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RESEARCH ARTICLE

FOUNDATION CHARACTERIZATION IN IKATE AREA SOUTHWESTERN NIGERIA USING ELECTRICAL RESISTIVITY TOMOGRAPHY AND CONE PENETRATION TEST

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ABSTRACT

The establishments of the nexus between the underlying geology and engineering properties are fundamentals to the safe, economic and serviceable designs of civil engineering structures. Cone Penetration Test (CPT) and Electrical Resistivity Tomography (ERT) are critical tools in foundation parameterization especially within Quaternary sediments serving as foundation of engineering structures. Both techniques were used to obtained point data and lateral continuity of geologic units within Ikate Area of Lagos Metropolis for foundation parameterization. Measurements which comprising 4 profiles of 2D resistivity imaging using the Wenner electrode configuration; 1 borehole and 12 cone penetration tests (CPT) were taken with Pasi Terrameter, percussion rig and the 10.0 tons penetrometer respectively. The ERT results interpreted using Dipro software were presented in Pseudo-sections while the cone penetration test results analysed with Microsoft Excel were represented as resistance curves. Interpretation from the two methods integrated with the borehole results reveals the presence clay, peat and sand of varying properties. The uppermost layer consists of medium dense sand followed by clay/peat of very low resistivity (< 3.5 ohm-meter) covering about 6. 0 – 8.0m in depth and terminating in another layer of sand (8.0 – 15.0m). The last sandy layer with cone resistance range between 30 – 120kg/cm^2 is considered a suitable layer upon which deep foundation may be founded. Shallow foundation capacity estimates at depths 0.2 – 4.0m derived from direct CPT data using three different computation techniques gives value range from 1.7 – 49.4kg/cm^2, 0.7 – 15.2kg/cm^2 and 0.4 – 12.6kg/cm^2 respectively. Deep foundation for skyscrapers within the area are advised to be founded within the competent layer encountered beyond 10.m depth.

KEYWORDS

Cone Penetration Test, Electrical Resistivity Tomography, Ikate Area, Shallow Foundation, Bearing Capacity, Nigeria

1. INTRODUCTION

Foundation parameterization is an essential component of civil engineering design process and one of the main steps towards a safe and economic foundation construction purpose. Information related to local soil conditions will aid in proper risk assessments and setting up of disaster mitigation measures. Such parameterizing procedure is particularly useful in sedimentary terrains underlain by recent depositions with sediments having heterogeneous mechanical attributes. The sedimentary succession within Lagos metropolis are punctuated with several lithologic units possessing physico-mechanical properties considered inimical to the foundation of engineering structures in the area (Ademeso et al., 2016, Faseki et al., 2016). Among the methods used in characterizing the subsurface layers and the determination of their bearing capacities are Electrical Resistivity Tomography (ERT), laboratory testing, Cone Penetration Test (CPT), Standard Penetration Test (SPT), full scale pile load test and using predetermined values recommended by codes. Many researchers have deployed various geophysical and geotechnical techniques to adequately mirror the subsurface conditions (Adiat et al., 2017; Faseki, 2018; Ademeso, 2021). More so, the adoption of advanced technology has necessitated the use of different electrical resistivity methods in solving problems that cut across civil engineering, archaeology, hydrology and environmental management (Adiat et al., 2017; Olatinsu et al., 2019).

The use of ERT method is often favored due to its ability to provide relevant data between separate borehole positions over large area while the CPT procedure is preferred due to its ability to detect discrete horizons that would normally be missed using drive samples at specific depth intervals. In foundation evaluation for building construction, ERT provides relevant data connected to early detection of potentially hazardous subsurface conditions (Oladele et al., 2015). The ERT wide application is due to its efficiency, low cost and high resolution capable of discriminating subsurface geology effectively (Coerts, 1996). It is armed with the capability to provide 1D, 2D and 3Dimensional subsurface images of an area. The CPT on its part is fast, economical and lend itself to empirical and analytical data interpretation process. In obtaining the bearing capacity using CPT, the direct and indirect approaches are used. The direct method used measured values of cone resistance with some modifications scaled to derive the respective capacity of each layer. Different direct method in use are as proposed by (Eslaamizaad and Robertson, 1992; Owkati, 1970; Meyerhof, 1976; CFEM,1992; Tand et al., 1994). The indirect method use friction angle and undrained shear strength values derived from CPT data based on bearing capacity theory. The direct method is

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however preferable as it eliminates errors associated with the scale effect and conversion of CPT field data to equivalent foundation parameters.

The combination of both methods in foundation characterization in the focus area will provide sufficient parameters needed for adequate design of safe foundation as well as avert potential foundation failure that may arise as a result of imposing excessive structural loads on the soil. Such combination of geoengineering tools is very important in Ikate area of Lagos metropolis due to the recent nature of the Alluvium deposits, hydraulic sand filing and frequent structural failures occurring in Lagos in general.

