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Site Investigations of Subsurface Conditions Using Electrical Resistivity Method and Cone Penetration Test at Medina Estate, Gbagada, Lagos, Nigeria

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Abstract: Several buildings at Medina Estate, Gbagada, Lagos State, have undergone differential settlement of various degrees. An investigation was therefore carried out to unravel the prevalent subsurface geological conditions. 1D and 2D resistivity measurements alongside cone penetration tests were carried out within the undeveloped part of the estate. The results of the tests showed the site to be underlaid by various shades of clay occurring from existing ground to over 20m in many parts of the site. Sands of appreciable thickness were found to occur at depth range of 14 to over 25m in some parts of the site. The information obtained showed that the soil at shallow depths consists of an extensive layer of material of extremely low shear strength and a corresponding high volume of compressibility potential, thus making shallow foundation impossible except some form of soil improvement.

Key words: Geophysical · Geotechnical · Unfossilifereous · Geoelectric · Resistivity

INTRODUCTION

Presently, the population of Lagos is put at fifteen million [1]. In recent years several companies and private individual have been engaging in infrastructural developments to meet the ever increased human population since the Government alone could not meet the housing demands by the people. Often times, these service providers have failed in several aspects of engineering code of conduct practices relating to construction activities. Recent studies showed that many of them do not engage the services of professionals in order to maximize profits, the adverse effects been poor building constructions which ultimately leads to gradual or sudden collapse of such structures.

Since nearly every civil engineering structures must be erected on the surface of the earth, it is important that enough information on the strength and the fitness of the host earth materials must be ascertained before the actual construction work commences, hence the need for this exercise. The performance of an infrastructural element or facility is considered good if it performs as designed and provides an acceptable level of service over its intended life [2]. However, engineering structural performance depends majorly on the geological materials, load, climatic and environmental conditions. The deterioration of the structure during in-service operations can be manifested by excessive deformations or various kinds of distress of strength types. Geological materials such as clay are a major structural hazard and cause extensive damage world- wide every year. They pose serious problems to engineering structures particularly in areas of rapid urban growth. Expansive soils owe their characteristics to the presence of swelling clay minerals. When wetted, the clay minerals absorb water molecules and expand. When dried, it shrinks and leaves large voids in the soil. Different methods have been developed over the years to establishing faster and less expensive ways of estimating the various subsurface earth materials. Such methods include geophysical and geotechnical techniques.

Geophysical methods can provide some of the required information to delineate those materials in subsurface space. Such information includes overburden thickness, horizontal and vertical lithological extents, depth to water table, fault zones etc. Electrical resistivity and seismic exploration methods are the most common techniques used for this purpose [3-7]. In geotechnical studies, cone penetration test is the most widely used [4].

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From the cone resistance reading, the soil bearing capacity can be determined. The spate of sudden collapse of engineering structures coupled with rapid increase of infrastructural development in Lagos State informed this study.

MATERIALS AND METHODS

Geological Setting: The study area lies within the Dahomey sedimentary basin. The basin extends from the eastern part of Ghana through Togo and Benin Republic to the western magin of the Niger Delta (Fig. 1a). The base of the basin consists of unfossiliferous sandstones and gravels weathered from underlying Precambrian basement. On top of these are marine shales, sand stones of Albian to Santonian ages deposited prior to the Santonian tectonic episode [6]. The Quaternary geology of the study area comprises the Benin Formation (Miocene to Recent), recent lithoral alluvium and lagoon/coastal plain sand deposits [8, 9]. The alluvial deposits consists mainly of sands with clay intercalations; litholoral and lagoon sediments formed between two barrier beaches and coastal plain sands [10].

Data Acquisition: The survey area was divided into a 20 x 20m square grid pattern (Fig. 1b). The electrical resistivity survey involved vertical electrical sounding (VES) using Schlumberger array system and horizontal profiling using dipole-dipole array system. Tetrameter SAS 1000 was employed in data collection. SAS stands for Signal Averaging System, a method whereby consecutive readings are taken automatically and the results averaged continuously. SAS results are more reliable than those obtained using single-shot systems. A total of 10 VES points and 4HP lines were covered. The data obtained were processed using WingLink software.

