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A COMBINATION OF ELECTRICAL RESISTIVITY AND CONE PENETRATION TEST TECHNIQUES FOR SUBSURFACE ASSESSMENT

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ABSTRACT

Geophysical and geotechnical methods were used with the aim of characterizing the subsurface in order to identify the cause of differential settlement of the structures in the Adeniji Adele Low Cost Housing Estate, Lagos Island, Lagos State. Twelve (12) Schlumberger Vertical Electrical Soundings (VES), five Wenner 2D resistivity imaging and eight Cone Penetration Test (CPT) data were acquired. The acquired VES, 2D data and CPT were processed .The integration of the VES and 2D resistivity imaging results reveal three to four geoelectric layers which are representatives of uneven distribution of subsurface soil materials corresponding to topsoil, sandy clay, clay and sand. The analysis of CPT data also delineates similar lithology but terminated at shallower depth. The conductive unconsolidated clayey soil / peat with the resistivity values 0.9 – 10 Ωm cum CPT values 2 to 4 kg/cm^2 experienced along noticeable depressed parts could have contributed to the cracking and differential settlement of the residential buildings in the study area. However, boring via percussion drilling should be embarked upon within the study area to confirm these findings.

Key words: Geophysical, Geotechnical, Unconsolidated, Competence, Settlement, Cracking.

INTRODUCTION

Characterization of subsurface soil and determination of soil strength are prerequisite for foundation design and of great importance because inhomogeneities in the foundation geomaterials are major origin of hazards on civil engineering structures (Ozegin et al., 2013). If a building is constructed on a site, without properly considering the underground strata or its load-bearing capacity, it may settle excessively or differentially, causing development of cracks in the building which may ultimately leads to its failure and collapse (Garg, 2007). Electrical characterization of soil was done by conducting surface electrical resistivity measurements and subsequently translating these data in terms of electrical properties of subsurface soil (Israil and Pachauri, 2003). Alternatively, in geotechnical studies, Cone Penetration Test (CPT) can provide rapid, accurate, and reliable results in assessing the engineering properties of soil. The CPT is a robust, simple and economical test that can provide continuous sounding of subsurface soil with depth, though geotechnical tests are time consuming and expensive.

However, geoelectric methods are efficient, cost-effective and usually employed in a broad range of geotechnical application from building site investigations with the aim of investigating subsurface geologic The conventional geotechnical tests are limited to a point evaluation, valid under certain assumptions and usually quite expensive to acquire hence the need for geophysical survey arises which is used to complement the point data acquired so that more information about the lateral extent of the subsurface can be acquired (Akintorinwa and Adesoji, 2009: Ayolabi et al., 2009). Furthermore, Engineering geophysics combined with geotechnical engineering focuses on the behavior and performance of soils and rocks in the design and construction of civil engineering structures (Soupios et al., 2007). Since structures and evaluating the depth to competent bedrocks that are stable and suitable for the development of civil engineering foundations (Adepelumi and Olorunfemi, 2000; Soupios et al., 2007). 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 (Ahmed, 2008).

This research work was carried out to characterize the subsurface soil in order to establish the cause of differential settlement of the two Storey buildings in the study area (Plate 1) using the Schlumberger vertical electrical sounding, Wenner 2-D resistivity imaging and cone penetration tests.

Plate 1: Picture showing some of the affected area

MATERIALS AND METHODS

The Study Area

The study area (Fig. 1) is situated in the city of Lagos in Lagos State Development and Property Corporation (LSDPC) Dolphin estate in Adeniji Adele, Lagos-Island within longitudes 3^0 23.690’ East and 3^0 23.850’ East and Latitudes 6^0 27.410’North and 6^0 27.574’ North. The area shares border with the Lagos Lagoon. It appears the area is a region of subsidence when compared with the adjoining Lagos landmass and thus, it is

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an active water flooding zone. The area is well vegetated with grasses, reeds and other plants that are peculiar to swamp or water lodged regions. The soil is water logged during wet season but the water drains in some part during hot weather leaving behind a highly fractured surface, while some other part are inaccessible being highly swampy. The geology of the area is derived from regional geology of Lagos which is made up of the youngest stratigraphic formation in the Dahomey basin named Benin formation also known as the coastal plain sands (Jones and Hockey, 1964). The lithoral 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). It falls within Oligocene to Recent age.

