Engineering Geophysical Evaluation of Suspected Weak Foundation Soils at National Theatre Iganmu, Lagos, Nigeria

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ABSTRACT: Foundation geotechnical research studies in semi-onshore environment are well known in literature. However, a study which incorporates geophysical with in-situ engineering site investigations around a structure undergoing differential settlement is uncommon. This research was carried out around the National Theatre area, Iganmu, Lagos, Nigeria. It was meant to determine the nature of the lithological layers, thicknesses and depth to competent level for the performance of subsoil systems under static loading. A total of ten (10) Cone Penetrometer Test (CPT), and twenty (20) Vertical Electrical Soundings (VES) were acquired along four (4) geotechnical boreholes. Four (4) traverses were also acquired with a maximum spread length of 200 m. The VES data were processed with curve matching and subjected to computer iteration techniques, the result obtained were presented as 1D resistivity profile. The horizontal profiling was also processed and presented as 2-D resistivity imaging. The study area was underlain by four distinct lithological layers. These were represented as topsoil, clayey sand/sandy clay, clay and clayey sand/clay. Electrical resistivity profiling and imaging clearly revealed the inhomogeneity nature of the subsoils, while the geotechnical presented soils with poor bearing values of predictably considerable settlement potential within the depth of 1 to 7 m. However, appreciable bearing values were prominent between depths of 8m and 10m around the structure. Adopting a pile foundation for high column load is recommended from depth of 8m during rehabilitation and upgrading of the structure.

KEYWORDS: Geophysical, engineering, lithological, foundation, structure.

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I. Introduction

A major aspect that has always been omitted in the engineered structure plan is the adequate information on the nature of the hosting Earth material, which defines subsurface conditions prior to construction exercise. According to Maton and Templeton (1973) and Ayolabi *et al*. (2010) geophysical methods have been employed to ascertain the subsurface geology with reference to different lithology. In particular, Olorunfemi, *et al*. (2004) proved the success of geoelectrical resistivity method in elucidating a subgrade soils engineering problem.

Adebisi and Fatoba (2013) recommended integrated instrumentation for proper assessment of the subsurface foundation investigation in an area underlain by soils derived from sedimentary rocks. Faseki, *et al*. (2016) identified highly compressible soil areas by using in-situ and laboratory geotechnical methods to unravel probable differential settlement, which is usually responsible for building collapse. The applications of electrical resistivity and penetration test investigations have allowed quantifying the subsoils in-situ characteristics prior to civil construction activities.

Foundation investigation of a site therefore, needs to take into consideration the economy and the engineering performance of a structure for an acceptable level of service over its intended life. Foundation materials should have sufficient strength to withstand structural load (Adeoti, *et al*. 2016). Other considerations are chemical factors, which could cause weakening leading to risk of exceeding the ultimate and serviceability limit states. Besides, poor construction materials, inadequate supervision, noncompliance to specifications are prospects to incidence of building collapse.

For these speculated reasons incessant collapse of buildings have been recorded in the past few years in Lagos and its environs. Recent geotechnical studies revealed incompetent subsurface layer as the major factor responsible for collapse of buildings. Although, blames were directed to building engineers who are fond of using inappropriate, inadequate or inferior materials in some quarters. The use of poor materials (especially concrete and steel) and reduction in the sizes and specifications of structural elements (foundations, columns, beams and floor thicknesses) are also noted to primarily responsible for the unabated rate of failures of on-going and existing structures in the area (Ademeso, *et al*. 2016).

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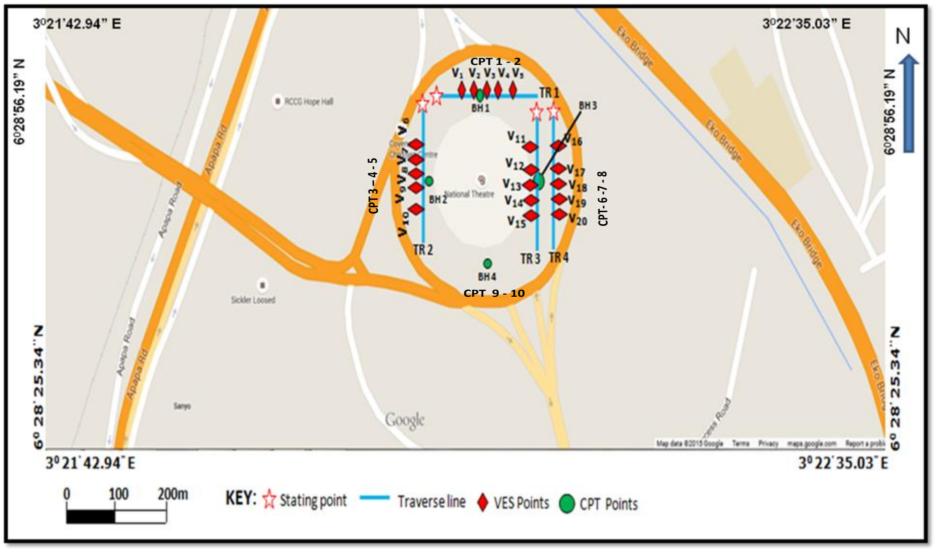


Figure 1: Map of the study area showing the electrical soundings (VES), boreholes (BH) and Cone Penetration Test (CPT) points.

The National Art Theatre is an architectural masterpiece located at Iganmu, Lagos. It covers an area of about 23,000 square meters. The vision of the complex is to facilitate the preservation and promotion of Arts and Culture in Nigeria and to be a rallying point for artistes. The complex also offers diverse venues, facilities and innovation for all kinds of programmes and activities. Hence house thousands of people at some point.

