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Integrated Geophysical and Geotechnical Methods for Pre-Foundation Investigations at Lagos State University of Science and Technology, Ikorodu, Southwestern Nigeria

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ABSTRACT

The recurrence of building collapses and resulting casualties is overwhelming in Lagos State as the state records the highest cases in recent times. This work used geophysical (Ground magnetic (GM) and Electrical resistivity imaging (ERI)) and geotechnical (Dynamic cone penetration test (DCPT)) methods in delineating the subsurface conditions for its competence in foundation structures. Ten profiles of 200 m ground magnetic data were collected at 2 m spacing likewise for Wenner arrays on each profile. DCPT data were collected at points 0 m, 50 m, 100 m,150 m, and 200m to the depth of 3 m on each of the profiles occupied by GM and ERI. The data obtained were processed and interpreted using RES2DINV software for ERI, Excel package for both Magnetic and DCPT. The ground magnetic results gives the minimum relative magnetic intensity as -1689.78 nT representing possible fault/fractured zone and maximum value of 2943 nTindicating area of competence for foundation structure. ERI results gives a resistivity value ranging from 2 Ωm – 7602 Ωm depicting four zones of incompetent/sub-competent clay/sandy clay, moderately competent clayey sand, competent sand and highly competent lateritic sand. DCPT results is in the average range 11.20% to 39.87% representing Clay materials fairly competent for foundation structures, sand and well graded gravel that is competent for construction purposes. To prevent building collapsed in the study area, areas of incompetent materials should be excavated, refill and compact with lateritic sand before foundation is put in place.

Keywords:
Building collapse,
DCPT,
Foundation Structure,
Software.

INTRODUCTION

Building or shelter which protects man from the local environment and gives the feeling of well-being is one of the human physiological needs on earth (Adagunodo and Oladejo, 2020). The success of building and other engineering structures which are directly established on the surface of the earth is among other factors dependent on the support offered by the foundation materials that bear the load of these structures (Terzaghi *et al*., 1996; Oshinowo and Falufosi, 2018). Unfortunately, a building that supposes to satisfy human's need has become worrisome to man as a result of its failure. A building is adjudged to have failed when it could no longer fulfil its functions and cannot be relied upon for safety again (Sunmonu *et al*., 2018; Adagunodo and Oladejo, 2020).

The alarming rate of building collapses (plate 1) in Nigeria today is very worrisome. The cost of damages to human lives and infra-structures, as a result of building collapse, may be difficult to estimate. Most often, this collapse could be as a result of improper investigation to determine the competence limit of the subsurface before a building is constructed (Shimobe and Spagnoli, 2020; Adewoyin*et al*., 2021). Hence, site investigations are conducted to discover the characteristics of the soil at the particular location towards determining their ability to support structures placed on them (Oghenero *et al*., 2014; Youdeowei and Nwankwoala, 2013; Oyediran and Falae, 2018).


Plate 1: 21-storey luxury apartment building that collapsed during construction in Lagos (GCR, 2024)

The Building Collapse Prevention Guild revealed that Lagos State tops the list of fatalities as over 271 buildings collapsed in the last 10 years which represent 50 per cent of a total of 541 recorded cases in the country between 1974 and 2022. Out of the 271 collapses recorded, at least 531 persons have died as the menace of crumbling structures continues to plague the nation's built industry (Ikpoto, 2023).

Many researchers have worked on site investigation of distressed building, and other spaces for proposed building construction using Geophysical and integrated geophysical/geotechnical methods such as Electrical Resistivity Imaging (ERI) (Osinowo and Falufosi, 2018), Electrical and Magnetic (Sunmonu *et al*., 2018), Electrical and Cone Penetration Test (CPT) (Coker *et al*., 2017a; Coker *et al*., 2017b),Seismic Refraction, CPT and Percussion drilling (Adewoyin*et al*., 2021), Electrical and boring hole sample collection for soil analysis (Oyediran and Falae, 2018), just to mention but a few. In this work integrated geophysical and geotechnical methods involving ground magnetic, ERI and Dynamic Cone Penetration Test (DCPT)were carried out to investigate the subsurface conditions of foundation structures in Lagos State University of Science and Technology, Ikorodu, South-western Nigeria to delineate the subsurface for building construction purposes.

Geology of the study area

The study area Ikorodu (figure 1) is part of Lagos State located within the Federal Republic of Nigeria. The geology of Lagos and its environs is an integral part of Dahomey Basin, which is the Eastern part of Sedimentary Basin that extends from Volta Delta state in Ghana to Okitipupa ridge in Nigeria. Lagos belongs to the Coastal Plain Sand formation which is made up of loose sediment ranging from silt, clay and fine to coarse grained sand (Coker, 2015).

