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Combined Geophysical And Geotechnical Techniques For Assessment Of Foundation Failure: A Case Study Lagos State Polytechnic, Ikorodu, Lagos, Nigeria

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Abstract: This study was carried out to assess the subsurface conditions around the school of technology complex in Lagos State Polytechnic, Ikorodu, using integrated geophysical and geotechnical techniques. The site lies within the Sedimentary terrain of southwestern Nigeria. Allied Ohmega Resistivity meter was used for data collection of 1-D and 2-D resistivitymeasurement while WinResist software and Dipro software were used for the processing respectively.The results of the vertical electrical sounding indicate that the depth to basement values ranges between 27.6 and 39.5m. The 2D resistivitysurvey has provided valuable information on the lateral and vertical variation of the layer competent for erecting foundation of engineering structures. The CPT probed an average depth of 4.8m and has identified material of very high shear strength associated with dense sand materials. The correlation of the three techniques used revealed similar soil layering consisting of topsoilsandy clay, coarse sand and sand.A mechanically stable coarse sand material was discovered as weathered layer which indicates high load bearing capacity suitable for foundation in the area and can support massive structures.

Keywords: Correlation, Depth to basement, Engineering structures, Sedimentary terrain, Weathered layer

I. INTRODUCTION

Geophysical investigation is one of the methods used in probing the soil/subsoil and subsurface for any engineering construction activities. The deduced soil characteristics are used as preliminary information to determine the suitability of the site for the proposed structure. If this crucial step is omitted, concealed geologic features within the subsurface may precipitate excessive total or differential settlement leading to failure or collapse of civil structures. Geophysical methods that have been found useful in pre and post–construction geotechnical investigations include the gravity, the electrical resistivity and the seismic refraction methods. Geophysical techniques of investigating the composition, structure and nature of the subsurface have reached a high degree of sophistication with the convergence of the need to investigate the earth for scientific and societal problems (Enikanselu, 2008).

Ayedun et al. (2012) explained that the incessant of building failure and collapse in the recent past has become a source of national concern and embarrassment in Nigeria. News reports of such incidents are frequently reported in the country by both the print and electronic media. In 2006 alone, no fewer than thirteen of such cases were recorded in Lagos State alone while statistics of the previous and subsequent years were not better off either. This prompted a study to empirically ascertain the causes of such building failure and collapse from the perspectives of the stakeholders (comprising of the professionals in the building industry, contractors and house owners/developers) with a view to proffering appropriate recommendations to guide against future occurrence. The study identified the use of sub-standard building materials, poor workmanship, incompetent contractors, faulty construction methodology, heavy downpour, non-compliance with specifications/standards, inadequate or lack of professional supervision, defective design and illegal conversion of existing structures as the major causes of building collapse in Lagos State, Nigeria. Recommendation was made to educate all stakeholders including the professionals in the building industry and building owners on the inherent dangers of building collapse and the need to be safety conscious while building houses.

In view of recent structural failures in Nigeria, Ayubaet al. (2012)therefore, intends to highlight causes of collapse of high- rise buildings, the roles of professionals and other participants play in the industry in terms of the use of building materials, placement and curing of concrete, modification in the use of a building, collapse of building induced by fire and other causes. The paper concludes by suggesting possible measures to be taken by government and other regulatory bodies in the building industry to avert this.

Coker J.O. (2015 b) measuredresistivity using 1-D and 2-D resistivity probing techniques and Geotechnical methods using Cone Penetrometer Test (CPT)to delineate the subsurface geology at the School of Management area, Lagos State Polytechnic, Ikorodu. The resistivity measurements were made with Allied Ohmega Resistivity meter. The 1-D vertical electrical resistivity sounding data were obtained using the Schlumberger electrode array while the 2-D resistivity data were obtained using the Wenner array. Two 2.5 tonnes Cone Penetration Test (CPT) and one borehore log was used for control.The acquired VES data were processed and interpreted using partial curve matching technique and 1D computer assisted forward modeling using WinResist software. DiproWin software version 4.0 was to process the 2D data. Based on the results of the investigations, the main lithological unit obtained consists of sandy clay and sand materials.The author concluded that,the northern part of the study area consist of sandy clay, a mechanically unstable soil formations which is capable of being inimical to building structures and the southern part consist of the sand layer which is viewed as the only competent geo-material for the foundation of any engineering structures within the study area.

