INTEGRATED GEOTECHNICAL AND GEOPHYSICAL INVESTIGATION OF A PROPOSED CONSTRUCTION SITE AT MOWE, SOUTHWESTERN NIGERIA

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ABSTRACT

The subsurface of a proposed site for building development in Mowe, Nigeria, using Standard Penetration Test (SPT), Cone Penetrometer Test (CPT) and Horizontal Electrical Profiling (HEP), was investigated with the aim of evaluating the suitability of the strata for foundation materials. Four SPT and CPT were conducted using 2.5 tonnes hammer. HEP utilizing Wenner array were performed with inter-electrode spacing of 10 – 60 m along four traverses coincident with each of the SPT and CPT. The HEP data were processed using DIPRO software and textural filtering of the resulting resistivity sections was implemented to enable delineation of hidden layers. Sandy lateritic clay, silty lateritic clay, clay, clayey sand and sand horizons were delineated. The SPT "N" value defined very soft to soft sandy lateritic (<4), stiff silty lateritic clay (7 – 12), very stiff silty clay (12 - 15), clayey sand (15- 20) and sand (27 – 37). Sandy lateritic clay (5-40 kg/cm2) and silty lateritic clay (25 - 65 kg/cm2) were defined from the CPT response. Sandy lateritic clay (220-750 Ωm), clay (< 50 Ωm) and sand (415-5359 Ωm) were delineated from the resistivity sections with two thin layers of silty lateritic clay and clayey sand defined in the texturally filtered resistivity sections. Incompetent clayey materials that are unsuitable for the foundation of the proposed structure underlain the study area to a depth of about 18m. Deep foundation involving piling through the incompetent shallow layers to the competent sand at 20 m depth was recommended.

Keywords: Standard Penetration Test, Cone penetrometer, Resistivity Section, Lithologic Texture, Foundation.

1 INTRODUCTION

The incessant incidence of building failure has assumed an alarming dimension in Nigeria. All engineering structures erected on the earth have their substructures (foundation) supported by soils and rocks. Unfortunately, adequate investigation of the subsurface prior to construction is habitually neglected. Therefore, the construction and structural integrity of any engineering structure that is safe and durable is primarily dependent on their supporting foundation which is largely a function of the nature and condition of the underlying soil materials. A number of previous studies have focussed on this subject matter [1],[2],[3],[4]. The purpose of a foundation is to transfer the super-structure loads to the underlying soil or rock without overstressing the soil or rock. A basic requirement of foundation is that the soil below it must be stable and safe from failure [5]. Among the various natural factors that directly influence the design of buildings is the geological factor (soil/rock). Not only do geological factor control the character of the foundation but they also determine the type of materials made available for construction [6]. This makes pre-construction characterization of a site highly imperative. Although, geotechnical methods, which provide high resolution but discrete information of the subsurface, are traditionally used for site characterization, there is an increasing interest in the use of geophysical methods in complementing geotechnical methods for subsurface characterization. This is because geophysical methods can be quickly, cheaply and non- invasively deployed in characterizing subsurface properties [7],[8],[9],[10]. Geophysical studies carried out prior to the intrusive geotechnical investigation in form of borings and trial pits may identify anomalies of engineering interest. The identification of these geophysical anomalies will guide positioning of borings and trial pits which will in turn results in borehole data being more representative of site conditions. Interpretation of geophysical data, though could provide lateral subsurface coverage, is generally ambiguous because several geologic scenarios could produce the observed anomaly and geophysical response of different soil/rock types overlap significantly [11], [12]. Integration of geophysical method with borehole data would serve as constraint on the geophysical interpretation and allows extrapolation of geotechnical results into areas where little or no borehole information is available. Amongst the many problems which require the input of geophysics is the identification of near-surface inhomogeneity/structures and determination of soil/rock properties through geophysical measurements. Such near surface features that have been delineated using geophysical methods include buried paleochannels, soft clay, faults, fractures, joints, cavities and fissures [13],[14], [15].

Hence, an integrated geophysical (electrical resistivity surveys) and geotechnical (Standard Penetration Test/ Standard Penetration Test) surveys were carried out at a proposed site for building development in Mowe, Nigeria with the aim of characterizing the properties of the subsurface materials for the purpose of determining their competencies. While discrete geotechnical information would permit determination of soil property and unambiguous interpretation of geophysical dataset, geophysics would enable extrapolation of geotechnical results into areas where little or no borehole information is available.