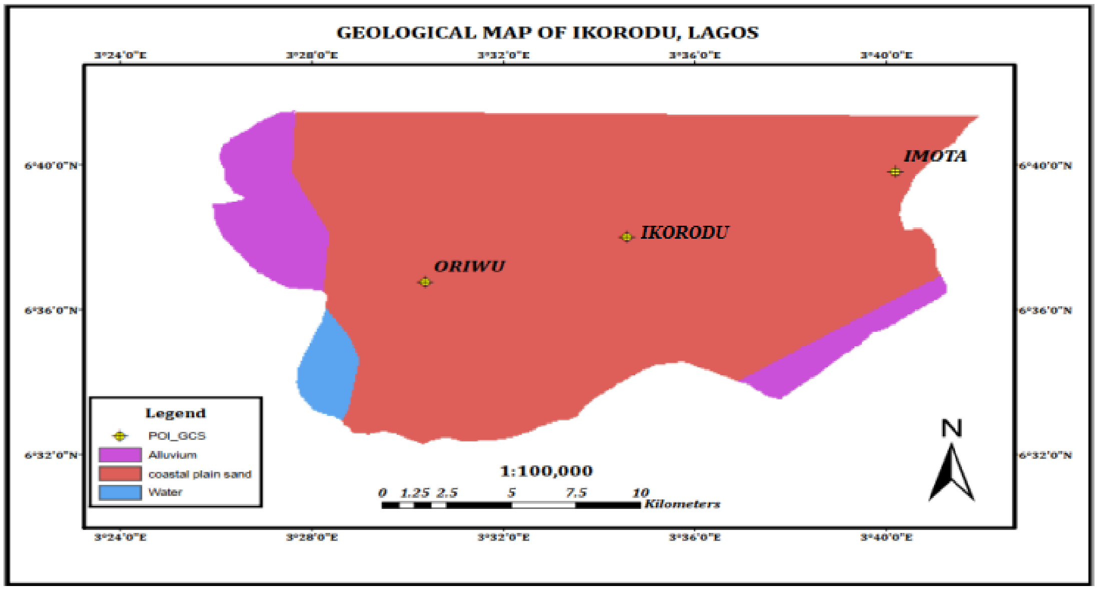


Figure 1: Geologic map of Ikorodu (Source: Epuh*et al*., 2020)

MATERIALS AND METHODS

Study Location

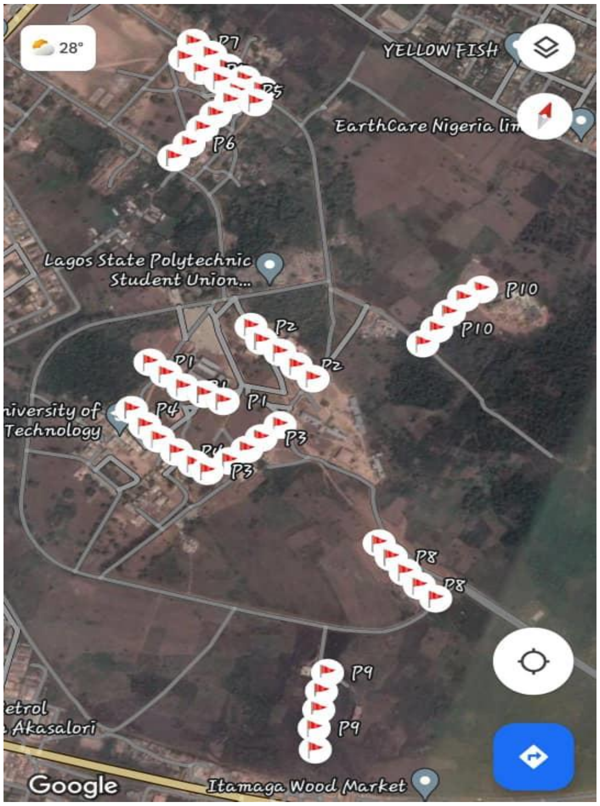


Figure 2: Site map of the study area indicating the ten profiles occupied

Plate 2: Equipment used for data collection: (a) Proton magnetometer (b)Terrameter and its accessories (c) DCPT apparatus

The instrument used for the ground magnetic survey is the Geometries Proton Precession Magnetometer, model G- 856 (plate 2(a)) which produces an absolute and relatively high resolution of the field and displays measurement in digital lighted readout. Ten Profiles were established at the study location with Profile length of 200 m and 2 m spacing. The values obtained were corrected for diurnal effect and plotted against horizontal distance for each profile noting the areas of anomalies.

Ten Profiles were occupied at the study location with electrical resistivity survey instrument called Ohmega Terrameter, (plate 2(b)) which produces resistance values. Wenner arrays (fig. 3) of profile length 200 m were deployed at 2 m, 4 m, 6 m and 8 m spacing. The resistance values were used to calculate the apparent resistivity values using equation (1).

$$\rho = 2\pi a \frac{\Delta V}{I} \qquad (1)$$

The apparent resistivity values for the 2D data set were inverted for true subsurface resistivity using RES2DINV version 4.0 inversion software and the resulting estimated models were presented as pseudosections and interpreted.

