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Combination of Geophysical and Geotechnical Methods for Foundation Studies at Ejirin, Epe, Lagos, Nigeria

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ABSTRACT

The neglect of near surface investigation by populace and government of Nigeria prior to engineering construction has caused incessant collapse of buildings, loss of lives and properties. This informed the use of combined geophysical and geotechnical methods to reveal the nature and competence of the subsurface strata prior to construction at Ejirin/Epe, Lagos, Nigeria. The two geophysical techniques used were 2-D electrical imaging and vertical electrical sounding (VES) while the geotechnical method adopted was the cone penetration test (CPT). The data were acquired along five (5) traverses and a borehole data was used to constrain the data interpretation. The 2-D, VES and CPT data were processed with Dipro, WinResist and Microsoft Excel software respectively. The 2-D and VES results revealed topsoil with resistivity of 91.6 – 1928.8 Ωm, clayey sand with resistivity of 350.5 – 1094.4 Ωm, lateritic clayey sand with resistivity of 1045.9 – 4920 Ωm, sand with resistivity of 341.3 – 1252.2 Ωm and sandstone with resistivity of 4125.9 – 11028.3 Ωm. The sand/sandstone of resistivity ranging 341.3 – 11028.3 Ωm and thickness ranging 19 – 80 m delineated at the fourth and fifth geo-electric layers represent the competent layers due to their resistive and suspected consolidated nature. The CPT was only able to delineate two layers with values of cone resistance ranging from 10 – 150 kg/cm^2 indicative of soft clay/ clayey sand and lateritic clayey sand to depth of 5 m. Hence, a deep foundation by piling with a minimum pile length of 45 - 50 m is required for the proposed multi-storey building.

1. INTRODUCTION

The frequent collapse of buildings over the years has caused huge loss of investments, lives and properties. Some of the collapse could have been avoided if thorough near surface investigation has been carried out prior to commencement of engineering construction. The structural failures, though rampant in developing countries could be associated with poor building design, poor structural plan, use of substandard building materials and unknown subsoil conditions (Folagbade, 2001; Makinde, 2007; Oladele *et al*., 2015; Adeoti *et al*., 2018; Oyedele *et al*., 2018).

Geophysical investigations are carried out to measure contrast in subsurface conditions which in turn determine the durability and safety of engineering structures. These physical properties depend on the nature and competence of the subsurface materials to support engineering structures (Sharma, 1997; Adelusi *et al.,* 2013). When foundation of structures is erected on less competent layers, it poses serious threat to the building and could eventually lead to its collapse (Adeoti *et al.,* 2009; Oyedele *et al.,* 2011). Electrical resistivity method is one of the most widely used geophysical techniques in foundation studies (Akintorinwa and Adesoji, 2009). This is because it is cheap, fast and provides good electrical contrast between the target of interest and the host material (Adeoti *et al.,* 2009; Oyedele *et al.,* 2011; Ayedun *et al.,* 2012; Adeogun *et al.,* 2019). Among the geotechnical methods used for assessment of strength of the subsurface condition are cone penetration test (CPT) and standard penetration test (SPT) (Baldi *et al.,* 1995; Adeoti *et al*., 2018; Oyedele *et al.,* 2018). The CPT provides information on the in-situ geo-mechanical properties of the soil; although this information is restricted to only one location (Eslaamizaad and Robertson, 1996; Adeoti *et al.,* 2018). The combination of geophysical and geotechnical methods would provide detail information about the subsurface.

Ejirin, Epe southwestern Nigeria is a developing rural settlement with industries and modern residential estates springing up on daily basis. These structures are heavy (multi-storey) in nature which require deep subsurface investigation before the emplacement of their foundations in order to avert the prevalent foundation failure either now or in the future. Therefore, the aim of this study was to use geophysical and geotechnical methods to delineate the suitable layer and determine the choice of foundation type that would be required for the proposed multi-storey building at Ejirin, Epe, Lagos State, Nigeria.

