Geophysical and Geotechnical Studies of a Proposed Structure at Akure, Southwestern Nigeria.

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Abstract

Geophysical and geotechnical studies were carried out at a proposed location for the construction of a multi-storey structure in Akure, Southwestern, Nigeria. The aim was to ascertain the suitability of this location for both Founding and Engineering structures. The geophysical investigation involved the Vertical Electrical Sounding (VES) technique using the Schlumberger configuration, Dipole-Dipole Horizontal Profiling and a geotechnical investigation. A total of twenty one (21) VES and five (5) Cone Penetration Test (CPT) locations were occupied within the study site. Dipole-Dipole Horizontal Profiling was occupied along traverses 1 and 2 within the investigated area. The electrode separation varies from 1 to 75 m. The investigation delineated three major layers which are topsoil, which is excavated before any foundation is laid. The second layer delineated was lateritic and the last was weathered layer. From the result obtained, depth to lateritic layer ranges from 1.1 to 9.0 m while resistivity defining the lateritic layer ranges from 150 Ωm to 792 Ωm. Some of the sounding curves generated over the VES stations and Dipole-Dipole Horizontal Profiling fairly correlated with those of the CPT profile. The high cone penetration resistance recorded at CPT point 4 and 5 is manifested as high geoelectric resistivity values recorded at VES 13. This shows that the soil has fairly low clay content. It also seen from the study that the geophysical studies has a greater depth penetration, and it also provide better layer characterization compared to geotechnical studies. The choice of foundation material, clay content and topography elevation should be taken into cognizance, since the load bearing capacity of the lateritic layer was appreciably high.

Key Words: Vertical electrical sounding, cone penetration test, dipole-dipole, foundation integrity.

Introduction

The Earth is complex in nature and very inhomogeneous in fracture distribution. The complexity of the earth materials is more pronounced in the basement complex regions while in the sedimentary terrain the soil properties may be reasonably uniform over long distance. While some areas are underlain by shallow bedrock or materials of higher load-bearing capacity, others may have significant superficial soil cover [2]. The near-surface bedrock is an excellent foundation support material as the load bearing is infinity high. In areas of thick overburden cover, the materials could have variety of engineering properties. While some may be very weak especially where the clay content is high others may be of high load bearing capacity especially if the aggregates are *gravelly*. The rate of failed structures in Nigeria has increased in recent times [8]. These structural failures are in most cases associated with the problem of poor quality of building materials, old age of buildings and improper foundation. In recent times, the land expanses in Akure have been opened to rapid development [7]. Despite this rapid growth and development, the impact of subsurface geologic structures in the area on the durability and easy maintenance of the erected structures have been seldom discussed. Vertical and near vertical cracks or discontinuities have been noticed in the walls of both old and recent buildings [4]. This assertion can be attributed to the minimal attention paid towards the use of geophysics in foundation studies. In Engineering Geophysics and site investigation, structural information and physical properties of a site are sought [10]. This is so because the durability and safety of the engineering structural setting depend on the competence of the material, nature of the subsurface lithology and the mechanical properties of the overburden materials [1]. Foundations are affected not only by design errors but also by foundation inadequacies such as sitting them on incompetent earth layers. For CPT, a cone at the end of a series of rods is pushed into the ground at a constant rate, and measurements are made of the resistance to the penetration of the cone. This is known as “cone resistance” or qc, which is the total force (Qc) acting on the cone divided by the projected area (Ac) of the cone. The cone resistance qc is a direct indicator of the strength of the soil at a given depth. Cost, efficiency, speed, simplicity, reliability, and the ability to provide near-continuous information on the soil properties with depth are the essential reasons for the increasing popularity of CPT [3]. The primary significance of CPT comes from the fact that it represents a miniature driven pile or foundation in soil; hence, the pile bearing capacity (pressure between a foundation and the soil which will produce shear failure in the soil) can be directly estimated from qc. Thus, CPT provides valuable constraints for all settlement and stability calculations. CPT qc responds to soil changes within five to ten times the cone diameter (standard = 35.6 mm) above and below the cone. It should be noted that valuable information that is provided by CPT is limited to its location [6]**.** CPTs are commonly performed tens or hundreds of meters apart. Soil models based on lateral interpolation of CPT data collected at a few locations at a given site obviously contain significant uncertainties, increasing the risk in engineering design.

This target of this work is to reveal the use of Geophysical and Geotechnical approaches as a reliable means of undertaking studies of construction sites as related to the Geologic nature of the environment thereby saving a lot of time and cost. Also, with the art of these methods, the fundamental problems of structures that have emerged problematic can be investigated, and remediation actions can be taken.

Description of the Study Area

The studied area is located within the Akure metropolis along Alagbaka, the capital city of Ondo State (Figure 1). It is situated between the UTM coordinates of Eastings 576759 - 576820 m and Northings 306455 - 306498 m. The study area is located within the sub-equatorial climatic belt of the tropical rain-forest with evergreen and broad-leaved trees with luxuriant growth layer arrangement. The area is characterised by uniformly high temperature and heavy well-distributed rainfall throughout the year. The average annual temperature ranges between 24^0C and 27^0C, while the rainfall is mostly conventional, peaks twice in July and September and varies between 1500mm and 2000mm per annum.