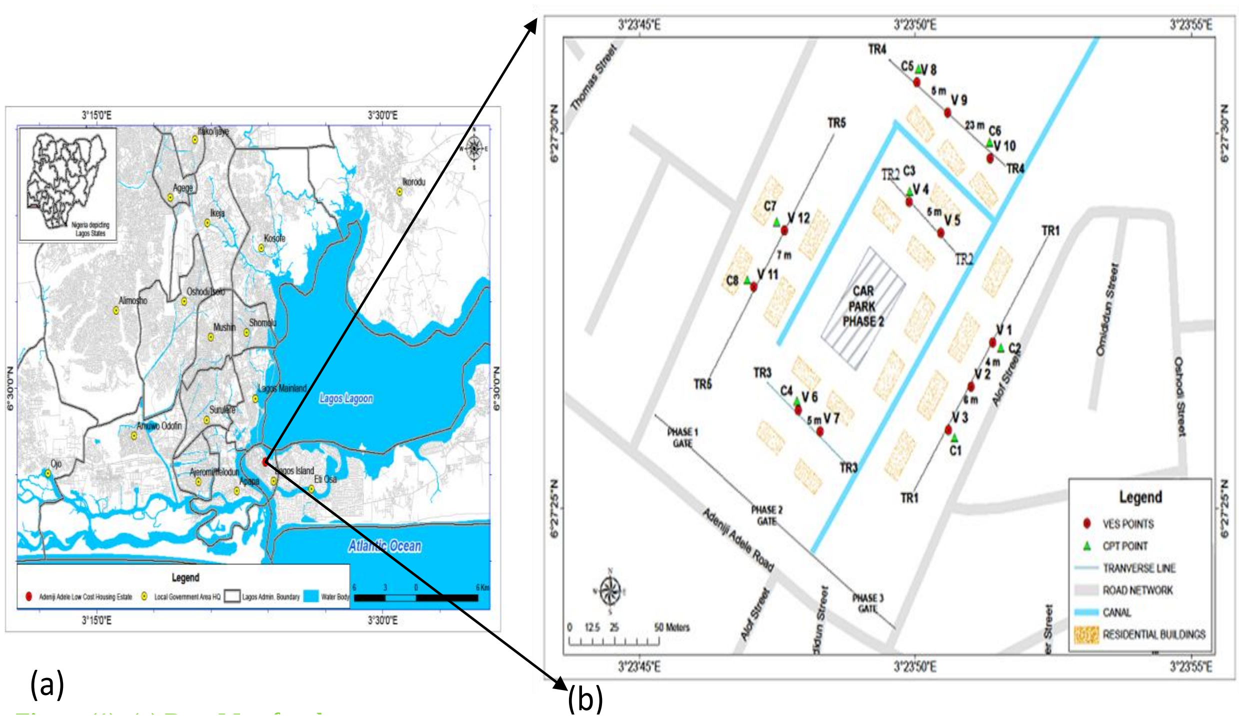

Figure (1): (a) Base Map for the survey site **(b) Base of the Study A**

Data Acquisition

Twelve (12) Vertical Electrical Sounding Stations and Five Wenner 2-D electrical imaging were acquired using resistivity meter (Plate 2a) at different points along the five traverses. The geodetic system of coordinates was obtained using Garmin 12 Global Positioning System. The Schlumberger current electrode separation (AB) was varied from a 2.0 m to 200 m at the VES locations arising from space availability. The Wenner array electrode configuration was used for the 2D resistivity imaging because its relative sensitivity to the vertical changes in the subsurface resistivity (Loke, 2004) therefore it is good in resolving vertical changes (i.e. horizontal structures) which can effectively help to delineate the lateral extent of deferent lithologies in the study area. Compared to other arrays, the

Wenner array has a moderate depth of investigation and the strongest signal strength which is an important factor because the survey was carried out at Adeniji Adele Low Cost Housing Estate area which has high background noise. Five (5) different profiles (A-E) were run with profile spacing depending on the accessible points on the field. Measurements were made at electrode spacing of 10 m interval using four (4) electrodes for traverses 1, 2 and 4 while 5 m interval for traverses 3 and 5 so as to be able to acquire better information because of their relatively shorter lengths.

