburden and crystalline basement rock. The overburden has resistivity varying from 100 Ωm to 500 Ωm while the fresh basement has resistivity varying from 501 Ωm to 3865 Ωm. The thickness of the overburden varies from 4m to greater than 25 m.

CPT 1 and CPT 2 were conducted at 65 m and 30 m on Traverses 1 and 3 respectively. The CPT was conducted to maximum depth of 0.75 m and 1.5 m at CPT 1 and CPT 2 respectively. The penetrative resistances indicated sand/gravel at these points. The bearing capacity of the sand at depths 0.75 m and 1.5 m for CPT 1 and CPT 2 respectively are 337.5 KN and 297.0 KN which indicated high load bearing.

The 2D resistivity structure along the four traverses showed that the overburden resistivity varies from 100 Ωm to 500 Ωm which indicates that the overburden is mainly sand. The penetrative resistances for CPT 1 and CPT 2 recorded to maximum depths of 0.75 m and 1.5 m, respectively also indicate that the subsurface material to the depth at CPT 1 and CPT 2 is sand.

Subsurface Competence Evaluation

Resistivity was used to evaluate the lithologic competence of the subsurface rocks in the study area. The topsoil resistivity varies from 116 Ωm to 191 Ωm, with a thickness of about 1.5 m. It is moderately competent (Table 4). The weathered layer is the second layer with resistivity varying from 92 Ωm to 327 Ωm and thickness of about 8 m to 13 m. This layer is also moderately competent. The fresh basement has resistivity varying from 877 Ωm to 12348 Ωm. This layer is highly competent.

Hence, the subsurface materials in the area are competent and can sustain shallow foundation of about 1.5 m depth on strong bearing capacity materials typical of basement complex terrains.

CONCLUSION

The results showed three subsurface layers based on the VES and 2D imaging results namely: topsoil, weathered layer crystalline basement bedrock. The topsoil is moderately competent; the weathered layer is also moderately competent while the crystalline basement bedrock is highly competent. The subsurface materials in the area are competent and can sustain shallow foundation which is typically not more than 1.5 m depth on strong bearing capacity materials in Basement Complex terrains. Hence, the collapse of the building did not result from incompetent subsurface material. Factors other than incompetent subsoil material i.e., human factors are believed to be responsible. This study has demonstrated the effectiveness of geophysical and geotechnical investigations in determining the competence of subsurface materials at engineering sites.

REFERENCES

Ali, K. (2015). "COREN President Assessing School Building Collapse in Jos". Retrieved from the net through www.dailytrust.com.ng/news/general/coren-assessing-collapse president / 110822. html on Saturday, March 05, 2016.

Ayinuola, G.M. and Olalusi, O.O (2004). Assessment of building failure in Nigeria, *African Journal of Science and Technology*. 5(1): 73-78.

Chendo I. G. and Obi N. I. (2015). Building collapse in Nigeria: The causes, effects, consequences and remedies. *International Journal of Civil Engineering, Construction and Estate Management,* 3: 41-49.

F.G. Boateng (2020). Building safe and resilient cities; lessons from Ghana. S. Awaworyi Churchill (Ed.), Moving from the Millennium to the Sustainable Development Goals, Palgrave Macmillan, Singapore (2020).

Idornigie, A.I., Olorunfemi M.O. and Omitogun, A.A., (2006). Electrical resistivity determination of subsurface layer, subsoil competence and soil corrosivity at an engineering site in Akungba- Akoko, South-western Nigeria. *Ife Journal of Science*, 8(2): 159-177.

Nwosu, E.E., Hassan, A.O. and Eneche, E., (2017). Geospatial analysis of the impact of urban built-up development on the distribution of suitable solid waste dumpsites in Ile-Ife, Nigeria. *American Journal of Environmental Engineering*. 82-92.

Obaje, N. G. (2009). Geology and Mineral Resources of Nigeria (221 p). Berlin: Springer.
doi: 10.1007/978-3-540-92685-6.

Onochie, C.F.A., (1979). The Rainforest Ecosystem: An Overview in the Nigerian Rainforest Ecosystem, D.U.U. Okali (ed). *University of Ibadan Press*: Ibadan; 1–13.

Orewole, M.O., Alaigba, D.B. and Oviasu, O.U., (2017). Riparian corridors encroachment and flood risk assessment in Ile-Ife: a GIS perspective. *Open transactions on geosciences*, ISSN(Print): 2372-6458 ISSN(Online): 2372-6466.

P. O. Awoyera, J. Alfa, A Odetoyan and I. I. Akinwumi (2021). Building Collapse in Nigeria during recent years – Causes, effects and way forward. IOP Conf. Series: Materials Science and Engineering. 1036 (2021) 012021.

Rahaman, M.A., (1988). Recent advances in the study of the basement complex of Nigeria: Precambrian Geology of Nigeria. *Geology Survey of Nigeria*, p. 11-41.

White. (1983). The Vegetation of Africa. UNESCO: Paris.

Wikipedia (2021): https://en.wikipedia.org/wiki/2021. Accessed 22nd May, 2021.