Integrating geophysical with geotechnical methods proffer solutions discrete information usually got from conventional engineering soil characterization methods that lack complete imaging of the subsurface. Geophysical data interpretation can image the subsurface to the depths of competent layer and evaluate the real distribution of geological earth material.

This study is aimed at delineating the geologic features using 1-D and 2-D resistivity probing techniquesand Geotechnical methods using Cone Penetrometer Test (CPT).

Location and Geology of the Study Area

Nigeria lies approximately between latitudes 4^oN and 15^oN and Longitudes 3^oE and 14^oE, within the Pan African mobile belt in between the West African and Congo cratons (Figure 1). The Geology of Nigeria is dominated by crystalline and sedimentary rocks both occurring approximately in equal proportions (Ayolabi et al, 2012 and Coker, 2015 a). The crystalline rocks are made up of Precambrian basement complex and the Phanerozoic rocks which occur in the eastern region of the country and in the north central part of Nigeria. The site of investigation is School of Technology area, Lagos State Polytechnic, Ikorodu Campus. Ikorodu is a suburb of Lagos which is purely sedimentary and falls in Dahomey Basin.The climate is predominantly the rainforest characterized by two seasons-the wet season (between April-October) and the dry season (between November-March).

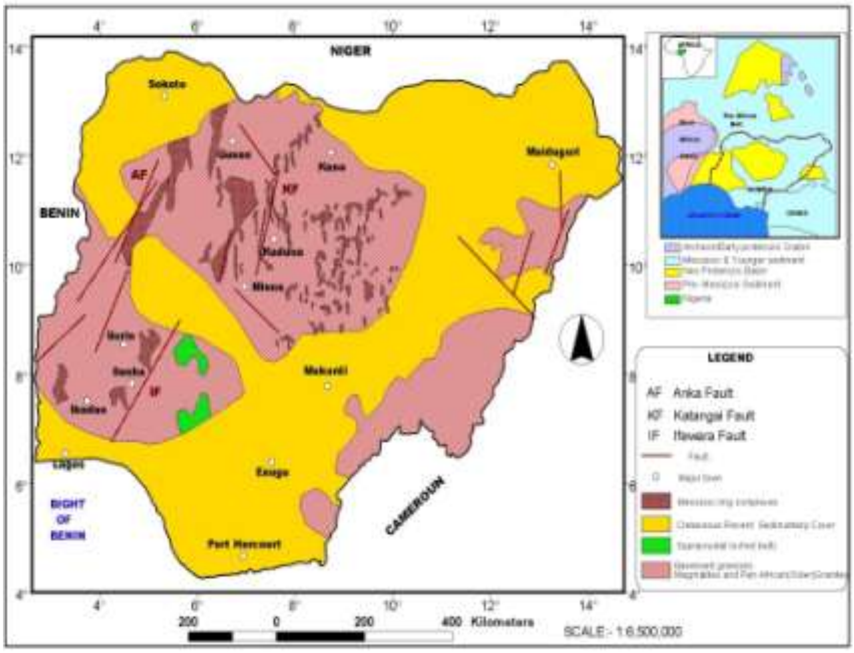

Figure 1: Regional Geology of the Pan-African Shield of Nigeria, Inset Geological Map of Africa (Modified after 1994 edition of the Geological Survey of Nigeria Map).

II. METHODOLOGY

Geophysical Investigation and Processing

Three traverses were established across the study area with four electrodes of equal spacing moved along each profile of the traverses. The spacing was varied for 10m, 20m, 30m, 40m, 50m and 60m in turns (Figure 2).The investigation was done in the N-S direction and six (6) Vertical Electrical Sounding (VES) stations were occupied along the traverses usingthe Schlumberger configuration. The electrode spacing (AB/2) was varied from 1-200m.The resistivity measurements were made with Allied Ohmega Resistivity meter.