The study area (Figure 1) is located within longitudes 03̊ 21’42.94’’E and 03̊ 22’35.03’’E and latitudes 06̊ 28’32.34’’N and 06̊ 28’56.19’’N. It is underlain by the sedimentary formation in the Dahomey Basin, in the tropical Southwestern Nigeria (Adebisi, *et al*. 2016). The basin stretches from the Southwestern Nigeria through Togo to the Volta region of Ghana. It is a combination of inland, coastal and offshore.

The near surface to foundation soils at National Theatre is part of the onshore Cretaceous strata of the basin, which according to Okosun (1990) is about 200 m thick. It comprises expansive clays, which are inimical to safe foundation of engineering structures. Appreciable differential settlement on the building is noticeable and calls for a site investigation in its accessible surrounding. This is inevitable in order to determine the depth to competent foundation soils for the purpose of upgrading and rehabilitating the structure. Information from this study will also be a guide to engineers in the design of safe foundation for structures in the location.

II. CONTRIBUTION TO KNOWLEDGE

It is obvious that several foundation geotechnical research studies in semi-onshore environment have been carried out. In some cases electrical resistivity and in-situ geotechnical site methods were employed. However, a full scale of near surface geological knowledge and effect of forces exerted by a structure on the equilibrium performance of foundation soil systems under static loading condition is yet to be researched.

This study established site specific geotechnical conditions around an existing structure, which is experiencing noticeable differential settlement. This was done with a combination of field measurement through electrical resistivity measurement and penetration resistance of foundation soils. Geotechnical boreholes were used to elucidate the nature of the lithological layers and depth to different soil types level.

The uniqueness of this study is the presentation and discussion of complex geological characteristics of the subsurface in terms of soil types and strata. The results of this study would be a guide to giving room for upgrading and rehabilitating an existing structure. It would further help to enhance foundation techniques for minimizing differential settlement and maintain sufficient reserve strength throughout the service life of a structure.

III. MATERIALS AND METHODS

Twenty (20) Vertical Electrical Sounding (VES) for soil resistivity were acquired along four traverses using the Schlumberger electrode array configuration. A 2-D electrical resistivity survey was carried out along four (4) traverses using the Wenner electrode array configuration. This made use of a PASI Resistivity meter at sequences of electrodes interval of 5 m, 10 m, 15 m, 20 m, 25 m and 30 m respectively.

The VES data were interpreted for the determination of the true resistivity and thickness of each subsurface layer by partial curve matching technique with master curves developed for horizontally multi-layered earth models, the comparison of resistivity with the anomaly curves and characterization of curves were based on the resistivity of subsurface layers. The interpretation was aided using computer iteration software ‘WINRESIST’. The VES results obtained from the interpreted software were used to generate a geo-electric section for each of the variation in the overburden from one depth to another.

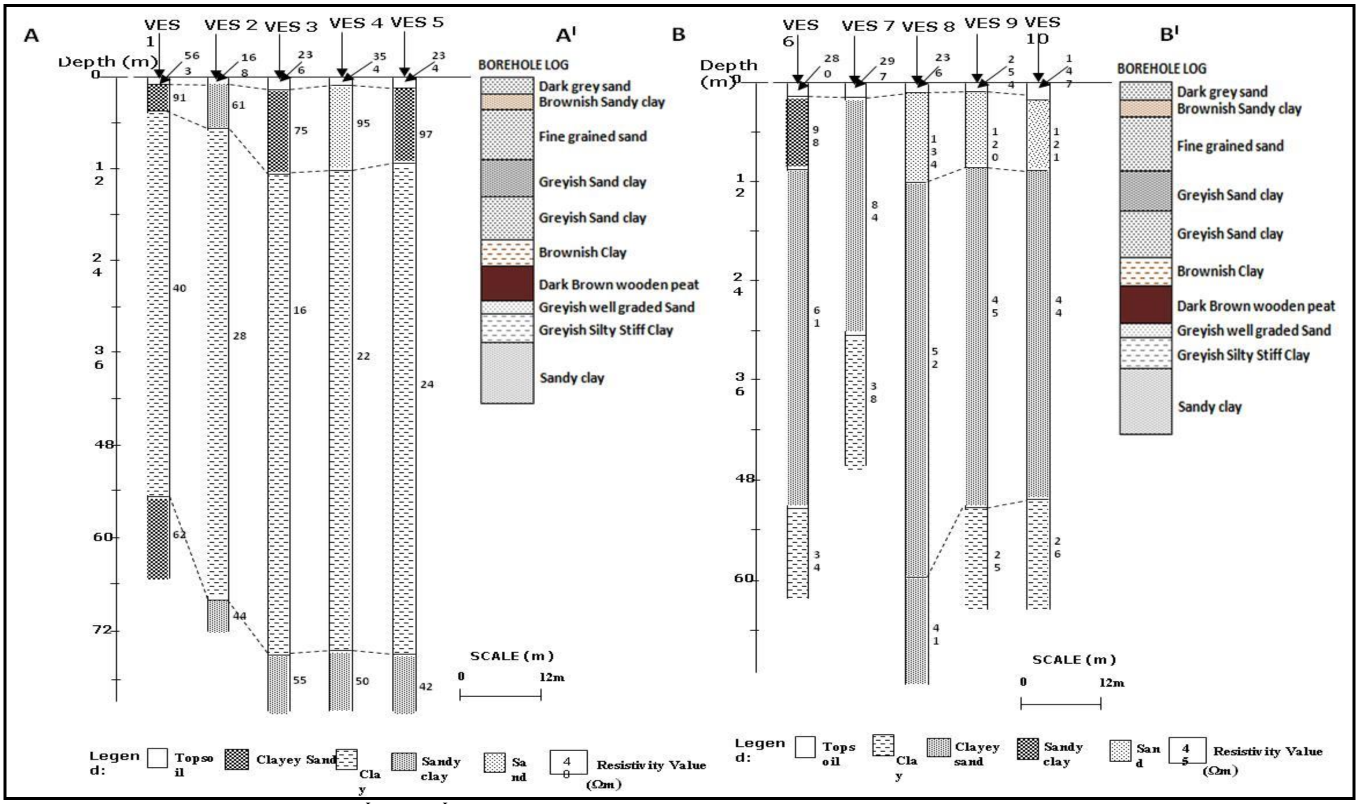


Figure 2: Geo-electric Section along AA^I and BB^I.

