IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)
e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 4, Issue 5 Ver. II (Sep. - Oct. 2016), PP 21-28
www.iosrjournals.org

Application Of Geotechnical And Geophysical Methods To Investigate Tilt Buildings At Lagos State, Nigeria

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Abstract: *A geophysical and Geotechnical sounding were executed at the swamp and creek areas in Bariga, Makoko and Oworoshoki, Lagos-State, Nigeria. The study aim is to reveal why building tilts to a particular direction using both Constant Separation Technique (CST) and Vertical Electrical Sounding (VES) chaperoned with Borehole log (BH) and Cone Penetration Test (CPT). The Schlumberger and Wenner configuration were used for the data acquisition. Models obtained from the 2D inversion of each VES were used for constructing the Geo-electric section which exhibits the Geo-electric characteristics of the geological units present in the area namely topsoil, clayey sand, organic clay, fibrous peat and sand. Then the borehole logging and cone Penetrometer exhibit close relationship between their litho-strata. At various zones, the delineated heterogeneous deposits soft organic clay and fibrous peat are highly susceptible subsidence. Pertinently, buildings in this area are tilted towards an angle of 18˚ N and 11˚E at the time of investigation due to the soil incompetency which tends to amplify compressibility and reduction in the soil strength. Shallow foundation is considered unsuitable for a building in the area. Therefore, necessary densification of shallow sand may be needed to strengthen soil competence to a proposed depth ranging from 15 to 20m in these locations.*

Keywords:*Cone penetration Test (CPT), Constant Separation Techniques, Densification, soil competence, Vertical Electrical Sounding (VES)*

I. Introduction

The tilting nature of buildings in coastal areas in Lagos has increased in the recent times. Nigerian Institute of Structural Engineers (NISE) believes that structural failure is the major cause. While one will not rule out completely the possibility of poor materials and structural failure, the most fundamental cause is the foundation failure caused by soft consistency of the soil. The need for site characterization for engineering construction has become very important so as to prevent loss of valuables and lives that always accompany such failure. Building collapse has been advanced level in this coastal areas, due to grainy building material, and soil competency. Less periodically mentioned the natural tectonic activities like earthquake, tremor and faulting on which the buildings are entrenched**{1}.** The most fundamental determinant is the foundation failure caused by soft consistency of the soil. Geologists, geophysicists and environmental experts have associated the problems with weak soil strata and wrong foundation choice **{2}.**

People ignorantly build on site underlain by stratified clays with low permeability that shrink and swell as the water content in the voids changes. The water content changes can be caused by seasonal rain cycle, poor drainage, buried decaying vegetation etc. This subsequently leads to differential settlement that culminates into structure tilting**{3}**. In recent years, several organizations and private individuals have been engaged in infrastructural development but recent studies showed that many of them do not engage the services of professionals in order to maximize profits; the effect being poor building constructions which may ultimately lead to gradual or sudden tilting and collapse of such structures **{4}.**

Geophysical methods are adequate non-destructive mode of stratigraphy determination at the same time, geotechnical methods are essential for engineering characterization of the subsoil deposits that would have direct interaction with the proposed structure on the site. In recent times the assimilation of geophysics and geotechnical methods to engineering construction has become a promising approach **{5, 6}**. Geotechnical techniques using Cone Penetrometer Test (CPT) measure values of cone resistance and sleeve friction. It is Cost efficiency, expeditious, chastity, authenticity and the capacity to give perpetual clues on the soil deposits with depth. The Penetrometer resistance parameters were used for lithological classification and estimation of the soil strength **{7, 8}.**

1.2 Geology of the study area

The study area is located at Bariga, Makoko, and Oworonshoki, Lagos, South-West Nigeria between Latitudes 003° 22’44.9” East and 003° 23’ 43.8” East and Longitudes 06°29’55.1” North and 06° 32’49.2” North. The swamp and creek are occupied by migrants originally from the neighboring Benin Republic and some Egun, Ilajes and Ijaw from Ondo, Delta, Rivers, Bayelsa and other coastal state in Nigeria. The logon shares boundaries with Oworoshoki, Bariga Makoko, Apapa and Ikorudu are water logged regions. The soil is water logged during wet season but the water drains in some part during hot weather leaving behind a fracture surface, while some other parts are inaccessible as a result of them being highly swampy. The geological formation is the Dahomey basin stratigraphic formation named as the Benin coastal plain sands formation that extends from Ghana Volta Delta state to Okitipupa ridge in Nigeria. The lithological deposits belong to the coastal pain sand formation made up of loose sediment ranging from silt, organic clay/peat, and granular sand. The coastal belt falls within the upper Palaeocene to Eocene and Oligocene to Recent Alluvium **{9,10,11,12, 13, 14}.**

II. Methodology

2.1 Geophysical Survey

Vertical Electrical Sounding (VES) and 2D Electrical Imaging were conducted for the geophysical survey using Electrical resistivity carried out along six traverses in three different locations. Eighteen (18) Vertical Electrical Sounding Stations were acquired at different points along the six traverses. The geodetic system of coordinates was obtained using Garmin 12 Global Positioning System. The Schlumberger current electrode separation (AB) was varied from a minimum of 2.0 m to a maximum ranging from about 160 m to 220 m at the VES locations. The direction of the electrode spread of the VES points are in the North-South and West – East direction. The VES was interpreted manually and systematically using WinRes software with a maximum RMS error of 1.3 – 2.6. their curve types are between QH, KH, KQ, QHK, KQH AND HKH having four to five layers.