2. Location and Geology and of The Area

The study area is in Ikate Ancient Community with in Lekki Phase I in Eti-Osa local government area of Lagos State. It is in the southeastern part of the state (figure 1) and lies between latitudes $6^0\ 30^I\ 37^{II}$ and $6^0\ 30^I\ 18^{II}$ N and longitude $3^0\ 36^I\ 3^{II}$ and $3^0\ 35^I\ 34^{II}$ E in southwestern Nigeria. It is a zone of coastal creeks and lagoons developed by barrier beaches associated with sand deposition. It is situated in the Nigeria sector of the Dahomey Basin and near the eastern margin of the basin (figure 2). The Basin is surrounded westerly by faults and varying tectonic structures connected with the landward extension of the fracture zone. Its eastern limit is denoted by the Hinge line and a fault structure pinpointing the western limit of Niger Delta (Obaje, 1992). It is equally bounded northerly by the Precambrian Basement Rock and the Bright of Benin in the south. The chronological arrangements of rock units within the area from the uppermost are the Benin Sands, Ilaro Formation, Oshosun Formation, Akimbo Formation, Ewekoro Formation, and Abeokuta Group lying on the Southwestern Basement Complex of Nigeria (Jones and Hockey, 1964). The Ewekoro Formation overlying the Abeokuta Group consists of limestone, shale and clay members and is dated Palaeocene. The Ilaro Formation overlies the Ewekoro Formation and is of Eocene age. The Coastal Plains Sands unconformably overly the Ilaro Formation and is Pleistocene to Oligocene in age. The lithology consists essentially of sands, silts and clay deposits with traces of peat in part. The Quaternary sediments which comprises Benin Sand and Recent Alluvium serves as foundation of civil engineering structures in the area and is therefore the focus of the current work.

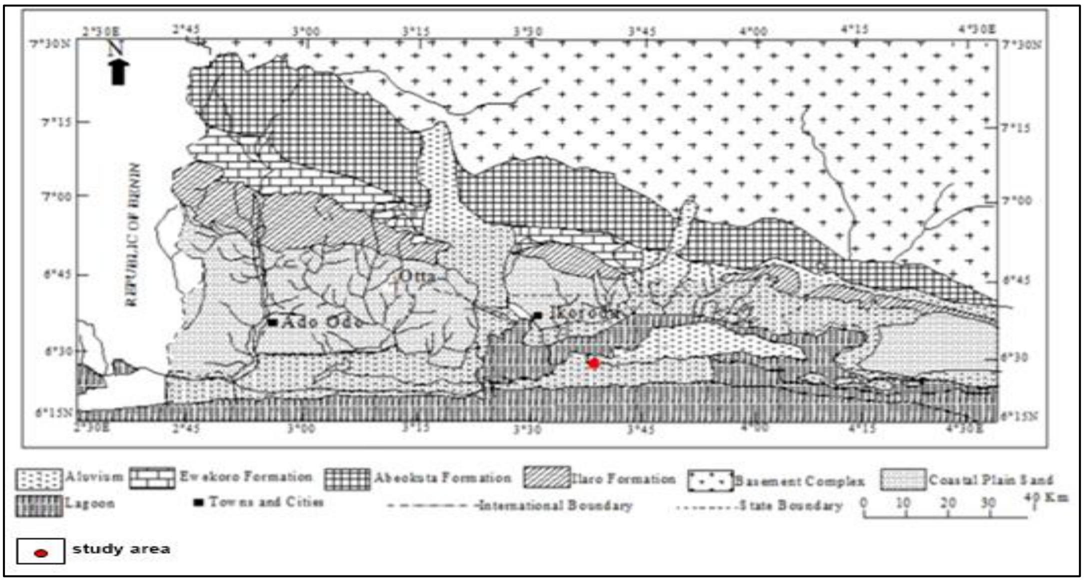

Figure 1: The Geological Map of the Study Area (Modified and Olorode, 2012).