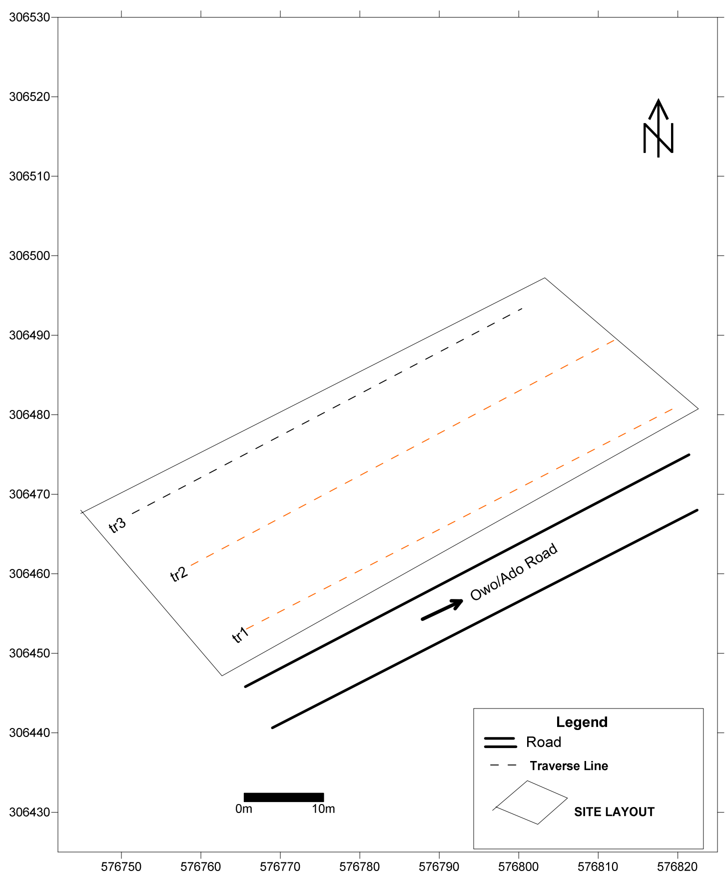

Figure 1. Base Map of the Study Area

Geology of the study area

Akure is located within the crystalline basement complex terrain of southwestern Nigeria. The area is generally underlain by basement rocks categorised by [9] as migmatite gneiss, quartzite, politic schist, biotite granite, charnocknite, granite gneiss and porphyritic granites. The main outcrops in the area are migmatite gneiss, porphyritic granite and charnockite, while biotite occurs as a discrete body at the southern part of the area as shown in the Figure 2. The study area is underlain by migmatite gneiss which is a coarsely grained crystalline metamorphic rock having quartz, feldspar and mica as its constituent. Biotite granite.

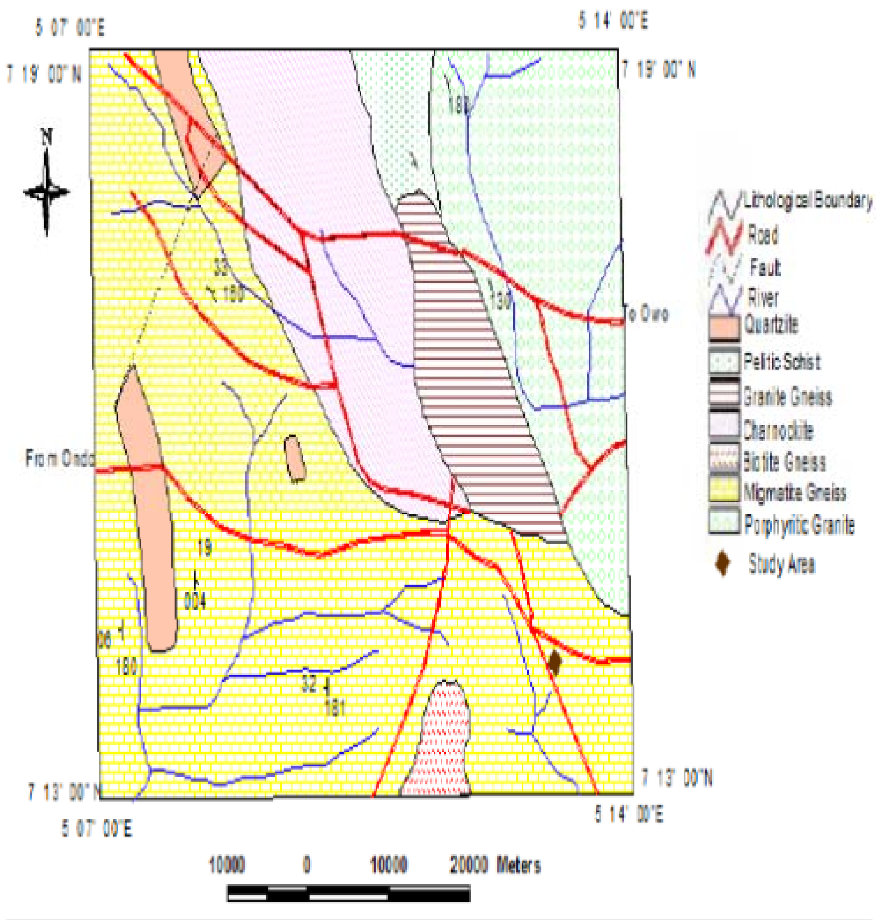

Figure 2. Geological Map of Akure Showing the Study area

Methodology

Geophysical Survey

Three traverses of about 70 m were established in an approximate E - W direction (Figure 3). The electrical resistivity method utilized the dipole-dipole profiling and the vertical electrical sounding (VES) techniques. The dipole-dipole survey was used to determine the lateral and vertical variation in apparent resistivity of the subsurface beneath the three established traverses. The VES involved the use of

Schlumberger array. Twenty one (21) sounding stations were occupied along the three established traverses and the current electrode spacing (AB/2) was varied from 1 to 65 m. In order to process the electrical resistivity data, the apparent resistivity values were plotted against the electrode spread (AB/2). This was subsequently interpreted quantitatively using the partial curve matching method and computer-assisted 1-D forward modeling with WinResist 1.0 version software [11]. The dipole-dipole data were inverted into 2-D subsurface images using the DIPPRO™ 4.0 inversion software [5]. 2-D electrical imaging of the subsurface was obtained using dipole-dipole configuration. The inter-electrode spacing of 5 m was adopted while inter-dipole expansion factor (n) was varied from 1 to 5. Resistivity values were obtained by taking readings using the ohmega resistivity meter.

Geotechnical Survey

Cone Penetration tests were performed at a total of five (5) locations within the study area (Figure 3). The tests were carried out to a depth of 4.5 m. The Dutch static penetration measures the resistance of penetration into soils using apex angel of 60^0 and a base of 10 sq cm. The cone Penetrometer test is a means of ascertaining the resistance of the soil. The layer sequences are interpreted from the variation of the values of the cone resistance with depth. The test was carried out by securing the winch frame to the ground by means of anchors. These anchors provided the necessary power to push the cone into the ground. The cone and the tube were pushed together into the ground for 20 to 25 cm; the cone was pushed ahead of the tube for 3.5 cm at a uniform rate of about 2 cm/sec. The resistance to the penetration of the cone registered on the pressure gauge connected to the pressure capsule was recorded. The tube was thereafter pushed down and the procedure enumerated above was repeated. Cone resistance and sleeve friction are plotted against depth using the series of recorded gauge readings obtained. The resistance profile was then obtained by plotting corresponding cone and Successive cone and sleeve resistances readings against depths. The profiles were correlated with geophysical data to provide information on the variation of strata and material strength across the site.

