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| Research Article |

Subsurface Geotechnical Competence Evaluation Using Geoelectric Sounding and Direct Cone Penetrometer Test at Plural Garden Estate, Ilaramokin Southwestern Nigeria

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Abstract: In order to evaluate the geotechnical competence of the subsurface soil materials at Plural Garden Estate, Ilaramokin Southwestern Nigeria, geotechnical investigations involving geoelectric sounding and Direct Cone Penetrometer Test (DCPT) was carried out in the estate. A total of 27 VES points and 8 DCPT points were occupied across the study area. A, H, K, Q and KH are the five sounding curve types delineated in the area. Resistivity values of the top soil, weathered layer, fractured layer and fresh bedrock vary from 65-864, 156-1698, 28-217, 433-12167 ohm-m respectively, while their thicknesses vary from 0.7-3.7, 2.4-10.5 and 6.3-40.1 m in the upper three layers respectively. The geoelectric sounding results were presented as depth slices at depths of 0.5, 0.75, 1.0 and 2.0 m competency maps. Larger part (70 to 80 %) of the surfaces (1.0 and 2.0 m) considered in the study area are characterized as moderate to high competent. The depth slice iso-resistivity maps indicated that geotechnical competence increases with depth within the shallow depths considered (0.5, 0.75, 1.0 and 2.0 m). Geotechnical test involving DCPT were done at common depth of 1.0 m to validate the 1.0 m competency map. The DCPT agreed with the geoelectrical derived 1.0 m depth slice competence map. Some zones suspected to be very low and low competence were revealed to be competent based on DCPT suggesting that the low resistivity may be due to the presence of non-plastic clay and moisture.

Keywords: Subsurface; geotechnical competence; geoelectric sounding; Direct Cone Penetrometer

INTRODUCTION

Thorough investigations of the subsurface's lithology and structures are very essential in evaluating geotechnical competence (Coker, 2015a; Olayanju et al., 2017). Poor geotechnical competence arising from presence of geologic structures such as fractures, joints, faults, cavities and sinkholes are responsible for collapse of many engineering structures (Adeyemo & Omosuyi, 2012; Adelusi et al., 2013; Adeyemo et al., 2014; Longoni et al., 2016; Ademila et al., 2020; Airen, 2021). Presence of expansive clay minerals (such as illite, chlorite, montmorillonite, halloysite among others) in the subsoil materials can results in differential settlement in the subsoil materials leading to foundation failure (Egwuonwu et al., 2011; Das & Roy, 2014; Okoro et al., 2014). Other geologic conditions capable of precipitating foundation problems are shallow depth to bedrock, poor soil strength and shallow static water level (Ugwu & Ezema, 2013; Adeyemo et al., 2020).

Many building collapses in Nigeria have been linked to absence of pre-foundation studies. Most of these buildings were built on sub-soils materials with inadequate bearing capacity to support the weight of such building. The necessity of site characterization for construction purposes is very important so as to prevent loss of valuable lives and properties that always accompany such collapse. Some non-geological reasons why buildings may be susceptible to collapse have been advanced, which include poor quality of building materials, non-adherence to standard practice, salinity, poor maintenance practices, faulty design of foundation and aging of buildings (Oyedele et al., 2011; Oseghale et al., 2015; Oyediran & Famakinwa, 2015; Pegah & Liu, 2016).

Geophysical methods are found to be very useful and reliable in assessing the suitability of an area for the construction of an engineering structure such as buildings, roads, bridges, dams among others

(Olayanju et al., 2017; Adeyemo et al., 2020; Pegah & Liu, 2016). Geophysical methods are suitable for determining the depth to the bedrock, detecting the presence of bedrock structures (voids, joints, fractures and faults), delineating presence of expansive clay minerals and other potentially dangerous subsurface conditions before the erection of any engineering structure (Soupious et al., 2007; Ademila, 2015). For better assessment of geologic materials, geotechnical methods are combined with geophysical investigation to assess the competence of the subsoil materials to avoid foundation failures (Owoyemi & Awojobi, 2016; Alawode et al., 2020). Combining the two methods helps to provide control and ground-truth information of the subsurface (Olatinsu et al., 2018). Geophysical and geotechnical methods complement each other in site investigation (Adejumo et al., 2016; Coker, 2015b; Adiat et al., 2017; Oladunjoye et al., 2017; Bayode & Egbebi, 2020).

In order to ensure stability of building foundations and to prolong the life span of the buildings in the estate, proper geotechnical assessment of the proposed site is considered imperative. The research hypothesis of this study was hinged on the fact that geotechnical investigation such as DCP test are conventionally recognized as tools for assessing subsoil geotechnical competence, while geophysical investigation is gradually becoming popular in subsurface geotechnical competence evaluation. Deploying DCP test as a follow up to geoelectric sounding survey will enhance the degree of confidence of subsoil competence evaluation and if good correlation is established between the two methods, then geoelectric sounding methods can be relied upon for geotechnical competence evaluation in similar geologic terrain.

Description of the study area

Ilaramokin is a fast-growing town, near Akure Southwestern, Nigeria. There is a need for an adequate housing development that can cater for the increasing population and standard of living in the community. Housing development improves the quality of life of residents leading to better health, jobs creation, security and population diversity. The desire to provide adequate and befitting accommodation for the growing population of the town led to the creation and development of the satellite estate, Plural Garden estate along Ilesha-Akure highway.

Plural Garden Estate, Ilaramokin is located along Ilesha-Akure highway, Southwestern Nigeria. The estate is situated about 5 kilometers west of Akure metropolis (Figure 1). The study area is located within 732110-732189 mE (Easting) and 812025-811776 mN (Northing) of the Universal Transverse Mercator (UTM). Ilaramokin is bounded at the north by Ikota and Ijare towns, at the east by Ipinsa and Akure, at the south by Ipogun and Ibule towns and at the west by Igbaraoke and Ero. All these adjoining towns are connected by the major Akure-Ilesa highway and many other minor roads.