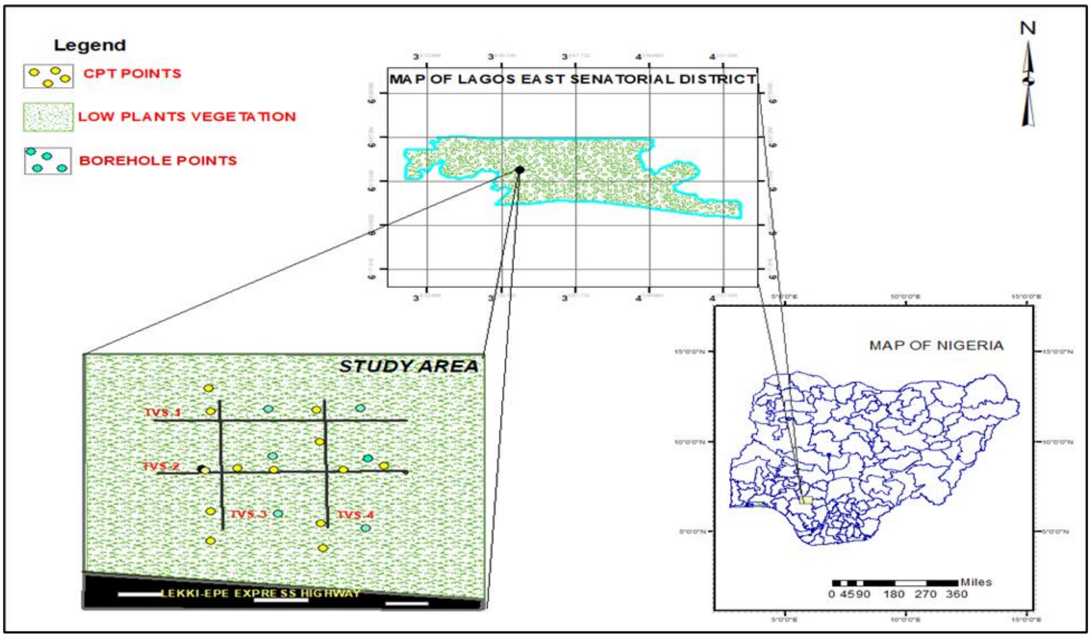

Figure 2: Base Map of the Study Area.

3. Materials and Method

The electrical resistivity method deploying Wenner array system to generate 2D profile of the subsurface was used. It was executed via Constant Separation Traversing (CST) techniques with PASI terrameter. The Resistivity data were recorded along four transverse lines, 100 m long, at inter-electrode spacing ranging from 5m to 30m. The Wenner array was chosen due to its strong signal strength and sensitivity to vertical changes in subsurface resistivity below the centre of the array (Loke, 2000). The data collected were processed using Dipro for modelling software (windows, 2001). The inversion was carried out as outline by (Sasaki, 1992; Loke and Barker, 1996). The starting model was constructed directly from the field measurements. After data processing, results were presented in form of colour cross-sections denoting variation of earth resistivity values with depth. Borehole data were further used to constrain the resistivity interpretation for different lithologies. One borehole was drilled up to 30.0m at the centre of the site to retrieve soil samples for laboratory study and constrained the data from both ERT and CPT. Nine cohesion-less and five cohesive samples retrieved from the boreholes were subjected to grain size analyses and Atterberg limit tests respectively. Execution of cone penetrometer test was done at twelve locations by forcing a hardened steel cone with a base area of 1000 mm^2 at an apex angle of 60° continuously into the ground and measuring its resistance to penetration. The 10.0-ton equipment measuring both end resistance and sleeve friction was deployed. The CPT was carried out in such a way that the CPT 1 – 3 was centered on traverse one, CPT 4 – 6 on traverse two, CPT 7 – 9 on traverse three and CPT 10 – 12 on traverse four respectively. The successive readings were plotted on excel software to generate resistance profiles while the obtained parameters were used in calculation of bearing capacity for shallow foundation. The three methods adopted for the estimation of the ultimate and allowable bearing capacity of soil between the depth of 0.20m and 4.0m are;

Canadian Foundation Engineering Manual (1992) designated as CFEM recommended an equation for evaluation of allowable bearing capacity using:

$$qa = 0.10 * qc$$

Also, using safety factor of 3 ultimate bearing capacity (q_{ult}) is

$$qult = 0.30 * qc$$

Eslaamizaad and Robertson (1996) designated as EAR; $qult = kqc$

where k is a correlation factor and is a function of B/D_f; shape of footing and sand density.

Owkati (1970) designated as OWK

$$qult = 28 - 0.0052(300\ qc)^{1.5} \text{ strip footings}$$

$$qult = 48 - 0.009(300\ qc)^{1.5} \text{ square footings}$$

q = in terms of kg/cm^2.

q_{ult} = ultimate bearing capacity, q_c = cone end resistance, q_a = allowable bearing capacity

4. Results and Discussion

The results of the ERT and CPT is presented in form of pseudo-sections and resistances profiles in figures 3 – 6 and 7 – 8 respectively.