2. MATERIALS AND METHODS

2.1. Location and Geology of the Study Area

Ejirin is a developing rural settlement. It is situated in Epe, Lagos State, Nigeria. It lies within the Latitude 6°36’30.0’’N – 6°37’30’’N and Longitude 3°52’30’’E – 3°54’00’’E (Figure 1). The study area is close to the Epe lagoon with dispersing vegetation and it is accessible through Ikorodu / Epe express road. Ejirin in Lagos State falls within the Dahomey Basin. The Dahomey Basin is a combination of inland/coastal/offshore basin that stretches from Southeastern Ghana, Togo and the Republic of Benin to Southwestern Nigeria (Figure 2). The Basin is stratigraphically divided into the Imo group and the Abeokuta group where the study area is situated. The Abeokuta group is subdivided into three formations. The Ise Formation is the oldest Formation (Neocomian) and overlies the basement complex. It consists of conglomerate at the base, gritty to medium grained loose sand and capped by kaolinite clay (Omatsola and Adegoke, 1981) with maximum thickness of about 1.8 km. The Afowo Formation is the second deposit composing of coarse to medium grained sandstone with intercalation of thick shale, siltstone and claystone. The Araromi formation is the youngest sediment of this group; it is composed of shale, fine-grained sand, interbed of limestone, clay and lignite bands (Omatsola and Adegoke, 1981). Its age ranges from Maastrichtian to Paleocene.

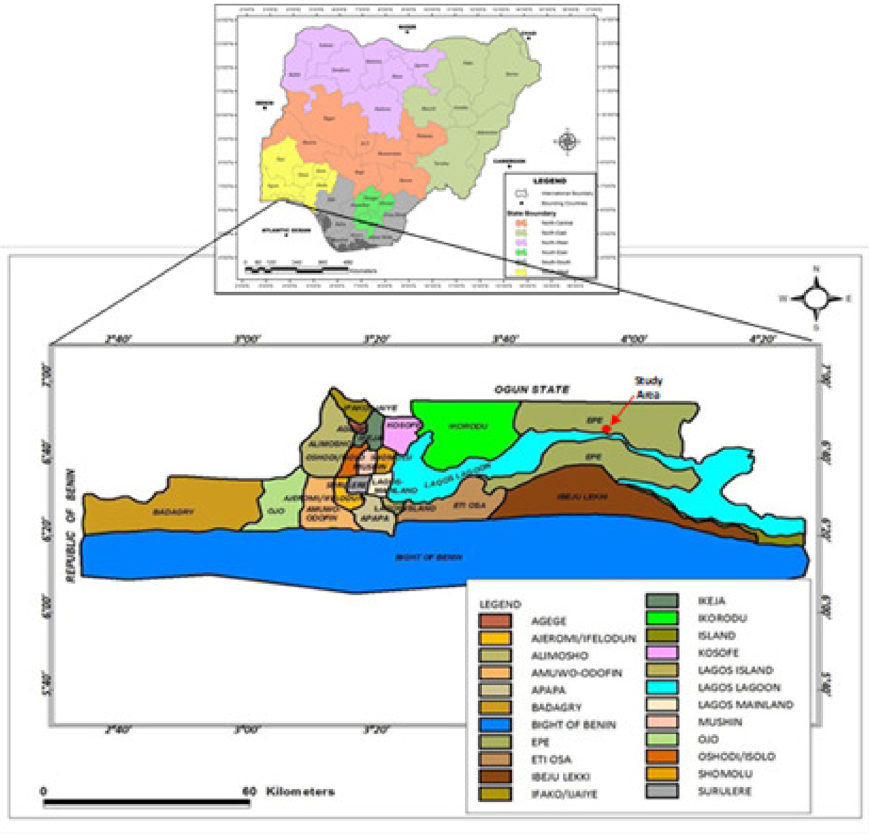

Figure 1: Location map of the study area (modified after Afolabi *et al.,* 2017)