Forward modelling was used to calculate the apparent resistivity values of the 2-D resistivity data using Dipro software. The 'DIPROWIN' software amortizes the bulk data into a series of horizontal and vertical rectangular blocks, with each box containing a number of records. The electrical resistivity of each block is then calculated to produce an apparent resistivity pseudo-section.

The in-situ geotechnical investigation for foundation was conducted using a Dutch cone penetrometer (CPT), standard D 3441 ASTM (2004) at ten (10) locations. Four (4) geotechnical boreholes were also drilled for subsoils assessment with respect to locations of electrical sounding. This involves pushing a manually instrumented cone tip into the soil at a controlled rate of 2 cm/second. The equipment is a 2.5 tons capacity machine equipped with four anchors, and a cone having a base of 1000 mm^2 and apex angle of 60^0. The penetration resistance of soils encountered in the process was read from the pressure gauge attached to it. Furthermore, cone resistance was plotted against the depth in reverse order using Microsoft Excel software. Samples recovered from geotechnical boreholes and the inferred lithologies were compared as a guide to the interpretation of the subsoil strata.

IV. RESULTS AND INTERPRETATION

A. Geophysical Interpretation

Four geo-electric layers were delineated along traverse 1 (Figure 2) for VES 1, 2, 3, 4 and 5. These are jointly denoted as AA$^{\mathbf{I}}$ stationed at 40, 60, 80, 100 and 130 m respectively. The first geo-electric layer represents the topsoil with electrical resistivity and thickness values ranging from 168 – 563 Ωm and 0.9 - 1.3 m respectively. This layer is inferred to compose of sand when correlate with the borehole log data. This layer is recommended as a safe foundation depth for low/light engineered structures. The second geoelectric layer has resistivity values that range from 61 – 95 Ωm and inferred thicknesses that range from 3.7 – 11.5 m within a total depth range of 4.4 – 12.7 m. This layer constitutes clayey sand and sand, can be recommended as a safe foundation depth for light to heavy engineering structures.

The third geo-electric layer was delineated as clayey material. It has resistivity values ranges of 16 – 40 Ωm and thicknesses range of 51.2 – 64.8 m with total depth that ranges from 55.7 – 76.1 m. This layer is disadvantageous to foundation of a structure as differential settlement could be the result. The fourth layer has resistivity values that range from 42 – 62 Ωm. This layer is inferred to comprise of clayey sand and sandy clay, however, its thickness could not be determined because current electrodes terminated at this zone.

Four geoelectric layers were delineated along traverse 2 for profile line BB$^{\mathbf{I}}$ stationed at 40, 60, 80, 100 and 130 m respectively. This section is along VES 6, 7, 8, 9 and 10 as shown in Figure 2. The first geoelectric layer represents the topsoil with resistivity values range of 147 – 297 Ωm and thicknesses that range between 1.0 and 1.9 m. This layer is inferred to compose of sand and correlates with the borehole

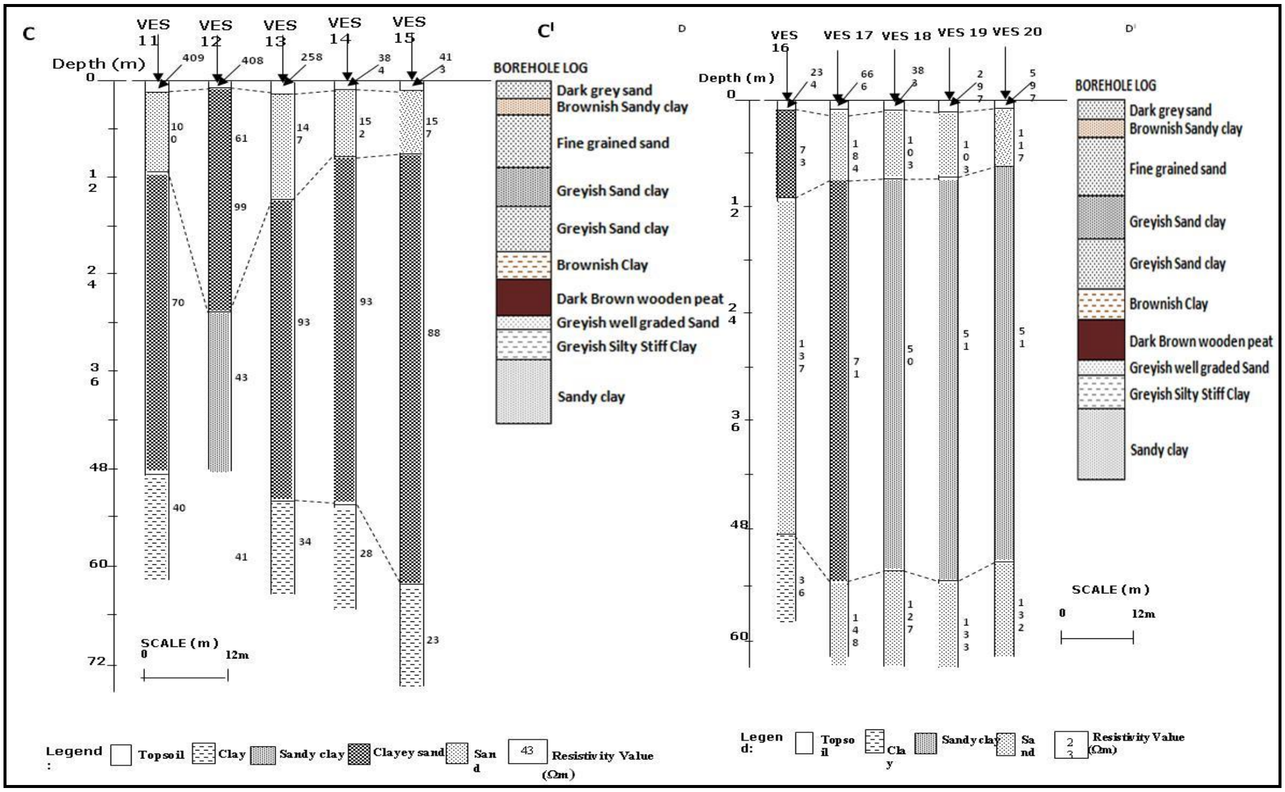


Figure 3: Geo-electric Section along CC^I and DD^I.