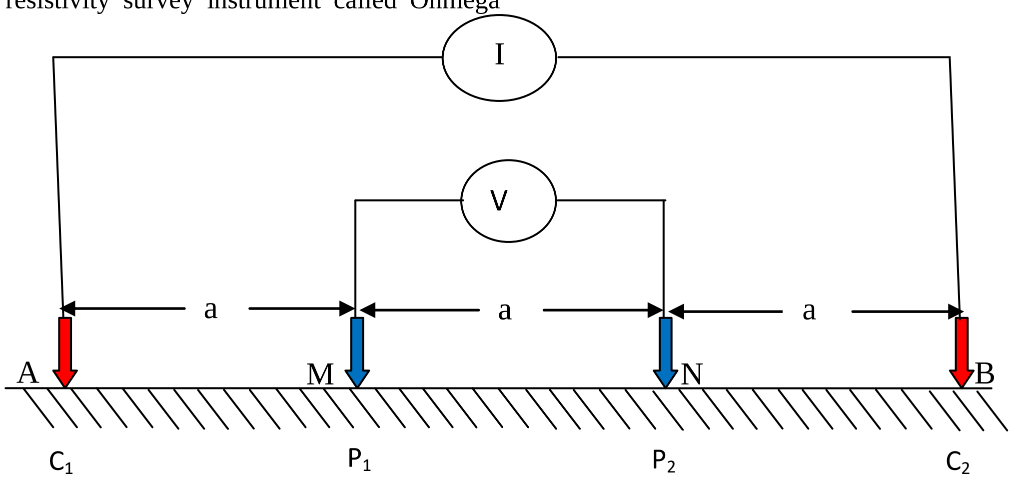


Figure 3: Wenner array arrangement for data acquisition

The DCPT (Dynamic Cone Penetration Test) (plate 2(c)) were conducted at five positions (0 m, 50 m, 100 m, 150 m and 200 m) per profile at maximum depth of 3.0 m. The number of blows and penetration depth were recorded during the DCPT. The California bearing ratio (CBR) values of the study area was evaluated from penetration index (mm) of the points on each profile using the equation (2).

$$\text{Log}_{10}\, CBR = 2.45 - 1.05710\ \log_{10}(PI) \qquad (2)$$

where PI = penetration index

The interpretation and analysis of CBR values obtained from equation (1) on each profile was carried out according to the values on table 1.

Table 1: General rating of Soil materials using CBR values (Source: Bowles, 1990; Saing *et al*. 2016)

CBR VALUE	CLASSIFICATION	USES	CLASSIFICATION SYSTEM
0-3	Very poor	Sub-grade	Organic High Plasticity, Clay High Plasticity, Silt High Plasticity, Organic Low Plasticity
3-7	Poor – fair	Sub-grade	Organic High Plasticity, Clay High Plasticity, Silt High Plasticity, Organic Low Plasticity
7-20	Fair	Sub-grade	Organic Low Plasticity, Clay Low Plasticity, Silt Low Plasticity, Sand Clay, Sand Silt, Sand Poorly Graded
20-50	Good	Base, Sub-grade	Gravel Silt, Gravel Clay, Sand Well Graded, Sand Silt, Sand Poorly Graded, Gravel Poorly Graded
>50	Excellent	Base	Gravel Well Graded, Gravel Silt