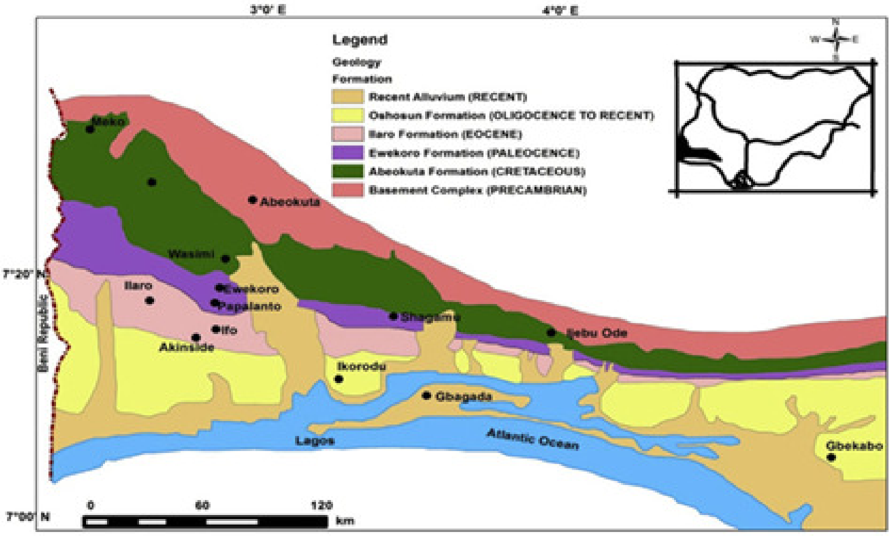

Figure 2: Geological map of the eastern Dahomey basin (Modified after Billman, 1976)

2.2. Geophysical Investigation

The geophysical surveys involved 2-D electrical resistivity imaging and vertical electrical sounding (VES) measured along five traverses (Figure 3) with the PASI resistivity meter 16 GL model. The 2-D electrical resistivity survey was conducted using the Wenner array with 10 m electrode spacing along the five traverses with spread length of 200 m. Following the 2-D measurements, twenty-five VES points were carried out across the five traverses with five VES points (1 – 5) on each traverse using the Schlumberger array with a maximum current electrode separation (AB) of 500 m. The VES points were selected based on the suspected anomalous response on 2D sections.

The 2-D electrical resistivity data was processed with the DiproWin software to generate pseudo-sections revealing the lateral and vertical variation of resistivity at the subsurface. The sounding curves generated from VES data were interpreted qualitatively and quantitatively using the standard and auxiliary curves. The estimated first order geo-electric parameters were put into the Win Resist software for inversion to produce true resistivity distribution. The lithologies of substrata were inferred from the model parameters and constrained by the borehole data obtained within the study area. The model parameters were used to generate geo-electric sections using AutoCAD software.

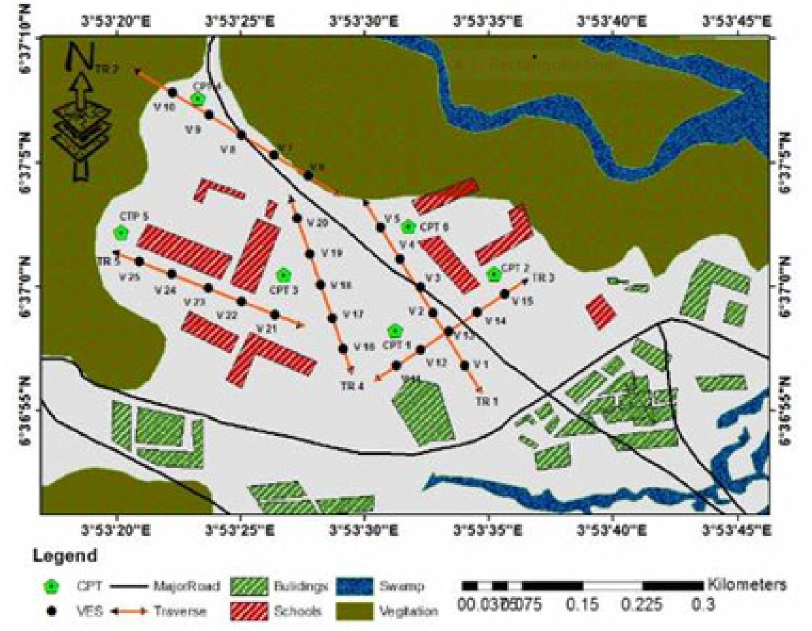

Figure 3: Base map of the study area

2.3. Geotechnical Investigation

A 2.5 tonnes CPT machine was used to measure the resistance of the ground at the surveying area by forcing the hardened steel cone with a base area of 1000 mm^2 at an apex angle of 60^o continuously into the ground while taking measurement of its resistance to penetration. The CPT readings terminated at the refusal of advancing cone into the subsurface. The subsurface lithology was assigned to the soil profile in accordance to Robert (1996) as presented in Table 1 and was correlated with the borehole data obtained within the study area. The CPT data was analyzed using Microsoft Excel 2016 package. The varying depth of the cone penetration was plotted against the measured subsoil resistance values.