4.1 Electrical Resistivity Tomography and Cone Penetration Test

The pseudo-sections generated along the four profiles are as arranged in figures 3 – 6. The pseudo-sections along all the traverses show that the subsurface soil sequence varies both vertically and laterally and imaged three geo-electric layers based on their respective resistivities. The layers include; clay, peat and sands with traces of silt in parts. Section along traverse one shows that the shallow subsurface varies laterally along the 100.0m stretch. The uppermost layer from the topsoil to approximately 2.50 – 3.0m is designated as sand. This layer of sand is considered a relatively competent layer to sustain shallow foundation loads. Beneath it is a layer of clay/peat with resistivity less than 3.50 ohm.m delineated vertically at 3 – 18.0m and horizontally along 25.0 – 45.0m stretch, this layer is not continuous laterally. The clear revelation of this undesirable layer by ERT emphasize its effectiveness over point data tools such as boring and CPT. The stretch from approximately 45.0 – 100.m and vertically from 2.50 – 18.0m reveals silty sandy layer. The signatures from CPT1 – CPT3 (figure 7) shows that the upper sandy layer has cone resistance that ranges between 4 – 120kg/cm^2 pinpointing a sandy layer which is consistent with the response from ERT as explained above. The low cone resistance value of 2kg/cm^2 at depth ranging from 2.50 – 8.0m (figure 7) is indicative of very soft clay and peat, this is also consistent with the ERT image (figures 3 – 6). Beyond that depth is an increase in the cone resistance signaling an encounter with another relatively resistive sandy layer. Also, along traverse two, three and four, three geo-electric layering consisting of sand. clay and peat were delineated (figures 4 – 6). The signatures from CPT 4 -6, CPT 7 – 9 and CPT 10 – 12 (figures 7 – 8) completely correlate with the results from ERT. The low cone resistance of 2 – 4$kg.cm^2$ defined the soft clay and peat zones along all traverses. The appearance of sand at depth above 8.0m were indicated with gradual rise in cone resistances up to 110kg/cm^2 to the refusal depth at 13.0m. The high strength values associated with depths

between 11 – 13.0m is suggestive of competent layer through which deep foundation may be founded. This encouraging relationship between ERT and CPT further emphasize the importance of using both as complementary tools in investigation for subsurface anomalous zones for engineering applications rather than the use of one of the methods in isolation.