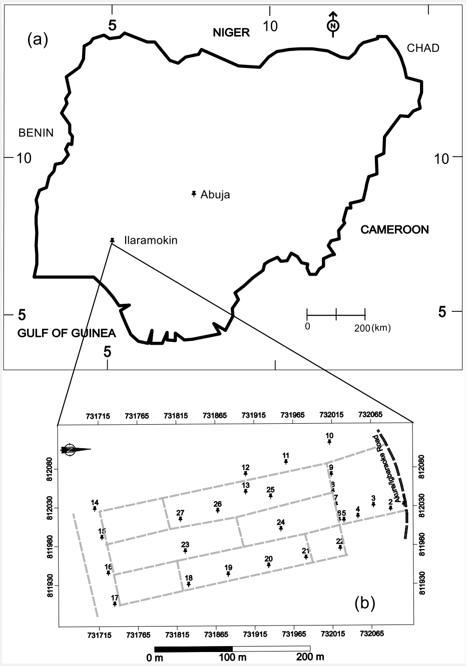


Figure 1. Location maps of the study area; (a) Nigeria layout map (b) Basemap of Plural Estate, Ilaramokin

Plural Garden estate is situated on moderately undulating terrain with surface elevation varying from 345 to 351 m above mean sea level (Figure 2). Ilaramokin is underlain by rocks of the Precambrian Basement Complex of Southwestern Nigeria. The lithological units observed in the area include variably migmatized biotite-hornblende gneiss with intercalated amphibolite. Low lying outcrops of migmatite-gneiss complex are situated in the town while boulders of amphibolite/charnockite rocks are located in the central and north central areas of the town. The area falls within the humid tropical climatic zone which is characterize by two seasons. A typical wet season extends from April to October, while the dry season extends from November to March. Annual rainfall ranges between 100 and 1500 mm, with average wet days of about 100. Annual temperature varies between 180 and 340 °C (Iloeje, 1980).

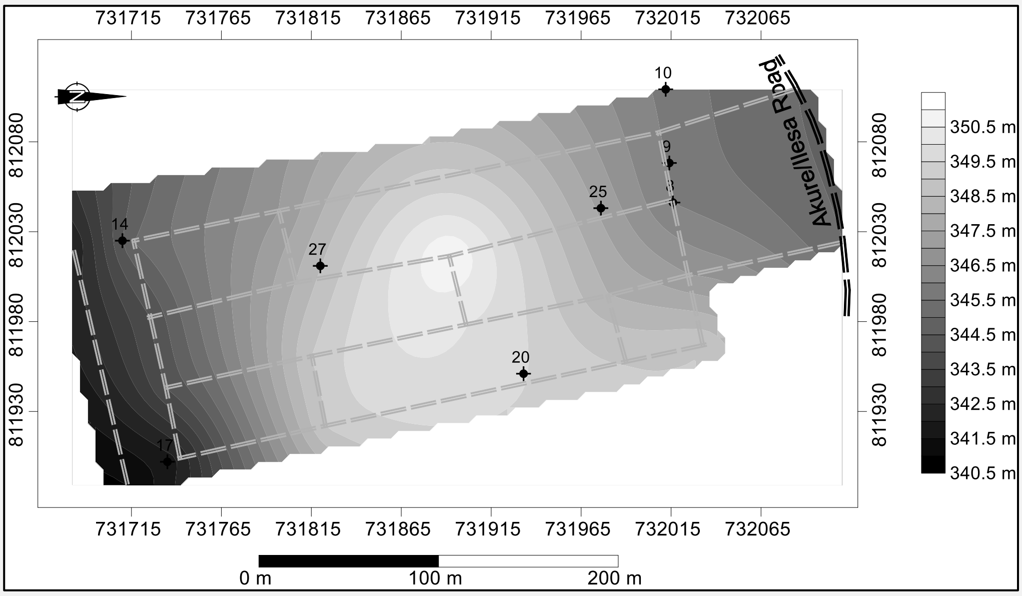


Figure 2. Elevation map of the study area

MATERIALS & METHODS

A combination of vertical electrical sounding (VES) and dynamic cone penetrometer tests were utilized in this work. The choice of VES technique is based on its high resolution and non-intrusive nature. The VES technique allows for delineation of shallow to medium subsurface layers, their resistivity and thickness values (Keller & Frischknecht, 1966; Koefeod, 1979). Layer resistivity value have been used to infer subsurface layer lithology and geotechnical competence (Idornigie & Olorunfemi, 2006; Adiat et al., 2017; Oladunjoye et al., 2017; Bayode & Egbebi, 2020).

The dynamic cone penetrometer test is a direct, speedy and non-intrusive means of evaluating the subsurface layer load bearing capacity and competence. The geotechnical investigation such as DCP test are conventionally recognized tools for assessing subsoil geotechnical competence, while geophysical investigation methods are gradually becoming popular in subsurface geotechnical competence evaluation. In this study, DCP test was deployed as a follow up to geoelectric sounding survey at Plural Garden Estate, Ilaramokin Southwestern Nigeria in order to enhance the degree of confidence of subsoil competence evaluation in the study area.