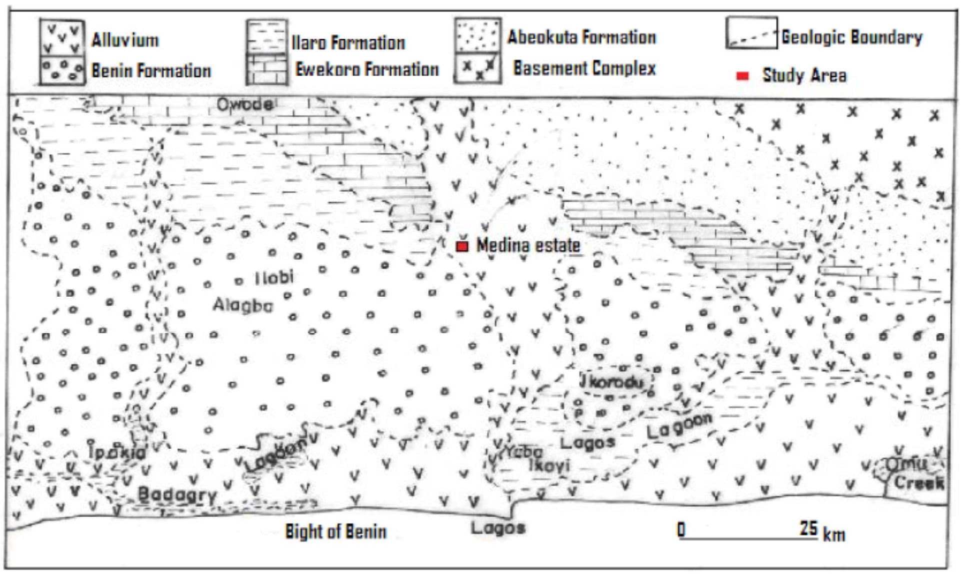


Fig. 1a: Geologic map of Lagos showing the study area (modified from Offodile, 2005)

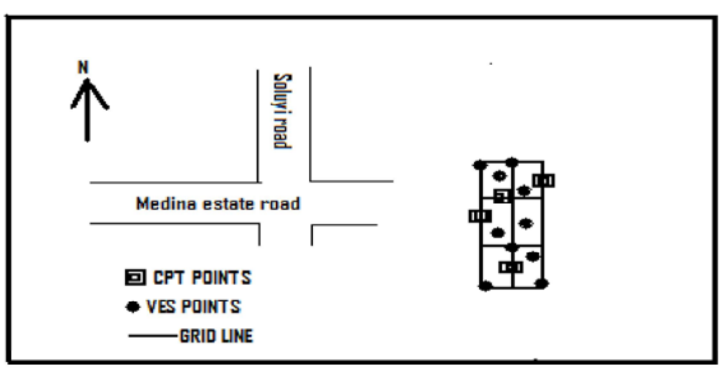
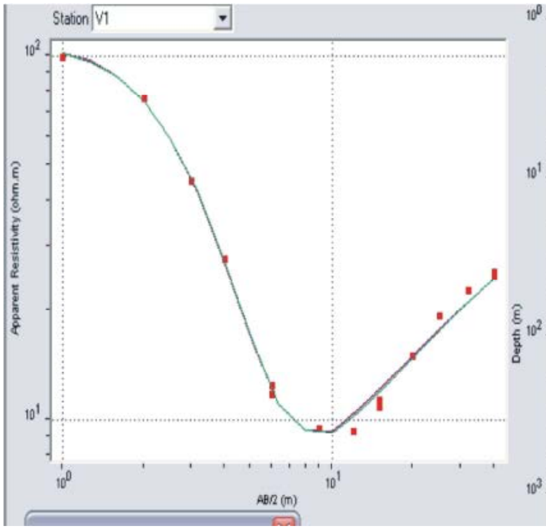
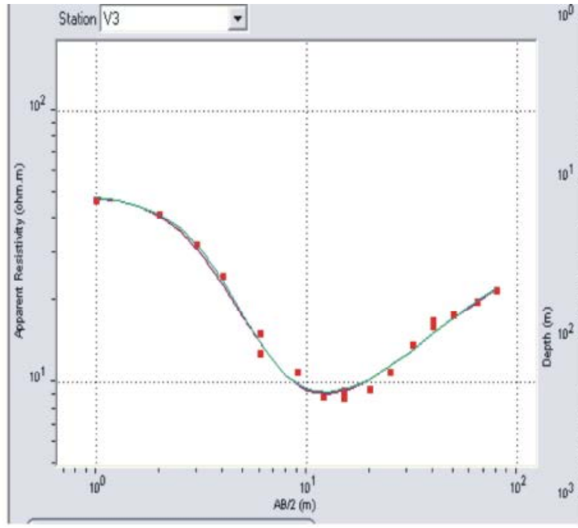