The Wenner array electrode configuration was used for the 2D resistivity imaging. These electrode configurations are well suited for constant spacing data acquisition systems, so that many data-points can be recorded simultaneously for each current injection. Six (6) different profiles were run with profile spacing depending on the accessible points on the field. Measurements were made at sequences of electrodes at 5 m interval using four (4) electrodes so as to be able to acquire better information because of the relatively shorter length of profile. Quantitative and qualitative analysis were made using the Dipro-Win software for the pseudo inversion.

2.2 Geotechnical Survey

Cone Penetration Tests (CPT) was performed at total of six (6) locations within the study area using the Dutch static penetrometer. It measures the resistance of penetration into soil using a 2.5 tons, 600 steel cone 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 2cm/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.

Cone penetrometer data were processed by plotting the cone resistance against the depth in each location point using Microsoft Excel software. Table 1.1 and 1.2 below shows the values of cone resistance and the corresponding lithology that can be inferred based on the result obtained and was also used as a guide in this study.

Table 1: Cone resistance value for a corresponding lithology of cohesive soil (After Garg, 2007) [15]

Cone End Resistance Value (Kg/cm^2)	Soil Type	Inferred CU Values (KN/m^2)
0-4	Very Soft Clay	20
0-6	Soft Clay	20-40
6-10	Firm Clay	40-75
10-20	Stiff Clay	75-100
Above 20	Very Stiff Clay To Hard Clay	100-150 And 150

Table 2: Cone resistance value for a corresponding lithology of granular soil (After Garg, 2007) [15]

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

III. Result And Discussion

Three station was probed at three different locations with namely Bariga, Makoko and Oworoshoki in understanding the sub-surface structures.

3.1 Bariga Station

At every station A (Bariga), two CST traverse A and B were probed in the N-S and E-W direction in other to determine the tilting direction of structures via there stratigraphy. On the CST, a lateral spread of 120m ware surveyed to a depth of 25m with resistivity value ranging from 0 – 3 Ωm and 0 – 11Ωm in the N-S and E-W direction respectively. On Traverse A, VES 1, 2, and 3 were acquired at 45 m, 55 m and 75 m electrode spacing positions respectively on point on the CST also, on traverse B, VES 4, 5, and 6 were acquired at 55 m, 60 m and 70 m electrode spacing positions respectively. The VES result measured on every CST traverse were correlated, chaperoned with some borehole log data and CPT data.

Along Traverse A (Fig.1a), Within the lateral distance of 0 – 52m at depth beneath 0 – 15m had an average resistivity values ranging from 0.71 – 1.40 Ωm, the subsoil unit is predominantly symptomatic of clay/peat across the section.The geoelectric layer at depth between 10m and 25 m on a horizontal spread of 53 – 100m, had resistivity ranging from 1.8 – 3.7 Ωm delineates clayey-sand and clay/peat across the profile. The clay/peat materials with resistivity (0.71 – 0.9Ωm) are noticed across the lateral distances within depth interval (0 - 8m.) is the most prominent materials alone the horizontal spread, extensive at this depth. Also onTraverse B (Fig.2b), within the lateral spread of 0 – 38m at depth of 0 – 25m had an average resistivity values ranging from 0.75 – 3.0Ωm, the subsoil unit is predominantly symptomatic of clay/peat across the section. The geoelectric layer at depth between 5 m and 25m on a lateral distance of 39 – 78m, had a resistivity value range of 3.0 – 12Ωm is inferred to be clayey sand across the profile. The organic clay/ fibrous peat deposits with resistivity (0.75 – 4.2Ωm) are noticed the horizontal spread at depth interval of (0 – 5m) which is the most prominent and laterally extensive at this same depth. The CST result agreed to a high degree with the VES (1 – 6) geoelectric strata as shown in Fig. 3 and Fig.4 respectively.

The CPT curves (Fig. 2a &2 b) at Bariga shows an average cone resistance value of 0 - 9 kg/m² to a depth of 15.25m observed in the readings. This zone is indicative of clay/peat. After this zone, the cone resistance value began to increase steadily and from a depth of 15.25 m - 20 m with an average cone resistance value ranging from 12 -150 kg/m² was recorded, indicating a zone which could probably consist of sand or granular soil. The anchor pulled up at this point and could not go any deeper. It was observed that buildings foundation in this environment are within the organic clay/ fibrous peat with weak strength characteristics due to the compressible nature.Pertinently,buildings at this area are tilted towards an angle of 18˚ N and 11˚E at the time of investigation due to thesoil incompetency.