RESULTS AND DISCUSSION

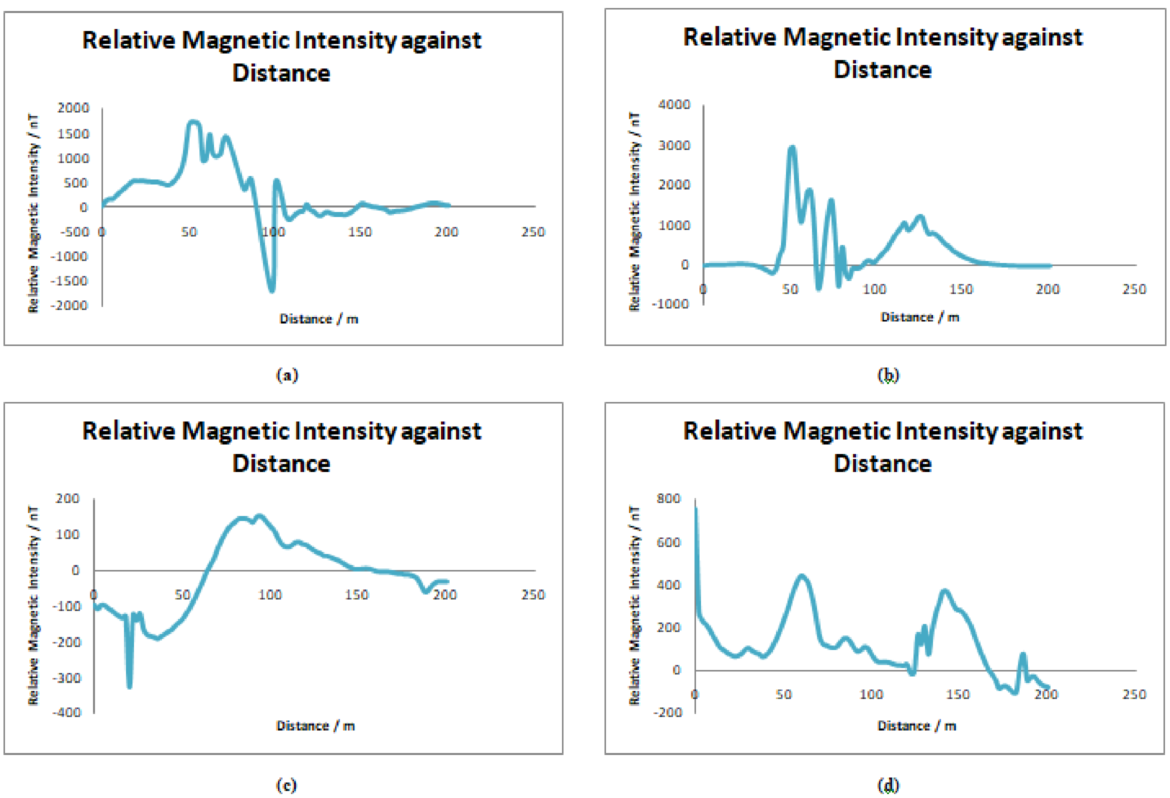


Figure 4: Relative magnetic intensity plots of profiles 1 – 4 (a – d)

The relative magnetic intensity values within profile one (fig. 4(a)) varies from -1689.78 nT to 1658.60 nT while that of profile two (fig. 4(b)) range from -559.27 nT to +2943.86 nT. Profile three's magnetic intensity (fig. 4(c)) values range from -326.84 nT to 156.02 nT and in profile four (fig. 4(d)), the magnetic intensity varies from -98.05 nT to 752.11 nT.

The relative magnetic intensity values of profiles one to four revealed areas of low magnetic intensities corresponding to faults or fractured zones that are incompetent for foundation structures. Areas of high relative magnetic intensities were also identified as competent zones suitable for erecting foundation structures.

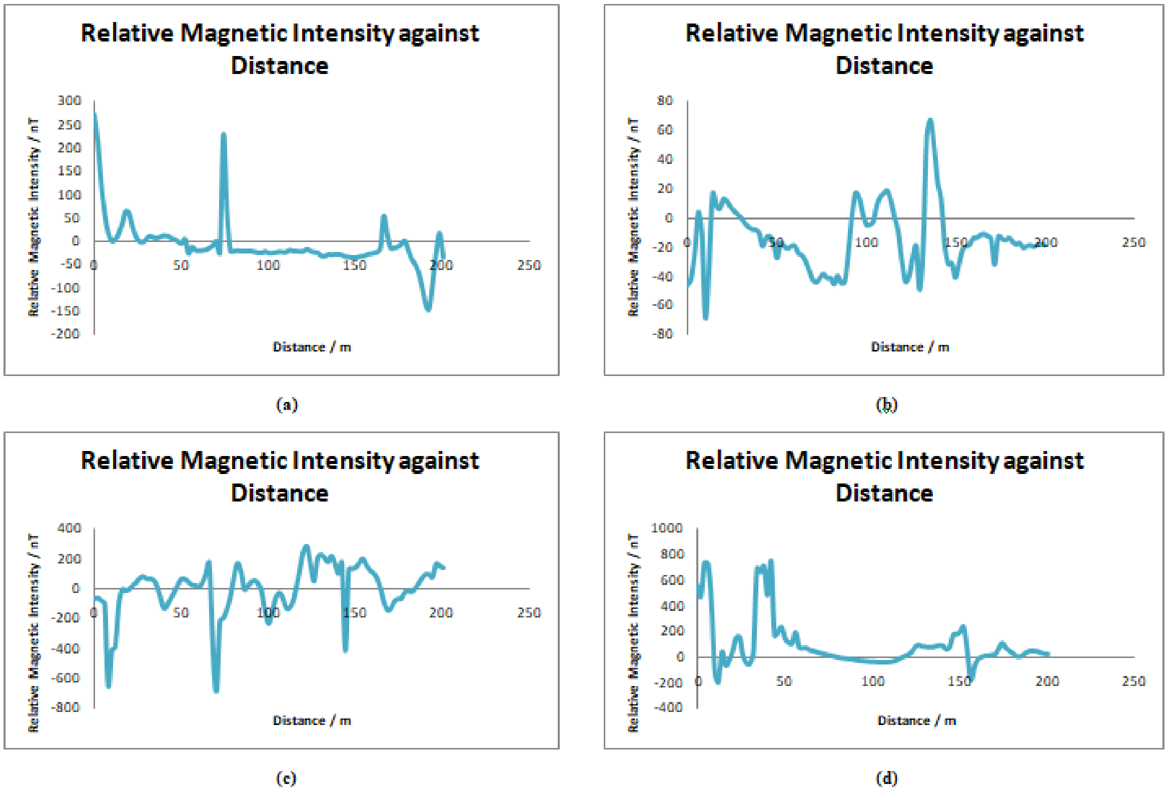


Figure 5: Relative magnetic intensity plots of profiles 5 – 8 (a – d)

Profile five (fig. 5(a)) exhibits magnetic intensity values ranging from -144.01 nT to 273.59 nT while profile six (fig. 5(b)) displays magnetic intensity values within the range of -69.04 nT to 66.97 nT. The magnetic intensity in profile seven (fig. 5(c)) ranges from -681.62 nT to 281.66nT and profile eight (fig. 5(d)) exhibits a magnetic intensity range from -197.01 nT to 740.93nT.