log data. It may be recommended as competent to support foundation low/light engineering structure. The second geoelectric layer has resistivity and thickness values that range from 84 to 134 Ωm and from 8.8 to 11.2 m respectively with total depth range of 10.4 – 13.3 m. This layer is inferred to be sandy clay and can only support light to medium engineered structure.

The third geoelectric layer was deduced as clayey sand from resistivity values ranging between 44 and 61 Ωm. Inferred thickness values also range from 39.7 to 48.5m with total depth range of 51.2 – 60.8 m. This layer may provide safe foundation support for light engineering structure. The fourth geoelectric layer has resistivity values that range from 25 to 36 Ωm, which is inferred to compose of clay and not favourable to found an engineering structure.

For VES 11, 12, 13, 14 and 15 denoted as CC^I stationed at 40, 60, 80, 100 and 130 m respectively (Figure 3) along traverse 3, four (4) geo-electric layers were delineated. The first geo-electric layer which represents the topsoil has resistivity values that range from 258 to 413 Ωm and thicknesses ranging between 0.9 - 1.4 m. This layer is composed mainly of sand and correlate well with the borehole log data, the layer could be adjudged competent in its ability to support an engineering structure. The second geo-electric layer has resistivity and thickness values that range from 66 to 157 Ωm and from 8.5 to 28.3 m with a total depth range of 8.8 – 29.2 m. The composition of this layer varies between clayey sand and sand. Its ability to support light to giant engineering structure is not in doubt except area beneath VES 12.

The third geo-electric layer was delineated to comprise clayey sand and sandy clay with resistivity values that range from 43 to 93 Ωm and thicknesses that varies between 38.1 and 54.4 m within a total depth range of 49.6 – 63.2 m. The fourth geo-electric layer has resistivity values which range from 23 to 41 Ωm. This layer is inferred to compose of clay and it is detrimental to foundation of any engineering structure.

The geo-electric section along traverse 4 for VES 16, 17, 18, 19 and 20 (Figure 3) are denoted as DD^I stationed at 40, 60, 80, 100 and 130 m respectively. Four geoelectric layers were delineated along this profile line. The first geoelectric layer represents the topsoil with resistivity values that range from 234 to 597 Ωm and thicknesses that range from 0.8 to 1.3 m. This layer can be adjudged competent since it composes mainly of sandy sediments. It also correlates well with the borehole log data and can favourably support foundation of low/ light engineering structure. The second geoelectric layer has resistivity values that vary from 73 to 184 Ωm, and thickness values that ranging from 6.6 to 10.2 m within a total depth range of 7.5 and 11.1 m. This layer constitutes clayey sand/sand and could be recommended as a competent support for both light and medium engineering structures. However, excavation and re-enforcements should be done beneath VES 16.

The third geoelectric layer was delineated as sandy clay and sand with resistivity values that range between 50 and 137 Ωm. Its thickness ranges from 38.4 to 45.9 m within a depth range of 37.4 – 55.2 m. The fourth geo-electric layer has resistivity values that range from 36 to 148 Ωm. It composes of clay and sand, specifically the clay material delineated beneath VES 16 is not favourable to supporting any engineering structure.

Results of the Constant Separation Traversing (CST) data acquired along the traverse lines are presented in Figure 4 (a-d). These indicate the distribution of subsurface resistivity with a total spread length of 200 and 50 m maximum depth of penetration. The various lithological layers are represented in a colour format, based on the resistivity distribution of the subsurface layers. The 2-D resistivity section along traverse one shown in Figure 4a reveals that the electrical resistivity of the topsoil ranges from about 35 to 813 Ωm to depth of about 5 m beneath the subsurface. The second geo-electric layer has resistivity values range of 35 – 6241 Ωm and depth ranges from about 5 – 12 m. Both first and second geoelectric layers are inferred to compose of clayey sand and sand formation, which are capable of supporting light and medium engineering structures. The third geo-electric layer is composed of clay/clayey sand/sand with resistivity values that range between 27 and 171 Ωm within a depth range of 8 – 50 m. Low resistivity recorded in this layer is indicative of predominantly clayey soil which is inimical to founding engineering structure.

The 2D resistivity section shown in Figure 4b is the resistivity - depth model along the second traverse. It reveals that the topsoil has electrical resistivity values ranging between 100 to 500 Ωm to depth of about 5 m beneath the subsurface. This layer is also adjudged to support giant engineering structure because it is mainly sand. The second geoelectric layer has resistivity values that range from 80 to 143 Ωm and thickness that range from about 4 to 12 m. This layer is composed of clayey sand and sand which can provide a favourable support for both light and giant engineering structures.

Beneath the second geo-electric layer, is a sandy material delineated at lateral distance of 20 to 75 m. It has electrical resistivity values which range from 100 to 500 Ωm within a thickness range of about 11 – 50 m below the surface. This sandy material can also favourably support any giant engineering structure. The third geoelectric layer is delineated at lateral distance of 80 – 180 m. It composes clay with resistivity values ranging from 3 to 10 Ωm within a depth range of 9 -50 m. The third geo-electric layer is mostly clayey and inimical to safe foundation of an engineering structure.