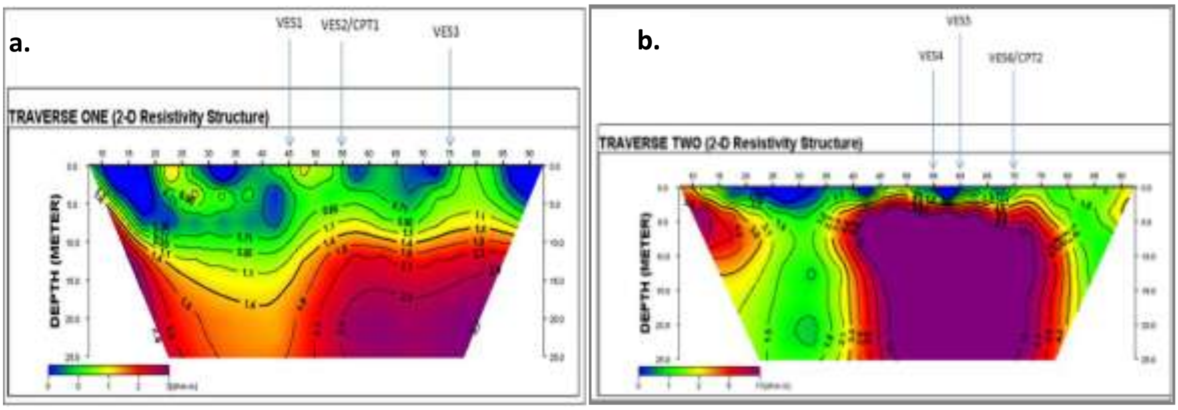

Fig.1: 2-D resistivity imaging along (a) traverse Aand (b) traverse B.

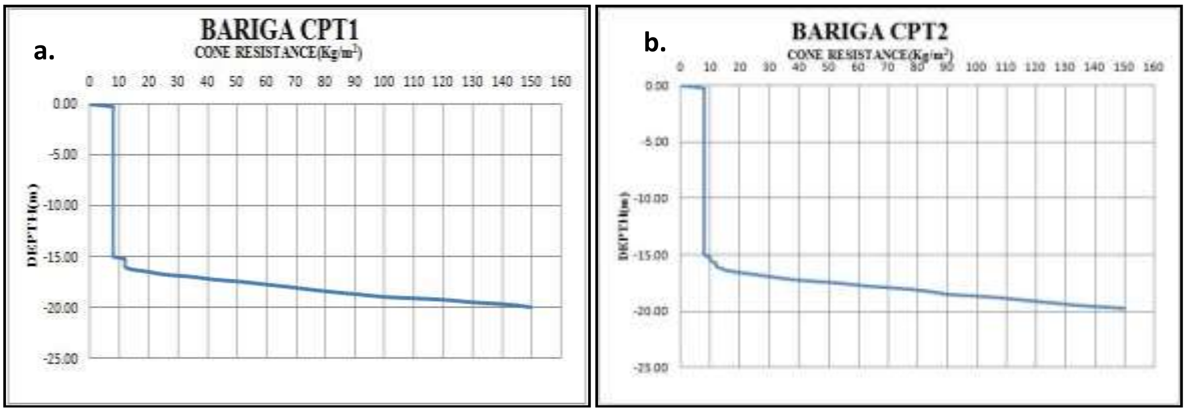

Fig.2: Cone resistance on (a) traverse A and (b) traverse B.

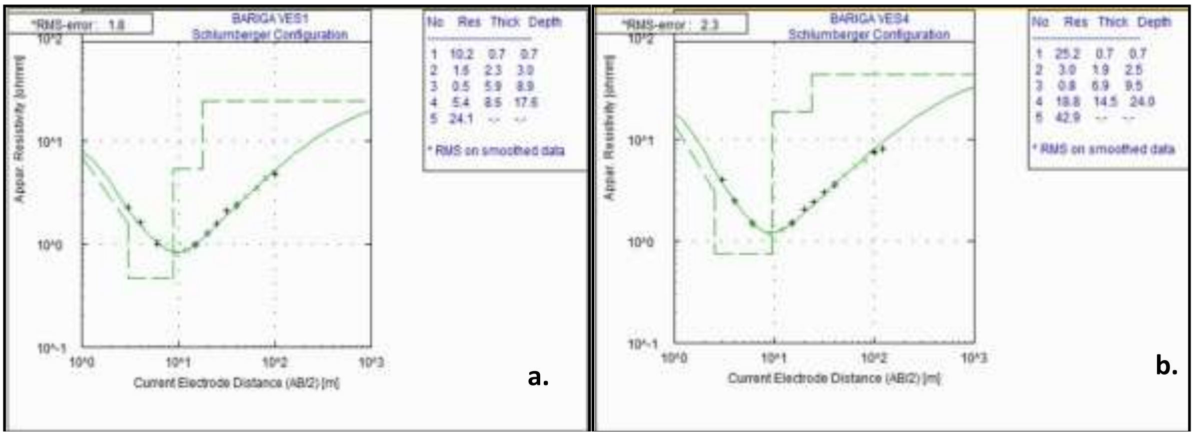

Fig. 3. Vertical Electric Sounding result for (a) traverse A and (b) traverse B.