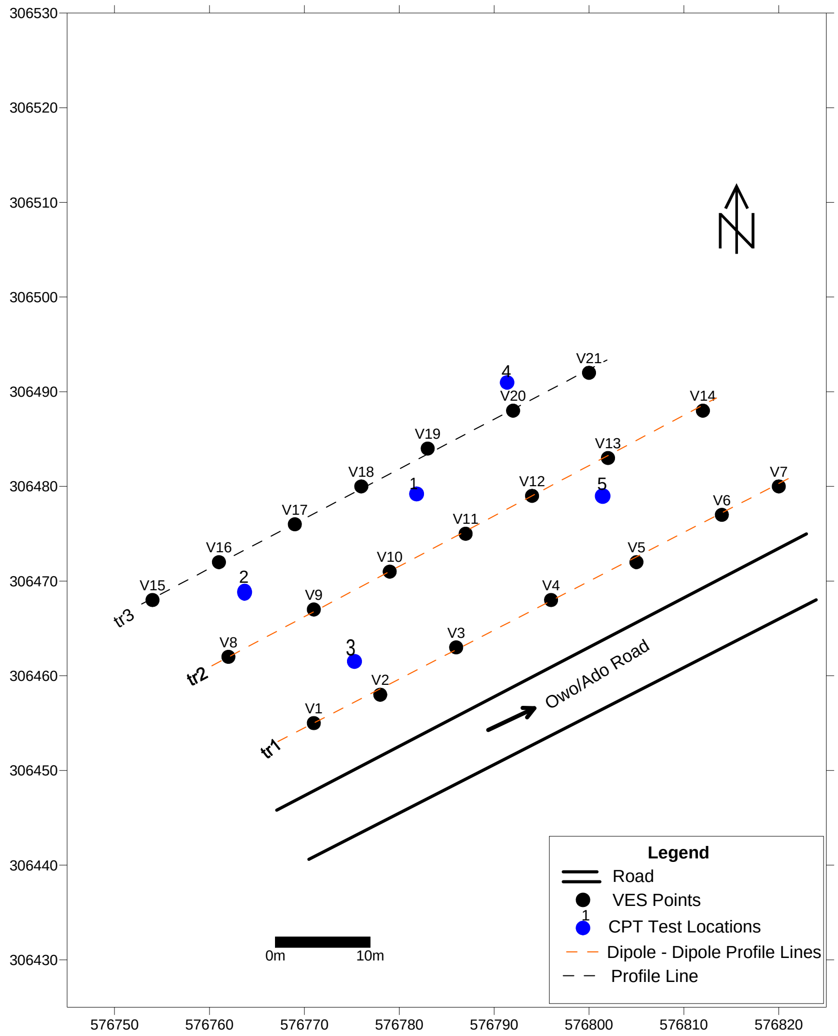

Figure 3: Data acquisition Map of the Study Area.

Results and Discussion

The results of the study were presented as Sounding curves geo-electric sections, pseudo sections and graphs

Characteristic of the VES curves

Curves types identified ranges from K, Q, KH, HK and KHK varying between three to five geo-electric layers. The KH curve type predominating. Typical curve types in the area are as shown in Figure 4(a-e)

