
GEOPHYSICAL AND GEOTECHNICAL INVESTIGATION OF SUBSOIL CONDITIONS FOR FOUNDATION STUDY

By

Oyedele, K.F.¹, Adegbola, R.B.^{2,*}, Adebisi, N.O.³, Lawal, A.F.¹¹ Department of Geosciences, University of Lagos, Akoka, Lagos, Nigeria.² Department of Physics, Lagos State University, Ojo, Lagos State, Nigeria.³ Department of Earth Science, Olabisi Onabanjo University, Ago-Iwoye, Ogun State, Nigeria.[*adeqbolaji@yahoo.com](mailto:adeqbolaji@yahoo.com)

ABSTRACT

In the past couple of years Lagos State, Nigeria has been experiencing collapse of buildings. This has necessitated the means for a proactive geophysical and geotechnical assessment of areas where buildings will be sited soon or sometime in the future. This led to the investigation of an open field at C.M.S Grammar school, Lagos to identify competent subsurface materials which can host stable, safe and durable structures. The geophysical and geotechnical investigation were carried out by acquiring eight (8) Vertical Electrical Soundings (VES), two (2) Wenner traverses and two (2) Cone Penetration Test points respectively. The electrical resistivity data were processed and interpreted using Winresist and DiproWin software. The results revealed three layers: clayey topsoil, dry/partially saturated sand and clay/sandy clay. The topsoil has resistivity values that vary from 8 to 67 ohm-metre, with thickness value that ranges between 0.5 and 1.4 m. The second layer shows resistivity values that vary between 158 and 797 ohm-metre which possibly suggests a saturated and or dry sandy lithology and has potentially the best mechanical property and competency. This sandy layer occurs at depth whose value ranges from 0.5 m to 1.4 m and thickness value that ranges from 14.2 m to 56 m. The layer indicated that shallow foundation such as footings (spread, combined or strap) is possible within this area. Although the CPT carried out did not penetrate deep enough to properly sample this sandy lithology due to hardness of the ground, it was able to show that the very near surface with depth to about 1.5 m was of incompetent nature based on the cone resistance values and the calculated allowable bearing capacity. Hence, this region should be avoided.

Keywords: Assessment, competency, lithology, mechanical property, footings

INTRODUCTION

The frequency of building collapse in the recent past has become a major issue in Nigeria, the occurrences and magnitude of the losses being recorded in terms of lives and properties are becoming worrisome and alarming. The collapse is mostly experienced in cities of Lagos, Abuja and Port Harcourt - among the existing structures and those under construction (Ibrahim, 2013). The building collapse rate has become so uncontrolled that one has virtually lost count of the number of these disasters. These structural

failures are often times associated with the problem of poor quality of building materials, old age of buildings and improper foundation (Oyedele et al., 2011). Foundations are affected not only by design errors but also by foundation inadequacies such as sitting them on incompetent earth layers. When the foundation of a building is erected on less competent layers, it poses serious threat to the building which can also lead to its collapse (Amadi, 2012, Adelusi et al, 2013). Apart from the likely presence of incompetent layers such as soft, young clay or peat, faults, fractures or

cavities could also be present all of which are inimical to superstructures.

The absence of site investigation with the view of cutting overall cost of the engineering project is a mistake that should be avoided by all means. A proper site investigation will help to determine the nature and properties of the sub surface conditions. For engineering structure to have a long life span and provide safety for lives and properties, adequate pre-construction investigation must be carried out to locate and assess the strength and competency of the subsurface host materials. In areas without good subsurface conditions to support a superstructure, some form of soil improvement scheme may be recommended but only after detailed analysis of the subsoil conditions. This has necessitated the need for detailed geotechnical and geophysical studies of the subsurface structure for present and future construction of engineering projects.

In the light of this, geophysical and geotechnical assessment of the subsoil condition at C.M.S Grammar school were undertaken. For the geophysical survey, the electrical resistivity method is known to be good for subsoil and engineering site investigation (Olorunfemi and Meshida, 1987; Ayolabi et al., 2004; Sudha et al., 2009). This method can also be used to provide information on subsurface conditions such as evaluation of soil salinity (Rhoades et al., 1989), groundwater and mining surveys (Olorunfemi and Okhue, 1992) and mapping of growth fault (Saribudak, 2010). For the geotechnical, Cone Penetration Tests (CPT)

soundings can be very effective in site characterization, especially sites with discrete stratigraphic horizons or discontinuous lenses. It is a valuable method of assessing subsurface stratigraphy associated with soft materials, discontinuous lenses, organic materials (peat), potentially liquefiable materials (silt, sands and granule gravel), and landslides. The technique is fast, reliable, repetitive and economical which make it a widespread method in site investigation (Robertson and Cabal, 2009). Geotechnical-geophysical survey is often the most cost-effective and rapid means of obtaining subsurface information, especially over large study areas (Sirles, 2006).