The acquired VES data were processed and interpreted using partial curve matching technique and 1D computer assisted forward modeling using Resist version 1.0 software. The final interpreted results were used for the preparation of geoelectric sections.The 2D data were presented in form ofpseudosections and interpreted by DiproWin software version 4.0 toprovide both lateral and vertical information of thestudy area. The interpretation was qualitative.The Dipro software gives a 2-D invertedresistivity value as a function of depth.

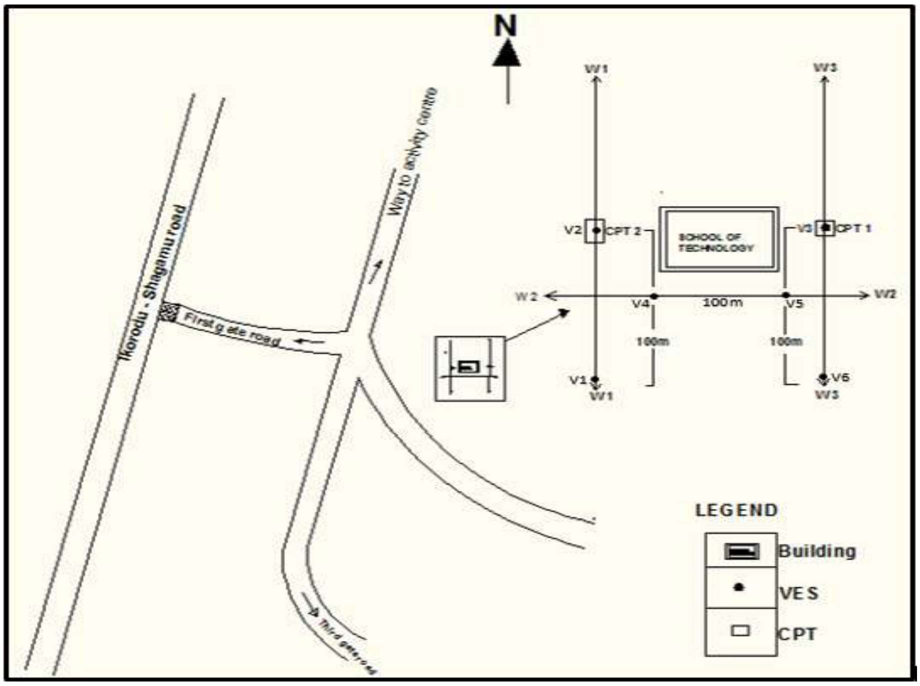

Figure 2: Base map of the study area showing the data points

GeotechnicalInvestigation and Processing

Generally, methods of observing the soils below thesurface (to obtain information about the soil conditions), obtaining samples, and determining physical properties of the soils and rocks below the surface, include test pits, trenching (particularlyfor locating faults and slide planes), boring, and in situ tests such as cone penetration tests (CPT) or SPT (Ayolabi et al, 2012). The Cone Penetrometer Test (CPT) was the geotechnical method employed for this study. Cone penetration testing (CPT) is a continuous measurement of resistance to penetration of the cone tip (q_c) and frictional resistance(f_s) (Lunne et al, 1997 and Coerts, 1996). Measurements can also be made of other soil parameters using more specialized cones such as pore water pressure (piezocone), electrical conductivity, shear wave velocity (seismic cone), pressuremeter cone, etc. Equation (1) shows the relationship between cone end resistance and sleeve frictional resistance.

$$R_f = \frac{q_c}{f_s} \text{Equation 1.}$$

where $R_f =$ frictional ratio

Two CPT tests were conducted in the study area corresponding to a VES points on a profile to constrain the geophysical results. 60^0 cone head was penetrated to the ground through a set of 1m long rods. Measurements were taken at every 0.25m penetration of the rod into the ground.A linear graph of cone resistance against depth of penetration was done by Excel software. The maximum cone resistance(q_c) value at refusal was determined.