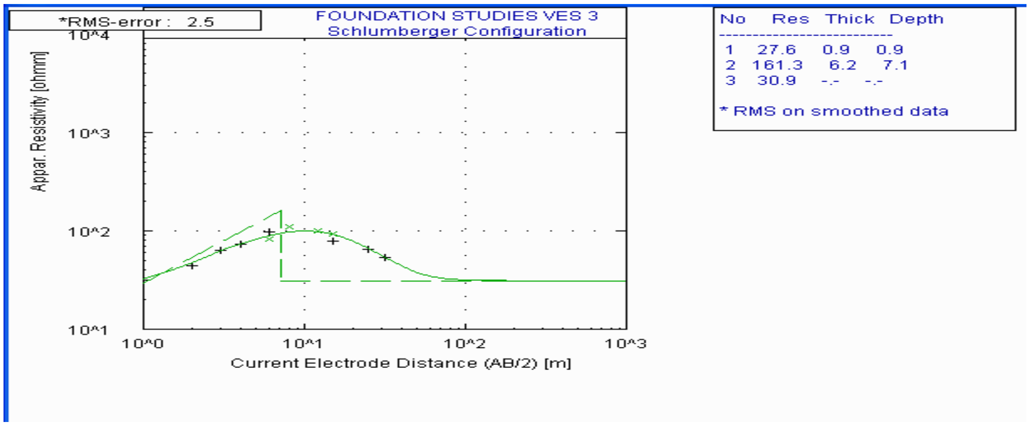

Figure 4a. Typical ‘K’ Sounding Curve

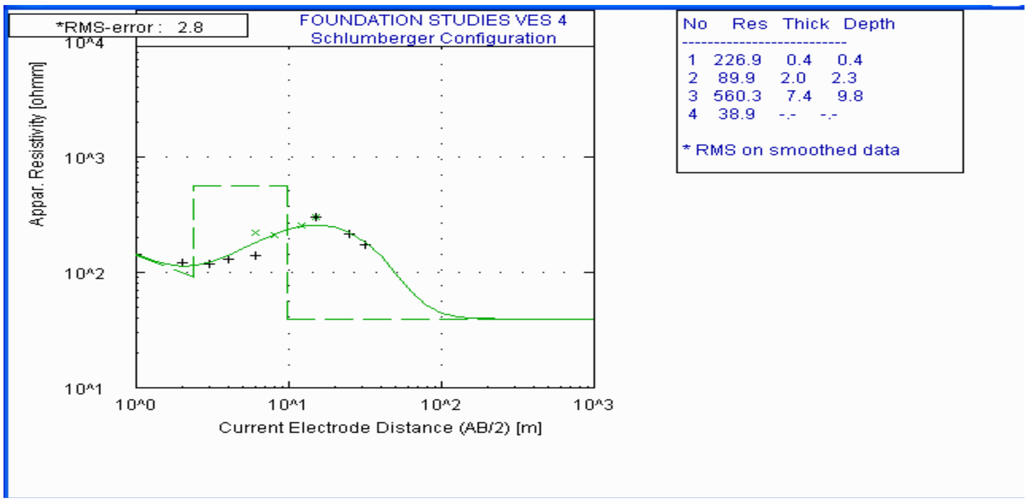

Figure 4b. Typical ‘HK’ Sounding Curve

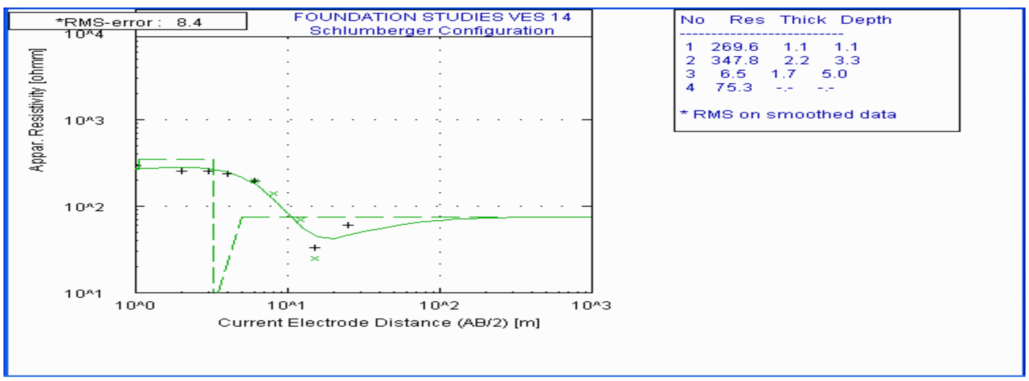

Figure 4C. Typical ‘KH’ Sounding Curve

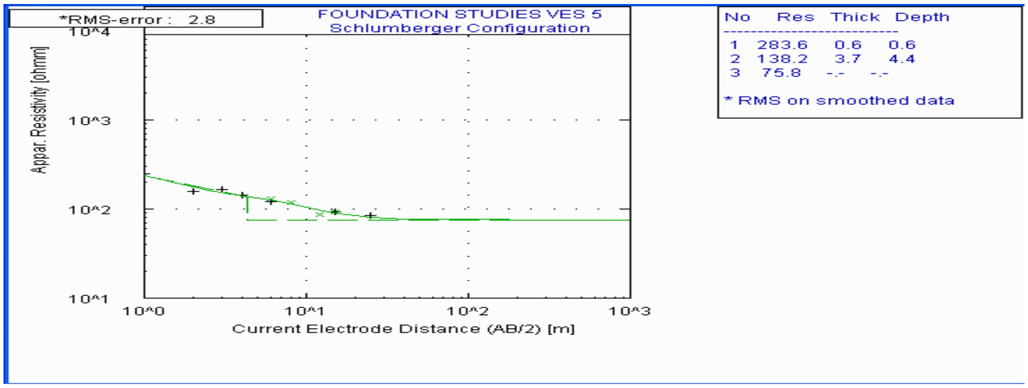

Figure 4d. Typical 'Q' Sounding Curve

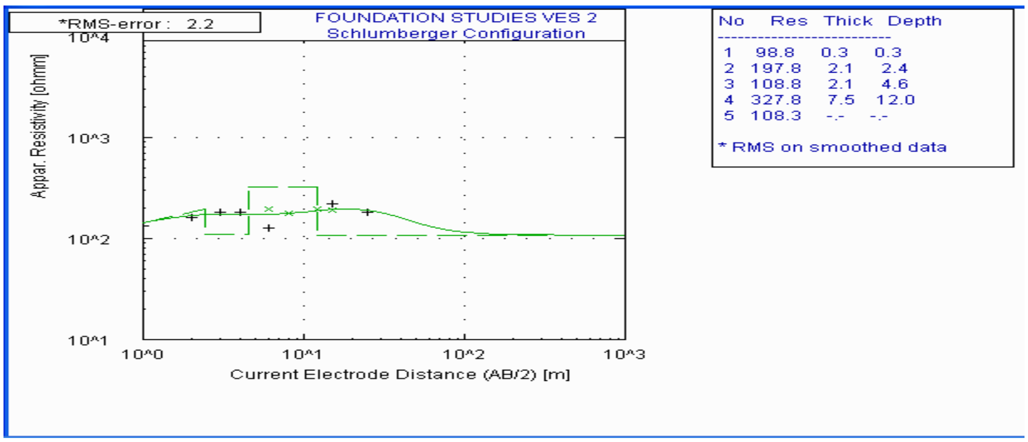

Figure 4e. Typical 'KHK' sounding curve

Geoelectric and Lithological characteristic along the three Traverses

The geoelectric sections were represented by the 2-D view of the geo-electric parameters (depth and resistivity) derived from the inversion of the electrical resistivity sounding data The geoelectric section along Traverse 1 (Figure 5a) attempted to correlate the geoelectric sequence across the study area. The geoelectric sections identified three geoelectric/geologic subsurface layers. The topsoil comprising of clay, clayey sand and sandy clay with the resistivity values ranges from 28 to 637 Ω-m with its thickness varies from 0.3 to 1.6 m, the clayey coarse sand/laterite resistivity values range from 138 to 560 Ω-m and thickness ranges from 2.1 to 7.4 m while the weathered layer resistivity varies from 16 to 122 Ω-m. the resistivity values of the topsoil are indicative of clay, sandy clay and clayey sand. This layer may not be of any particular interest since topsoil usually is excavated. Hence, the foundation of the proposed structures cannot be found on this layer.

On Traverse 2 (Figure 5b), three subsurface geologic layers were also delineated along this traverse. From the geoelectric section, the top soil, lateritic layer and weathered layer were determined. The topsoil comprising of clay, clayey sand and sandy clay with the resistivity values ranges from 71 to 489 Ω-m with its thickness varies from 0.5 to 7.0 m, the clayey coarse sand/laterite resistivity values range from 153 to 792 Ω-m and thickness ranges from 1.1 to 9.0 m while the weathered layer resistivity varies from 32 to 188 Ω-m. the resistivity values of the topsoil are indicative of clay, sandy clay and clayey sand. This layer may not be of any special interest since topsoil is normally excavated. Hence, foundation of the proposed structures cannot be found on this layer.