The 2-D resistivity section along traverse three is shown in Figure 4c. The topsoil has resistivity values that range from about 100 – 619 Ωm to a depth of about 5 m. The second geo-electric layer has resistivity value that ranges from 100 – 600 Ωm and depth ranges of about 5 to 28 m. Both the first and second geoelectric layers are composed of sand materials and can be adjudged to support heavy engineering structure. The third geoelectric layer has resistivity values that range from 20 to 50 Ωm composed of clay, and sandy clay within the depth range of 10 – 50 m. On the basis of soil type, this layer cannot support foundation of engineering structure. Within this geoelectric layer at lateral distance range of 135 – 180 m is dominantly clay with resistivity values range of 2 – 8 Ωm.

The 2-D electrical resistivity section along traverse four revealed that the topsoil has resistivity values that range from about 100 to 143 Ωm within a depth range of 0 to about 5 m. This layer comprises clayey sand which can support a medium engineering structure. Beneath the topsoil is the second geoelectric layer which composes of sand with

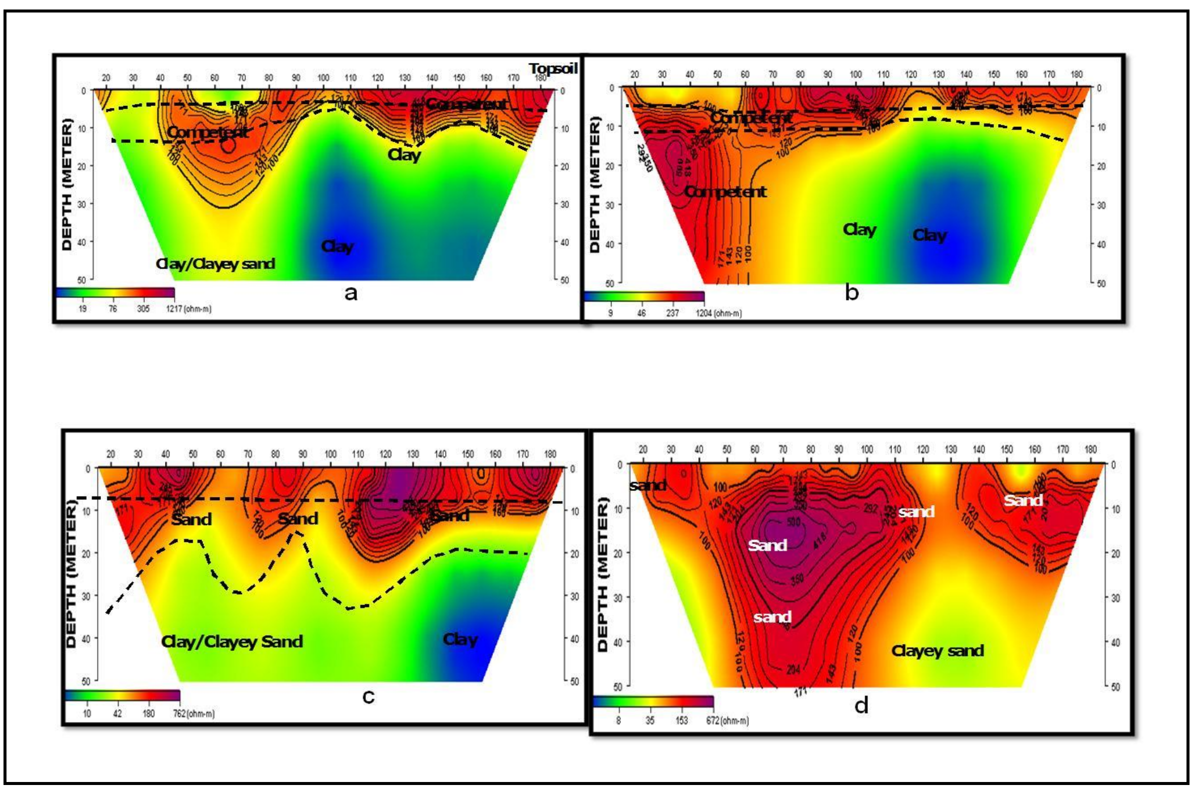


Figure 4 (a-d): 2-D resistivity sections along traverses one to four.

resistivity values that ranges from 100 to 143 Ωm. This sand formation extends from a depth of 5 to 50 m. These second geo-electric and third geo-electric layer layers have sandy soil composition which can favourably support heavy engineering structure. However, at a lateral distance of 115 – 155 m range, a clayey sand material was delineated having resistivity values range of 30 - 40 Ωm.

B. Geotechnical Interpretation

Selected penetration resistance versus depth curves are shown in Figures 5 (a-d). Coerts (1996) related soil's maximum cone resistance (q_c) to competency with respect to grain-size and density. Therefore, highest q_c values recorded at Test Points 1-10 corresponding to points of the maximum bearing capacity (Garg, 2007). At Test Points 1-2 for the foundation soils shows a gradual increase in resistance of the soil with depth. Sharp peaks are observed from 1 m, 4.5 m and 5.5 m to a depth of 10.8 m with maximum cone resistance (q_c) value of 156 kg/cm^2 as shown in Figure 5a. The maximum bearing capacity estimated is 432 kN/m^2. This rapid increase in resistance value could be attributed to an increase in sand content or increase in compaction density of the foundation soils with depth.

The selected penetration resistance versus depth curve (Figure 5b) at Test Points 3-4-5 for the foundation soils also shows a gradual increase in resistance of the soil with depth. Prominent sharp peaks are observed from 2 m, 4.5 m and 8 m with a rapid increase to a depth of 10.4 m. The maximum q_c value recorded 155 kg/cm^2 which corresponds to a bearing value of 426 kN/m^2.