Cone Penetration Tests (CPT) was performed at total of eight (8) locations within the study area using the Dutch static Penetrometer (Plate 2b). CPT 1- CPT 8 were carried on VES 3, 1, 4, 6, 8, 10, 12 and 11 respectively. It measured the resistance of penetration into soil using 2.5 tones, 60^0 steel cones with an area of 10.2 cm^2. 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/s. The resistance of the penetration of the cone registered on the pressure gauge connected to the pressure capsule was recorded. The tube was then pushed down and the procedure described above was repeated for subsequent location samplings.

Plate 2: (a) Field Staff, PASI 16GL resistivity meter and its accessories (b) Dutch Cone Penetrometer

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RESULT

Data Processing

The quantitative interpretation of the depth sounding curves was carried out by adopting the partial curve matching technique (Bhattacharya and Patra, 1968). The results of the VES curves obtained from the partial curve matching were then used to constrain the interpretation by the computer using iteration software known as WINRESIST. The result of the computer iteration shows the quantitative analysis to know the resistivity, thickness and depth. The geoelectric sections were generated by AUTOCAD software. This involved the combination of two or more interpreted VES results along a profile. Inversion modeling was used to calculate the true resistivity values of 2-D resistivity data using DIPPRO software. Cone Penetrometer data were processed by plotting the cone resistance against the depth in each location point using Microsoft Excel software. Borehole data were not available within the study area, however, Tables 1 and 2 were used as a guide to infer the measured cone resistance subsurface lithology based on the measured cone resistance values (Garg, 2007).

Table 1: Cone resistance value for a corresponding lithology of cohesive soil (After Garg, 2007)

Cone End Resistance Value (Kg/cm^2)	Soil Type
0-4	Very Soft Clay
0-6	Soft Clay
6-10	Firm Clay
10-20	Stiff Clay
Above 20	Very Stiff Clay to Hard Clay

Table 2: Cone resistance value for a corresponding lithology of granular soil (After Garg, 2007)

Cone End Resistance Value (Kg/cm^2)	Soil Type
0-40	Very Loose to Loose
40-120	Medium Dense
120-200	Dense
Above 200	Very Dense

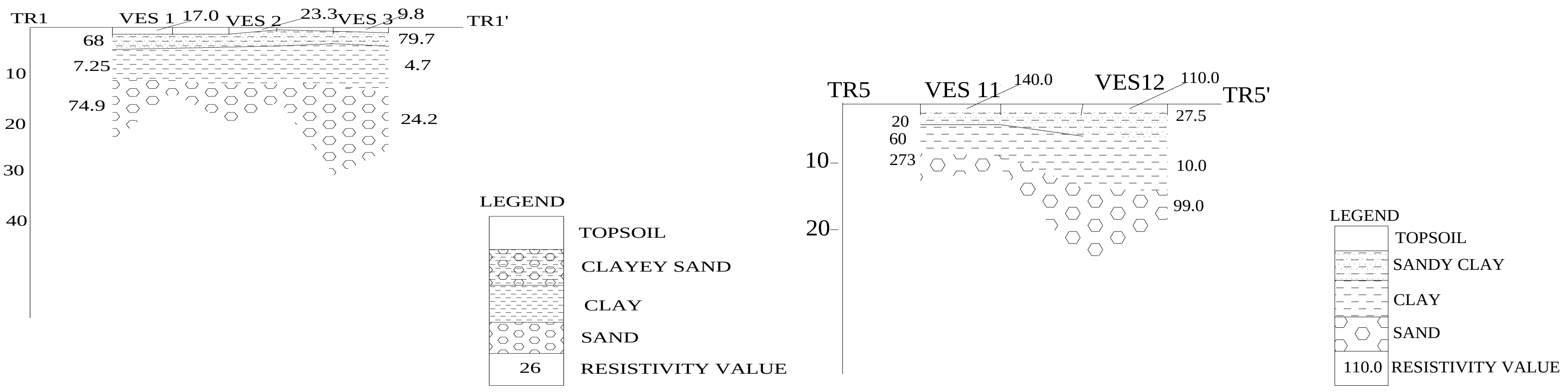

Fig. 2a: Geoelectric sections along Traverses 1(TR1) and 5 (TR5)