2 SITE CHARACTERISTICS AND GEOLOGICAL SETTING

The study area is located in Mowe (near Lagos), along Lagos - Ibadan expressway, Nigeria (Figure 1).

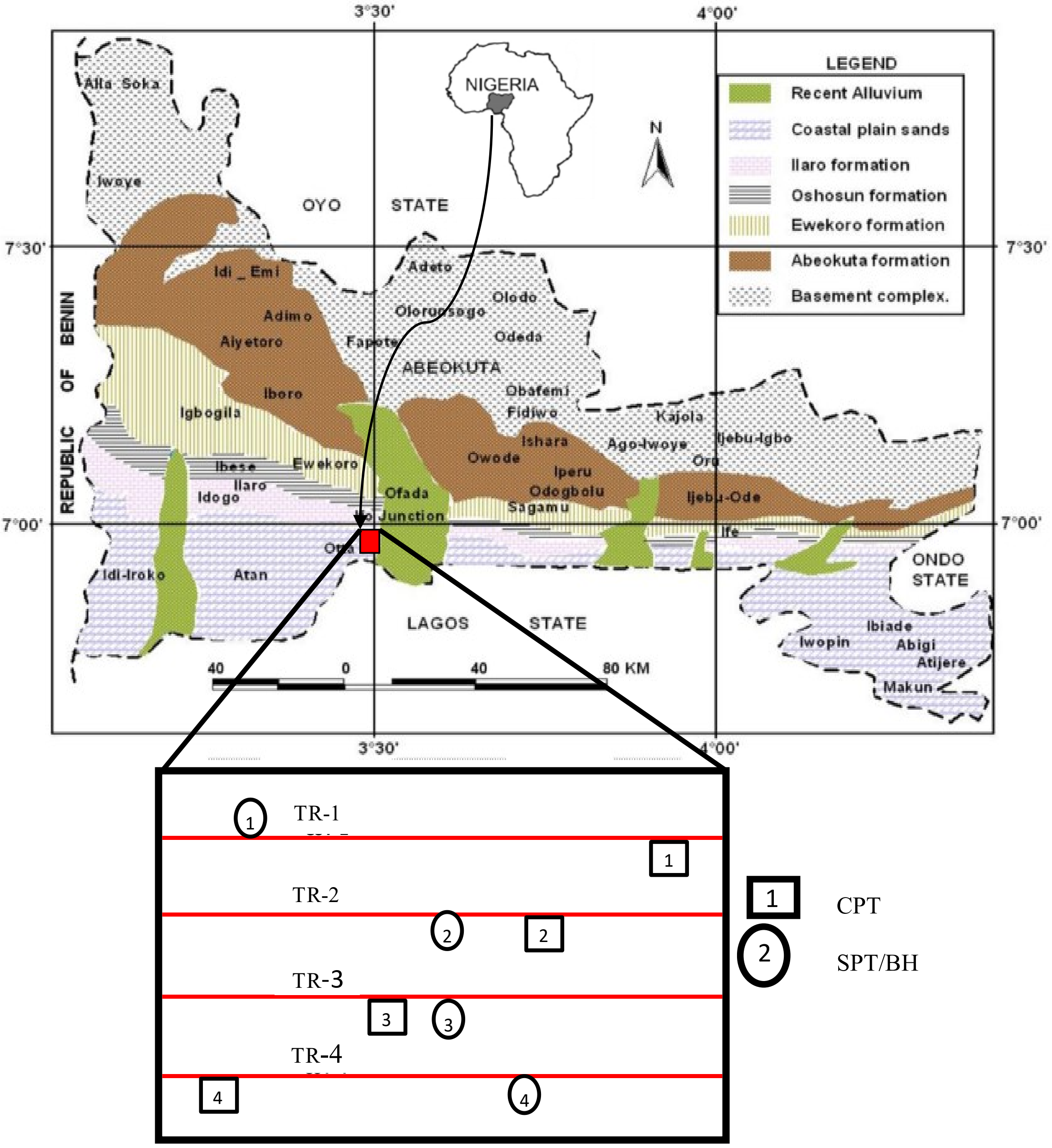

Figure 1: Location, Geological Setting [20] and Base Map of the Study Area

The site is bounded within latitudes $06^0$49.57'N and $06^0$6050.83'N and longitudes $03^0$3027.45'E and $03^0$3028.60'E. The investigated site is situated about 24 km from Lagos metropolis and about 700 m off Lagos - Ibadan Express way. The surface of the area is covered with sandy/clayey materials and is vegetated with tall grasses. The geology of the site is that of Cretaceous successions of the Dahomey Basin. The oldest Formation in the basin is Abeokuta Formation reported to be 250-300m thick [16]. It consists of arkosic sandstones and grits, tending to carbonaceous towards the base. Abeokuta Formation is in turn overlain by the Ewekoro/Akinbo/Oshosun Formations. The Ewekoro Formation consists of a sequence of sandstone, shale, limestone and clay varying between 100-300 m thick. This is further overlain by the Ilaro Formation, which has been reported to be deposited in transitional environment [16]. It consists of poorly sorted sandstones alternating

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with shale and clay. The sequence is capped by the Coastal Plain Sands which consists of a sequence of predominantly continental sands and some lenses of shale and clay [17].

3 METHODOLOGY

Geotechnical Investigation

Standard penetration test

Within the study area, Four (4) boreholes (coded SPT/BH-1 – SPT/BH-4) were drilled to 30m depth using a percussion motorized Shell and Auger rig that employs light cable percussion boring techniques. Locations of the boreholes were chosen so as to have a good coverage of the site with minimal number of holes and to provide control for interpretation of HEP around the site. The boreholes were to provide a first-hand look at subsurface stratigraphy at discrete locations, thereby providing crucial ground-truthing about the type of the subsurface materials. SPT were conducted in each of the boreholes where a soil sampler (split spoon) with an outside diameter of 50 mm and internal diameter of 35 mm and 650 mm long was connected to the drill rod and driven 450 mm into the soil by repeated blows from a hammer weighing 63.5kg and falling a free height of 760 mm based on methodology adopted by [18].The SPT were carried out at 2m depth interval and the boreholes were terminated at 30m depth. The penetration resistance, expressed as the number of blows (N-value) required to drive the sampler through a full distance of 300 mm after an initial penetration of 150 mm, was recorded [19].