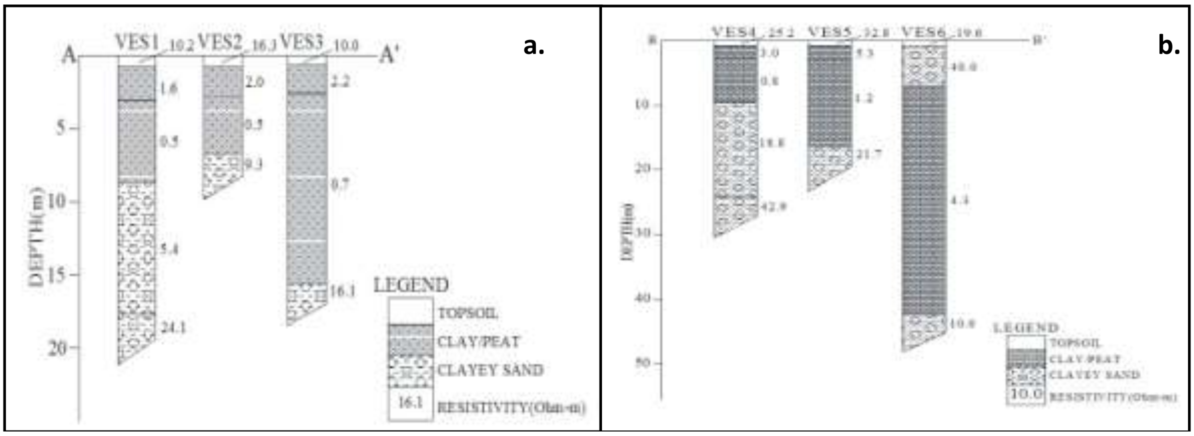

Fig. 4. Geoelectric Section along (a) traverse A and (b) traverse B.

3.2 Makoko Station

At every station B (Makoko), two CST traverse C and D were probed in the N-S and E-W direction in other to determine the tilting direction of structures via their stratigraphy. On the CST, a lateral spread of 100m ware surveyed to a depth of 25m with resistivity value ranging from 0 – 44Ωm and 0 – 56Ωm in the N-S and E-W direction respectively. On Traverse C, VES 7, 8 and 9 were acquired at 35 m, 45 m and 55 m electrode spacing positions respectively on point on the CST also, on traverse D,VES 10, 11, and 12 were acquired at 50 m, 60 m and 80 m electrode spacing positions respectively. The VES result measured on every CST traverse were correlated, chaperoned with some borehole log data and CPT data**.**

Along Traverse C (Fig. 5a), at depth beneath 5 m with resistivity values ranging from 6.2 – 27 Ωm, the subsoil unit is symptomatic of clay/peat/clayey sand across the section. The geoelectric layer at depth between 5 m and 25 m having resistivity ranging from 0.52 – 10 Ωm is predominantly diagnostic of clay/peat across the profile. The peat materials with resistivity 0.52 – 1.4 Ωm are noticed at lateral distances 15 - 45 m and 65 – 80 m with depth interval of 8 - 25 m and becoming more prominent and laterally extensive at this same depth. The Clayey sand materials with resistivity 17 – 27 Ωm appear to be more noticeable at depth interval 0 - 5 m at lateral distance 10 - 40 m and 50 – 70 m respectively. Also, the corresponding Traverse D (Fig. 5b), the depth below 5 m has a resistivity values ranging from 1.0 – 56 Ωm, the subsoil unit is indicative of clay/peat and clayey sand across the section. The geoelectric layer at depth between 5 m and 25 m having resistivity ranging from 0.71 – 3.7 Ωm is a representative of clay/peat across the profile. The clay/peat materials with resistivity 1.0 – 4.6 Ωm are noticed across the profile at lateral distance of 10 – 80 m with depth interval of 2 - 25 m. The Clayey sand materials with resistivity 13 – 56 Ωm appear to be more noticeable at depth interval 0 - 2 m at lateral distance 10 - 55 m of the profile. The CST result agreed to a reasonable degree with the VES (7 – 12) geoelectric strata as shown in Fig. 7 and Fig.8 respectively.