LOCAL GEOLOGY OF THE STUDY AREA

Lagos belongs to the Coastal Plain Sand which is made up of loose sediment ranging from silt, clay and fine to coarse grained sand. The littoral lagoonal deposits are made up of clay, silt, and sands of coastal plains. The coastal belt varies in width from about 8 kilometres near the Republic of Benin border to 24 kilometres towards the eastern end of the Lagos Lagoon (Jones and Hockey, 1964). The exposed rock unit in the area consists of poorly sorted sands with lenses of clays. The sands are in part cross bedded and show transitional to continental characteristics (Nton, 2001). The age Oligocene to Recent was assigned to this formation on the basis of fauna contents.

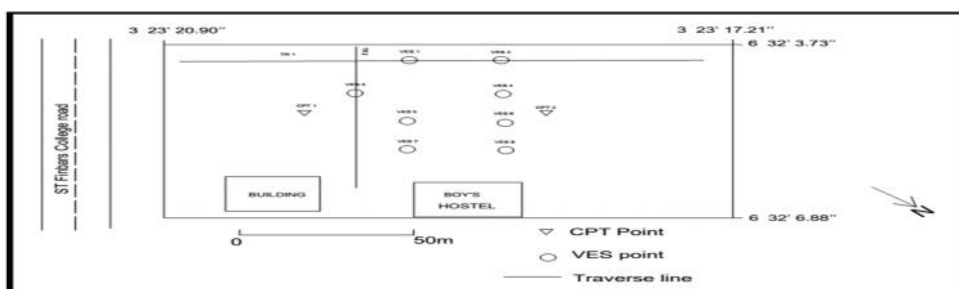


Figure 1.0: Base map of the survey area

The study area is an open field at C.M.S Grammar school in Bariga, Lagos, Nigeria. It has a flat lying topography with little vegetation for most parts except at the edges where the vegetation is much thicker. The soil of the area is fine grained in texture with a brown color (Figure 1.0).

MATERIAL AND METHODS

This study employed geophysical and geotechnical methods in characterizing the near surface geology for foundation studies. The geophysical method used was the electrical resistivity method using two techniques: 2D Wenner array and Vertical Electrical Sounding (VES) while the geotechnical survey involved solely the use of Cone Penetration Test (CPT). The electrical resistivity data was acquired using the PASI 16GL-N terrameter along two traverses with the Wenner alpha configuration as well as along eight VES points. The two Wenner traverses were acquired perpendicular to each other with one along the Northwest direction while the other is along the Northeast with a spread of about 150m with electrode spacing (a) 10m, 20m, 30m, 40m and 50m. The eight VES points taken within the survey area have a square-like arrangement with spacing of about 15m from each other (Figure 1).

Electrical Resistivity data acquisition and processing

Two traverses were occupied in the study and Wenner array was employed on each traverse. An inter traverse spacing of 10m was maintained within each traverse at first, after which we took readings for 30, 40 and 50 spacing for CST. One of the traverse runs approximately Northwest – Southeast while the second runs perpendicular to the first in a Northeast – Southwest direction. This traverse was set out to delineate relevant deeper subsurface structures which might possibly exist.

After acquisition the Wenner resistivity data was inputted and inverted using the Diprowin software.

The inversion method used was the finite element method (FEM) as this is capable of solving more complex geometries and boundaries with relative ease compared to the finite difference method (FDM). This produced a model of the ground subsurface resistivity variation both laterally and vertically. The VES data were plotted manually and curve matched with layer resistivity and thickness derived. These values were then inputted into the WINRESIST software for forward modeling. Based on the inputted model and the raw data, the software would aim to achieve the closest fit possible through a number of iteration process eventually coming out with a final resistivity and thickness model with the closest fit to the field data.