Generally, the relative magnetic intensity values of profiles five to eight revealed were characterised by low magnetic intensity zones corresponding to faults or fractured area that are not suitable for erecting foundation structures. There also exist areas of high relative magnetic intensities corresponding to competent zones suitable for erecting foundation structures.

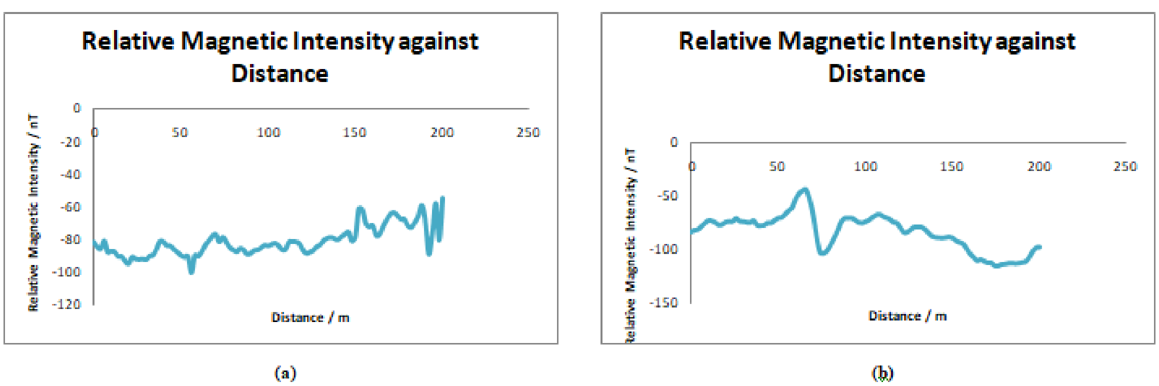


Figure 6: Relative magnetic intensity plots of profiles 9 – 10 (a – b)

Profile nine (fig. 6(a)) exhibits magnetic intensity values ranging from -100.05 nT to -55.04 nT and the magnetic intensity values in profile 10 (fig. 6(b)) span from -115.06 nT to 44.64 nT. Notable weakened zones, which could indicate faults or fractured joints, are visible along the path of profiles nine and ten.

Table 2: Results of average CBR of profiles 1 to 10

Profile	Average CBR / %	Lithology	Uses	Classification
1	11.57-30.08	fair -good	Sub-grade, Base	Organic Low Plasticity, Clay Low Plasticity, Silt Low Plasticity, Sand Clay, Sand Silt, Sand Poorly Graded, Gravel Silt, Gravel Clay, Sand Well Graded, Gravel Poorly Graded
2	11.20-30.57	fair -good	Sub-grade, Base	Organic Low Plasticity, Clay Low Plasticity, Silt Low Plasticity, Sand Clay, Sand Silt, Sand Poorly Graded, Gravel Silt, Gravel Clay, Sand Well Graded, Gravel Poorly Graded [
3	14.36-37.80	fair -good	Sub-grade, Base	Organic Low Plasticity, Clay Low Plasticity, Silt Low Plasticity, Sand Clay, Sand Silt, Sand Poorly Graded, Gravel Silt, Gravel Clay, Sand Well Graded, Gravel Poorly Graded
4	13.46-36.59	fair -good	Sub-grade, Base	Organic Low Plasticity, Clay Low Plasticity, Silt Low Plasticity, Sand Clay, Sand Silt, Sand Poorly Graded, Gravel Silt, Gravel Clay, Sand Well Graded, Gravel Poorly Graded
5	27.59-35.72	good	Sub-grade, Base	Gravel Silt, Gravel Clay, Sand Well Graded, Sand Silt, Sand Poorly Graded, Gravel Poorly Graded
6	31.02-33.50	good	Sub-grade, Base	Gravel Silt, Gravel Clay, Sand Well Graded, Sand Silt, Sand Poorly Graded, Gravel Poorly Graded
7	21.31-39.87	good	Sub-grade, Base	Gravel Silt, Gravel Clay, Sand Well Graded, Sand Silt, Sand Poorly Graded, Gravel Poorly Graded
8	17.61--36.09	fair –good	Sub-grade, Base	Organic Low Plasticity, Clay Low Plasticity, Silt Low Plasticity, Sand Clay, Sand Silt, Sand Poorly Graded, Gravel Silt, Gravel Clay, Sand Well Graded, Gravel Poorly Graded
9	16.44-23.75	fair –good	Sub-grade, Base	Organic Low Plasticity, Clay Low Plasticity, Silt Low Plasticity, Sand Clay, Sand Silt, Sand Poorly Graded, Gravel Silt, Gravel Clay, Sand Well Graded, Gravel Poorly Graded
10	18.93-31.11	fair –good	Sub-grade, Base	Organic Low Plasticity, Clay Low Plasticity, Silt Low Plasticity, Sand Clay, Sand Silt, Sand Poorly Graded, Gravel Silt, Gravel Clay, Sand Well Graded, Gravel Poorly Graded

On the average, the results of Dynamic Cone Penetration method (table 2) show that all the profiles are characterised by materials suitable as sub-grade or base materials classified as Gravel Silt, Gravel Clay, Sand Well Graded, Sand Silt, Sand Poorly Graded, Gravel Poorly Graded, Organic Low Plasticity, Clay Low Plasticity, Silt Low Plasticity, Sand Clay, Sand Silt, Sand Poorly Graded, Sand Well Graded which are fairly good for foundation structures.