Table 1: Classification of cone penetration test for granular soils (Robert, 1996)

Cone resistance (kg/cm^2)	Relative density
0 – 40	Very loose to loose
40 – 120	Medium dense
120 – 200	Dense
Above 200	Very dense

3. RESULTS AND DISCUSSION

3.1. Geophysical Results

The 2-D resistivity sections with geoelectric section overlay, CPT point and a borehole data are presented in Figures 4 (a - e). Figure 4a is the 2-D resistivity section along Traverse 1 (T1) with VES (1 - 5) stationed at 40, 60, 80, 100, and 130 m respectively and CPT 6 at lateral distance of 105 m. Three geoelectric layers are delineated in 2-D resistivity structures and the probed depth is 50 m while five geoelectric layers are delineated with maximum depth of investigation of 100 m. The topsoil has resistivity of 215 – 804 Ωm, at depth range 0 – 4 m. The second layer is characterized by clayey sand / lateritic clayey sand (602.5 – 1129 Ωm, at depth range 4 - 20 m). Third layer signifies lateritic clayey sand/ sandstone (1211.9 – 3779.4 Ωm, at depth range 22.7 – 50 m). The fourth geoelectric layer is sand/sandstone (532.1 – 11028 Ωm at depth range 39.7 – 72.2 m). The fifth layer is characterized with sand (314 - 941 from depth 63 m). In general, the fifth layer thickness in all the sections couldn't be defined because the current terminated at this layer.

Figure 4b is the 2-D resistivity section along T2 with VES (6 - 10) stationed at 40, 60, 90, 110, and 140 m respectively and CPT 4 at lateral distance of 140 m on the traverse. The topsoil has resistivity of 290 – 924 Ωm, at depth range 0 – 3 m. The second layer is characterized with clayey sand / lateritic clayey sand (924 – 2926.6 Ωm, at depth range 3 – 24.4 m). Third layer signifies lateritic clay sand/sandstone (1387 – 4818.8 Ωm, at depth range 14.4 – 50 m). The fourth geoelectric layer is sandstone (4125.9 – 11028 Ωm at depth range 18.4 – 85.2 m). The fifth layer is characterized with sand (842.4 – 1108.8 Ωm from depth 70 m). The fourth and fifth layers are considered competent for foundation emplacement due to their resistive nature.

Figure 4c is the 2-D resistivity section along T3 with VES (11 - 15) stationed at 50, 70, 90, 110, and 130 m respectively and CPT (1 and 2) at lateral distance of 50 m and 130 m on the traverse. The topsoil has resistivity of 91.6 – 681.4 Ωm, at depth range 0 – 2 m. The second layer is characterized with clayey sand / lateritic clayey sand (294.2 – 1666.6 Ωm, at depth range 2 – 5 m). Third layer signifies lateritic clay sand (747 – 2695.4 Ωm, at depth range 6.7 – 19.8 m). The fourth geoelectric layer is lateritic clay sand/sandstone (1116.7 – 7439.8Ωm at depth range 29.3 – 73.7 m). The fifth layer is characterized with sand (458.0 – 612.3 from depth 40 m). The fifth layer is considered competent for engineering foundation.

Figure 4d is the 2-D resistivity section along T4 with VES (16 - 20) stationed at 60, 80, 100, 120, and 140 m respectively and CPT 3 at lateral distance of 130 m along the traverse. The topsoil has resistivity of 215.0 – 1279.1 Ωm, at depth range 0 – 2 m. The second layer is characterized with clayey sand / lateritic clayey sand (1260.1 – 1782.4 Ωm, at depth range 2 – 100 m). Third layer signifies sand/ sandstone (432 – 8447.1

Ωm, at depth range 16 – 80 m). The fourth substratum is sand (538.1 – 977.9 Ωm from depth 33 m. The third and fourth layers are considered competent for foundation emplacement.