CONE PENETRATION TEST (CPT)

The Cone Penetrometer Test was performed at two points using a 2.5 tons' capacity machine. The equipment, which is manually operated, is furnished with a cone penetrometer having a base area of 1000mm² and an apex angle of 60°. With this arrangement, it was possible to measure the point resistance of the soils encountered as the cone and the rods were driven through the soil manually. All the dial gauges used in carrying out the tests were calibrated prior to the commencement of the tests and hence the results obtained are very reliable. The tests were terminated when the machine had achieved its maximum capacity and could no longer penetrate or when the anchorage was lifted. The cone reading (kg/cm²) was plotted against the depth penetrated. The amplitude of the curve is a function of the resistance of the material to the penetration of the curve. This is an indicative of its ability to withstand load. When a cone is pushed into the ground the pressure exerted on the end of the cone (cone end resistance 'q_c') is a direct indication of the strength and stiffness of the soil, i.e. it is more difficult to push a cone into a dense sand than, say, a soft clay. A plot of depth against the cone end

resistance was obtained using the Microsoft Excel software.

RESULT AND DISCUSSION

Electrical Resistivity Result

The electrical resistivity data acquired were interpreted and the results were displayed as 2-D pseudo-sections, geo-electric sections and sounding curves (Figure 2) along with their corresponding models. From the results, 3 geo-electric layers were delineated which are: top soil, partially saturated sand and clayey sand/ clay (Table 1). The topsoil has resistivity values

ranging from 7.7 to 66.8 ohm-metre with thickness between 0.5 and 1.4 m. The resistivity values of this topsoil suggest a clayey composition. The second layer shows resistivity values of about 158 to 797 ohm-metre which possibly suggests a partially saturated or dry sandy lithology with thickness values ranging from 14.2 to 56 m. The third layer has resistivity values from 40 to 207 ohm-metre which suggests clayey to sandy clay lithology with unknown thickness due to the inability of the current injected to exceed the layer thickness (Figure 3).