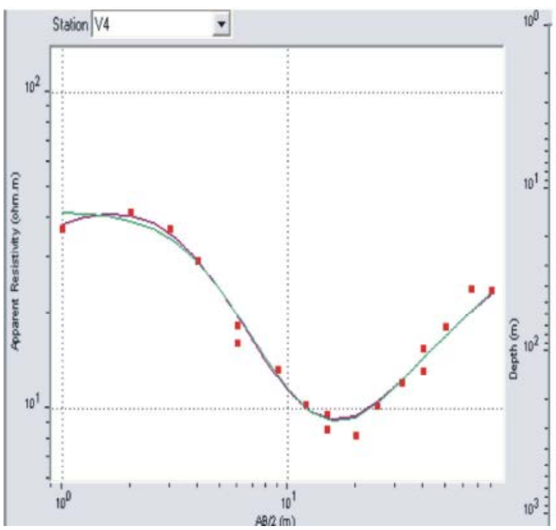
Fig. 1b: Site map showing the data collection points



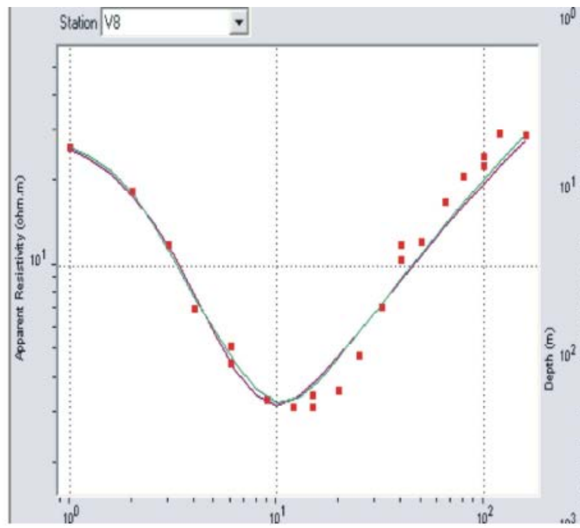
(a): VES 1



(b): VES 3



(c): VES 1



(d): VES 3

Fig. 2a-d: Samples of 1D resistivity models of the study area

A WingLink data-base contains the data for all surveys carried out in the area of interest. Information on the central meridian, the projection used for the station coordinates and the linear units used for distances and depths are stored in the database properties. By this technique, minor errors due to manual interpretation are eliminated. Typical example of 1D models or 2D models of WingLink plots is given in Figures 2 and 3.

The cone penetrometer test (CPT) was carried out at 5 locations on the grid lines by forcing a hardened steel cone with a base area of 1000mm^2 at an apex angle of 60° continuously into the ground and measuring its resistance to penetration. The 2 ½ ton equipment is a manually operated unit furnished with a single cone that can measure the end resistance, q_c only. The cone was advanced at regular intervals of 25cm and the corresponding pressure required to advance it is transmitted to a gauge which in turn records this pressure value. This procedure was repeated until the required depth is either reached or the total resistance to penetration of the tubes and cone reaches the capacity of the machine. Successive cone resistance readings were plotted against depth to form a resistance profile which indicates the strata sequence penetrated. Table 1 showed the lithology identified from CPT data compared with that of VES data.