Geophysical method (Vertical Electrical Sounding)

Vertical electrical sounding (VES) using Schlumberger configuration was adopted for the geoelectric sounding survey. Twenty-seven (27) VES positions were occupied across the study area (Figure 3). Resistance values were read off the resistivity meter and subsequently apparent resistivity values (ρ_a) are calculated using equation for Schlumberger configuration below.

$$\text{Thus, } \rho_a = 2\pi R\left[\frac{L^2 - l^2}{4l}\right] \tag{1}$$

When L>>>l i.e. $L^2 - l^2 \approx L^2$
Such that,

$$\rho_a = \frac{\pi R L^2}{2l} \tag{2}$$

Equation 2 can also be written as;

$$\rho_a = \frac{\pi R \left({}^{AB}/_{2}\right)^2}{MN} \tag{3}$$

The apparent resistivity (ρ_a) values were subsequently plotted on a bi-log paper as VES curves and then interpreted using conventional manual curve matching technique (Keller & Frischknecht, 1966; Koefeod, 1979). The interpreted results were iterated using window Resist, a 1-D forward modelling software (Vander Velpen, 2004). The VES results were used to generate different iso-resistivity maps of the study area.

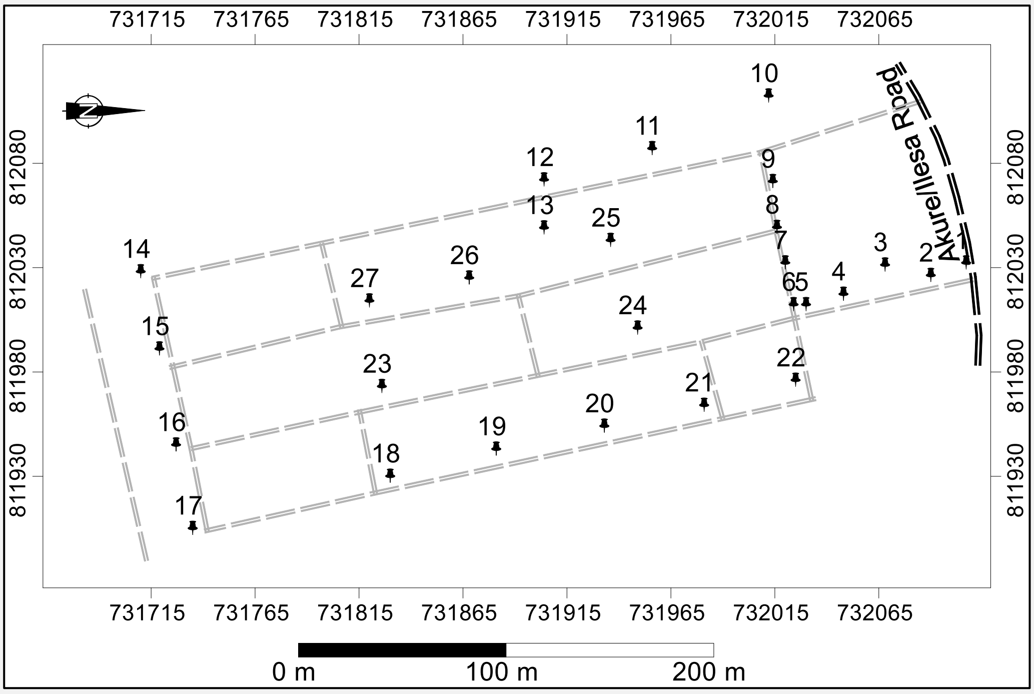


Figure 3. Map of study area showing VES points

Geotechnical method (Dynamic Cone Penetrometer tests)

The Dynamic Cone Penetrometer tests (Figure 4) were conducted at common depth of 1.0 m which was guided by Vertical electrical sounding (VES) results. The Dynamic Cone Penetrometer consists of a hammer, guide, anvil, driving rod, and cone tip. The dynamic impact for the penetration was performed by dropping an 8 kg hammer from a free-falling height of 575 mm. The impact energy was transferred through the driving rod with a diameter of 16 mm, and the energy transferred at the cone tip with a diameter of 20 mm leads to the cone penetration into the subgrade. For each dynamic impact, the DCPI is measured, which is used for continuous subgrade profiling. The DCPI can be simply obtained using the following equation.

$$\text{DCPI [mm/blow]} = D_n+1 - D_n \ (1) \tag{4}$$

Where, D_n is the penetration depth of the DCP at a blow count of n. The DCPI is the only obtainable strength index from the DCP test, and it depends on the energy transferred at the cone tip that might reduce the reliability of the DCP results. Once the test apparatus is assembled the DCP is placed at the test location and the initial penetration of the rod is recorded to provide a zeroing scale. While holding the rod vertically, the weight is raised to the top of the rod 575 mm above the anvil and dropped.