On Traverse 3 (Figure 5c), three subsurface geologic layers were also delineated along this traverse. From the geo-electric section, the top soil, lateritic layer and weathered layer were determined. The topsoil comprising of clay, clayey sand and sandy clay with the resistivity values ranges from 58 to 493 Ω-m with its thickness varies from 0.7 to 1.0 m, the clayey coarse sand/laterite resistivity values range from 175 to 523 Ω-m and thickness ranges from 1.9 to 6.8 m while the weathered layer resistivity varies from 31 to 168 Ω-m. the resistivity values of the topsoil are indicative of clay, sandy clay and clayey sand. This layer may not be of any special interest since topsoil is normally excavated. Hence, the foundation of the proposed structures cannot be found on this layer.

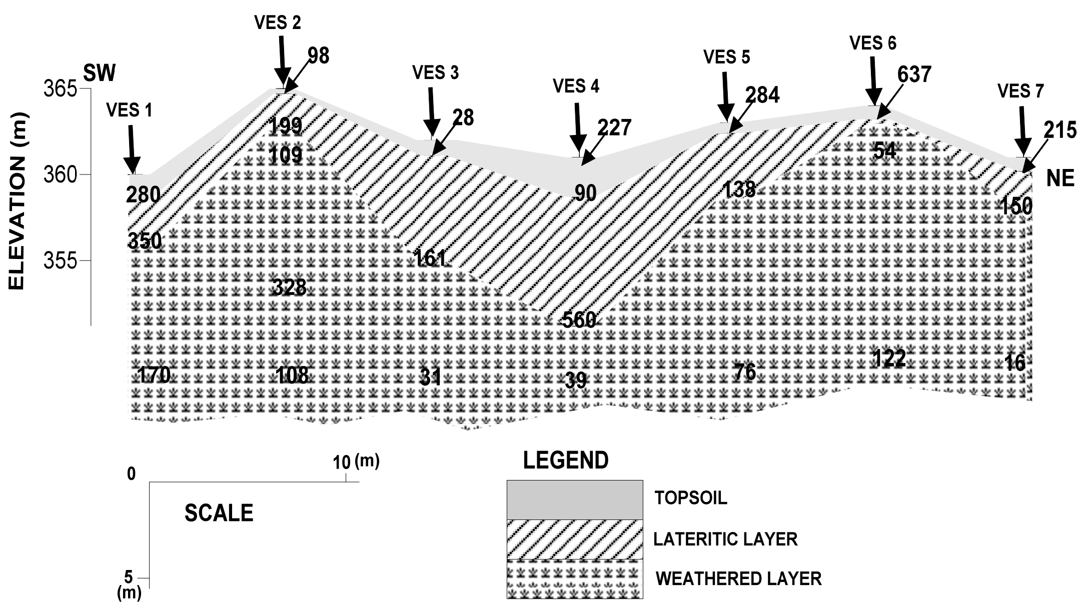

Figure 5a. Geoelectric Section along Traverse one

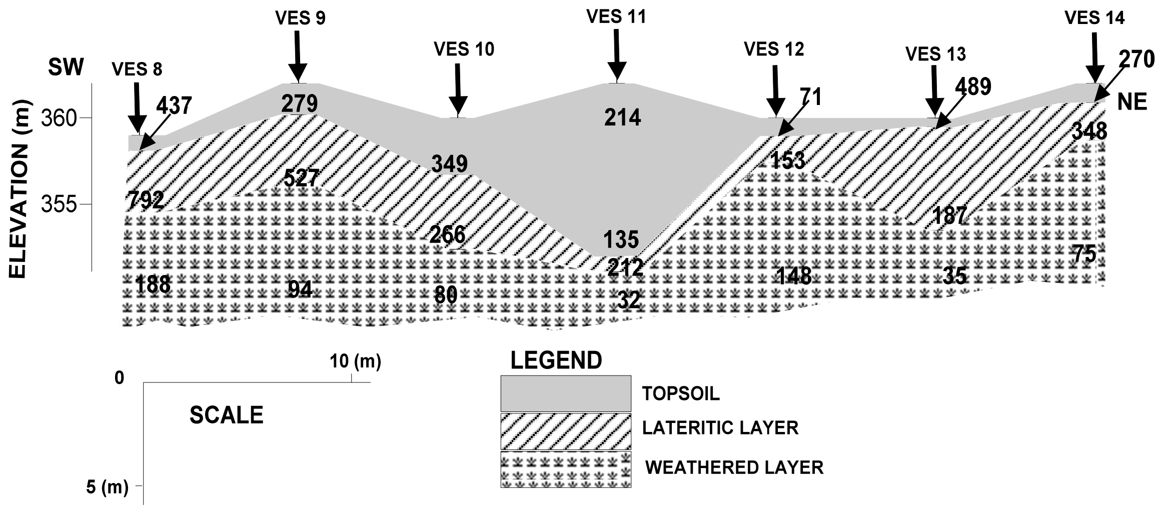

Figure 5b. Geoelectric Section along Traverse two

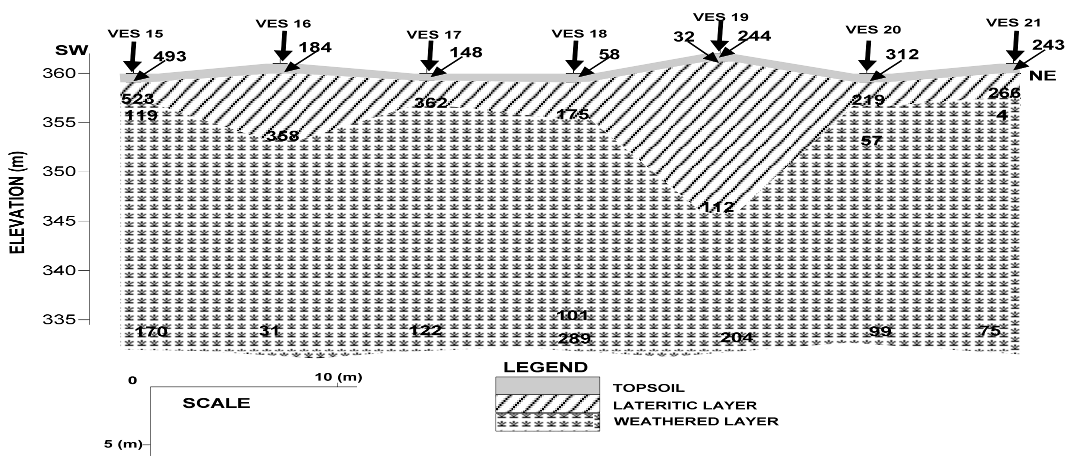

Figure 5c. Geoelectric Section along Traverse three

Dipole-dipole Pseudosections

The 2-D Pseudosection was produced from the dipole-dipole data taken along the two traverses (Figure 6a, b). It was set up to have a 2-Dimensional clear view of the subsurface because it shows an interpretation of unilateral data and its contours. These also have information as the geoelectric section. It delineated topsoil, weathered/fractured layer (thickness 5 to 12 m) and the fresh bedrock. The resistive parts are seen in the lower part of the section which is the fresh bedrock while the green and blue coloured parts are the fractured part of the section. A suspected linear feature was delineated at distance 40 to 65 m (Figure 6a).