The CPT curves (Fig. 6a &6b) at Makoko shows an average cone resistance value of 0 - 5 kg/m² to a depth of 10.25 - 11 m observed in the readings. This zone is diagnostic of organic clay and lose silt. After this zone, the cone resistance value began to increase steadily and from a depth of 11 m – 16.5 m with an average cone resistance value ranging from 10 -150 kg/m² was recorded, indicating a zone which could probably consist of sand or granular soil. The anchor could not go any deeper which indicates a mechanically stable layer and was pulled up at this point.From the geophysical and geotechnical spatial parameters investigated, the heterogeneous deposits soft organic clay, loose silt and granular sand constituting the first strata within the swamp and creek are compressible loose and are the cause of tilting and sinking heavy building construction. Necessary densification of shallow sand may be needed to strengthen soil competence in this location.

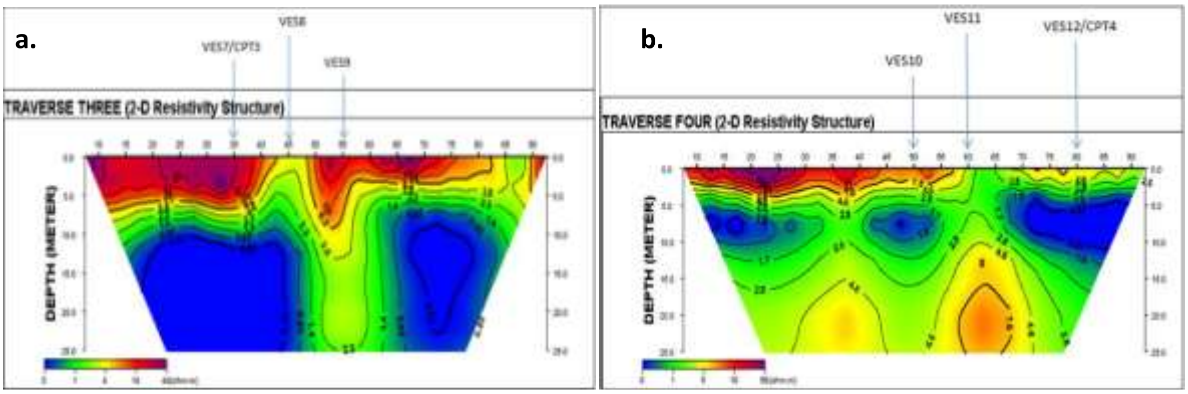

Fig.5: 2-D resistivity imaging along (a) traverse Cand (b) traverse D.

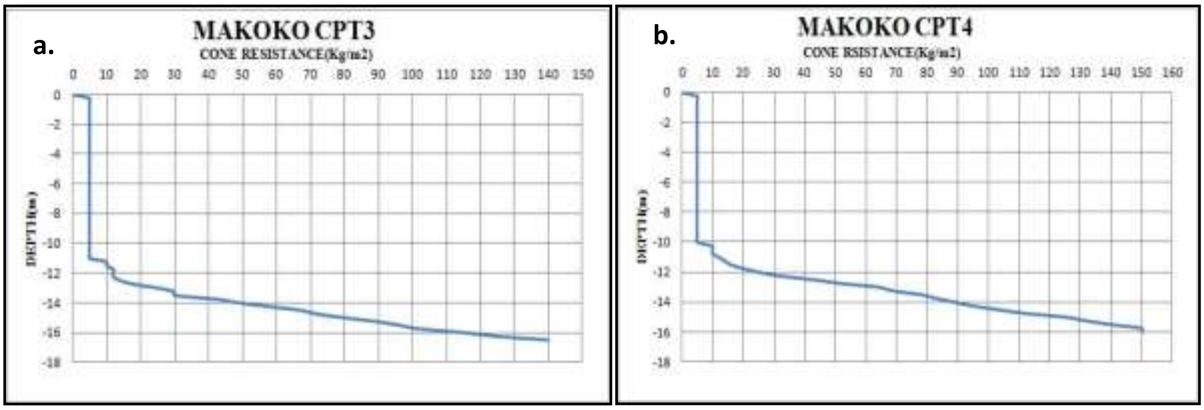

Fig.6: Cone resistance on (a) traverse C and (b) traverse D.