SOUNDING CURVE AND GEO-ELECTRIC SECTIONS

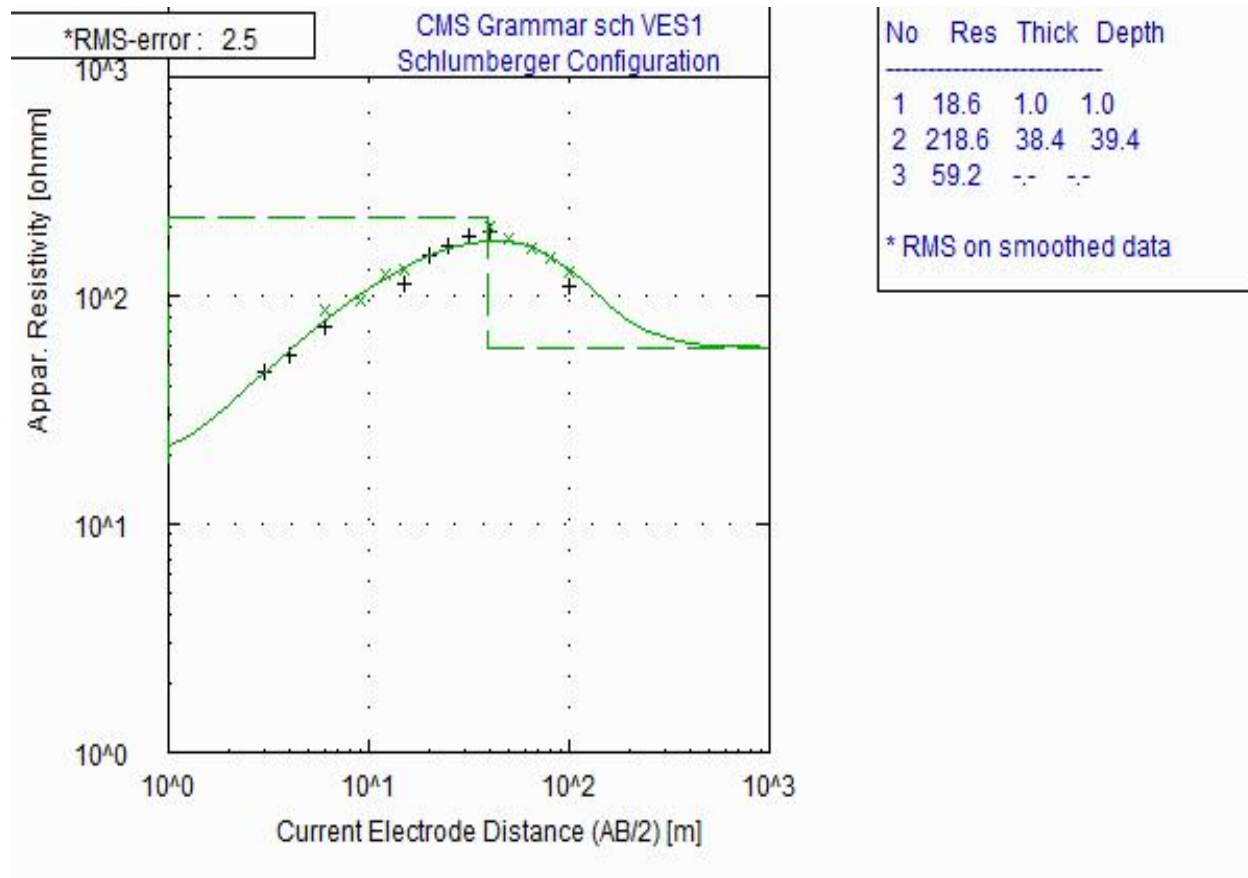


Figure 2.0: Typical sample of sounding curve for VES I

Table 1. Interpreted VES data

VES	Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Lithology
	1	19	1.0	1.0	Topsoil
1	2	219	38.4	39.4	Partially saturated Sand
-	3	59			Clay
	1	25	0.7	0.7	Topsoil
2	2	158	42.8	43.5	Saturated Sand
	3	40			Clay
	1	8	0.6	0.6	Topsoil
3	2	327	14.2	14.8	Partially saturated Sand
	3	79.8			Clay
	1	27	0.5	0.5	Topsoil
4	2	607	31.2	31.7	Dry sand
	3	147			Sandy clay
	1	66.8	1.3	1.3	Topsoil
5	2	530.6	56	57.3	Dry sand
	3	164.2			Sandy clay
	1	43.3	1.4	1.4	Topsoil
6	2	796.6	37.9	39.3	Dry sand
	3	158.4			Sandy clay
	1	7.7	0.6	0.6	Topsoil
7	2	217	20.8	21.5	Partially saturated Sand
	3	39.9			Clay
	1	47.2	0.8	0.8	Topsoil
8	2	699.7	32.0	32.8	Dry sand
	3	206.7			Sandy clay