Cone Penetration Test

The presence of soft clayey materials in the shallow subsurface necessitated the use of Cone Penetration Tests (CPT) in the investigated site. CPTs were performed at four locations, chosen so as to have constraining geotechnical information for interpretation of geophysical data in areas with no borehole coverage, within the study area to determine the strength of subsurface materials. The CPTs were carried out by forcing a hardened steel cone with a base area of 1000 mm^2 at an apex angle of 60^0 continuously into the ground and measuring its resistance to penetration based on methodology adopted by [21]. The 2.5 ton equipment is a manually operated unit furnished with a single cone that can measure the end resistance q_c only. The cone was advanced the ground at a controlled rate of 1cm/sec and the corresponding pressure required to advance it is recorded by a gauge. This procedure was repeated up to 5 m depth of drilling refusal. Successive cone resistance readings plotted against appropriate depths, form a resistance (strength) profile which indicates the sequence penetrated [6]

Geophysical Investigation

Horizontal Electrical Profilings (HEP) using Wenner array were conducted along the four traverses established within the study area using a PASI 16GL-N Earth Resistivity Meter. The direction of the traverse lines were chosen to be perpendicular to the regional structures in the area. The length of the traverses 1 and 4 was 250m while the presence of obstruction (Large cargo containers) restricted the length of traverses 2 and 3 to 200m. The profiling utilized Wenner array with a fixed electrode spacing of 10 m and an expansion factor (n) which varies from 1 to 6 along each of the four traverses occupied. The data were inverted by DIPRO software to provide both lateral and vertical resistivity variation of the study area. Geological interpretation of the resistivity sections was constrained by the borehole logs. In order to remove the effect of progressive transition from one geoelectric layer to the other, textural filtering of the geo-electric section was carried out. Textural filtering is a low-pass filtering of the inverted data in order to remove high frequency and other noise components. The result has a smoothening effect that permits identification of gross lithology or texture. The filtering allowed us to accurately delineate the boundaries of the subsurface strata. The filtering tool has excellent space-scale localization properties allowing delineation of thin layers. The use of such filtering was necessary to permit a reliable interpretation of the resistivity data. The obtained resistivity lithologic sections show improved correspondence with borehole log.