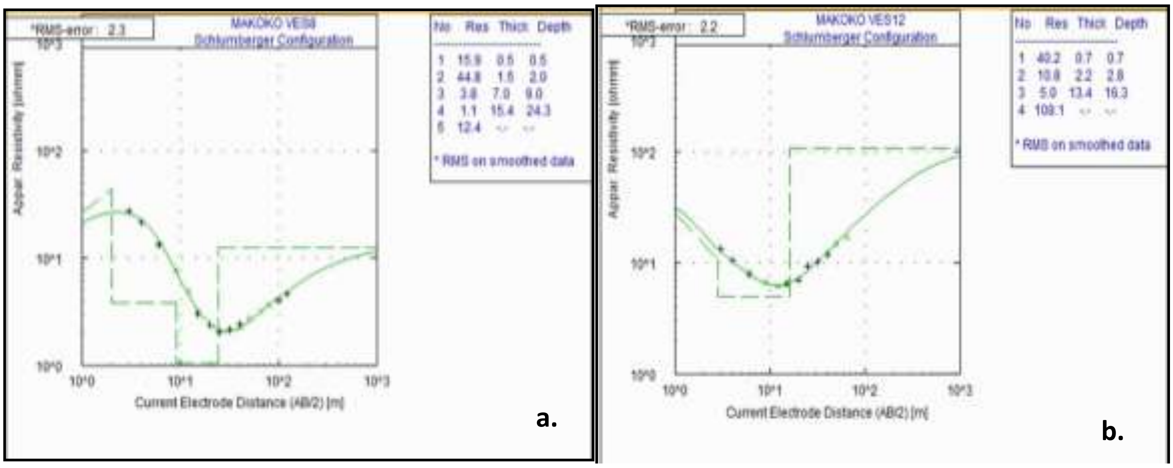

Fig. 7. Geoelectric Section along (a) traverse C and (b) traverse D.

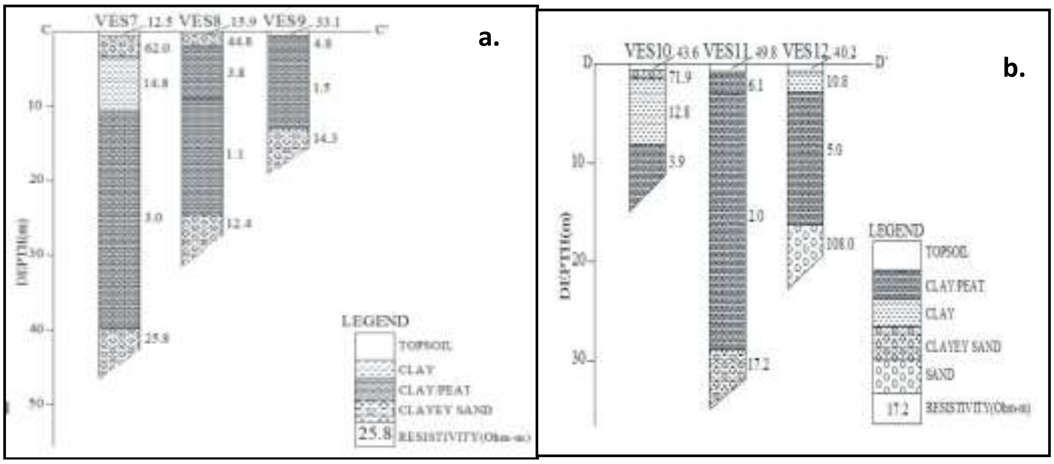

Fig. 8. Geoelectric Section along (a) traverse Cand (b) traverse D.

3.3 Oworoshoki Station

At every station C (Oworoshoki), two CST traverse E and F were probed in the N-S and E-W direction in other to determine the tilting direction of structures via their stratigraphy. On the CST, a lateral spread of 100m ware surveyed to a depth of 25m with resistivity value ranging from 0 – 25Ωm and 0 – 32Ωm in the N-S and E-W direction respectively. On Traverse E, VES 13, 14 and 15 were acquired at 50 m, 60 m and 70m electrode spacing positions respectively on point on the CST also, on traverse F, VES 16, 17, and 18 were acquired at 50 m, 60 m and 80 m electrode spacing positions respectively. The VES result measured on every CST traverse were correlated, chaperoned with some borehole log data and CPT data.

At Traverse E (Fig. 9a), the geoelectric lateral distances 1 - 100 m with depth interval of 0 - 25m are mixture of symptomatic organic clay or fibrous peat and loose silts deposits with resistivity 0.43 – 2.6 Ωm and are prominently extensive at these strata. The geoelectric layer at depth interval 8 - 25 m at lateral distance 65 - 75 m of the profile were predominantly a Clayey sand deposits with resistivity 10 – 16 Ωm. Along Traverse F (Fig. 9b), The topsoil consists of organic clay and clayey sand with resistivity value ranging from 0.37 to 32 Ωm. The resistivity 0.37 – 3.5 Ωm of the organic clay or fibrous silt mixtures deposited are predominantly symptomatic noticed across the profile at lateral distance 10 – 90 m with depth interval of 0 - 25 m and are prominent extensive. The Clayey sand materials with resistivity 11 – 32 Ωm appear to be noticeable at depth interval 0 - 2 m at lateral distance 55 - 65 m of the profile.The CST result agreed to a reasonable degree with the VES (13, 14, 15, 16, 17 and 18)geoelectric strata as shown in Fig. 11 and Fig.12 respectively.