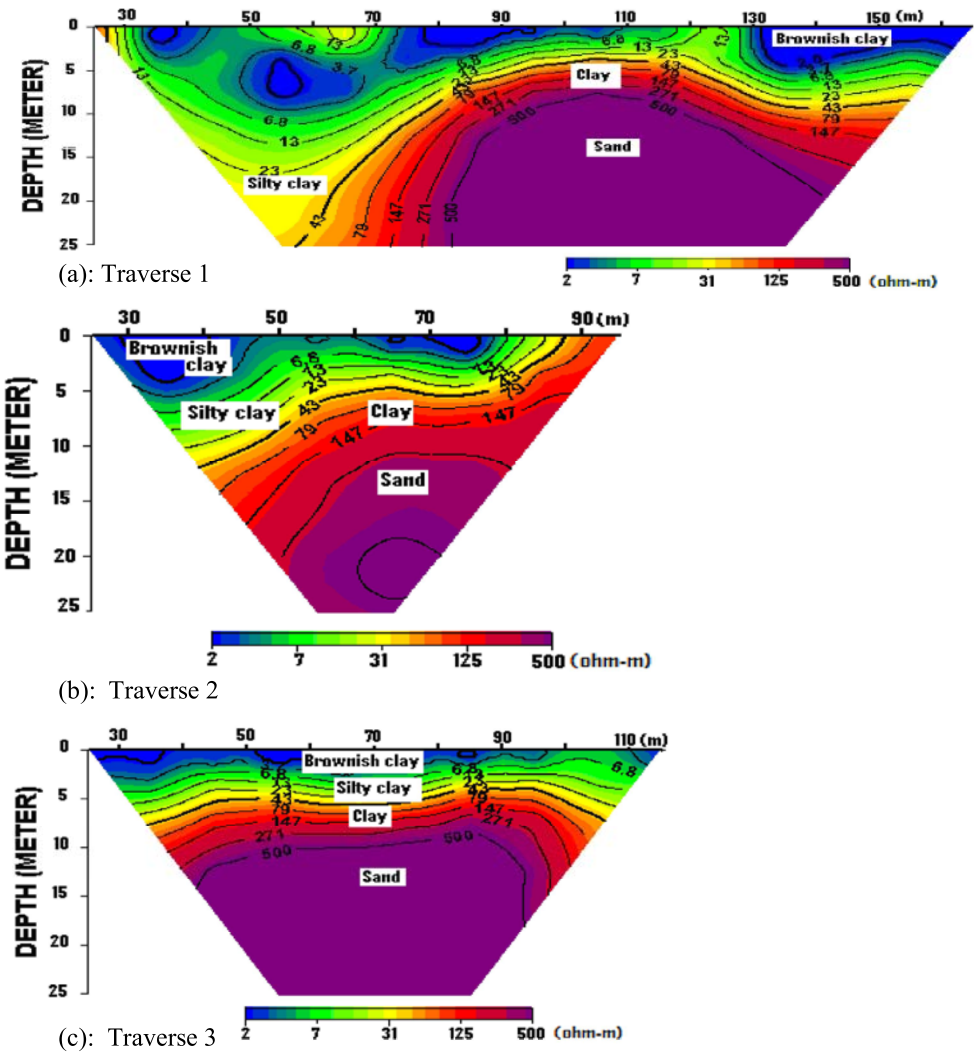


Fig. 3a-c: Samples of 2D resistivity pseudosections of the study area

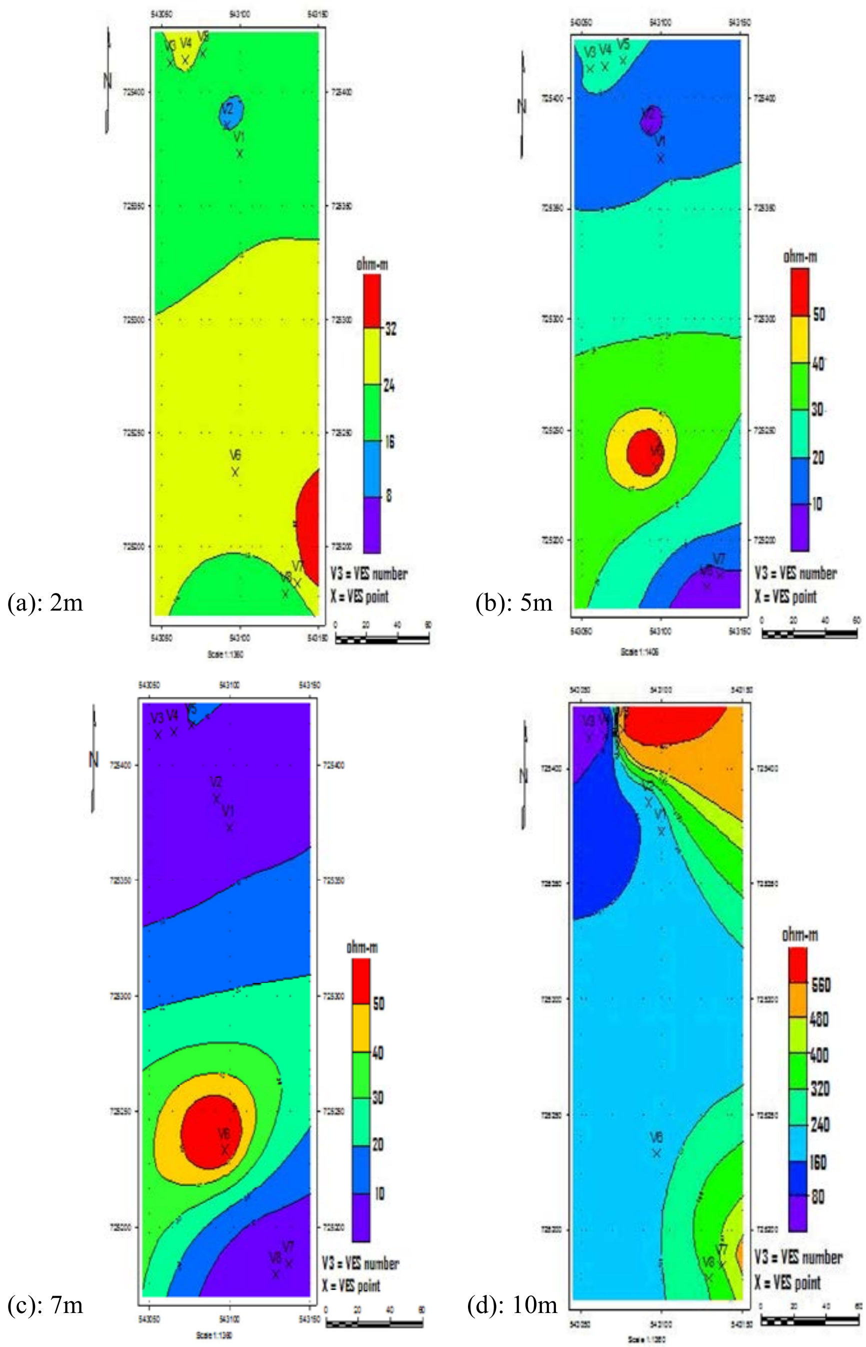
RESULTS AND DISCUSSIONS

The area of study consists of four geoelectric layers (Figs. 2 and 3). The first layer is represented by brownish clay deposit of variable grade with average thickness value of 1.4m. The second layer with higher resistivity value was made up of silty clay with an average thickness value of 7.6m. The third layer is hard clay of higher resistivity value than the second layer. Figures 3a to 3c showed the vertical and the horizontal extent of the subsurface stratigraphy of the area covered. The third layer has an average thickness value of 8.6m. Within the available space of investigation, the estimated total vertical thickness of clay layers was in excess of 18m. The results of 1D probing and 2D profiling as seen in Figures 2 and 3 are the same with lesser depth in 1D result, but with more detailed information of sediments successions in 2D results. The results of this study showed clearly that the sediment depositions varied in subsurface space.