4 RESULTS AND DISCUSSION

Subsurface stratigraphy

The four boreholes logs interpreted (Figure 2) revealed the subsurface sequence to 30m depth. The sequence consists of approximately 1.5 m thick sandy lateritic clay that was underlain by about 4.5 m thick reddish brown silty lateritic clay. The silty lateritic clay is underlain by about 14 m thick grey silty clay. The silty clay overlies 10 m thick grey clayey sand. The fifth stratum represents grey medium to coarse sand at depth of about 20 m. The boreholes provided information on the stratigraphy of the site that was employed in constraining the interpretation of horizontal electrical profiling.

Soil Types and SPT Blow Counts

Interpretation of SPT blow counts was guided by [22] generally used for shallow foundation investigations. The result of SPT on the overburden materials shows blow counts ("N" values) that increased progressively with depth (Table 1). The "N'' value for the sandy lateritic clay was generally <4 indicating very soft to soft soil type. The silty lateritic clay indicated 7 to 12 "N'' values signifying stiff soil type. The silty clay layer was characterized by 12 to 15 "N'' values interpreted as very stiff soil. Between 15- 20 blow counts was recorded for the clayey sand. This implied a medium dense granular soil. The medium – coarse grained sand gave 27 – 37 blow counts which is indicative of dense soil.

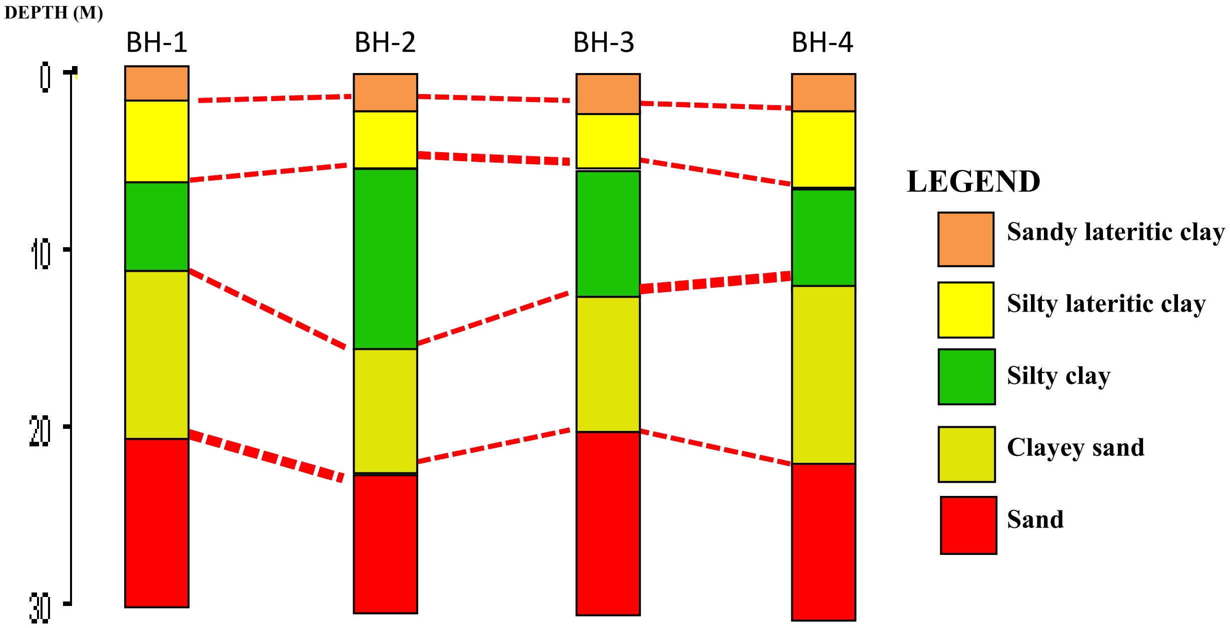

Figure 2: Correlated Lithology in the 4 boreholes. It reveals the subsurface stratification to 30m depth.

Table 1: Results of the SPT Tests

S/N	LITHOLOGY	DEPTH RANGE OF EACH LAYER (m)	RANGE OF SPT BLOW COUNTS ("N'' VALUES) FOR EACH LAYER	LITHOLOGIC INTERPRETATION
1	Sandy lateritic clay	0.00 - 1.45	<4	Very soft - soft
2	Silty lateritic clay	1.45 - 4.65	7 - 12	Stiff
3	Silty clay	4.65 - 12.00	12 - 15	Very stiff
4	Clayey sand	12.00 - 20.70	15 - 20	Medium dense
5	Medium-coarse sand	20.70- 30.00	27 - 37	Dense

Cone Penetration Result

Author [23] provided a guide for estimating soil type from the results of Cone Penetration Test. The CPT interpretation was ground-truthed with lithologic sequences from the boreholes. The CPT plots (Figures 3a - d) defined two subsurface layers of sandy lateritic clay and silty lateritic clay. The ~ 3 m thick upper layer was characterized by 5-40 kg/cm^2. Beneath the 3 m depth, the cone resistance ranges from 25 - 65 kg/cm^2 indicating silty lateritic layer. The depth extent of this layer could not be ascertained from the CPT because drilling refusal was attained at 5 m depth.