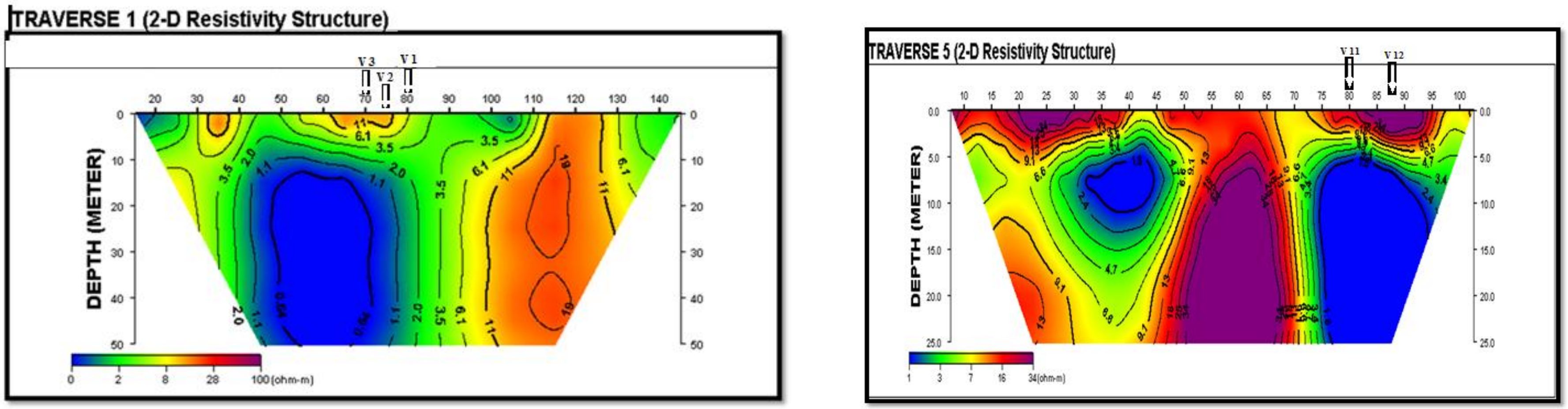

Fig. 2b: 2-D Resistivity structures along Traverses 1 and 5

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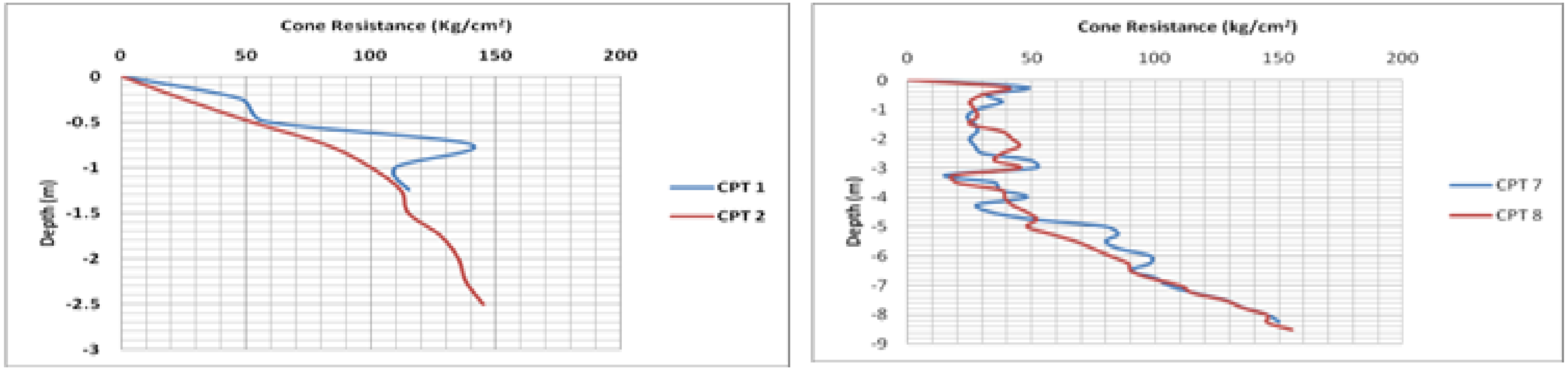

Fig. 2 c : Cone Penetration curves 1,2,7 and 8.