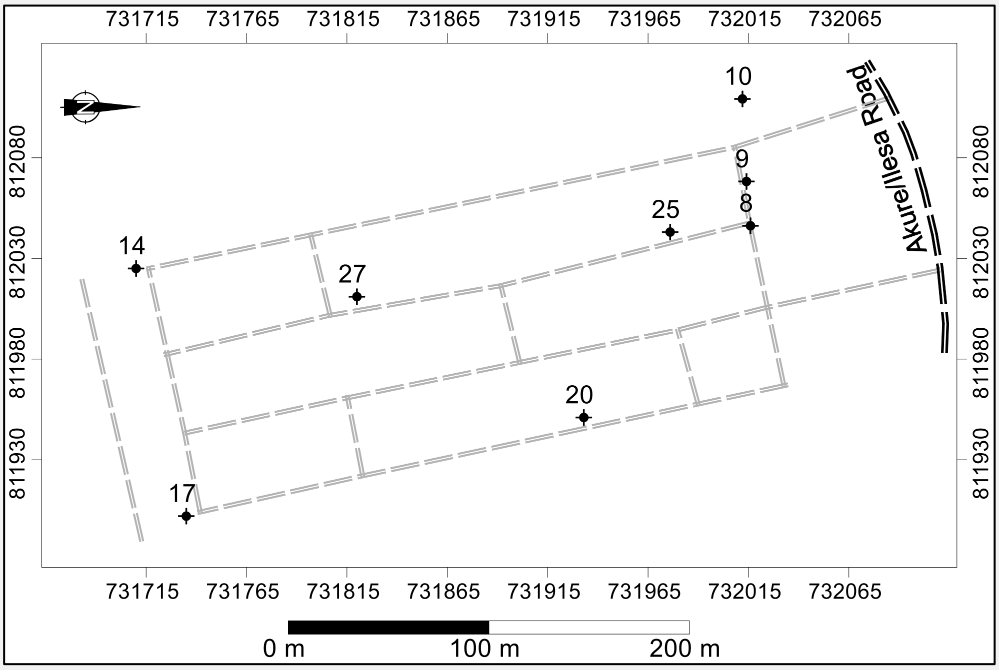


Figure 4. Map of study area showing DCPT points

RESULTS AND DISCUSSION

Vertical Electrical Sounding Results

The Vertical Electrical Sounding (VES) results delineated three to four geoelectric layers across the study area namely the topsoil, weathered layer, partially weathered/partially fractured basement and presumed fresh basement. The resistivity of the top soil, weathered layer, partially weathered/partially fractured basement and presumed fresh basement varies from 65-864, 156-1698, 28-217 and 433-12167 ohm-m respectively, while their thicknesses vary from 0.7-3.7, 2.4-10.5 and 6.3-40.1 m in the top soil, weathered layer, partially weathered/partially fractured basement respectively. The A, H, K, Q and KH are the five sounding curve types delineated across the area (Table 1). The KH curve is the predominant curve type in the area with percentage of occurrence of 45%, the A curve type has 25% occurrence, the H curve has 20% occurrence, while the K and Q curves are the least with 5% occurrence each (Table 1). The VES results were presented as depth slice maps at different depth surfaces (0.5, 0.75, 1.0, 1.5 and 2.0 m) classified into different geotechnical competence zones (Table 2) according to Idornigie & Olorunfemi (2006).

The 0.5 m depth slice iso-resistivity map of Ilaramokin (Figure 5) indicated that about 75% of the estate can only be considered as moderately competent (100-350 Ωm) and highly competent (above 750 Ωm) areas, while about 25% of the area, the southwestern and southeastern parts of the area are considered to be incompetent area (0-100 Ωm).

The 0.75 m depth slice Iso-resistivity map (Figure 6) reveals that at this depth surface, about 65% of the estate, the center region can be considered to be moderately competent (100-350 Ωm), while about 20% of the area, the northeastern parts are considered to be competent (350-750 Ωm) and highly competent (above 750 Ωm) areas. Some parts of the eastern and south western areas are incompetent zones.

The 1.0 m depth slice Iso-resistivity map (Figure 7) indicates that at this depth surface, about 75% of the area can be considered to be moderately competent (100-350 Ωm), while about 25% of the area, the northeastern parts are considered to be competent (350-750 Ωm) and highly competent (above750 Ωm) areas. It is interesting to note that there is an increase in the area considered to be competent at this surface; this is probably due to the shallow depth to fresh basement rocks in this area.

The 2.0 m depth slice iso-resistivity map (Figure 8) indicates that about 80% of the estate can only be considered as moderately competent (100-300 Ωm), while about 15% of the area, the north eastern part of the area is considered to be competent zones (400-750 Ωm) and highly competent (above 750 Ωm) zones. A small portion of the estate at the south western part is incompetent.

Table 1. Summary of the VES Results

VES No	Easting	Northing	Resistivity $\rho_1/\rho_2/\ldots\ldots/\ \rho_n$ (Ωm)	Thickness $h_1/h_2/\ldots\ldots/h_n$ (m)	Curve Type
1.	732107	812029	90/780/168/5505	0.7/6.3/31.7	KH
2.	732090	812023	131/1081/217/1480	0.6/2.4/28.8	KH
3.	732068	812028	94/393/84/4432	1.0/7.3/17	KH
4.	732048	812014	89/413/104/1454	1.1/5.7/21.5	KH
5.	732030	812009	71/580/52/5924	0.9/4.2/14.4	KH
6.	732024	812009	78/312/28	1.0/10.5/6.3	KH
7.	732020	812029	80/980/68/10045	0.7/4.1/14.2	KH
8.	732016	812046	119/908/94/2185	0.9/6.1/23.2	KH
9.	732014	812068	864/1698/264	3.7/0.8	Q
10.	732012	812109	282/513/173/324	0.7/6.6/38.0	KH
11.	731956	812084	294/471/191/925	1.0/7.4/28.7	KH
12.	731904	812069	131/43/2652	5.2/17.9	H
13.	731904	812046	66/99/1800	0.8/40.5	A
14.	731710	812025	112/63/1490	1.9/15.1	H
15.	731719	811988	104/60/3231	1.2/16.7	H
16.	731727	811942	114/53/522	2.4/10.1	H
17.	731735	811902	65/39/390	1.0/7.3	H
18.	731830	811927	92/217/105/786	0.9/3.5/7.8	KH
19.	731881	811940	162/205/361	1.0/14.2	A
20.	731933	811951	88/343/146/534	1.0/5.8	KH
21.	731981	811961	105/385/141/433	1.2/4.7/6.5	KH
22.	732025	811973	108/184/7	2.4/17.5	K
23.	731826	811970	76/266/2174	0.8/26.1	KH
24.	731949	811998	155413/180/12167	2.3/8.3/40.1	AH
25.	731936	812040	99/157/421	1.2/15.1	A
26.	731868	812022	310/156/1086	1.7/19.9	H
27.	731820	812011	96/285/82/1253	0.7/2.9/13.1	KH

Table 2. Soil Competence Rating (After Idornigie and Olorunfemi, 2006)

Resistivity (Ωm)	Possible Lithology	Competence Rating
<100	Clay	Incompetent
100-350	Sandy clay	Moderately Competent
350-750	Clayey sand	Competent
>750	Sand/Laterite/Bedrock	Highly competent

The depth slice iso-resistivity maps (Figures 5-8) indicated that within the shallow depths considered (0.5, 0.75, 1.0 and 2.0 m) in the study area geotechnical competence increases with depth.