The CPT curves Fig 10 (a & b) at Oworonshoki shows an average cone resistance value of 0 - 5 kg/m² to a depth of 8 – 8.25 m observed in the readings. This zone is symptomatic of clay/peat. After this zone, the cone resistance value began to increase steadily and from a depth of 9 m – 14.25 m with an average cone resistance value ranging from 15 -150 kg/m² was recorded, indicating a zone which could probably consist of sand or granular soil. The anchor pulled up at this point and could not go any deeper due to its mechanical stability of the subsurface. The fibrous peat and organic clay are highly susceptible to subsidence and are also affected by environmentalconditions such as temperature, overburden and moisture, which vary irregularly the loose granular sand is cohesionless**{16, 17}**. From the result shown below, the tilting of building in this area is due to soil incompetency is pertinently due to presence of large peat organic clay which leads to amplify compressibility and reduction in the soil strength

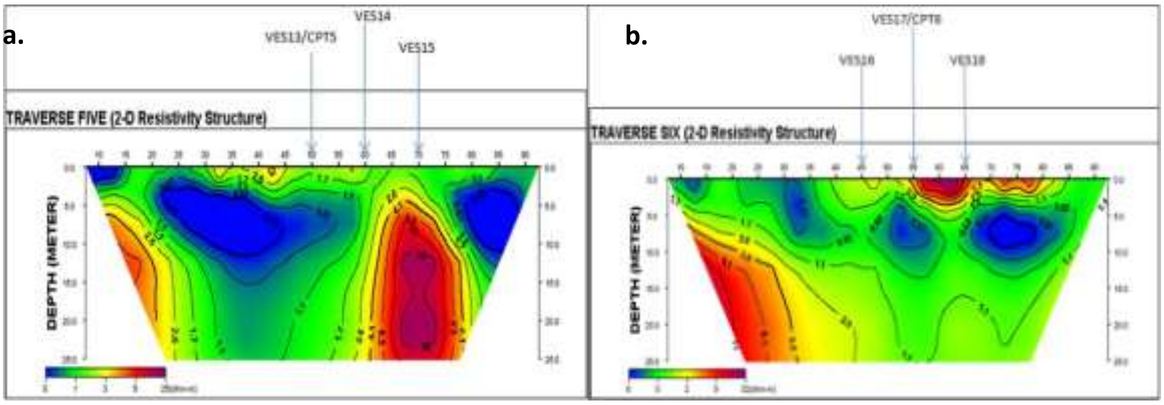

Fig. 9: 2-D resistivity imaging along (a) traverse Eand (b) traverse F.

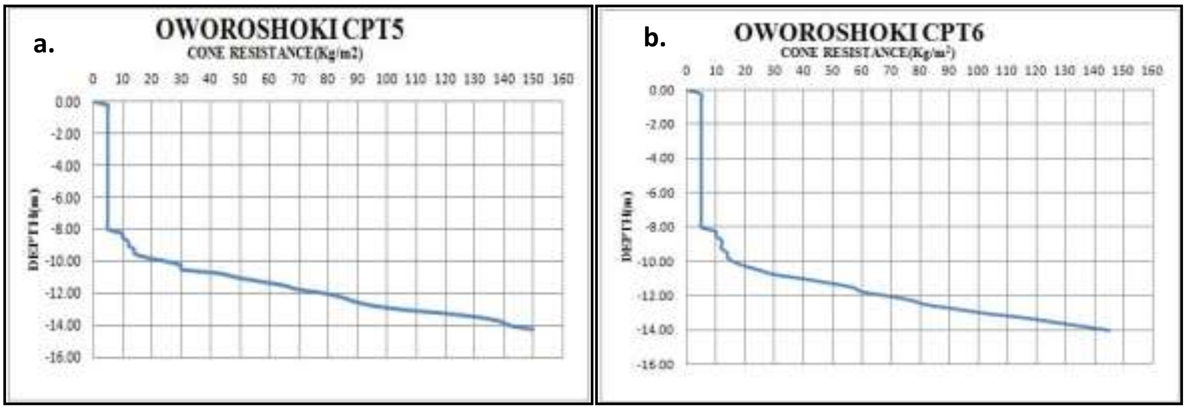

Fig. 10: Cone resistance on (a) traverse Eand (b) traverse F.