III. RESULTS AND DISCUSSION

Vertical Electrical Sounding(Schlumberger Array)

The summary of the interpreted VES results with its inferred lithology for the School of Technology is presented in Table 1.The sample model curve of thestudy area for VES 2 is shown in figure 3. The results of the VES sounding at each of the profilesshowed sounding curves with 4-layered type, characteristics of a typicalsedimentary terrain.The curve types identified within the study area include HK, AK and KH type with the HK as the predominant curve type.

Table 1: Summary of the VES Results for School of Technology

Ves No	Layers	Resistivity (□ m)	Thickness (M)	Depth (M)	Curve Type	Inferred Lithology
1	1	477.5	1.2	1.2	**Hk**	Topsoil
	2	192.5	11.4	12.6		Sandy Clay
	3	831.5	15.0	27.6		Coarse Sand
	4	217.6				Sand
2	1	128.1	1.1	1.1	**Hk**	Topsoil
	2	105.9	9.3	10.4		Sandy Clay
	3	901.4	23.6	34.0		Coarse Sand
	4	356.5				Sand
3	1	129.3	1.2	1.2	**Hk**	Topsoil
	2	153.2	6.6	7.8		Sandy Clay
	3	998.9	20.2	28.0		Coarse Sand
	4	404.3				Sand
4	1	266.0	1.4	1.4	**Ak**	Topsoil
	2	526.9	3.3	4.7		Sand
	3	813.9	29.7	34.4		Coarse Sand
	4	122.9				Sandy Clay
5	1	67.7	1.3	1.3	**Kh**	Topsoil (Clay)
	2	593.8	12.5	13.8		Coarse Sand
	3	132.4	36.0	49.8		Sandy Clay
	4	171.2				Sand
6	1	641.8	1.3	1.3	**Hk**	Topsoil
	2	168.5	11.4	12.7		Sandy Clay
	3	862.7	26.8	39.5		Coarse Sand
	4	314.2				Sand

The interpreted results revealed the presence of 4 geoelectriclayers, which compose of topsoil, sandy clay, coarse sand and sand. The topsoil of the lithology has resistivity values between the range 67.7 and 641.8 ohm-m and thickness range of 1.1 to 1.4m. The low resistivity value of 67.7 ohm-m is found in VES 5 interpreted as clay with the weathered layer resistivity value of 132.4 ohm-m and high thickness value of 36.0m interpreted as sandy clay but terminates with sand material, a competent material. The second layer has same lithology of sandy clay except VES 4 which is of sand material. The resisitivity range and the thickness are 105.9 – 593.8 Ωm, and 4.7– 13.9m.

The weathered layer lithology is the same for all the VES's except VES 5 and is mainly coarse sand a competent materials with thickness of range 15.0 and 29.7.m and a close high resistivity values between 813.9 and 998.9 ohm-m. The corresponding last layer is underlain by sand material of resistivity 171.2–404.3 ohm-m with a range of depth to basement values between 27.6 and 39.5m.