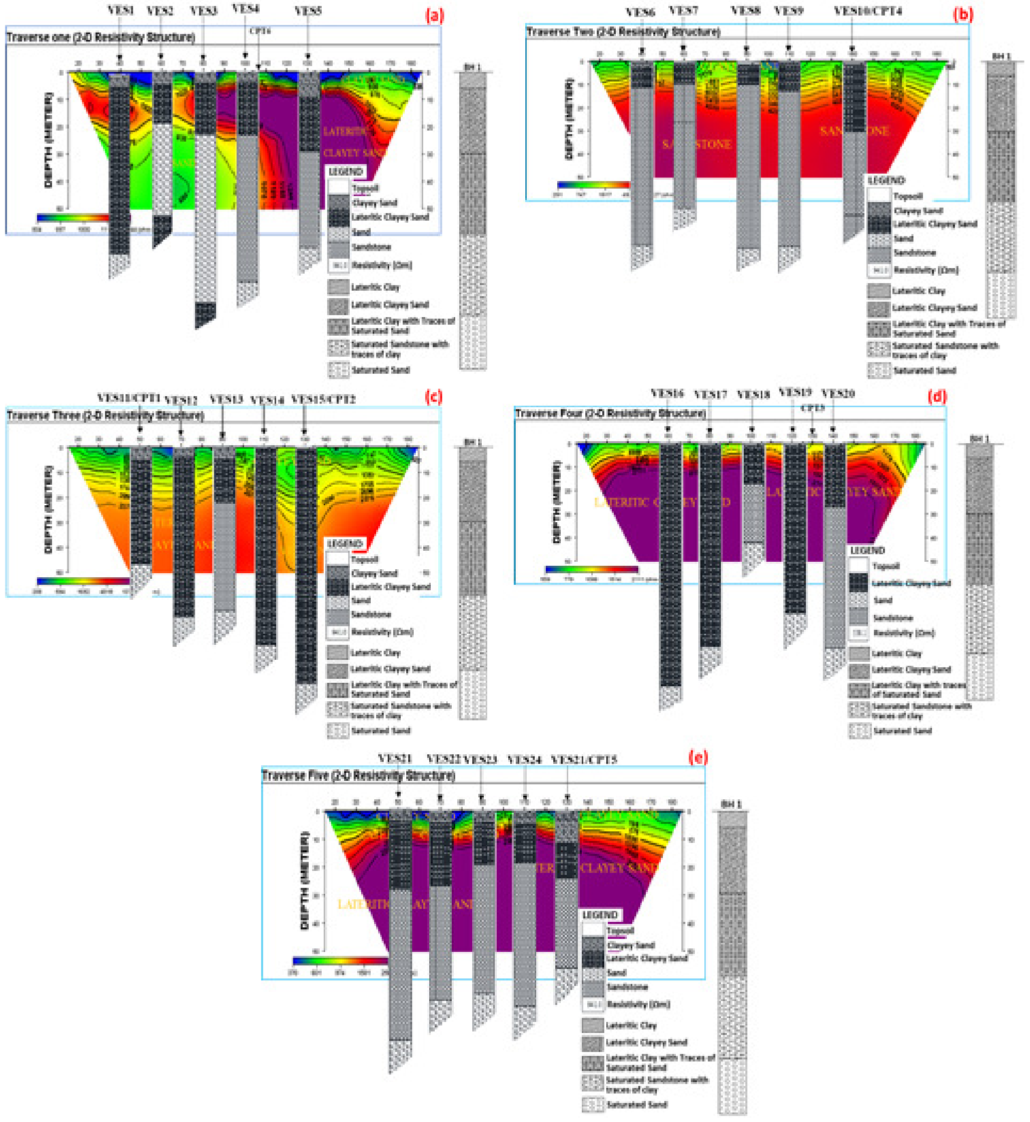

Figure 4: 2D Resistivity Section/Structure along (a) TI (b) T2 (c) T3 (d) T4 (e) T5