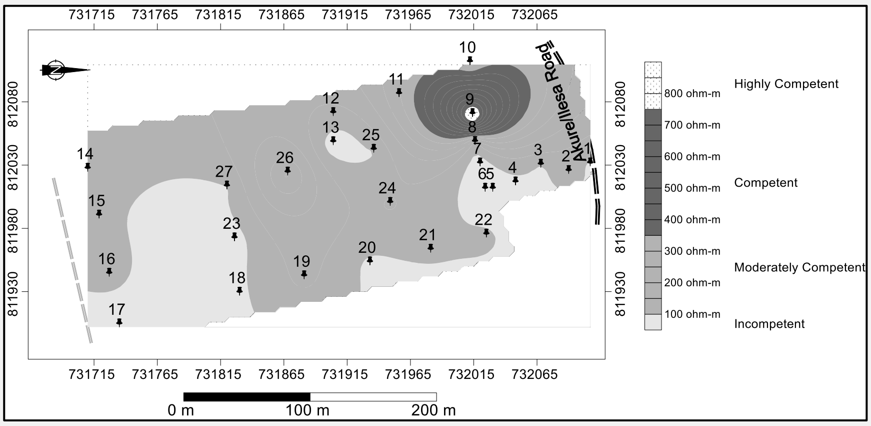


Figure 5. 0.5 m depth slice competency map

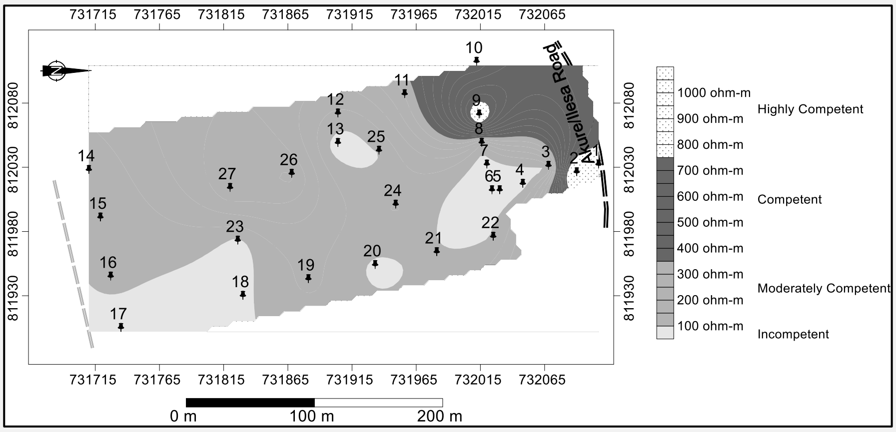


Figure 6. 0.75 m depth slice competency map

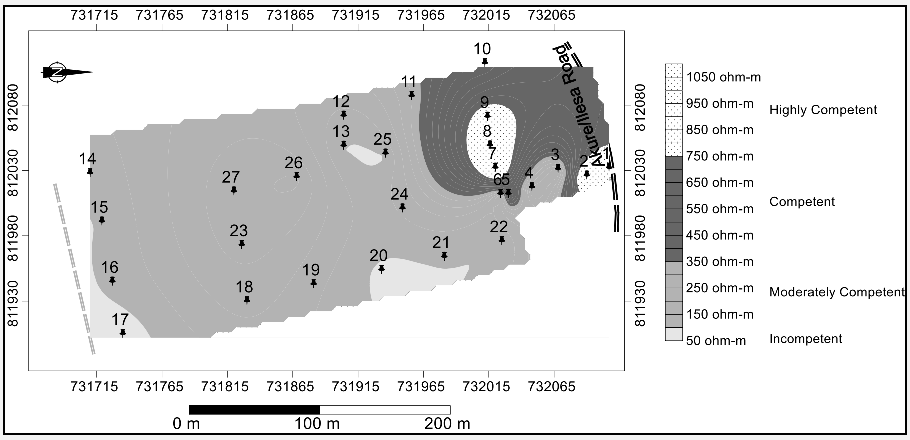


Figure 7. 1.0 m depth slice competency map

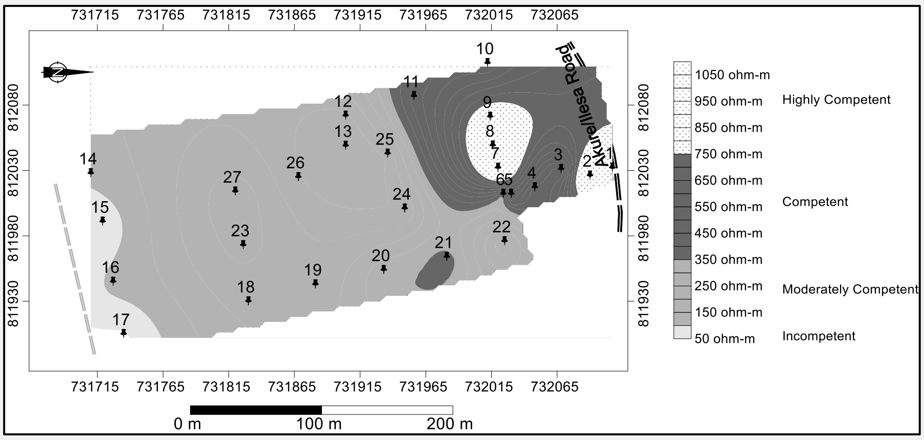


Figure 8. 2.0 m depth slice competency map

Geotechnical Test Results

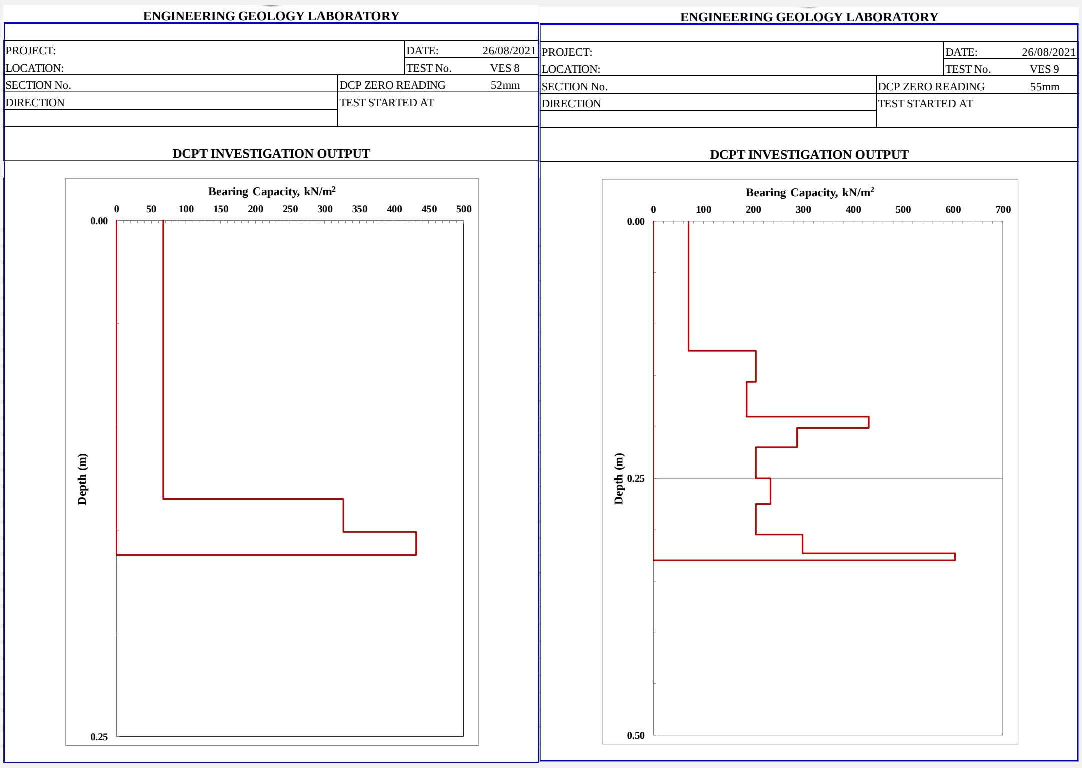
Dynamic Cone Penetration Tests (DCPT) can assist in determining the near subsurface soil materials bearing capacity. Soil type can also be inferred from DCPT values (Tables 3 and 4). DCPT was carried out at 8 different locations in the study area using the Dutch type (DIN) apparatus. The DCPT were conducted to determine the bearing capacity of the near subsurface soil materials with depth up to the maximum depth of 1.0 m. The tests were taken at VES points 8, 9, 10, 14, 17, 25 and 27 to validate the results from the electrical resistivity data at 0.5m and 0.75 m (Figures 5 and 6). From the result, the bearing capacity values at 0.5 m (Figure 9) varies from 70-326 (kN/m²). This correlates well with the geophysical data that 55% of the estate can only be considered as moderately competent (100-300 Ωm).

Table 3. Non-Cohesive Soils Rating with bearing capacity (Bearing Values BS: 8004)

Bearing Capacity (KN/m²)	Soil
<100	Loose Sand
100-350	Medium Dense Sand
>300	Compact sand
>200	Loose gravel or sand
200-600	Medium dense sand
>600	Dense Sand/Gravel

Table 4. Cohesive Soils Rating with bearing capacity (Bearing Values BS: 8004)