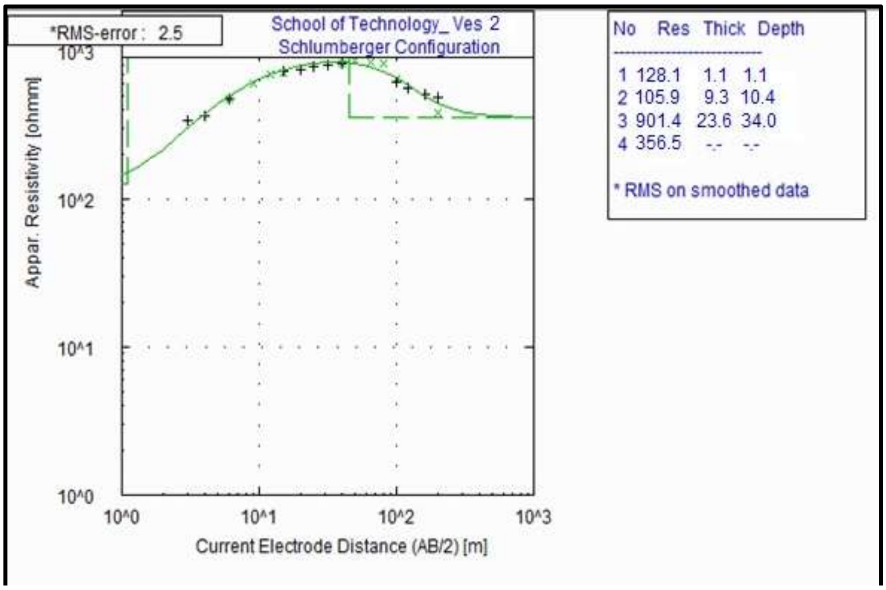

Figure 3: Sample of 1-D resistivity model curve for VES 2.

2D Imaging (Wenner Profiling)

A total spread of 220m was surveyed in profile W_1W_1as shown by the 2D resistivity structure in Figure 4 and a depth of 50m was probed from theNorth – South direction.

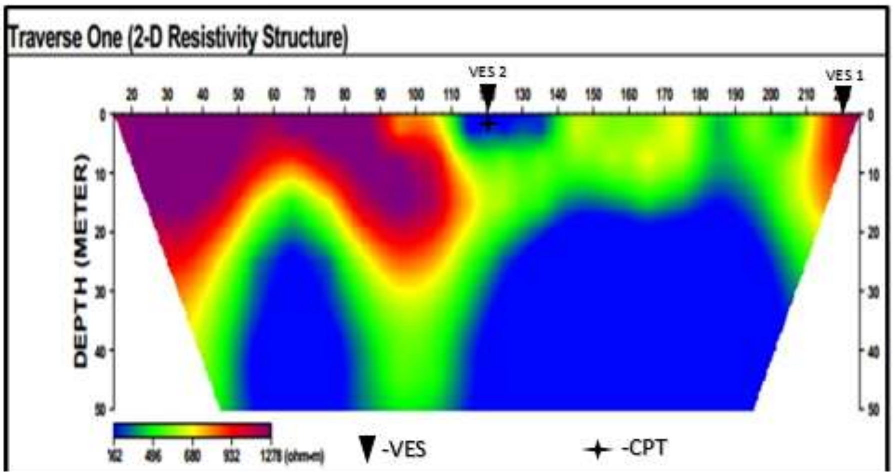

Figure 4: 2D Resistivity pseudo-section for traverse one

The 2D resistivity structure has resistivity values ranging from 162 -1278Ωm. From 0 – 90m on the surface shows a high resistivity values ranging from 1000 -1278Ωm Other geoelectric units are made up of resistivity range of 160 – 700Ωm and 800 -1193Ωm which stretches along the section from about a lateral distance of 20 – 110m and 150 – 220m, which indicates regions of sand and coarse sand to a depth range of about 0 – 20m and 0 – 50m. From the trend of the inferred lithology, it is obvious that the area is essentially made up of coarse sand materials at high depth of 25 – 50m which VES was unable to reveal.

Geoelectric Section along W_1W_1

It comprises of VES 1 and 2 stationed at 220m and 120m on traverse W_1W_1,as Figure 5 shows its geoelectric section. It has four geoeletric layers which varies from topsoil, sandy clay, coarse sand and sand. The topsoil is characterized by resisitivity values ranging from 128.1-477.5 Ωm and layer thickness 1.1 - 1.2m. The second, third and fourth layers all have same lithology for VES 1 and VES 2 which are sandy clay, coarse sand and sand respectively. The resisitivity range for the second, third and fourth layers are 105.9 -192.5Ωm, 831.5 - 901.4Ωm and 217.6 - 356.5Ωm respectively. While the thickness of the second and third layers are 9.3 - 11.4m and 15.0 – 23.6m respectively. The thickness of the fourth layer could not be determined because the current terminated at this horizon as shown by the resistivity curves in Figure 3.