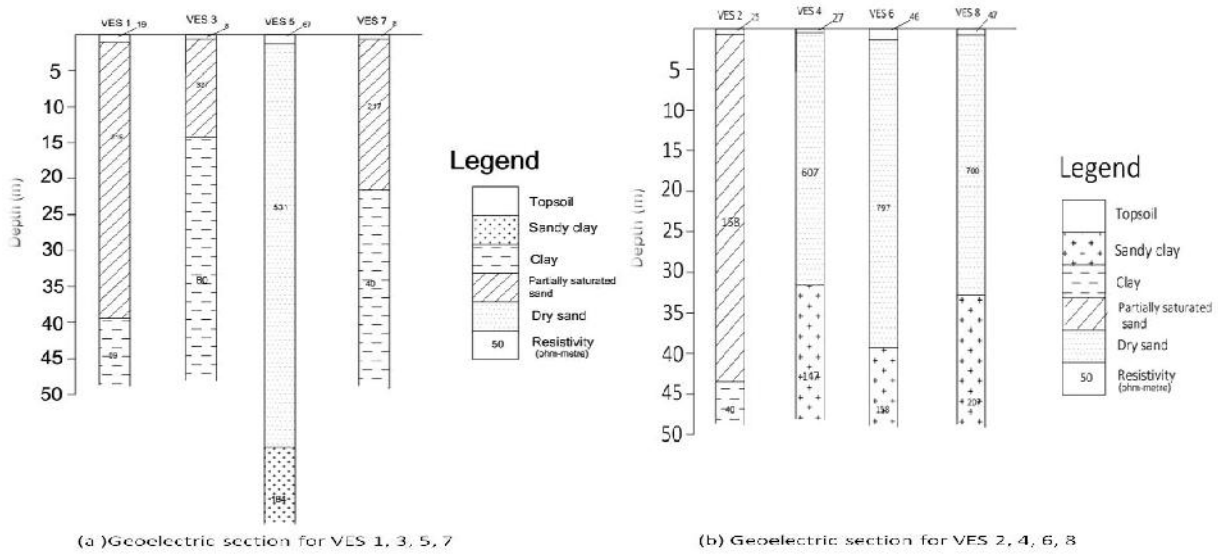


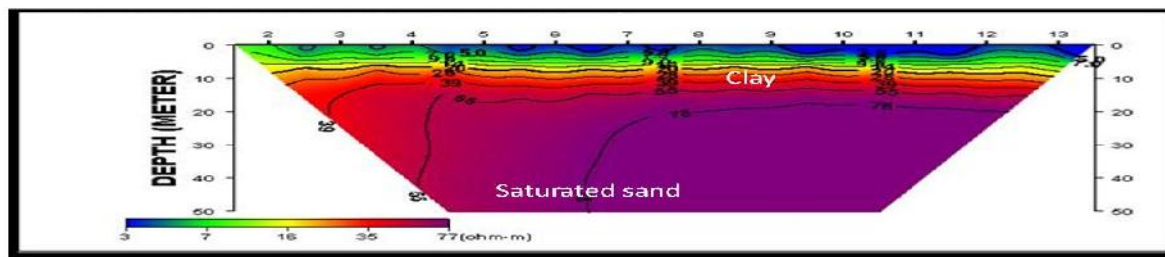
Figure 3.0: Geo-electric sections

2-D Electrical resistivity profiles

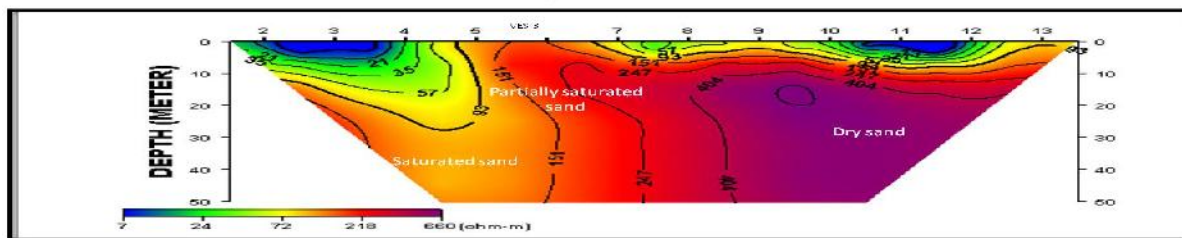
Traverse 1

Resistivity model for traverse 1 is about 150 m long shows a gradual and steady increase in resistivity with depth. The geometry and spacing of the contour interval suggests layers are laterally continuous along

the traverse with little lateral variation in geological properties. This traverse shows low resistivity regions at shallow depths and higher resistivity regions in the deeper parts. The relatively higher resistivity zones may be due to saturated sands while the lower resistivity zones may be due to clay materials present.



2-D resistivity structure of Traverse 1



2-D resistivity structure of Traverse 2

Figure 4.0: 2-D Resistivity Structures (Traverse 1 and 2).

Traverse 2

Traverse 2 is about 150 m long which shows more variation in the subsurface electrical properties compared to traverse 1. This traverse also shows an increase in resistivity with depth. The shallow regions have relatively lower resistivity values which could be due to the presence of clayey materials, while at greater depths higher resistivity values dominates which could be an indication of sandy lithologies (saturated to dry). VES 3 was taken 50 m along this traverse. This traverse area reveals sand body close to the surface which extends to great depth. This is a good target for foundation building based on its shallow nature and thickness although detailed investigation may have to be employed to reveal more on its mechanical properties. Other regions of intermediate resistivity values can also be seen in the pseudo-section at about 30 to 40 m deep, these regions can be attributed to the presence of possible saturated/partially saturated sands.