Bearing Capacity (KN/m²)	Soil
<75	Soft Clays and Silts
75-150	Firm Clay
150-300	Stiff Clays
300-600	Hard Clays
200-600	Medium dense sand
>600	Dense Sand/Gravel


ENGINEERING GEOLOGY LABORATORY

PROJECT:
LOCATION:
DATE: 26/08/2021
TEST No. VES 8
SECTION No.
DCP ZERO READING 52mm
DIRECTION
TEST STARTED AT

DCPT INVESTIGATION OUTPUT

ENGINEERING GEOLOGY LABORATORY

PROJECT:
LOCATION:
DATE: 26/08/2021
TEST No. VES 9
SECTION No.
DCP ZERO READING 55mm
DIRECTION
TEST STARTED AT

DCPT INVESTIGATION OUTPUT

Figure 9. Bearing capacity result at VES 8 (left) and VES 9 (right)

Zones indicating high competency in the geophysical result at this depth was validated by DCPT to have high bearing capacity. From the result, the bearing capacity values at 0.75 m (Figure 9) varies from 95-186 (kN/m²). This correlates with the geophysical data that 65% of the estate can only be considered as moderately competent. However, the DCPT could not get to the depth of 1.0 m since the points of refusal were always reached before 1.0 m depth, and this shows that the estate is geotechnically competent at this depth slice. The higher the resistivity values the higher the bearing capacity of the soil (Tables 5 and 6). Idornigie & Olorunfemi (2006) revealed that high resistivity depicts competent geologic materials, such as sand or clayey sand formation, while very low resistivity suggests clay or sandy clay materials (often less competent to support the stability of heavy engineering structures).