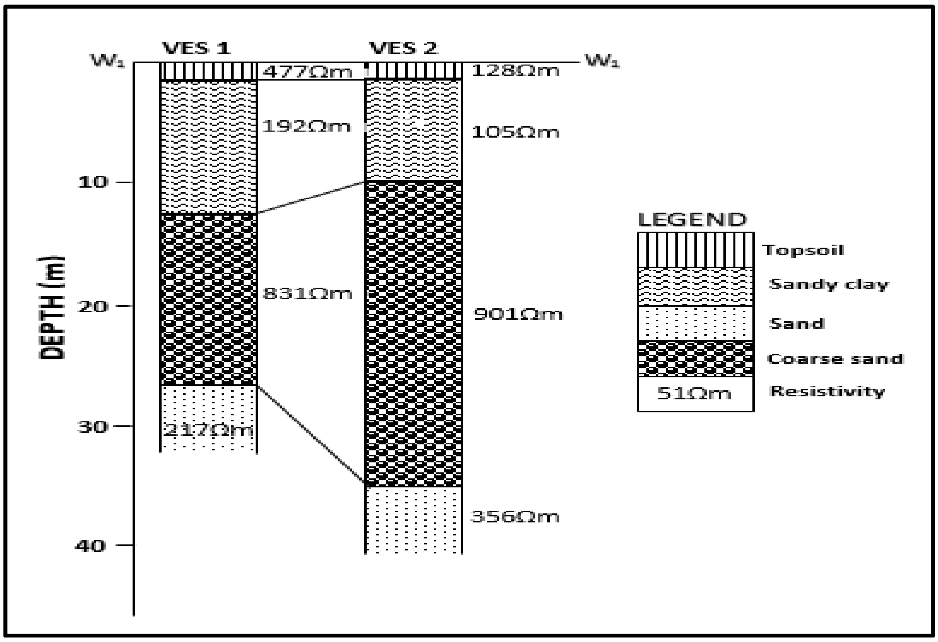

Figure 5: Sample of inferred geoelectric section beneath VES 1 and 2

Cone Penetration Test

CPT 1: The cone resistance reading for CPT 1 was recorded to a depth of 4.2m as shown in Figure 6, before the 2.5 tons Dutch Cone Penetrometer anchor pulled, from the surface to a depth of about 2m and a cone resistance about 20kg/cm^2 which is indicative of loose to medium dense granular soil and this value remained unchanged from the surface to this depth. While from a depth of 2m – 2.8m, the cone resistance value changed increased sharply to 70kg/cm^{2}indicating medium dense granular soil with this value maintain to a depth range of 2.8m – 4m while from a depth of 4m – 4.2m, the cone resistance readings increases to 180kg/cm^2 indicating dense sand. Presence of strange debris in the subsurface might prevent the cone penetrometer from penetrating the soil as it is a point source.

CPT 2: The cone resistance reading for CPT 2 was recorded to a depth of 4.8m as shown in 7, before the 2.5 tons Dutch Cone Penetrometer anchor pulled, from the surface to a depth of about 3m and a cone resistance of about 40kg/cm^2 is an indicative of loose to medium dense granular soil and this value remained unchanged from the surface to this depth. While from a depth of 3m – 4m, the cone resistance value changed increased sharply to 72kg/cm^{2}indicating medium dense granular soil while from a depth of 4m – 4.2m, the cone resistance readings increases to 120kg/cm^2 indicating dense sand. Presence of strange debris in the subsurface might prevent the cone penetrometer from penetrating the soil as it is a point source.