There exists gradual increase in resistance of the soil with depth at Test Points 6-7-8 shown in a selected Figure 5c. However, little or no sharp peaks are observed in the penetration resistance versus depth curve. The foundation soil has a maximum q_c (132 kg/cm^2) at depth of 8.0 m, amounting to a bearing capacity of 364.5 kN/m^2. A gradual and rapid increase in q_c of the soil at Test Points 9-10 (Figure 5d) exists to a depth of 8.4 m at a maximum bearing capacity of 383.4 kN/m^2 estimated from q_c value of 135 kg/cm^2.

Qc	Depth	Const.	BC
0	0		
4	-0.25	2.7	10.80
8	-0.5	2.7	21.60
12	-0.75	2.7	32.40
16	-1	2.7	43.20
4	-1.25	2.7	10.80
4	-1.5	2.7	10.80
6	-1.75	2.7	16.20
8	-2	2.7	21.60
9	-2.25	2.7	24.30
11	-2.5	2.7	29.70
10	-2.75	2.7	27.00
12	-3	2.7	32.40
15	-3.25	2.7	40.50
17	-3.5	2.7	45.90
22	-3.75	2.7	59.40
24	-4	2.7	64.80
30	-4.25	2.7	81.00
32	-4.5	2.7	86.40
20	-4.75	2.7	54.00
24	-5	2.7	64.80
28	-5.25	2.7	75.60
12	-5.5	2.7	32.40
17	-5.75	2.7	45.90
21	-6	2.7	56.70
24	-6.25	2.7	64.80
20	-6.5	2.7	54.00
28	-6.75	2.7	75.60
33	-7	2.7	89.10
41	-7.25	2.7	110.70
44	-7.5	2.7	118.80
52	-7.75	2.7	140.40
55	-8	2.7	148.50
22	-8.25	2.7	59.40
26	-8.5	2.7	70.20
34	-8.75	2.7	91.80
58	-9	2.7	156.60
65	-9.25	2.7	175.50
71	-9.5	2.7	191.70
85	-9.75	2.7	229.50
97	-10	2.7	261.90
110	-10.25	2.7	297.00
125	-10.5	2.7	337.50
160	-10.75	2.7	432.00

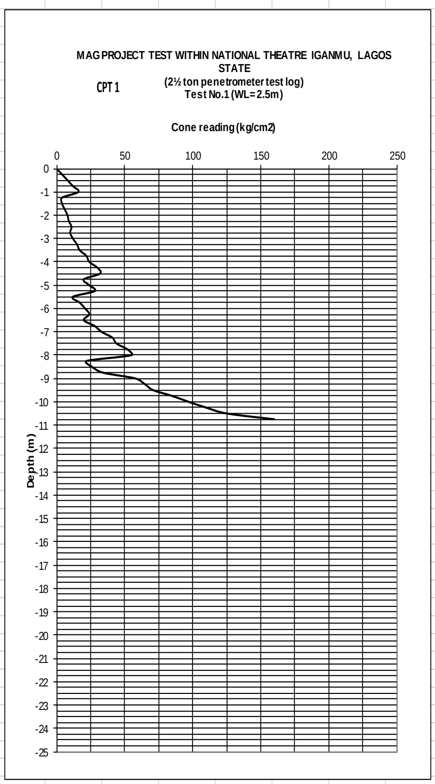


Figure 5a: Selected cone resistance versus depth curve at test point 1.

Qc	Depth	Const.	BC
0	0		
0	-0.25	2.7	-
0	-0.5	2.7	-
7	-0.75	2.7	18.90
9	-1	2.7	24.30
11	-1.25	2.7	29.70
14	-1.5	2.7	37.80
15	-1.75	2.7	40.50
15	-2	2.7	40.50
5	-2.25	2.7	13.50
6	-2.5	2.7	16.20
6	-2.75	2.7	16.20
7	-3	2.7	18.90
12	-3.25	2.7	32.40
12	-3.5	2.7	32.40
15	-3.75	2.7	40.50
17	-4	2.7	45.90
25	-4.25	2.7	67.50
27	-4.5	2.7	72.90
24	-4.75	2.7	64.80
26	-5	2.7	70.20
26	-5.25	2.7	70.20
19	-5.5	2.7	51.30
18	-5.75	2.7	48.60
20	-6	2.7	54.00
22	-6.25	2.7	59.40
17	-6.5	2.7	45.90
32	-6.75	2.7	86.40
35	-7	2.7	94.50
38	-7.25	2.7	102.60
41	-7.5	2.7	110.70
48	-7.75	2.7	129.60
53	-8	2.7	143.10
34	-8.25	2.7	91.80
36	-8.5	2.7	97.20
33	-8.75	2.7	89.10
38	-9	2.7	102.60
49	-9.25	2.7	132.30
64	-9.5	2.7	172.80
92	-9.75	2.7	248.40
124	-10	2.7	334.80
155	-10.25	2.7	418.50
158	-10.5	2.7	426.60