Table 5. Comparison apparent resistivity with bearing capacity at 0.5m

Location	Apparent Resistivity	Bearing Capacity
8	119.2	-
9	864.3	-
10	282.3	204
14	112.2	107
17	65.3	70
20	88.1	149

Table 6. Comparison apparent resistivity with bearing capacity at 0.75m

Location	Apparent Resistivity	Bearing Capacity
8	119	-
9	864	-
10	513	186
14	112.2	111
17	65.3	95
20	88.1	-

CONCLUSION

In order to evaluate the geotechnical competence of the subsurface soil materials at Plural Garden Estate, Ilaramokin Southwestern Nigeria, geotechnical investigations involving geoelectric sounding and Direct Cone Penetrometer Test (DCPT) was carried out in the estate. A total of 27 VES points and 8 DCPT were occupied across the area. Five sounding curve types (A, H, K, Q and KH) were the delineated in the area. The KH curve is the predominant curve type in the area with percentage of occurrence of 45%, the A curve has 25% occurrence, the H curve has 20% occurrence, while K and Q curves are the least with 5% occurrence each. The resistivity of the top soil, weathered layer, fractured layer and fresh bedrock varies from 65-864, 156-1698, 28-217, 433-12167 ohm-m respectively, while their thicknesses vary from 0.7-3.7, 2.4-10.5 and 6.3-40.1 m in the three upper layers respectively. The geoelectric sounding results were presented as depth slices at depths of 0.5, 0.75, 1.0 and 2 m competency maps. The depth slice iso-resistivity maps indicated that geotechnical competence increases with depth within the shallow depth slices (0.5, 0.75, 1.0 and 2.0 m) considered in the study area,

Geotechnical test involving DCPT were done at common depth of 1.0 m to validate the 1.0 m iso-resistivity depth slice competence map. DCPT characterized the soil into bearing capacity and depth relation; the top 1 m indicated a bearing capacity between 100-600 kPa and is classified as clayey sands with a mixture of silt and gravel overlaying 160-250 kPa probably consisting of non-cohesive sand. The DCPT agreed with 1.0 m iso-resistivity depth slice map, however zones suspected to be very low and low competence were revealed to be competent based on DCPT suggesting that the low resistivity may be due to the presence of non-plastic clay and moisture content.

This study established the existence of high degree correlation between the two methods adopted for this work. This study has revealed that VES and DCPT are complementary and thus geoelectric sounding can be utilize successfully in assessing geotechnical competence in the absence of the conventional geotechnical methods.

REFERENCES

Adejumo, S. A., Oyerinde, A. O., & Aleem, M. O. (2015). Integrated geophysical and geotechnical subsoil evaluation for pre-foundation study of proposed sit of vocation skill and entrepreneurship center at the Polytechnic, Ibadan, Southwestern Nigeria. *International Journal of Scientific and Engineering Research, 6*(6), 910-917.

Adelusi, A. O., Akinlalu, A. A., & Nwachukwu, A. I. (2013). Integrated geophysical investigation for post-construction studies of buildings around school of science area, Federal University of Technology, Akure, Southwestern, Nigeria. *International Journal of Physical Sciences, 8*(15), 657-669. https://doi.org/10.5897/IJPS2012.0204

Ademila, O. (2015). Integrated geophysical survey for post foundation studies in a typical basement complex of Southwestern Nigeria. *The Pacific Journal of Science and Technology, 16*(2), 274-285.

Ademila, O., Olayinka, A. I., & Oladunjoye, M. A. (2020). Land satellite imagery and integrated geophysical investigations of highway pavement instability in Southwestern Nigeria. *Geology, Geophysics and Environment, 46*(2), 135-157. https://doi.org/10.7494/geol.2020.46.2.135

Adeyemo, I. A., & Omosuyi, G. O. (2012). Hydrogeologic, electrical and electromagnetic measurements for geotechnical characterization of foundation beds at Afunbiowo, near Akure, Southwestern Nigeria. *Indian Journal of Science and Technology, 5*(2), 1-6. https://doi.org/10.17485/ijst/2012/v5i2.13

Adeyemo, I. A., Akinlalu, A. A., Mogaji, K. A., & Odumosu, O. O. (2020). Integrated analysis of geophysical data for road networks sub base lithology integrity assessment: a case study in crystalline basement complex, Southwestern Nigeria. *Journal of Geography, Environment and Earth Science International, 24*(4), 15-28. https://doi.10.9734/JGEESI/2020/v24i430215

Adeyemo, I. A., Omosuyi, G. O., Olayanju, G. M., & Omoniyi, G. K. (2014). Hydrogeologic and Geoelectric Determination of Groundwater flow Pattern in Alaba-Apatapiti layouts, Akure, Nigeria. *International Journal of Engineering Sciences, 3*(2), 44-52.

Adiat, K. A.N., Akinlalu, A.A., & Adegoroye, A. A. (2017). Evaluation of road failure vulnerability section through integrated geophysical and geotechnical studies. *NRIAG Journal of Astronomy and Geophysics, 6*(1), 244-255. https://doi.org/10.1016/j.nrjag.2017.04.006

Airen, O. J. (2021). The use of geoelectric methods for post-foundation assessments of distressed buildings in Ebute-meta, Mainland Local Government Area of Lagos State. *Current Journal of Applied Science and Technology, 40*(10), 104-119. https://doi.org/10.9734/cjast/2021/v40i1031363

Alawode, A. A., Adunoye, G. O., Obitayo, L. O., & Omisakin, A. O. (2020). Assessment of bearing capacity of soils in Ile-Ife. *African Journal of Environment and Natural Science Research, 3*(5), 10-20.

Bayode, S., & Egbebi, A. A. (2020). Subsoil characterization for foundation stability using geophysical and geotechnical methods. *Journal of Environment and Earth Science, 10*(6), 82-107.