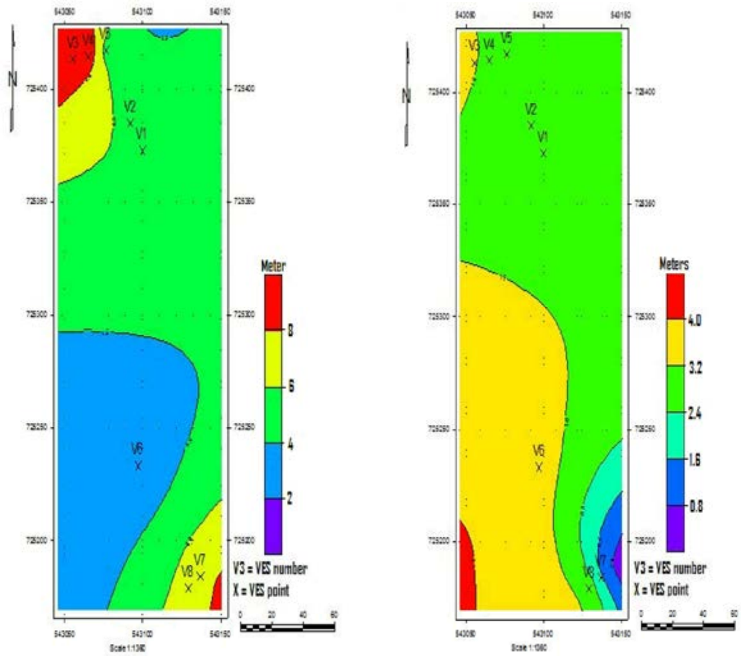
The fourth layer is sandy with higher resistivity value than the third layer and with an average thickness value of about 4.5m in some of the VES points as the current terminated in most of the VES points (Fig. 3). Table 1 compared some of the observed parameters at some selected points between VES and CPT data. Here it can be seen that the VES data showed clay thickness to vary from 1.46 to 5.68m which correlates well with CPT of 1.53 to 5.67m. However, the fourth layers of the geoelectric sections showed a sandy layer of some appreciable

Table 1: Comparison of some of the observed parameters at selected points between VES and CPT data

Location	Depth (m)	VES inferred clay Thickness (m)	VES inferred sand Thickness (m)	CPT derived clay Thickness (m)	VES layered Resistivity(Ωm)	CPT resistance (Kg/cm^2)
1	1.00	1.85	2.56	1.79	34.65	25.00
2	3.00	1,46	Nil	1,53	56.12	62.00
3	5.00	3.79	5.46	4.12	67.43	84.00
4	7.00	2.97	Nil	2.89	34.68	137.00
5	9.00	5.68	5.96	5.67	45.87	185.00

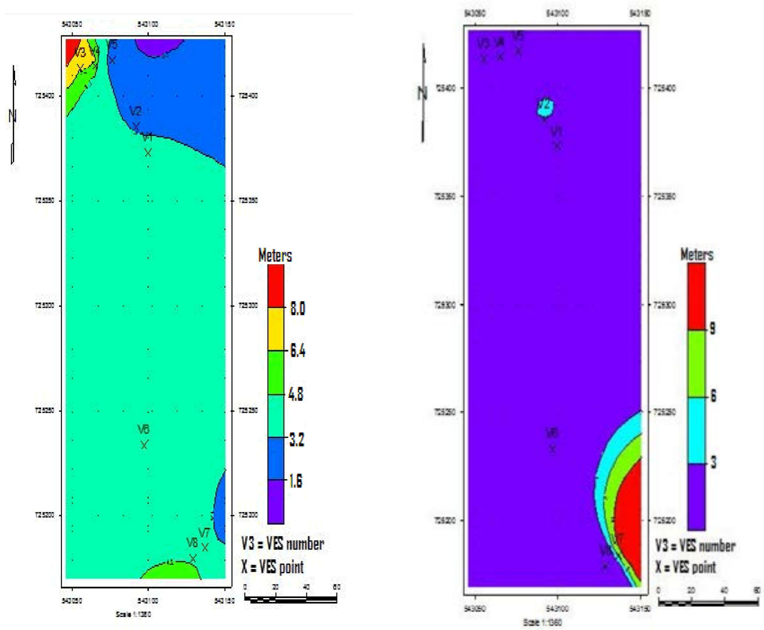


Figs. 4a-d: Isoresistivity layered models at 2, 5, 7 and 10m respectively



(a): Isopach map of clay layers (b): Depth to clay layers

Fig. 5: Maps of thickness of clay layers and depth to clay layers



(a): Sand isopach map (b): depth to groundwater table

Fig. 6a&b: Maps of thickness of sand layers and depth to groundwater table

thickness occuring beneath some of the VES points. The average sand thickness inferred from these VES data vary from 2.56 to 5.96m. But this was conspicuously absent from the CPT data. The inferred lithology from the VES data was correlated with the drilled borehole data. The borehole was drilled using the percussion method with the aid of a picon light cable rig equipped with in-situ standard penetration Test (SPT) accessories.