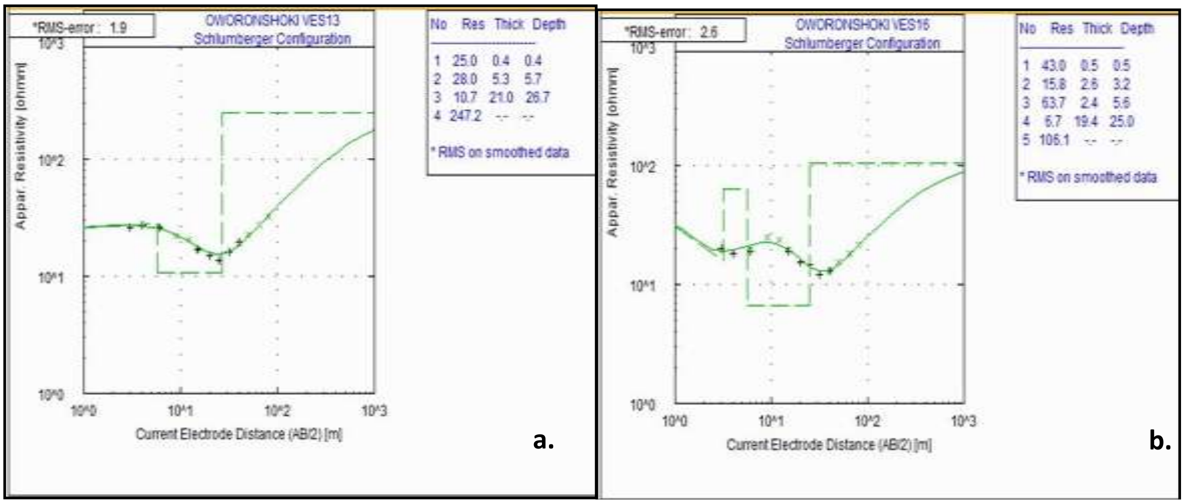

Fig. 11. Geoelectric Section along (a) traverse E and (b) traverse F.

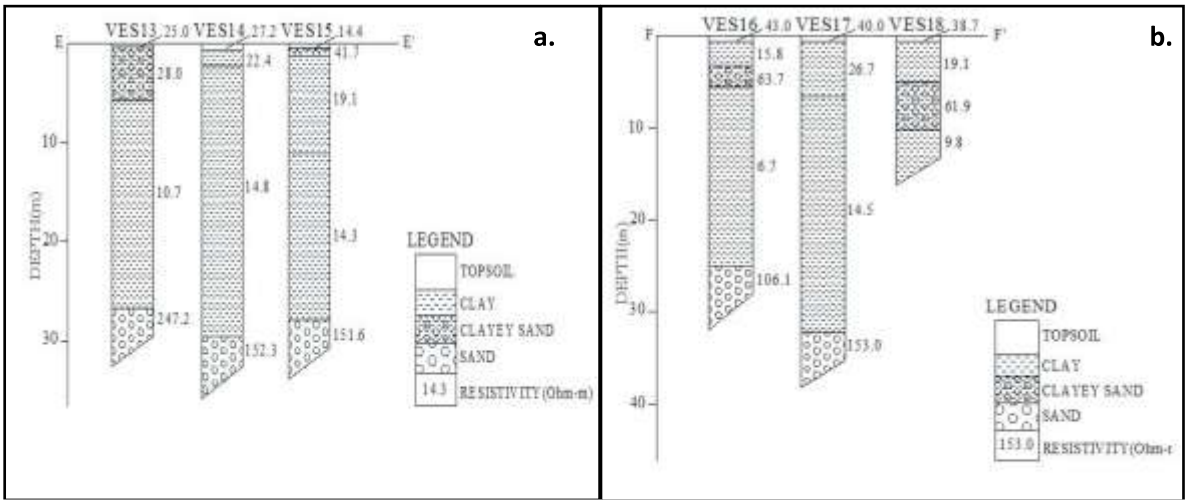

Fig. 12. Geoelectric Section along (a) traverse E and (b) traverse F.

IV. Conclusion

The Geotechnical and Geophysical sounding executed at Bariga, Makoko and Oworoshoki, reveals why buildings tilt in a particular direction using both Constant Separation Technique (CST) and Vertical Electrical Sounding (VES) and further investigation using both Borehole log (BH) and Cone Penetration Test (CPT). The combined analyses of results from the VES, 2D inversion reveal the soil to have similar layers namely topsoil clayey sand, clay, clay/peat and sand. While the borehole logging exhibit close relationship between their litho-strata.

At various zones, the delineated of heterogeneous deposits soft organic clay and fibrous peat are highly susceptible subsidence, that is, the presence of such deposits are instinctive unstable formation and inimical to building with the creek and swamp of the coastal area of Lagos. Pertinently, buildings at this area are tilted towards an angle of 18˚ N and 11˚E at the time of investigation due to the soil incompetency which leads to amplifies compressibility and reduction in the soil strength.

The CPT data correlates well with the VES interpretation with an average cone resistance value ranging between 150 kg/m² at a depth up to 20 m beneath the subsurface signifies region consisting Coarse sand deposits of suitable competency for buildings. Therefore, necessary densification of shallow sand may be needed to strengthen soil competence to a proposed depth ranging from 15 to 20m in these locations.Government could intervene by evacuating the whole area and then employ resin injection technology to the affected areas. Finally, the investigation parades the importance of integrating geotechnical and geophysical methods to engineering site characterization.

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