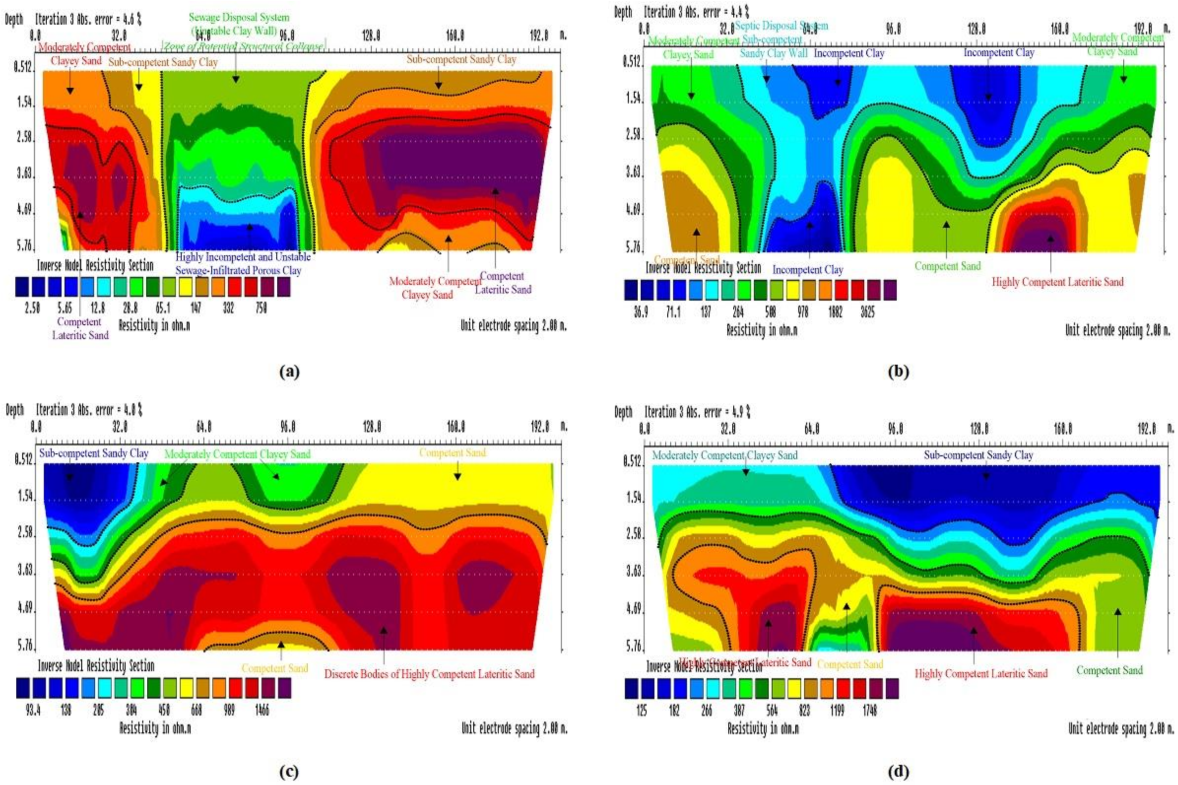


Figure 7: Electrical Resistivity Section along profiles 1 – 4 (a – d)

Geo-electric components of the subgrade of profile 1 (fig. 7(a)) exhibit a resistivity range of 2.0 Ωm – 960 Ωm. Four (4) geo-electric components are identified – Unstableclay wall and porous clay,slightly competent Sandy clay, moderately competent clayey sand andhigh competent lateritic zone within the sand layer.

In profile two (fig. 7(b)), the conditon of subgrade is similarly detailed on its resistivity section. Geo-electric components of the subgrade show a resistivity range of 19.6 Ωm – 4497 Ωm. There are four (4) main geo-electric components identified with resistivity values ranging from 19.6 Ωm – 105 Ωm for incompetent clay pocket, 130 Ωm – 200.5 Ωm for sub-competent sandy clay, 210 Ωm – 386 Ωm for moderately competent clayey sand, 400 Ωm – 990 Ωm for competent sand stratum and >1000Ωm for highly competent lateritic sand.

Profile three subgrade conditon is in-depthly described in its resistivity section (fig. 7(c)). The entire geo-electric characteristics of the subgrade span a resistivity range from 77 Ωm to 1943 Ωm. There are four distinct geo-electric components identified with resistivity values ranges from 77 Ωm to 171.5 Ωm for sub-competent sandy clay, 180 Ωm to 377 Ωm for moderately competent clayey sand, 400 Ωm to 823 Ωm for competent sand stratum, 989 Ωm – 1943 Ωm for very competent lateritic sand.