Cone Penetration Test Result

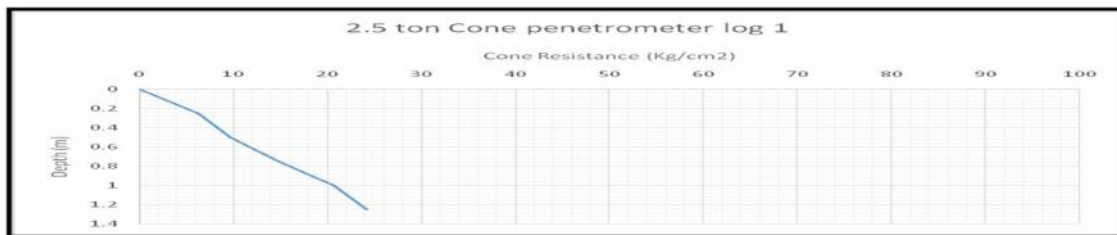
The graphs of the cone penetrometer reading are presented as penetration resistance against depth

(Figure 5). From the cone penetrometer tests, only one stratum was delineated which was the clayey topsoil based on its little resistance to penetration. The maximum depth penetrated by the cone penetrometer test is about 1.5 m which is still within the topsoil as deduced from the VES data. The readings show significantly low cone resistance of about 24 kg/cm² and below, which indicates clayey material between 0 and 1.5 m. The graph trend shows an increase in cone resistance with depth until the resistance was too great for the machine to penetrate at about 1.5 m probably due to the presence of the sand layer beyond this depth. The result from the CPT also shows that the depth to 1.5 m is unfit for any structure whatsoever except some form of soil improvement technique is used or the soil is excavated and replaced with more competent materials.

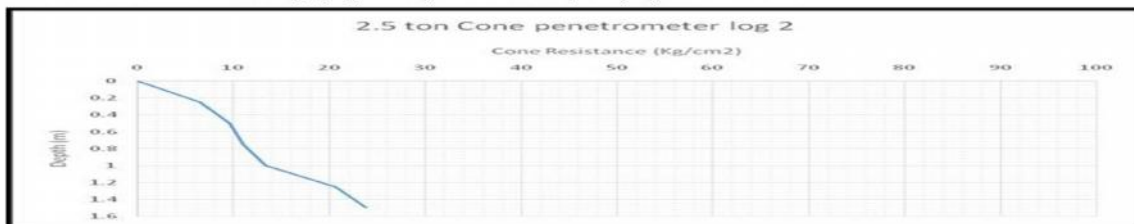
The graphs (Figure 5) show the variation of cone resistance with depth, using the Meyerhof's equation (Equation 1.0), the allowable bearing capacity of a soil can be calculated (Table 2.0)

$$q_a = 2.7q_c \text{ expressed in kN/m}^2 \tag{1.0}$$

where q_a is the allowable bearing capacity and q_c is the cone resistance



Plot of cone reading (Kg/cm²) versus depth (m) for CPT 1.



Plot of cone reading (Kg/cm²) versus depth (m) for CPT 2.

Figure 5.0: Plot of Cone reading Vs Depth for CPT 1 and CPT 2

For the purpose of foundation construction, an average value for penetrative resistance for competent

subsurface materials is taken as range of 50-100 kg/cm² depending on the structure to be erected.

CPT 1**Table 2.0a:** Allowable bearing capacity for the CPT values at point 1

Depth (m)	cone resistance (kg/cm ²)	cone resistance (kN/m ²)	allowable bearing capacity (q _a) (kN/m ²)
0.25	6.20	608.27	1642.34
0.5	9.65	946.20	2554.75
0.75	14.82	1453.10	3923.37
1.0	20.69	2027.58	5474.48
1.25	24.13	2365.51	6386.89

CPT 2**Table 2.0b:** Allowable bearing capacity for the CPT values at point 2

Depth (m)	cone resistance (kg/cm ²)	cone resistance (kN/m ²)	allowable bearing capacity (q _a) (kN/m ²)
0.25	6.55	642.06	1733.58
0.5	9.65	946.20	2554.75
0.75	11.03	1081.37	2919.72
1	13.44	1317.93	3558.41
1.25	20.68	2027.58	5474.48
1.5	23.79	2331.72	6295.65

Comparing the allowable bearing capacity for these CPT values to that of the average value for a competent subsurface material shows that the materials present within this depth range are very incompetent and thus are unsuitable for the construction of long lasting superstructures. The 2.5 ton CPT machine used for this project couldn't go further as the ground became harder and the machine couldn't penetrate further. This indicates that the second layer which is suggested to be sand has stronger mechanical properties compared to the topsoil as the machine terminated within this layer. Also the CPT plots for both points also show an increase in cone resistance with depth. Thus, competent subsurface materials are not far from the surface.