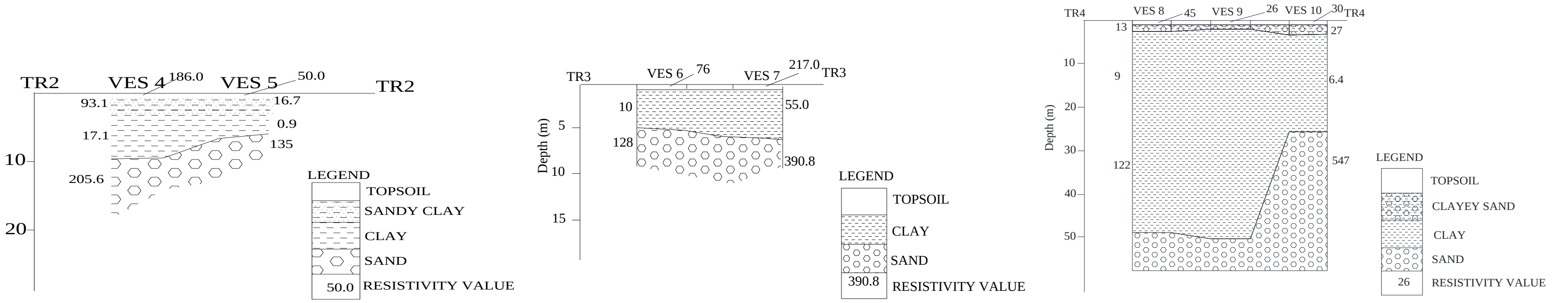

Fig. 3a: Geoelectric sections along Traverse 2 (TR2), 3 (TR3) and 4 (TR4)

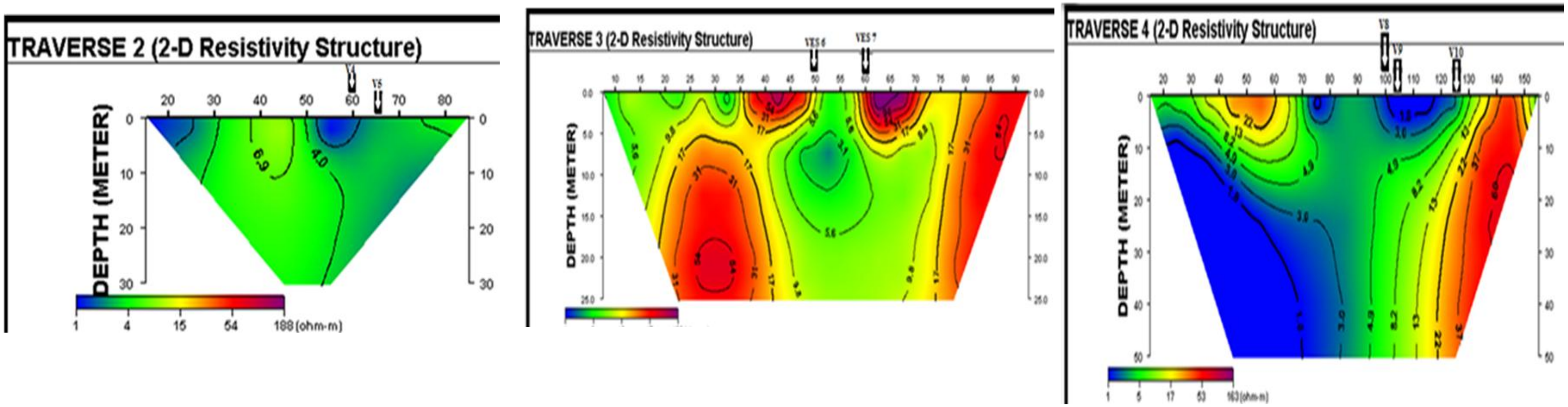

Fig.3b: Resistivity structures along Traverses 2, 3 and 4.