Figures 4a-d showed the isoresistivity layered model at 2, 5, 7 and 10m respectively. These maps show the contrasts in resistivity values which characterized the various shades of clay layers both vertically and

Table 2: Soil bearing capacity calculated from CPT data and subsurface lithology determined from both CPT AND VES data

S/N	Depth (m)	Range of Allowable Bearing Capacity (KN/m^2)	Subsurface lithology inferredfrom VES data correlated with (CPT) test log data
1	0.50	18.9-40.5	Brownish clay, silty clay
2	1.00	28.4-71.6	Brownish clay, silty clay
3	1.50	18.9-77.0	Brownish clay, silty clay
4	2.00	18.9-99.9	Brownish clay, silty clay, clay
5	2.50	21.6-133.3	Brownish clay, silty clay, clay
6	3.00	18.9-141.8	Brownish clay, silty clay, clay
7	3.50	21.6-151.9	Brownish clay, silty clay, clay
8	4.00	31.1-166.1	Brownish clay, silty clay, clay
9	11-over 25	Nil	Nil

horizontally. From these maps it could be deduced that the soil material encountered below the study area vary across the site. It also shown that resistivity values could be used to classify the subsurface rock distribution in an area with respect to their depth variation both vertically and horizontally.

Figures 5a and 5b showed the thickness of clay layers and the depth to clay layers respectively. These maps also showed clearly that the subsurface distribution/deposition of sediments was not uniform. The thickness of clay layers vary from 2 to over 8m. The highest value was obtained beneath VES 3 and 4 and the lowest value was obtained beneath VES 6. On the other hand, the depths to clay layers vary from 0.8 to over 4.0m. The highest value occurred beneath VES 3 and 6 while the lowest value was beneath VES 7. We also went further to provide the subsurface morphology of sand layer as encountered during the geophysical investigation (Fig. 6a). It can be seen that the thickness of the sand layers vary from 1.6 to over 8.0m. The highest value occurred beneath VES 3 while the lowest value was beneath VES 2,3 and 8. Figure 6b showed the depth to ground water table (GWT) within the studied area. The GWT vary from 3 to over 9m. The highest values occurred beneath VES 7 while the lowest value occurred beneath VES 1, 3,4,5,6, 8.

Table 2 showed the soil allowable bearing capacity calculated using the cone resistance values correlted with lithology obtained from both the CPT and VES data. The bearing capacity was calculated using Meyehorf equation.

$$q_a = 2.7\ q_c\ kN/m^2$$

Where q_a is the allowable bearing capacity

q_c is the cone resistance.

The values obtained above, shows clearly that shallow foundation may not be feasible except some form of soil improvement is carried out. This may involve excavating to about 20m and backfilling with granular soil compacted in thin layers to desired foundation level. The above approach may prove very cumbersome and difficult to achieve owing to the volume of earth to be moved. The alternative approach will be the adoption of deep foundations in the form of piles. Since the performance of a pile depends on a number of factors such as pile diameter, founding depth, methods of installation, etc, it is advisable that a specialist piling contractor is engaged whenever the need arises.

CONCLUSION

The integrated geophysical and geotechnical survey carried out in the study area revealed four geoelectric layers; cum brownish clay, silty clay, hard clay and sand respectively. The thickness of clay layers range from 2 to over 8m while the thickness of sand layers vary from 1.6 to over 8.0m. On the other hand the depths to clay layers vary from 0.8 to over 4.0m. The depths to ground water table vary from 3.0 to over 9.0m. A good correlation was found between the thickness of clay layers delineated from the VES data and that of CPT data.

Based on resistivity contrasts and cone penetration test, it is concluded that shallow foundation may not be possible except some form of soil improvement is carried out and this may looks cumbersome considering the volume of earth to be moved. The alternative approach may be the adoption of deep foundations in the form of piles.

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