CONCLUSION

For proper characterization and resolution of subsurface materials for engineering purposes, geophysical and geotechnical methods must be synergized in order to derive maximum information about the mechanical properties of the subsurface materials. Within the scope of this study, electrical resistivity data and cone penetration tests were used. The electrical data revealed three layers which were: clayey topsoil, dry/partially saturated sand and clay/sandy clay. For engineering purposes, the sand is the layer of interest as it has the best mechanical properties for hosting a structure. The resistivity data interpretation also indicates that the sand was very thick with an average thickness greater than 34 m hence this can comfortably host medium sized and tall

buildings over long periods of time with shallow foundations. The average depth to this sand layer was about 0.9 m. The cone penetration tests results showed that between 0 to approximately 1.5 m the subsurface was dominated by incompetent material which offers little resistance to penetration but at slightly greater depth the equipment could not penetrate further due to the higher stiffness within the second layer which was suggested to be a sand layer based on its resistivity values. Greater cone resistance should also be expected within the sand which is known to be the best for construction purposes and for most engineering projects based on its thickness and shallow depth of occurrence.

REFERENCES

- Adelusi A.O, Akinlalu A.A, Nwachukwu A.I (2013). Integrated geophysical investigation for post-construction studies of buildings around School of Science area, Federal University of Technology, Akure, Southwestern, Nigeria. Vol. 8(15), pp.657-669, 23 April, 2013.
- Amadi A.N, Eze C.J, Igwe C.O, Okunlola I.A and Okoye N.O (2012). Architect's and Geologist's View on the Causes of Building Failures in Nigeria. Modern Applied Science; Vol. 6, No. 6
- Ayolabi E.A, Adedeji J.K, Oladapo I.M (2004). A Geoelectric Mapping of Ijapo, Akure Southwest Nigeria and its Hydrogeological Implications. *Global J. Pure Appl. Sci.* 10: 441-446
- Ayolabi E.A, Ibok J.E, Folorunso F.A (2012). Engineering Site Characterisation Using 2-D and 3-D Electrical Resistivity Tomography. *Earth Science Research*; Vol. 2, No. 1
- Ibrahim R.B (2013). Monumental effects of building collapse in Nigerian cities: The case of Lagos Island, Nigeria. Basic Research *Journal of Engineering Innovation* Vol. 1(2) pp. 26-31
- Jones M.A, Hockey R.O (1964). The Geology of Part of Southwestern Nigeria. Nig. Geol. Surv. Bull.31:101.
- Nton M.E (2001). Sedimentological and Geochemical Studies of Rock Units in the Eastern Dahomey Basin, Southwester Nigeria. Unpublished Ph.D Thesis Uni. Ibadan. P. 315
- Olorunfemi M.O, Meshida E.A (1987). Engineering geophysics and its application in engineering site investigations (Case study from Ile-Ife area). *Nig. Eng.* 22:57-66.
- Olorunfemi M.O, Okhue E.T (1992). Hydrogeologic and geologic Significance of a Geoelectric survey at Ile-Ife. *Nigeria. J. Min. Geol.* 28(2):221-229.
- Oyedele K.F, Oladele S, Adedoyin O (2011). Application of Geophysical and Geotechnical Methods to Site Characterization for Construction Purposes at Ikoyi, Lagos, *Nigeria. Journal of Earth Sciences and Geotechnical Engineering*, vol.1, no.1, 2011, 87-100
- Rhoades J.D, Manteghi N.A, Shouse P.J, Alves W.J (1989). Estimating soil salinity from saturated soil-paste electrical conductivity. *Soil Sci. Soc. Am. J.* 53:428-433
- Robertson, P.K. And Cabal K.L (2009). *Guide to Cone Penetration Testing for Geotechnical Engineering. 3rd Edition. Gregg Drilling & Testing, Inc.* Signal Hill. -134pp
- Saribudak M (2010). *Geophysical Mapping of Hockley Growth Fault in NW Houston, Texas: A Few Surprising Results.* SAGEEP 2010:852-864
- Sirles, P.C. (2006). *Use of Geophysics for Transportation Projects. Transportation Research Board of the National Academies.* Washington, D. C. Project 20-5, Topic 36-08
- Sudha K, Israil M, Mittal S, Rai J (2009). Soil characterization using electrical resistivity tomography and geotechnical investigations. *J. Appl. Geoph.* 67:74-79.