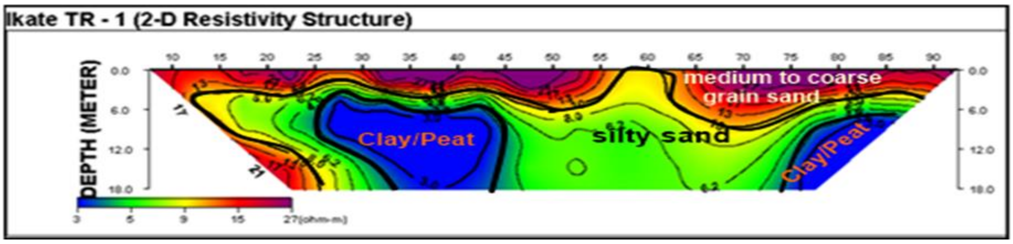

Figure 3: pseudo section showing the soil types along traverse 1

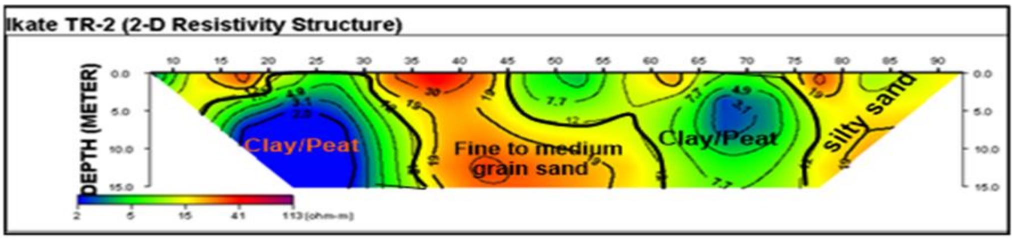

Figure 4: pseudo section showing the soil types along traverse 2

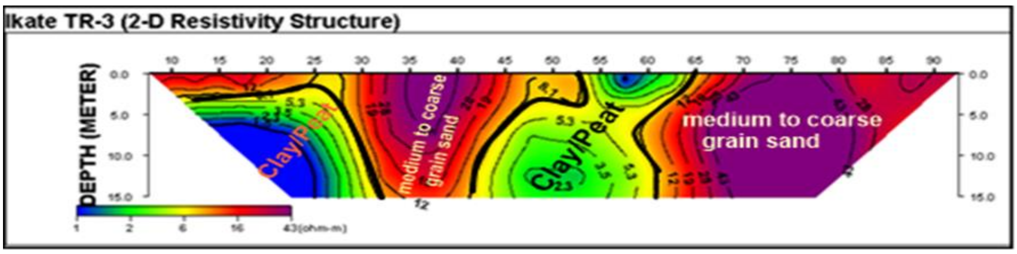

Figure 5: pseudo section showing the soil types along traverse 3

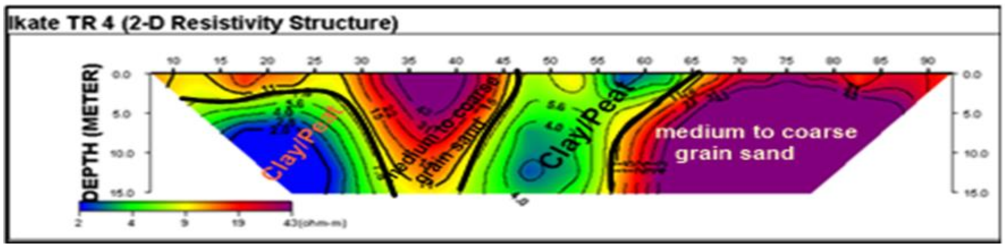

Figure 6: pseudo section showing the soil types along traverse 4

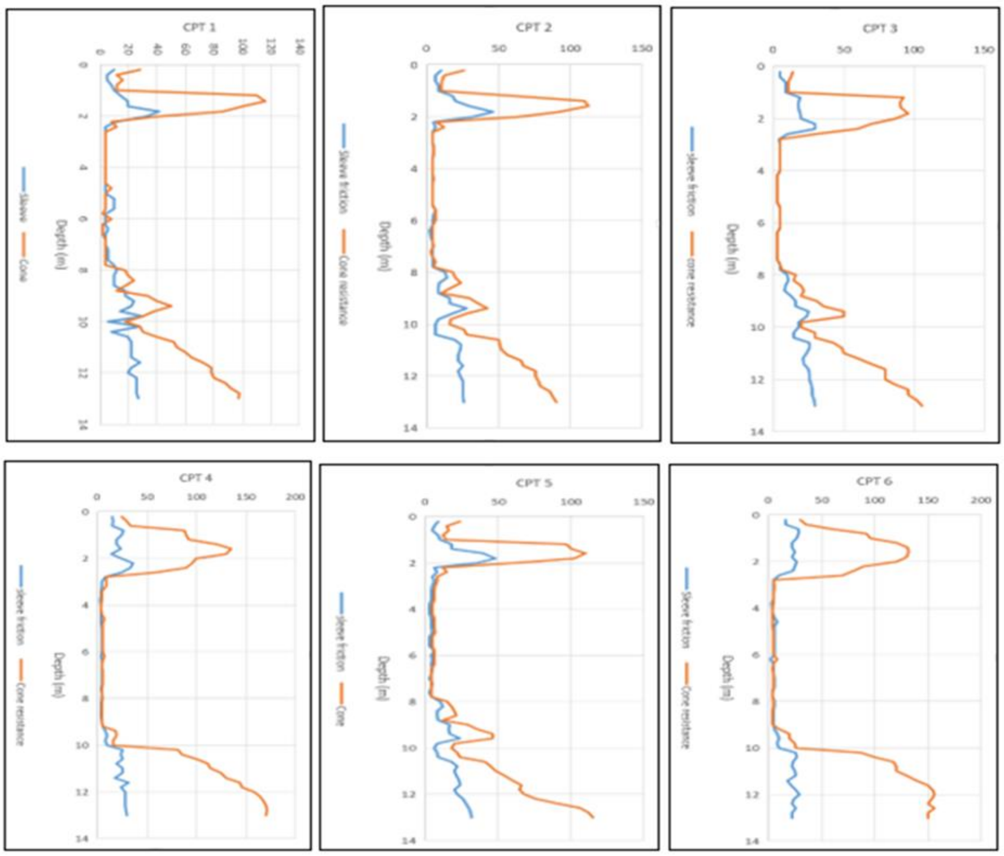

Figure 7: Stacked curves of cone resistance and sleeve friction versus depth CPT 1 – 6