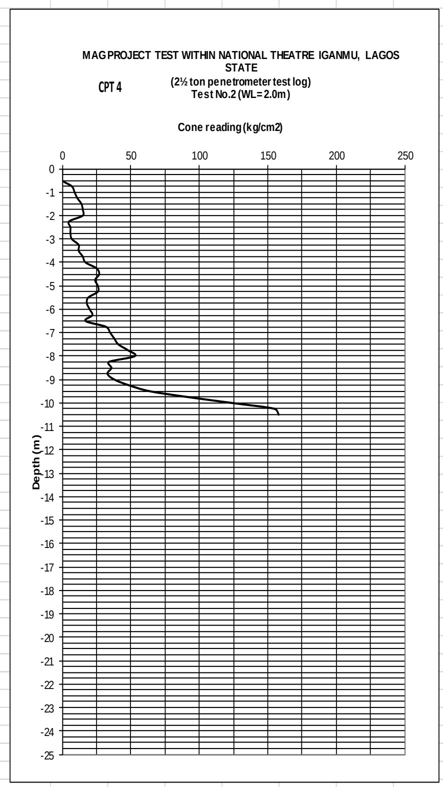
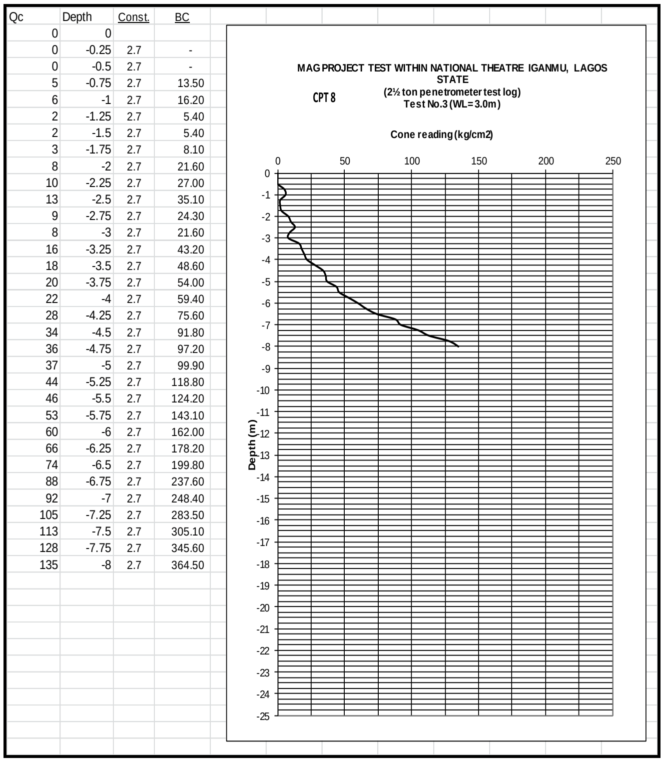
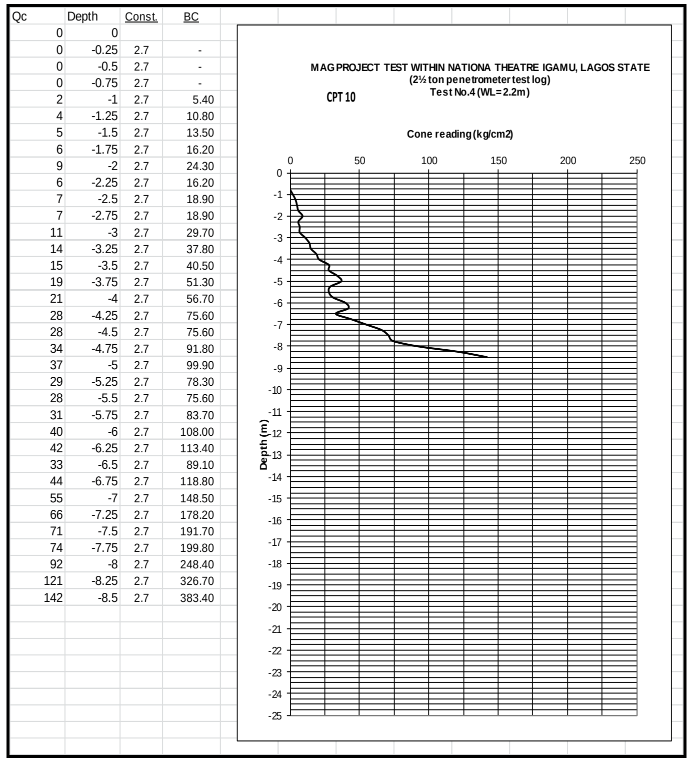


Figure 5b: Selected cone resistance versus depth curve at test point 4.



Qc	Depth	Const.	BC
0	0		
0	-0.25	2.7	-
0	-0.5	2.7	-
5	-0.75	2.7	13.50
6	-1	2.7	16.20
2	-1.25	2.7	5.40
2	-1.5	2.7	5.40
3	-1.75	2.7	8.10
8	-2	2.7	21.60
10	-2.25	2.7	27.00
13	-2.5	2.7	35.10
9	-2.75	2.7	24.30
8	-3	2.7	21.60
16	-3.25	2.7	43.20
18	-3.5	2.7	48.60
20	-3.75	2.7	54.00
22	-4	2.7	59.40
28	-4.25	2.7	75.60
34	-4.5	2.7	91.80
36	-4.75	2.7	97.20
37	-5	2.7	99.90
44	-5.25	2.7	118.80
46	-5.5	2.7	124.20
53	-5.75	2.7	143.10
60	-6	2.7	162.00
66	-6.25	2.7	178.20
74	-6.5	2.7	199.80
88	-6.75	2.7	237.60
92	-7	2.7	248.40
105	-7.25	2.7	283.50
113	-7.5	2.7	305.10
128	-7.75	2.7	345.60
135	-8	2.7	364.50

Figure 5c: Selected cone resistance versus depth curve at test point 8.



Qc	Depth	Const.	BC
0	0		
0	-0.25	2.7	-
0	-0.5	2.7	-
0	-0.75	2.7	-
2	-1	2.7	5.40
4	-1.25	2.7	10.80
5	-1.5	2.7	13.50
6	-1.75	2.7	16.20
9	-2	2.7	24.30
6	-2.25	2.7	16.20
7	-2.5	2.7	18.90
7	-2.75	2.7	18.90
11	-3	2.7	29.70
14	-3.25	2.7	37.80
15	-3.5	2.7	40.50
19	-3.75	2.7	51.30
21	-4	2.7	56.70
28	-4.25	2.7	75.60
28	-4.5	2.7	75.60
34	-4.75	2.7	91.80
37	-5	2.7	99.90
29	-5.25	2.7	78.30
28	-5.5	2.7	75.60
31	-5.75	2.7	83.70
40	-6	2.7	108.00
42	-6.25	2.7	113.40
33	-6.5	2.7	89.10
44	-6.75	2.7	118.80
55	-7	2.7	148.50
66	-7.25	2.7	178.20
71	-7.5	2.7	191.70
74	-7.75	2.7	199.80
92	-8	2.7	248.40
121	-8.25	2.7	326.70
142	-8.5	2.7	383.40

Figure 5d: Selected cone resistance versus depth curve at test point 10.