Coker, J. O. (2015a). Geophysical and geotechnical assessment of foundation failure: A case study of library complex area, Lagos State Polytechnic, Ikorodu, Lagos, Nigeria. *Research Journal in Engineering and Applied Sciences, 3*(7), 40-48.

Coker, J. O. (2015b). Integration of geophysical and geotechnical methods to site characterization for construction work at the School of Management Area, Lagos State Polytechnic, Ikorodu, Lagos, Nigeria. *International Journal of Energy and Science and Engineering, 1*(2), 40-48.

Das, A., & Roy, S. (2014). Effect of expansive soil on foundation and its remedies. *International journal of innovative research in science, engineering and technology, 3*(6), 92-95.

Egwuonwu, G. N., Ibe, S. O., & Osazuwa, I. B. (2011). Geophysical assessment of foundation depths around a leaning superstructure in Zaria Area, North-western Nigeria using Electrical Resistivity Tomography. *The Pacific Journal of Science and Technology, 12*(1), 472-486.

Idornigie, A. I., Olorunfemi, M. O., & Omitogun, A. A. (2006). Electrical resistivity determination of subsurface layers, subsoil competence and soil corrosivity at and engineering site location in Akungba-Akoko, southwestern Nigeria. *Ife Journal of Science, 8*(2), 159-177. https://doi.org/10.4314/ijs.v8i2.32216

Iloeje, N. P. (1980). *A new Geography of Nigeria (New Revised Edition).* London, UK; Longman Group.

Keller, G. V., & Frischknecht F. C. (1966). *Electrical Methods in Geophysical Prospecting.* Pergamon Press, Oxford.

Koefeod, O. (1979). *Geosounding principles, 1. Resistivity sounding measurements.* Elsevier Scientific Publ. Comp, Amsterdam, p 275.

Longoni, L., Papini, M., Brambilla, D., Arosio, D., & Zanzi, L. (2016). The role of the spatial scale and data accuracy on deep-seated gravitational slope deformation modeling: The Ronco landslide, Italy. *Geomorphology, 253*, 74-82. https://doi.org/10.1016/j.geomorph.2015.09.030

Okoro, L. C., Okeke, O. C., & Opara, A. I. (2019). Evaluation and treatment of swelling behavior of expansive soils in parts of Ohafia Southeastern Nigeria. *Academic Journal of Current Research, 6*(4), 1-20.

Oladunjoye, M. A., Salami, A. J., Aizebeokhai, A. P., Sanuade, O. A., & Kaka, S. I. I. (2017). Preliminary geotechnical characterization of a site in Southwest Nigeria using integrated electrical and seismic methods. *Journal of the Geological society of India, 89*, 209-215. https://doi.org/10.1007/s12594-017-0585-z

Olatinsu, O. B., Oyedele, K. F., & Ige-Adeyeye, A. A. (2019). Electrical resistivity mapping as a tool for post-reclamation assessment of subsurface condition at a sand-filled site in Lagos, southwest Nigeria. *SN Applied Sciences, 1*, 1-15. https://doi.org/10.1007/s42452-018-0028-5

Olayanju, G. M., Mogaji, K. A., Lim, H. S., & Ojo, T. S. (2017). Foundation integrity assessment using integrated geophysical and geotechnical techniques: case study in crystalline basement complex, southwestern Nigeria*. Journal of Geophysics and Engineering, 14*(3), 675-690. https://doi.org/10.1088/1742-2140/aa64f7

Oseghale, G. E., Ikpo, I. J., & Ajayi, O. D. (2015). Causes and Effects of building collapse in Lagos State, Nigeria. *Civil and Environmental Research, 7*(4), 34-43.

Owoyemi, O. O., & Awojobi, M. O. (2016). Assessment of Index Properties and Bearing Capacities of Soils for Infrastructure Foundations in Malete, Northcentral Nigeria. *Nigerian Journal of Basic and Applied Sciences, 24*(1), 82-89. https://doi.org/10.4314/njbas.v24i1.13

Oyedele, K. F., Oladele, S., & Adedoyin, O. (2011). Application of geophysical and geotechnical methods to site characterization for construction purposes at Ikoyi, Lagos, Nigeria. *Journal of Earth Science and Geotechnical Engineering, 1*(1), 87-100.

Oyediran, I. A., & Famakinwa, J. O. (2015). Geotechnical basis for building instability and failure: case study from Lagos, Nigeria. In *Engineering Geology for Society and Territory-Volume 5: Urban Geology, Sustainable Planning and Landscape Exploitation* (pp. 365-370). Springer International Publishing. https://doi.10.1007/978-3-319-09048-1_70

Pegah, E., & Liu, H. (2016). Application of near-surface seismic refraction tomography and multichannel analysis of surface waves for geotechnical site characterizations: A case study. *Engineering Geology, 208*, 100-113. https://doi.org/10.1016/j.enggeo.2016.04.021

Soupios, P. M., Georgakopoulos, P., Papadopoulos, N., Saltas, V., Andreadakis, A., Vallianatos, F., Sarris, A., & Makris, J. P. (2007). Use of engineering geophysics to investigate a site for a building foundation. *Journal of Geophysics and Engineering, 4*(1), 94-103. https://doi.org/10.1088/1742-2132/4/1/011

Ugwu, G. Z., & Ezema, P. O. (2013). 2D Electrical Resistivity Imaging for the Investigation of the subsurface structures at the proposed site for Kauridan estate at Ibagwa-Nike, Southeastern Nigeria. *International Journal of Scientific Research in Knowledge, 1*(12), 528. https://doi.org/10.12983/ijsrk-2013-p528-535

Vander Velpen, B.P.A. (2004). *Win RESIST Software Version 1.0.* ITC, IT-RSG/GSD, Delft, Netherlands.