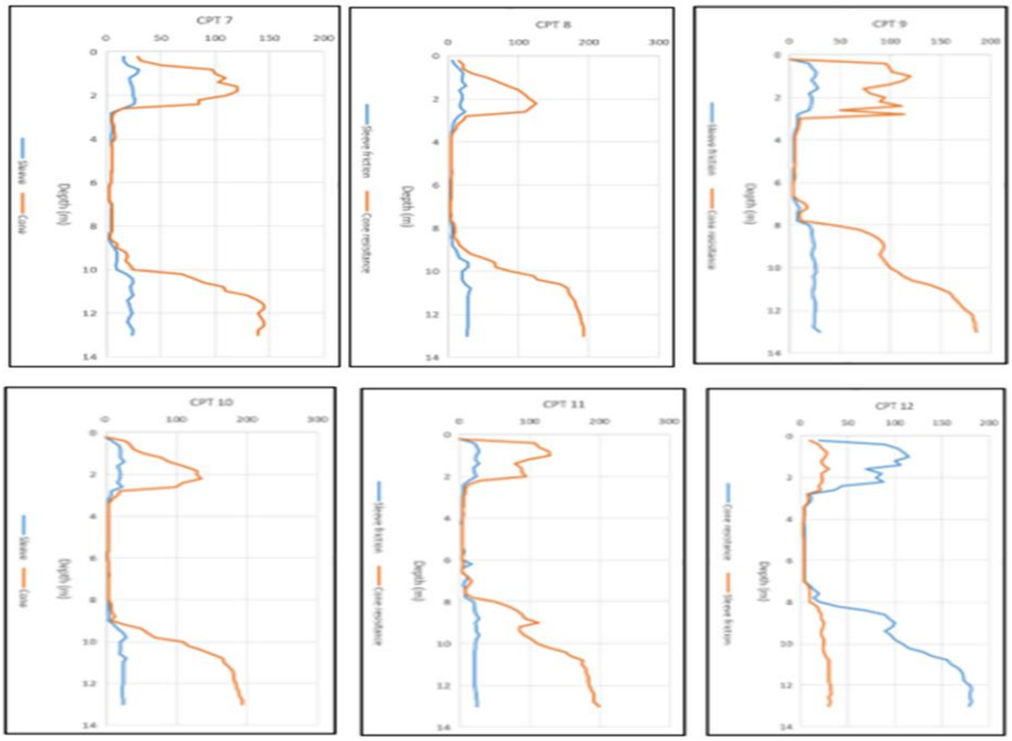

Figure 8: Stacked curves of cone resistance and sleeve friction versus depth CPT 6 – 12

4.2 Soil Stratigraphy and Laboratory Tests

The stratigraphy of the study location derived from boring and laboratory analysis is as described in table 1. It outlined that the shallow subsurface is made up of four distinct layers based on their geotechnical properties. They are; clay, peat and different shades of sands. Grain size analysis performed on nine samples of sand shows that they are essentially gap graded and poorly grained soil (figure 9) while Atterberg limit test carried out on five cohesive samples (figure 10) retrieved at depths ranging from 2.50 – 8.0m shows that three fall on high plasticity clay while the remainig two rest on high plasticity silt and high plasticity organic soils zones on the casagrande plasticity chat (Casagrande). Also, the natural moisture content for the sand ranges from 15 – 23% while that of clay and peat ranges from 60 – 83% (figure 11) pointing to a layer with appreciable compression potential rendering it undesirable for sustaining substantial structural loads.

Table 1: Summary of Stratigraphic Profile

Stratum Range (m)	Thickness of Stratum (m)	Descriptions of Stratum
Ground level 0.00 – 2.5	2.50	Loose grading to medium dense whitish fine to medium grained sand.
2.5 – 6.0	3.50	Soft dark grey silty sandy clay with organic clay and peat in parts
6.0 – 9.0	3.0	Grey very loose grading to loose fine to medium grained silty sand with traces of clay in parts.
9.0 – 15.0	6.0	Greyish loose grading to medium dense fine grained silty medium with sea shell.

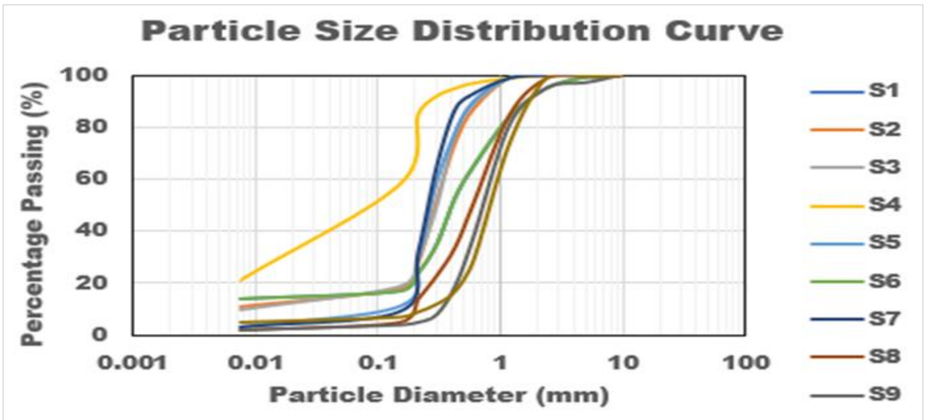

Figure 9: Semi-log plot of particle diameter versus percentage passing

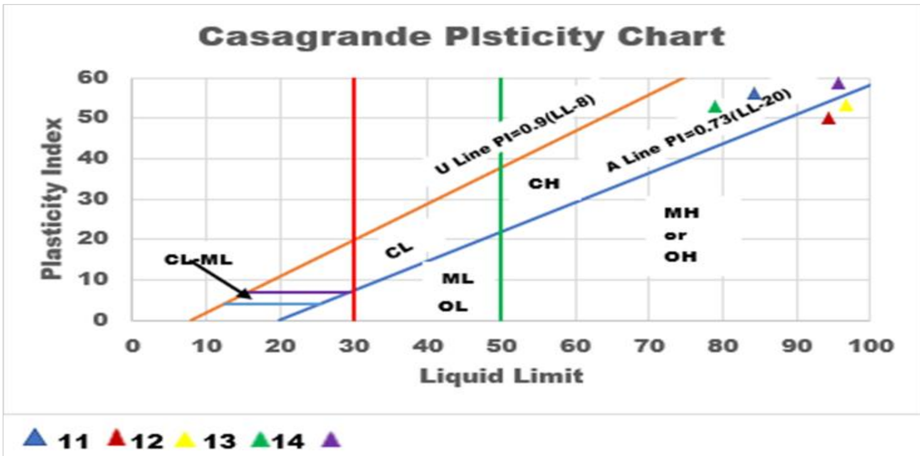

Figure 10: Casagrande Plasticity Plot of Samples 10 – 14.