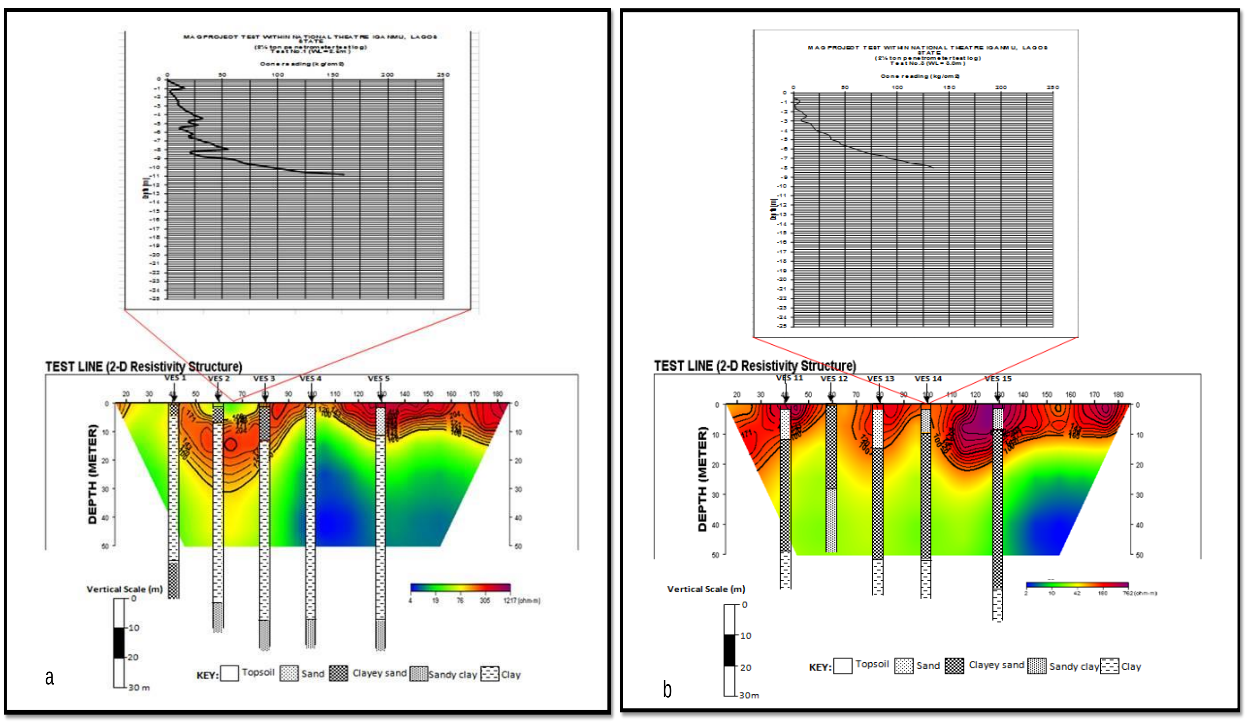


Figure 6: Correlation of the 2-D, VES and CPT Results along (a) Traverse One and (b) Traverse three.

C. Correlation of Geophysical and Geotechnical methods

Oyedele (2009) ascertained that electrical resistivity results (2-D and VES) can be correlated with the CPT data (Figures 6 a & b) to enable confirmation of the inferred subsurface lithological units as well as the bearing capacity of the studied foundation soils. For the VES 1, 2, 3, 4 and 5 there is correlation with the sand delineated on the 2-D result with resistivity range of 35 – 813 Ωm but extends to about 5 m beneath the surface which also correlate well with the borehole and CPT data to about 8.0 m. The second geo-electric layer from the 2-D section also correlates with the sand/clayey sand/sandy clay delineated beneath the VES points with resistivity values range of 61 – 95 Ωm. The third geo-electric layer is clay/sandy clay correlate well with the clay/sandy clay beneath the VES points with resistivity value range of 16 - 40 Ωm within a depth range of 8 – 50 m.

From VES 11, 12, 13, 14 and 15 the CPT data correlates with the sand delineated on the 2-D result but extends to about 5 m beneath the surface. This also correlates with the borehole and CPT data showing an increase in cone resistance to depth of about 8.4 m. The second geo-electric layer from the 2-D from depth of about 5 - 28 m correlates with the sand/clayey sand delineated beneath the VES points with resistivity values range of 66–157 Ωm. The third geo-electric layer which comprises sandy clay within the depth range of 8 – 50 m correlates with the CPT as well as the borehole data.

V CONCLUSION

The subsurface investigation within the premises of National Theatre Iganmu, Lagos revealed the lithological layers of suspected weak foundation soils to a considerable depth. The different subsurface soil layers were delineated on the basis of their electrical resistivity values penetration resistance of cone tip. The integrated geophysical and geotechnical methods have provided information regarding lithologic variability of the underlying soils sequence, which could help in the design of foundation of civil engineering structures.

The electrical resistivity method has provided adequate understanding of the nature of the ground, while the cone penetration data was able to identify the soil stratification and strength of the soil layers. Despite the inhomogeneity of the subsoils, appreciable bearing values were established at 8.0 to 10.0 m depth across the study area. Predictably, it is obvious that soils at test points 1, 4, 6 and 10 are underlain by soil layers of considerable poor bearing values. This has been responsible for the noticeable differential settlement of the structure. Adoption of pile foundation for high column loads would be appropriate in the study area between 8.0 and 10.0 m below the existing ground level when rehabilitation and upgrading of the structure is being carried out.

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