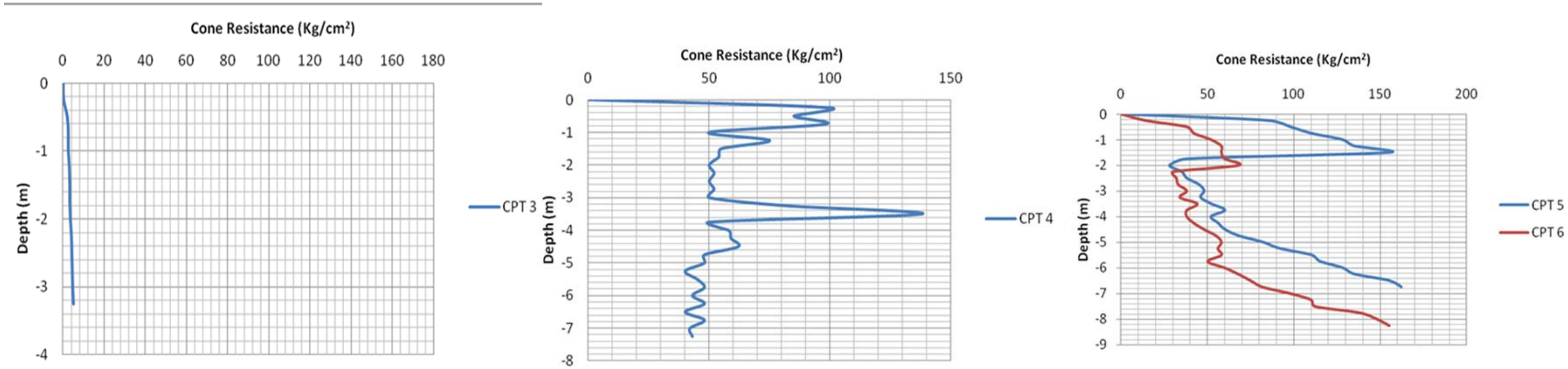

Fig. 3c: Cone Penetration curves 3,4,5 and 6

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DISCUSSION

In the Northeast-Southwest direction of the study area, the geoelectric sections (Fig. 2a) reveal four geoelectric layers which correspond to topsoil, clayey sand, sandy clay, sand and clay. The first layer has resistivity values ranging from 9.8 Ωm to 140 Ωm with thickness ranging from 0.9 m to 2.0 m (average thickness of 1.4 m); this is interpreted as the topsoil. The variation in thickness and resistivity values across the area show the uneven distribution of the overburden material. The second layer is symptomatic of clayey sand/Sandy clay with resistivity values between 20 Ωm to 79.7 Ωm and thickness ranging from 2 m to 4 m. This agrees fairly with the 2D resistivity structure (Fig. 2b) along this direction as shown by superposition of the VES over the 2D structure. The third layer indicates the presence of clay materials having very low resistivity values in the range of 4.7 Ωm - 10 Ωm. The thickness of the layer ranges from 5.4 m to 23.4 m. The 2D resistivity structures also show that this zone has dominantly low resistivity values which confirm the presence of the clayey materials. It can be observed that the VES data results show distinctly clayey materials with thickness on average of 20 m occurring beneath some of the VES (1-3, 11-12) stations. Hence, the geoelectric section and the 2-D resistivity structures show clearly that the sediment deposition varied in the subsurface. From the trend of the lithology, it is obvious that the area is essentially made up of conductive materials which generally connotes incompetency. The affected building which experienced differential settlement as a result of clay falls within traverse 5. However, the fourth layer of the geoelectric section shows sand formation with resistivity in the range 90 Ωm to 273 Ωm with the exception of VES 3 which is dominated by sandy clay having resistivity of 24 Ωm. The thickness of the layer could not be ascertained because the current terminated within the layer. The cone resistance increases with depth up to between 1.2 m and 2.5 m for CPT 1 and CPT 2 respectively with cone resistance values 115 kg/cm^2 and 132 kg/cm^2 (Fig. 2c). The cone resistance for CPT 7 and CPT 8 appears to experience almost the same value (about 50 kg/cm^2) within the soil material up to about 3 m which is indicative of clayey sand. There is a sharp increase after 4 m which is symptomatic of competent material (sand).