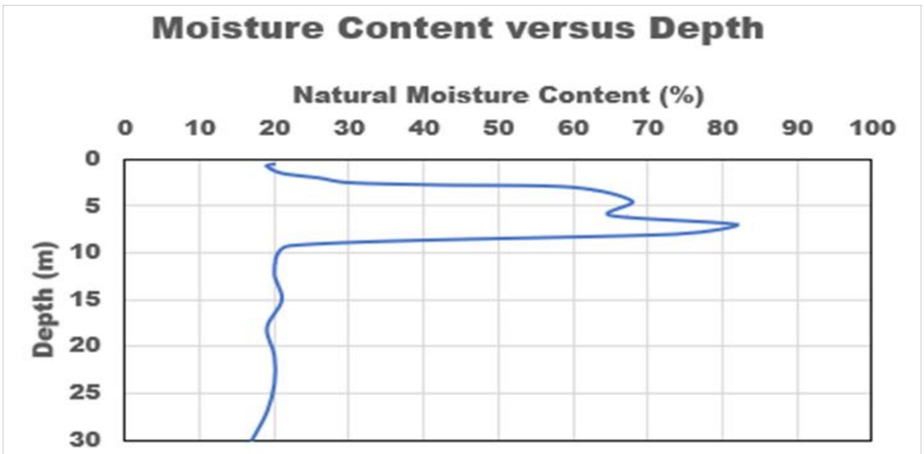

Figure 11: Variation of Moisture Content with Dept

4.3 Foundation Analysis

Bearing capacity estimation using direct CPT data was carried within shallow foundation zone at depth between 0.20 – 4.0m. The analysis reveals that bearing capacity estimated ranges from 1.7 – 49.4kg/cm², 0.7 – 15.2kg/cm² and 0.4 – 12.6kg/cm² using the method of respectively (figures 12 – 13) (Eslaamizaad and Robertson, 1996; Owkati, 1970; CFEM, 1992). This clearly indicate that method tend to return higher values of bearing capacity compared to the and methods (figures 12 – 13) (Eslaamizaad and Robertson, 1992; Owkati, 1970; CFEM, 1992). The drop in strength values reported at depth beyond 2.50m signals the onset of the soft clayey and peaty layers (figures 12 – 13). Also, the plot of moisture content versus bearing capacity values (figure 14) shows that the natural moisture content has direct relationship with bearing capacity as the moisture content increases with reduction in bearing capacity estimates. Finally, the significant increase in the cone resistances at depths beyond 10.0m is a pointer to competent strata with potential to serve as foundation of high rise structures in the area, this has similarity with the findings of, which established competent layer at depth beyond 15.0m in another part of the study area (Ishola et., 2022).

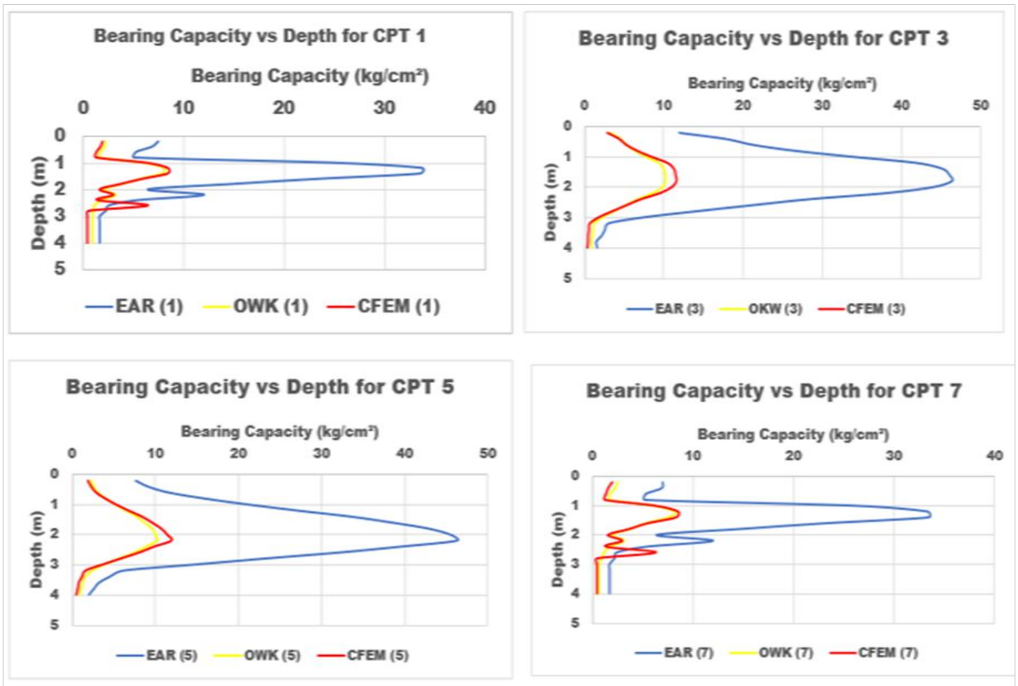

Figure 12: Shallow Foundation Bearing Capacity from CPT 1, 3, 5 and 7 using different methods