The 2-D pseudo-section was also produced from the dipole-dipole data taken along Traverse 2 (Figure 6b). These also have information as the geoelectric section. It delineated topsoil, weathered/fractured layer and the fresh bedrock. The highly resistive parts are seen at the upper part of the section which is the fresh bedrock while the green and blue coloured parts are the weathered/fractured part of the section. A suspected linear feature was delineated at distance 35 to 60 m along Traverse 2

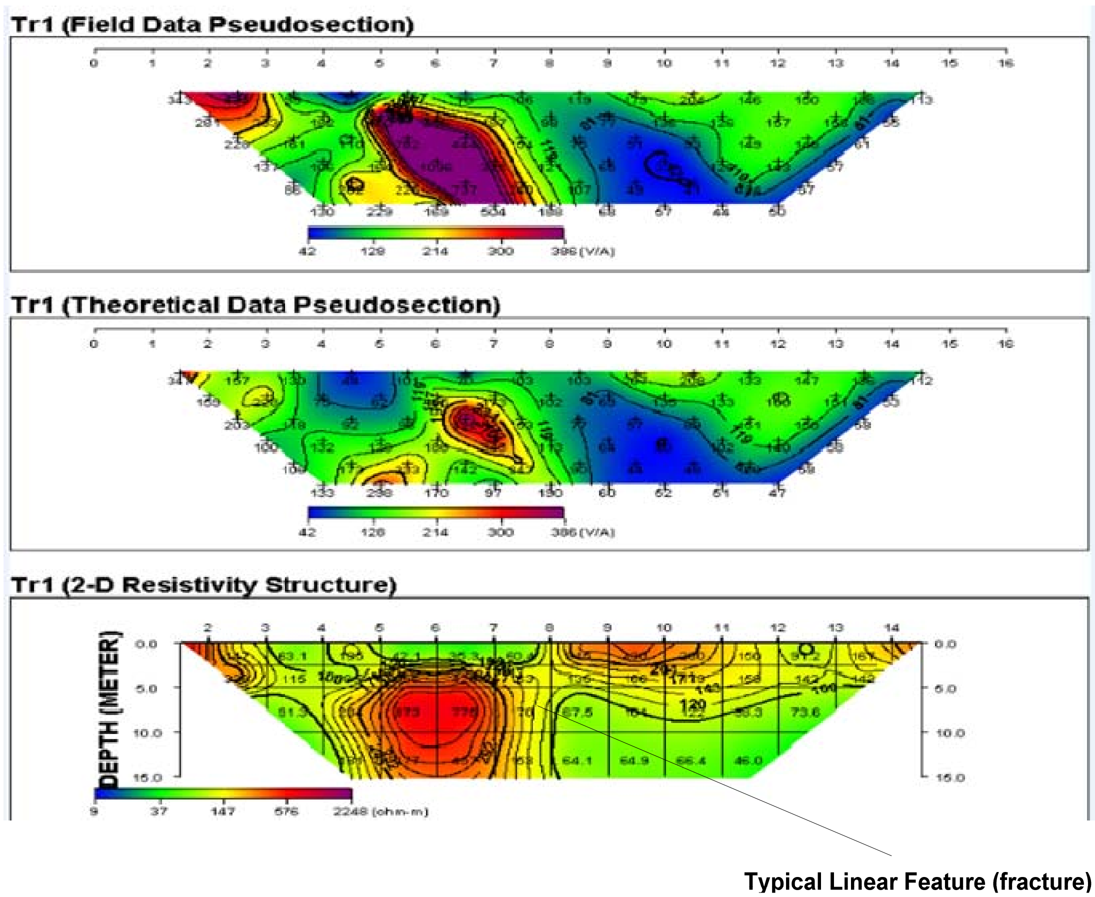

Figure 6a. Dipole – Dipole Horizontal Profiling along traverses 1

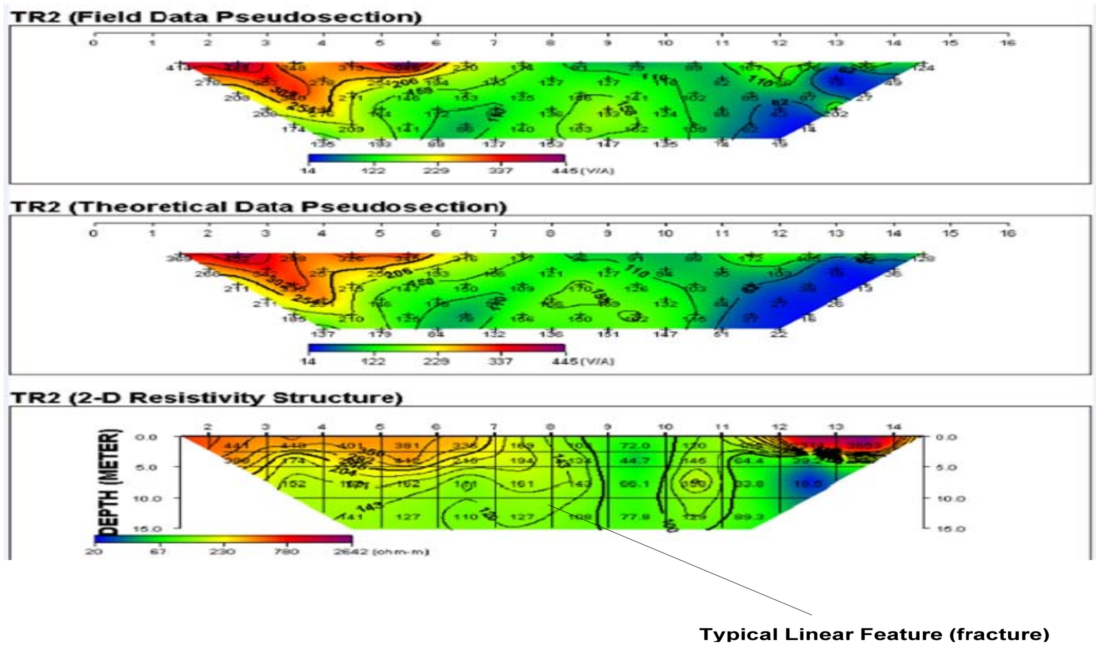

Figure 6b. Dipole – Dipole Horizontal Profiling along traverses 2

Geotechnical Results

The Cone penetration test plots Figure 7(a-e), varies from 2bar to 150bar with a maximum depth of 4.25 m. The layer sequences were interpreted from the variation of the values of the cone resistance plotted against depth. The CPT points have very low cone resistance values. This illustrates that the soil consists of conductive clayey materials.