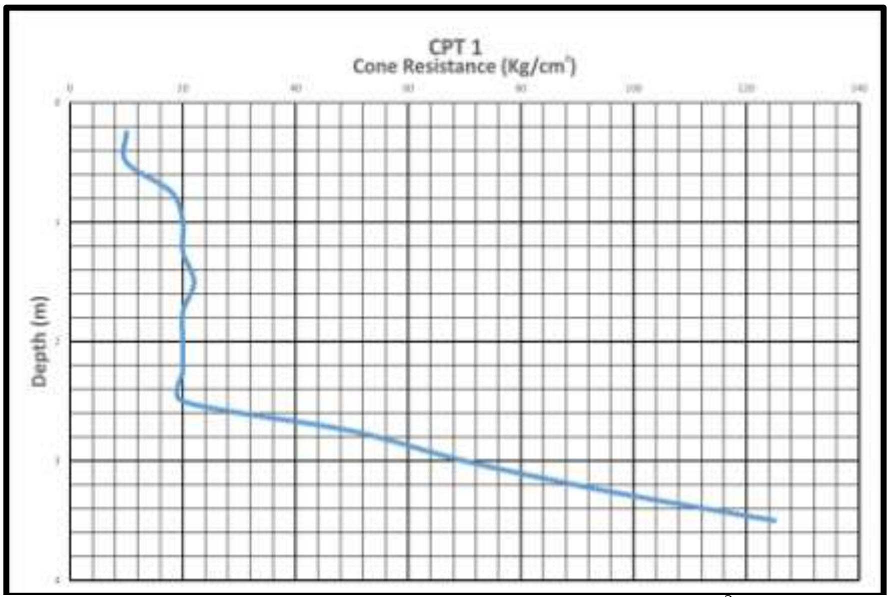

Figure 6: A Graph of Depth (m) against Cone Resistance (kg/cm^2) for CPT 1

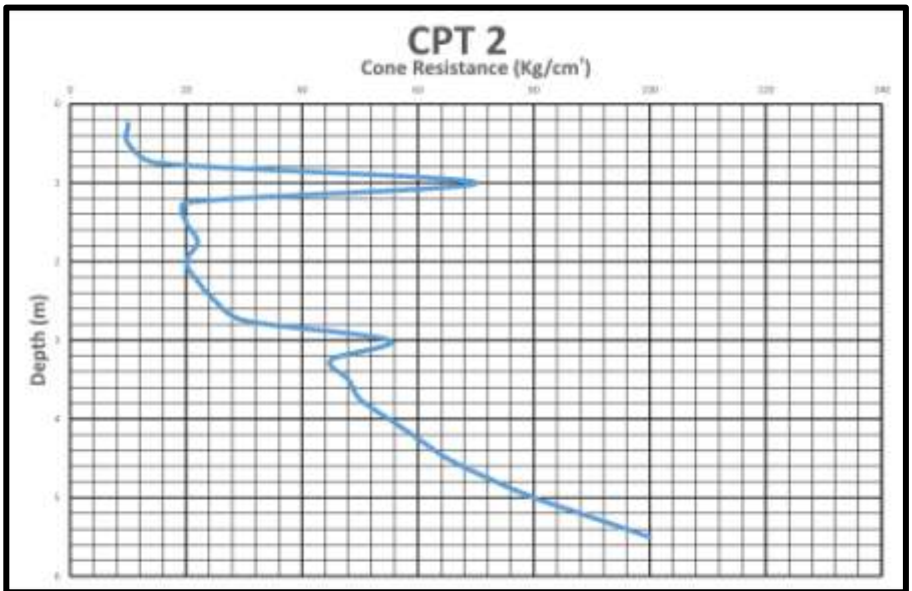

Figure 7: A Graph of Depth (m) against Cone Resistance (kg/cm^2) for CPT 2

IV. Conclusion

Geophysical and geotechnical investigations have been carried out at the School of Technology area, Lagos State Polytechnic, Ikorodu and it shows a good agreement. Six vertical electrical sounding, three 2D resistivity traverses and two CPT, were carried out in order to identify the depth to competent layer for foundation of engineering worksand high rise buildings in the area. The results of the vertical electrical sounding indicate that the depth to basement values ranges between 27.6 and 39.5m. The 2D resistivitysurvey has provided valuable information on the lateral and vertical variation of the layer competent for erecting foundation of engineering structures. The CPT probed an average depth of 4.8m and has identified material of very high shear strength associated with dense sand materials.

The correlation of the three techniques used revealed similar soil layering consisting of topsoil, sandy clay, coarse sand and sand.A mechanically stable coarse sand materialwas discovered as weathered layer which indicates high load bearing capacity suitable for foundation in the area and can support massive structures.

This study has showed the usefulnessof integrating geophysical and geotechnical methodsto delineate the lateral and vertical variations of the subsurface layers and its implication in engineering structures.

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