Two Dimensional Resistivity Structures

The resistivity sections along the four traverses showing both lateral and vertical variations in the subsurface lithology with depth are presented in Figures 4a - 7a. Four layers including sandy lateritic clay (220-750 Ωm), clay (< 50 Ωm), clayey sand (70-155 Ωm) and sand (415-5359 Ωm) were delineated. Refined lithologic texture of the resistivity sections (Figures 4b – 7b) show sharp interfaces of subsurface layers. Layers showing better correspondence with borehole logs were delineated. The upper layer was differentiated into 2 to 4 m thick sandy lateritic clay and 1 to 2.5 m thick silty lateritic clay - which was obscured in the resistivity section (traverses 2 and 3). Exposures of silty lateritic clay were observed in traverses 2 and 3 (Figures 5b and 6b) at about 160 – 170 m and 40 m respectively. The clay unit underlying the silty lateritic clay ranges from 14 to 18 m in thickness. Clay bodies were exposed in traverses 1 and 4 (Figures 4b and 7b) between locations 30 - 40 m and 0 – 45 m respectively. The thick clay grades into clayey sand in traverses 1 and 4 (Figures 4b and 7b) and therefore showed undistinguishable texture. Sand unit was identified at depths greater than 24 m. Some sand body occurs in pockets within the clayey sand in traverses 2 and 4 (Figures 5b and 7b).

Evaluation of Subsurface Sequences for Foundation Purpose

The geologic sequence beneath the study area is composed of the sandy lateritic clay, silty lateritic clay, clay, clayey sand and sand. The sandy and silty lateritic clay layers are characterized by relatively low resistivity, low penetration resistance (<65 kg/cm^2) and SPT blow counts (0 - 20) characteristic of low competence materials that is unsuitable for shallow foundation [24].