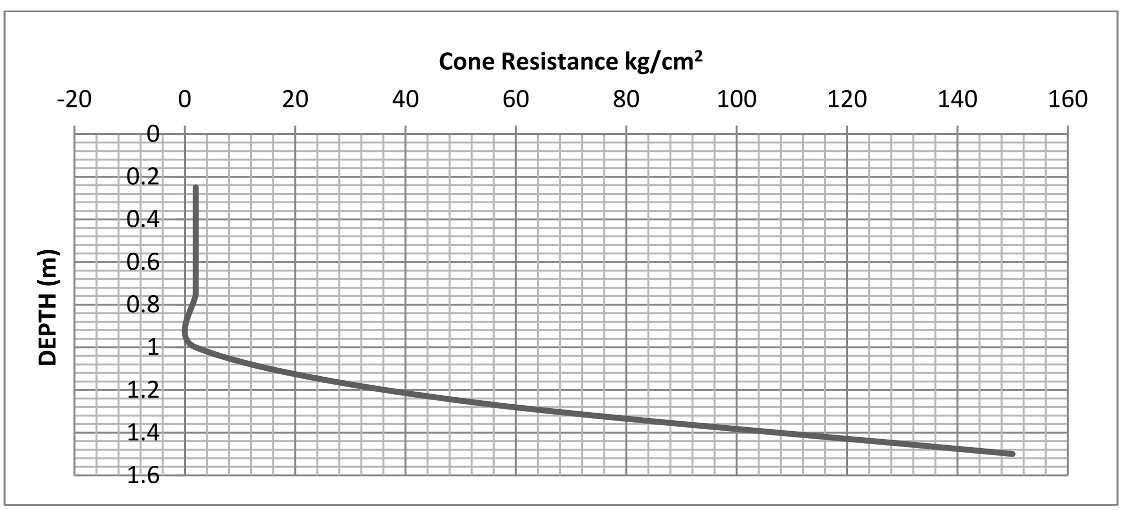

Figure 7a. CPT Test carried out in point 1

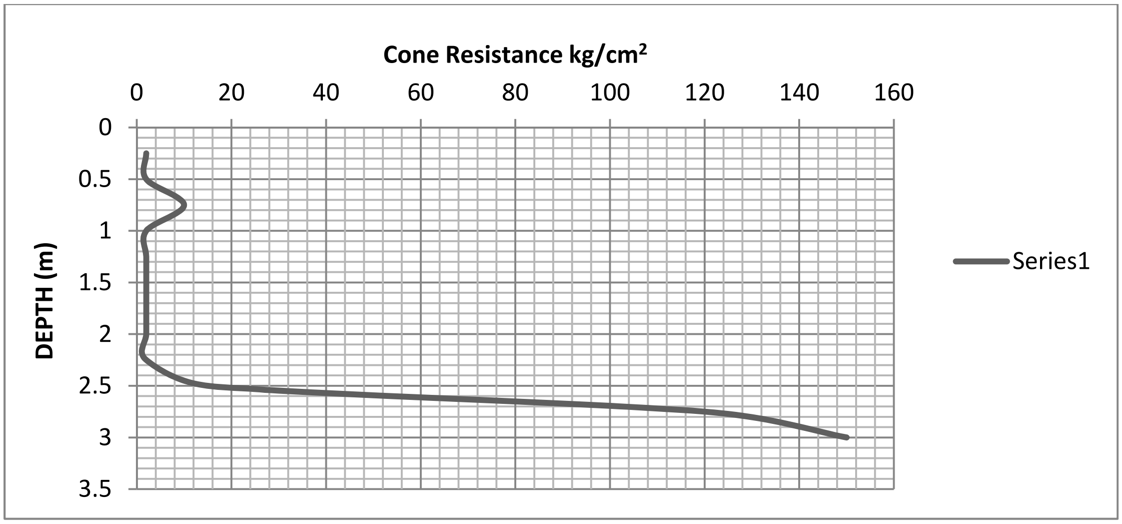

Figure 7b. CPT Test carried out in point 2

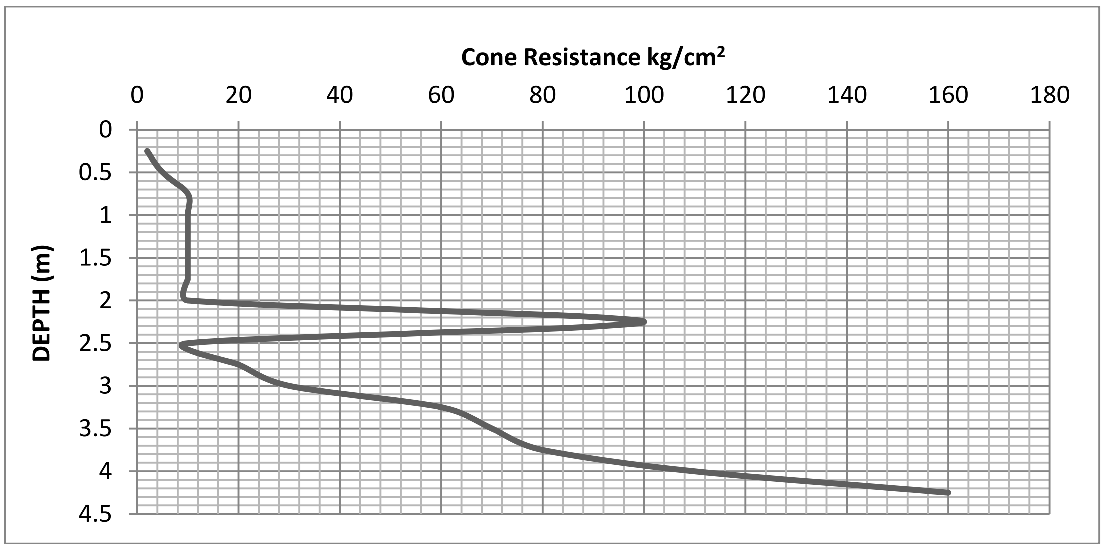

Figure 7c. CPT Test carried out in point 3

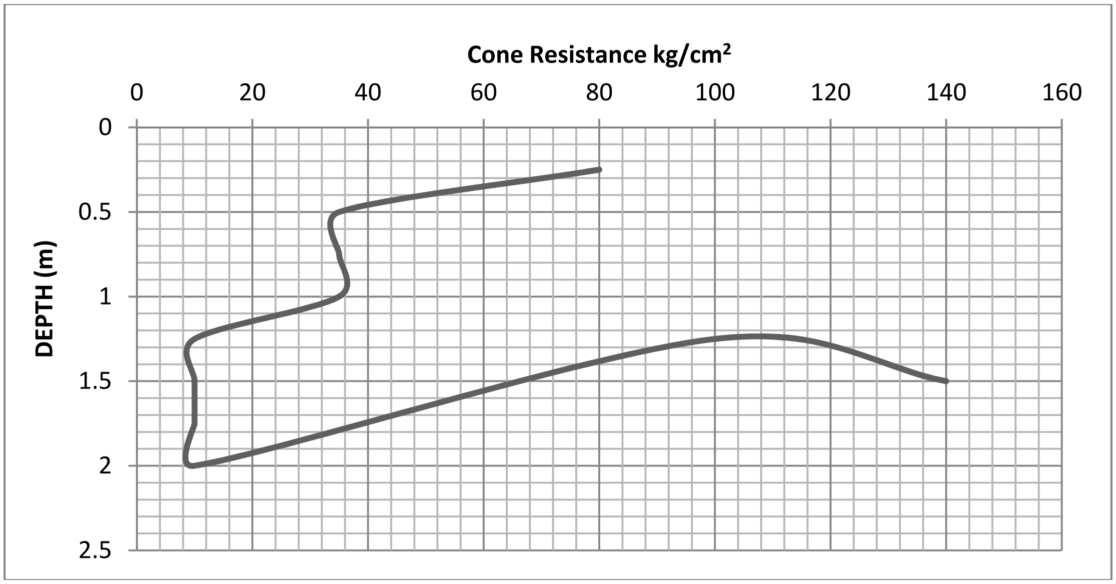

Figure 7d. CPT Test carried out in point 4

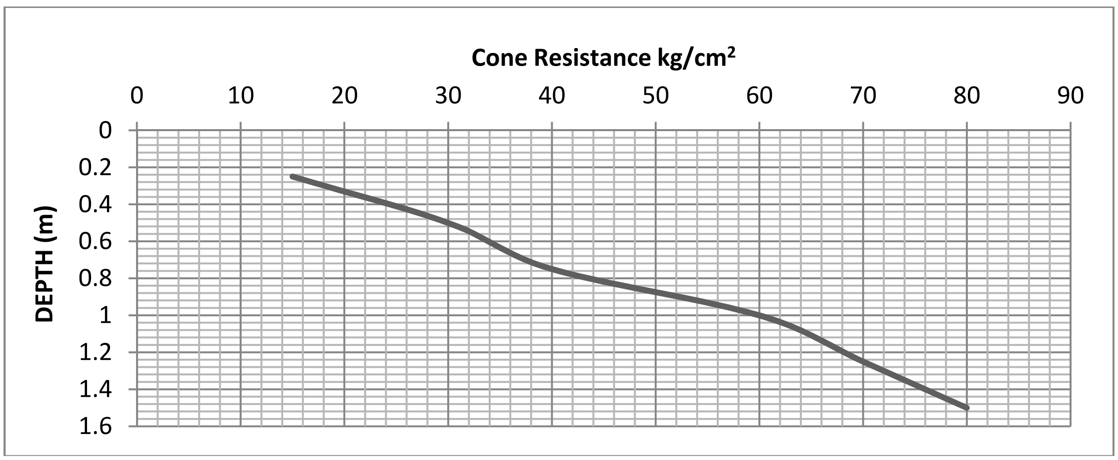

Figure 7e. CPT Test carried out in point 5

Comparison of Geophysical and Geotechnical Results

The result obtained from geophysical and geotechnical studies displays similar trend. The geoelectric section, dipole-dipole pseudosections and cone penetration charts illustrates that where there is an increase in apparent resistivity increase in resistance was also recorded. The high cone penetration resistance recorded at CPT points 4 and 5 was manifested as high geoelectric resistivity values recorded at VES 13. This shows that the soil has fairly low clay content. The difference between both methods is that the depth of penetration is higher for electrical resistivity method. Increases in resistivity value were observed at point where the penetration of the cone becomes impossible. Therefore, both methods can serve as a tool in imaging the nature of the subsurface.

Conclusion

The study has shown the relevance of geophysical site study for foundation design consideration. It can effectively complement the routine geotechnical studies. Geophysics, therefore, remains a very vital tool which can be applied in civil engineering work. The investigation delineated three significant layers which are topsoil, which will be excavated before any foundation can be laid. The second layer delineated was lateritic and the last was a weathered layer. From the result obtained, depth to lateritic layer ranges from 1.1 to 9.0 m while resistivity defining the lateritic layer differs from 150 Ωm to 792 Ωm. Some of the sounding curves generated over the VES stations and Dipole-Dipole Horizontal Profiling were fairly correlated with those of the CPT profile. The high cone penetration resistance recorded at CPT point 4 and 5 was manifested as high geoelectric resistivity values recorded at VES 13. This shows that the soil has fairly low clay content. it can also be seen from the study that the geophysical studies has a greater depth penetration, and it also provide better layer characterization compared to geotechnical studies. The choice of foundation material, clay content and topography elevation should be put into consideration, since the load bearing capacity of the lateritic layer is appreciably high.

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