In Northwest-Southeast direction, the geoelectric sections (Fig.3a) from VES 4-10 along the three traverses (T2-T4) show three to four geologic layers. These layers denote topsoil, sandy clay, clayey sand, sand and clay.

The first geologic unit, topsoil, along the sections has resistivity ranging from 26 Ωm to 217 Ωm with thickness ranging from 0.4m to 1.9 m. This is composed of conglomeratic materials. The second horizon is diagnostic of sandy clay / clay / clayey sand with thickness between 1.6-2.6m. The resistivity oscillates between 10 Ωm to 93.1 Ωm. The third stratum is composed of clay material along TR2 and TR4. This horizon has resistivity 0.9 -17.1 Ωm with layer thickness between 3.8 and 48.3m. The resistivity of the 2D section (Fig. 3b) ranges along these traverses (TR 2 and TR 4) complement the VES results with resistivity values between 0.9 Ωm and 5.6 Ωm with corresponding thickness in the range 2 m to 8.2 m. However, the third geologic layer in geoelectric section along T3 and the fourth horizon in geoelectric sections along T2 and T4 are symptomatic of sand with resistivity 122 Ωm - 547 Ωm.

The thickness of the zone could not be ascertained as current terminated within the layer. The 2-D section (Fig. 3b) along the route shows resistivity values ranging from 26 Ωm to 45 Ωm beneath VES 8, 9 and 10 as seen on the resistivity structure along traverse 4. This could be indicative of clay. This result of VES also correlates well with the 2D section along this traverse. The cone resistance value at CPT 3 (Fig. 3c) falls within 4 kg/cm^2 from the top to a depth of about 3.2 m. This is indicative of peat / soft clay. This information has affinity for very high compressibility and shear failure. The plot for CPT 4 experiences sharp increment to a depth of about 1.0 m with cone resistance of about 100 kg/cm^2. This could be representative of sand. Thereafter, the curve drops almost uniformly to a depth of 7.4 m with cone resistance values between 42 kg/cm^2 and 75 kg/cm^2, indicative of sandy clay /clayey sand / stiff clay except at a depth between 3.0 m and 4.0 m where there is a spike in cone resistance value. This suggests the presence of a boulder; a rock fragment with grain size greater than 25.6 cm in diameter. The cone resistance increases to a depth of between 1.5 m and 2.0 m with resistance values of 155 kg/cm^2 and 70 kg/cm^2 for CPT 5 and CPT 6 respectively (Fig 3c). This suggests sandy formation which is a competent layer. The resistance later decreased slightly and then increased to a depth of 6.5 m and 8.2 m respectively with cone resistance value of 155 kg/cm^2 and 152 kg/cm^2 and this again is symptomatic of a competent layer.

In this study, Twelve Vertical Electrical Sounding, five 2D resistivity imaging, Eight Cone Penetration Test data were obtained at the study area in order to characterize the subsurface situated at Adeniji Adele low cost housing Estate in Lagos Island area of Lagos State.

The integration of the VES and 2D resistivity imaging results reveal three to four geoelectric layers which are representatives of uneven distribution of subsurface soil materials corresponding to topsoil, sandy clay, clay and sand. The analysis of CPT data also delineates similar lithology but terminated at shallower depth. The conductive unconsolidated clayey soil / peat with the resistivity values 0.9 – 10 Ωm cum CPT values 2 to 4 kg/cm^2 experienced along noticeable depressed parts could have contributed to the cracking and differential settlement of the residential buildings in the study area However, further study using boring with standard penetrometer test should be embarked upon to confirm the subsurface information for detailed analysis.

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