Along Profile four, the subgrade condition is comprehensively covered in its resistivity section (fig. 7(d)). Looking at the whole set of geo-electric components of the subgrade, the resistivity range is from 97.5 Ωm to 2297 Ωm. Four (4) distinct geo-electric components have been identified, with resistivity values ranging from 97.5 Ωm to 182 Ωm for sub-competent sandy clay, 224 Ωm to 475.5 Ωm for moderately competent clayey sand, 480 Ωm to 994 Ωm for competent sand stratum, > 1000 Ωm for highly competent lateritic sand.

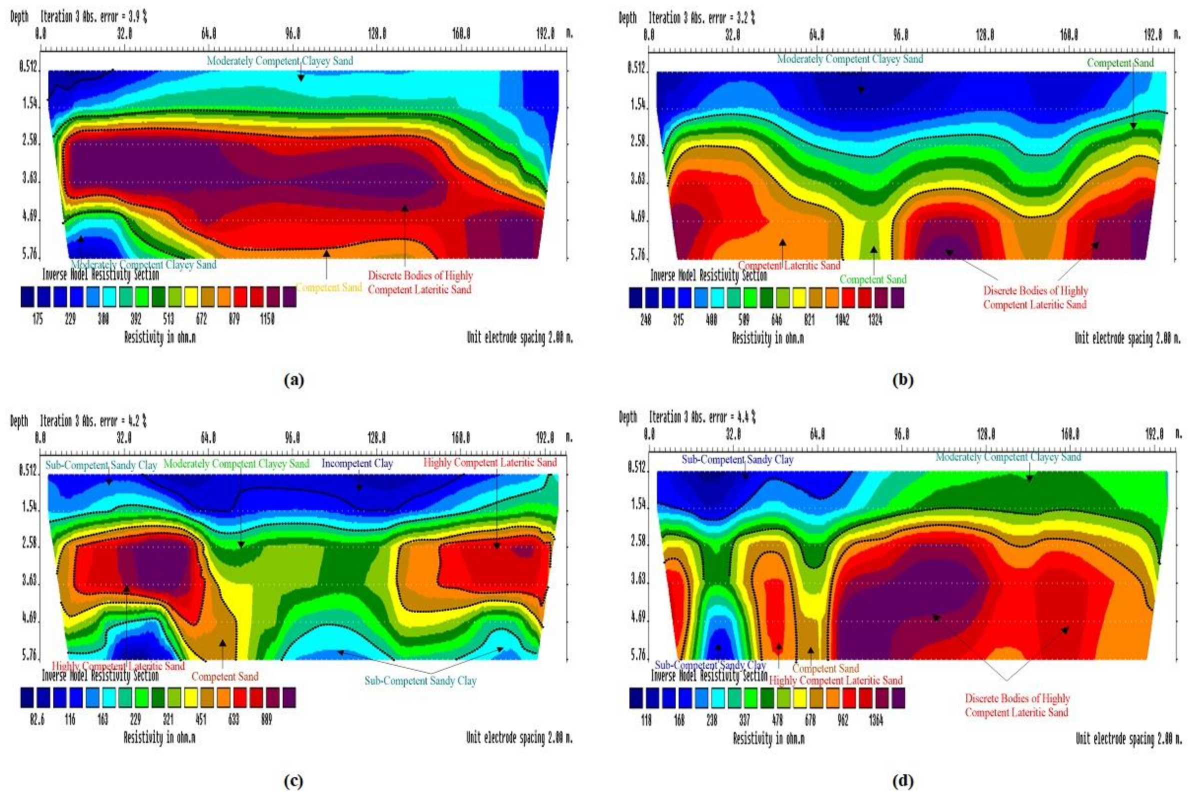


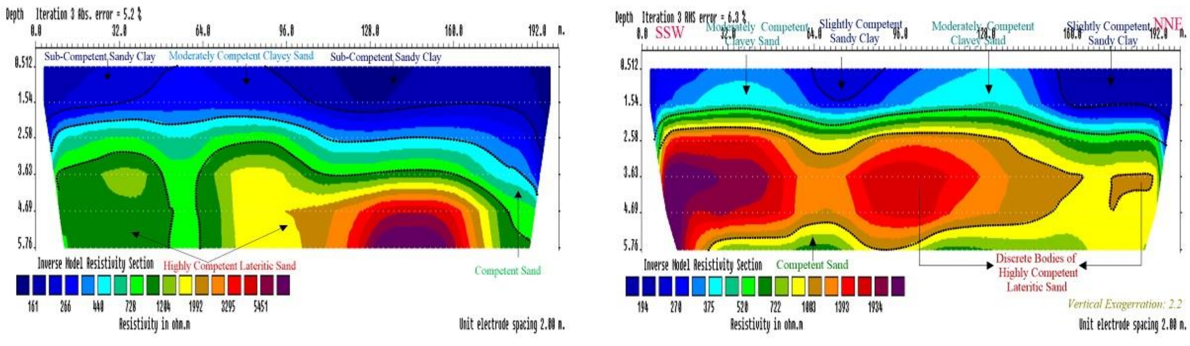
Figure 8: Electrical Resistivity Section along profiles 5 – 8 (a – d)

The resistivity section (fig. 8(a)) thoroughly describes the condition of the subgrade along profile five. In a general sense, the resistivity range of the entire geo-electric components of the subgrade is 121 Ωm – 1692 Ωm. Four (4) geo-electric components have been identified. The resistivity of these components varies from 121 Ωm – 175 Ωm for sub-competent sandy clay, 200 Ωm – 458 Ωm for moderately competent clayey sand, 513 Ωm – 879 Ωm for competent sand stratum, and > 1000 Ωm for highly competent lateritic sand.