Figure 4e is the 2-D resistivity section along T5 with VES (21 - 25) stationed at 50, 70, 90, 110 and 130 m respectively and CPT 5 at lateral distance of 130 m on the traverse. The topsoil has resistivity of 174.0 – 1279.1 Ωm, at depth range 0 – 3 m. The second layer is characterized with clayey sand / lateritic clayey sand (350.5 – 1782.4 Ωm, at depth range 3 – 15 m). Third layer signifies lateritic clay sand (1045.9 – 3868.6 Ωm, at depth range 6.7 – 50 m), the fourth substratum is sandstone (5092 – 7349.0 Ωm at depth range 29 – 90 m), and the fifth layer is characterized with sand (412.8 – 1252.2 Ωm from depth 57.9m). The fourth and fifth layers are considered competent for foundation emplacement due to their consolidated nature.

3.2. Geotechnical (CPT) Results

The plots of depth against cone penetration resistance for CPT (1 – 6) are shown in Figure 5. The maximum depth of refusal was 5 m. The CPT plots show two subsurface strata which are very soft clay/ clayey sand and lateritic clayey sand. The top soil is between depths (0.1 – 1 m), and it reflects steady increase in load resistance between (10 – 100 kg/cm^2) which is indicative of soft clay/ clayey sand materials. At a depth range of 1 to 1.2 m, the load resistance decreased from 100 to 10 kg/cm^2 which might be due to presence of very soft clay. The continuous increase in cone resistance 18 to150 kg/cm^2 at depth range 1.3 to 5 m connotes lateritic clayey sand (Robert, 1996). The lateritic clayey sand deep to 5 m depth is not competent enough to support the proposed multi-storey building.

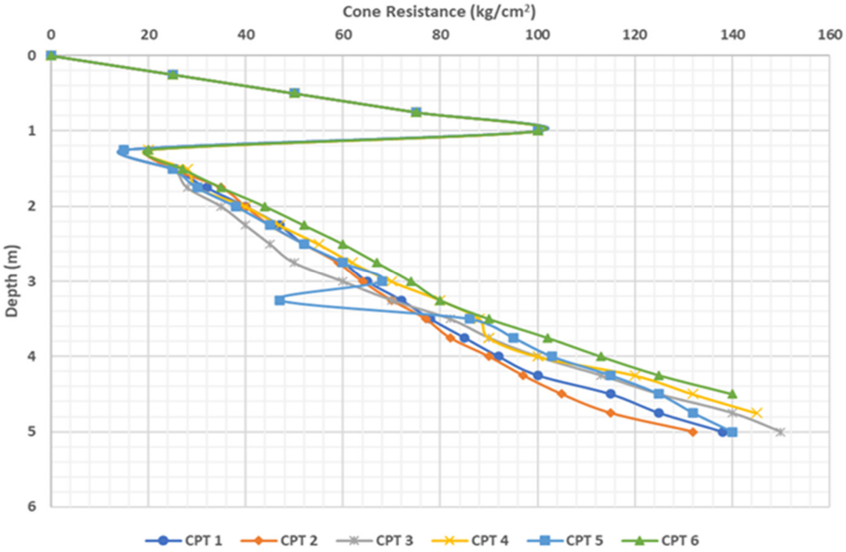

Figure 5: Plot of depth (m) against cone resistance (kg/cm^2) for CPT (1 – 6)

4. CONCLUSION

The geophysical and geotechnical investigations carried out prior to construction of structures at Ejirin, Epe, in Lagos State revealed the nature of the subsoils in the study area. This includes topsoil, clayey sand, lateritic clayey sand, sandstone and sand with resistivity variation (208 – 11028.3 Ωm). The combined methods delineated sand/sandstone at the fourth and fifth geo-electric layers at depth range of 33 – 90 m which is inferred to be competent to support the foundation of the proposed multi-storey building. Hence, a deep foundation through Piling with a minimum pile length of 45 – 50 m is recommended for construction in the study area. It is important to note that the results of the 2-D resistivity imaging, VES and CPT correlates significantly with the borehole log information obtained within the study area.

5. ACKNOWLEDGEMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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