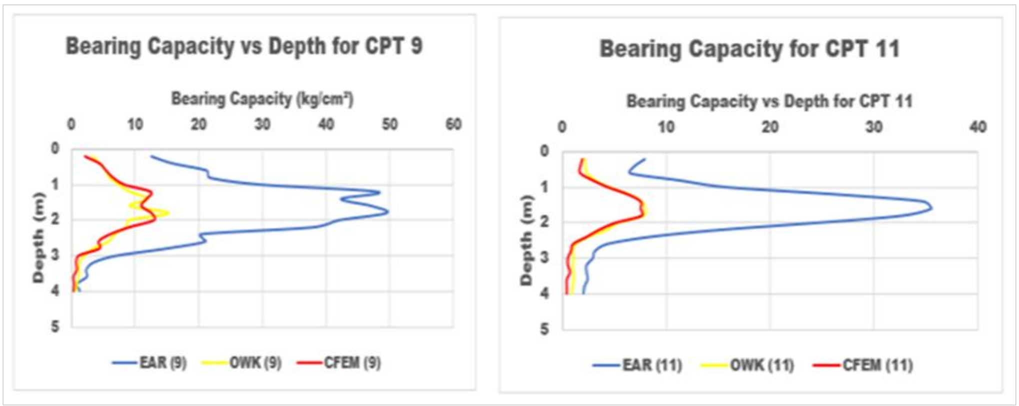

Figure 13: Shallow Foundation Bearing Capacity from CPT 9 and 11 using different methods

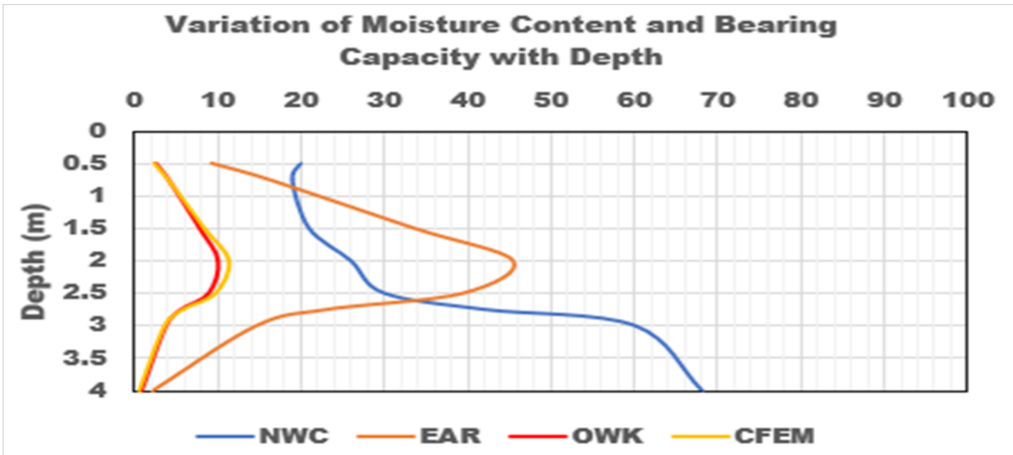

Figure 14: Variation of Moisture Content and Bearing Capacity Values with Depth

5. Conclusion

- The results of ERT and CPT have revealed that the subsurface within the study area is underlain by peat, sandy clay and different shades of sands.
- The study has shown that the complementary role of both ERT and CPT. ERT can mirror the subsurface anomalous zones while the CPT approach helps in generating parameters for foundation design purpose
- Shallow foundation bearing capacity calculation using direct CPT data within the shallow foundation depths generates values of 1.7 – 49.4kg/cm^2, 0.7 – 15.2kg/cm^2 and 0.4 – 12.6kg/cm^2 for Eslaamizaad and Robertson, Owkati and CFEM methods. This clearly indicate that the Eslaamizaad and Robertson method reteurn higher values of bearing capacity than those of Owkati and CFEM
- The study also demonstrates the effectiveness of ERT and CPT in mapping subsurface anomalous zones especially peaty and clayey soils for civil engineering construction
- This study has further shown that the moisture content has no direct relationship with bearing capacity of shallow foundation especially in essentially sandy soils.

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