Profile six is presented in the resistivity section (fig. 8(b)). The subgrade's geo-electric components show a resistivity range of 214.5 Ωm – 1888 Ωm. There are four identified geo-electric components. Moderately competent clayey sand has a resistivity range of 214.5 Ωm – 454.5 Ωm, competent sand ranges from 490 Ωm – 821 Ωm, competent lateritic sand ranges from 932 Ωm – 1000 Ωm, and highly competent lateritic sand has a resistivity of > 1000 Ωm.

The detailed subgrade condition along Profile seven is extensively presented in the resistivity section (fig. 8(c)). In a general sense, the resistivity of the entire geo-electric components of the subgrade ranges from 65.9 Ωm to 1115 Ωm. There are four geo-electric components with resistivity ranges: 16.7 Ωm – 99.3 Ωm for incompetent clay, 110 Ωm – 196 Ωm for sub-competent sandy clay, 200 Ωm – 386 Ωm for moderately competent clayey sand, 451 Ωm – 600 Ωm for competent sand stratum, and > 1000 Ωm for highly competent lateritic sand.

The resistivity section (fig. 8(d)) provides a comprehensive overview of the subgrade condition along Profile eight. In a broad sense, the resistivity of the entire subgrade's geo-electric components ranges from 93 Ωm to 1766 Ωm. Four (4) geo-electric components have been identified, with resistivity ranging from 93 Ωm to 200 Ωm for sub-competent sandy clay, 203 Ωm to 460 Ωm for moderately competent clayey sand, 478 Ωm to 820 Ωm for competent sand stratum, and 900 Ωm to 1766 Ωm for highly competent lateritic sand.



(a) (b)

Figure 9: Electrical Resistivity Section along profile 9 – 10 (a – b)

The subgrade condition in profile nine is extensively described in the resistivity section (fig. 9(a)). Overall, the entire geo-electric elements of the subgrade show a resistivity range of 108 Ωm – 7602 Ωm. A total of four (4) geo-electric elements have been identified. The resistivity of these components varies from 108 Ωm to 214 Ωm for sub-competent sandy clay, from 250 Ωm to 360 Ωm for moderately competent clayey sand, from 440 Ωm to 980 Ωm for competent sand stratum, and is above 1000 Ωm for highly competent lateritic sand.

A detailed description of the subgrade condition along profile ten is provided in its resistivity section (fig. 9(b)). The geo-electric properties of the subgrade show a resistivity range of 166 Ωm to 2715 Ωm, confirming the absence of clay. Four (4) geo-electric components have been identified. The resistivity of these components varies from 117 Ωm to 137 Ωm for incompetent sandy clay pockets, from 150 Ωm to 187 Ωm for slightly competent superficial sandy clay, from 221 Ωm to 376 Ωm for moderately competent clayey sand, from 505 Ωm to 940 Ωm for competent sand stratum, and is greater than 1000 Ωm for highly competent lateritic sand.

Discussion

Area of anomalies on each profile is revealed by the ground magnetic investigation carried out at the study area. The relative magnetic intensity against horizontal distance along all profiles show a range of values from -1689.78 nT on profile one to +2943.85 nT on profile two which represents fault/fractured zone of low intensities and competent zone of high intensity respectively. These areas of low and high spikes of intensities indicate fault/fractured zones that are incompetent for foundation structures while area of high spikes of magnetic intensities represents competent zones for foundation structures. The average California Bearing Ratio (CBR) of the study area range from 11.20% on profile two to 39.87% on profile seven which is interpreted as soil of fair to good characteristics suitable for sub-grade and base materials for foundation structures. Electrical resistivity tomography results of the subsurface of the study area has the range of resistivity value across the profiles from 2 Ωm on profile one – 7602 Ωm on profile nine revealing four (4) main geo-electric components were of incompetent clay, sub-competent sandy clay, moderately competent clayey sand, competent sand and lateritic sand. Areas characterised by incompetent clay and sub-competent sandy clay are not suitable for foundation structures, moderately competent clayey sand zones required compartment while competent sand and lateritic sand are good for foundation structures.

CONCLUSION

This research work has revealed the geoelectrical parameters of the study location and the integrated approach of geophysical and geotechnical methods give a clear picture of the subsurface on which foundation structures are to be constructed or were constructed. Ground magnetic method deployed revealed the area of anomalies within the study area for the deployment of other methods. The California bearing ratio values of the study area gives materials of soil with fair to good characteristics suitable for use as subgrade and base materials in foundation structures. The areas of low resistivity adjudged to be incompetent zones and competent zones characterized by high resistivity values were identified with the electrical resistivity imaging results. The study area is characterized by the presence of incompetent clay and sandy clay, moderately competent clayey sand, competent sand and highly competent lateritic sand. It is recommended that area of incompetent/sub-competent materials in the study area be removed and filled with competent lateritic sand before foundations are put in place in such area.

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