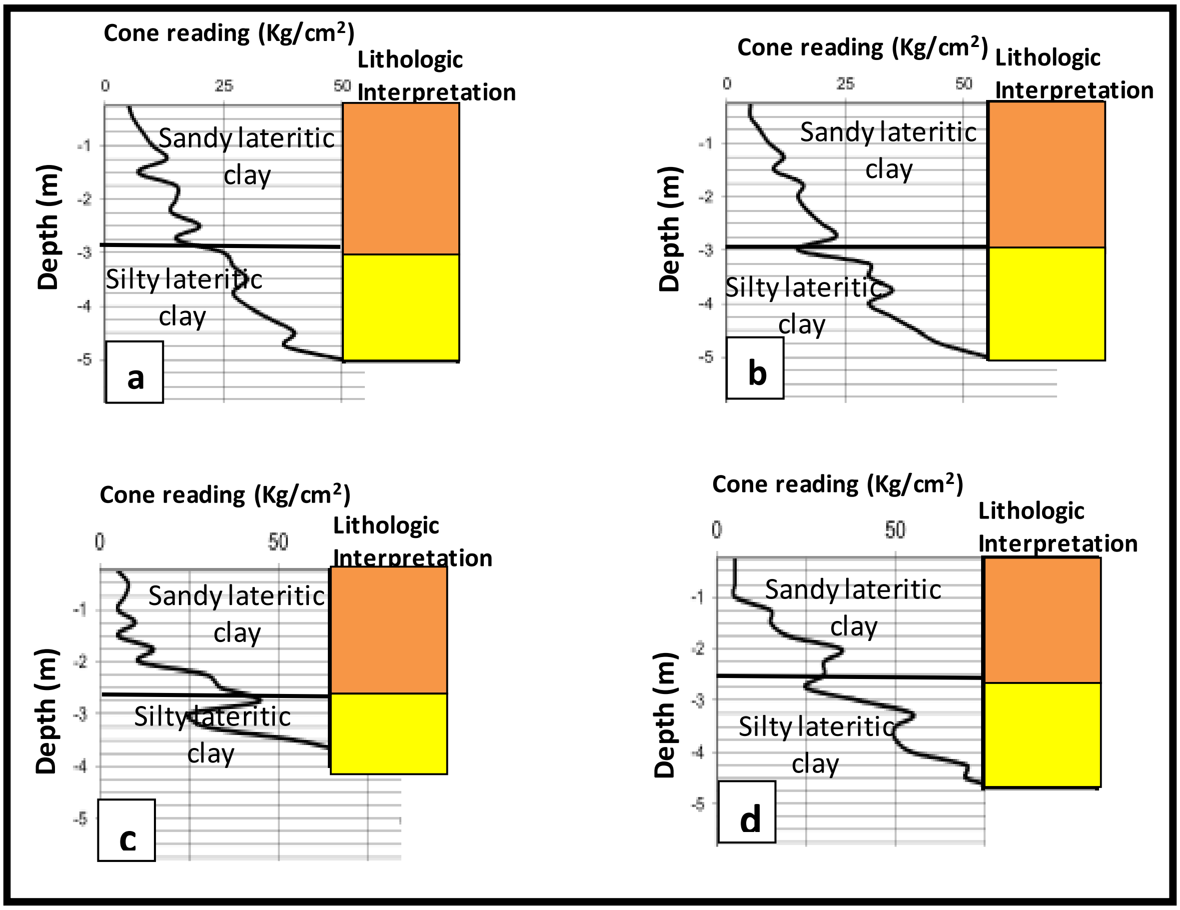

Figure 3: CPT curves from the study site

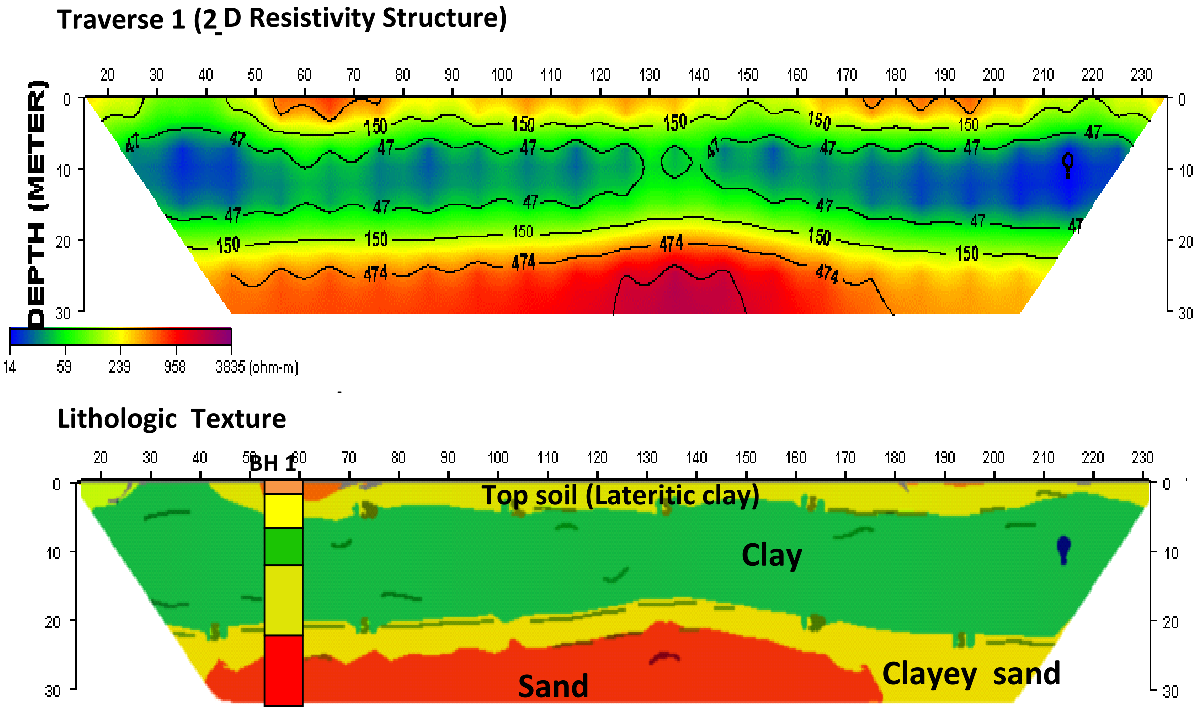

Figure 4: (a) 2-D resistivity structure along traverse 1 and (b) the corresponding filtered lithologic texture with borehole lithologic log superimposed

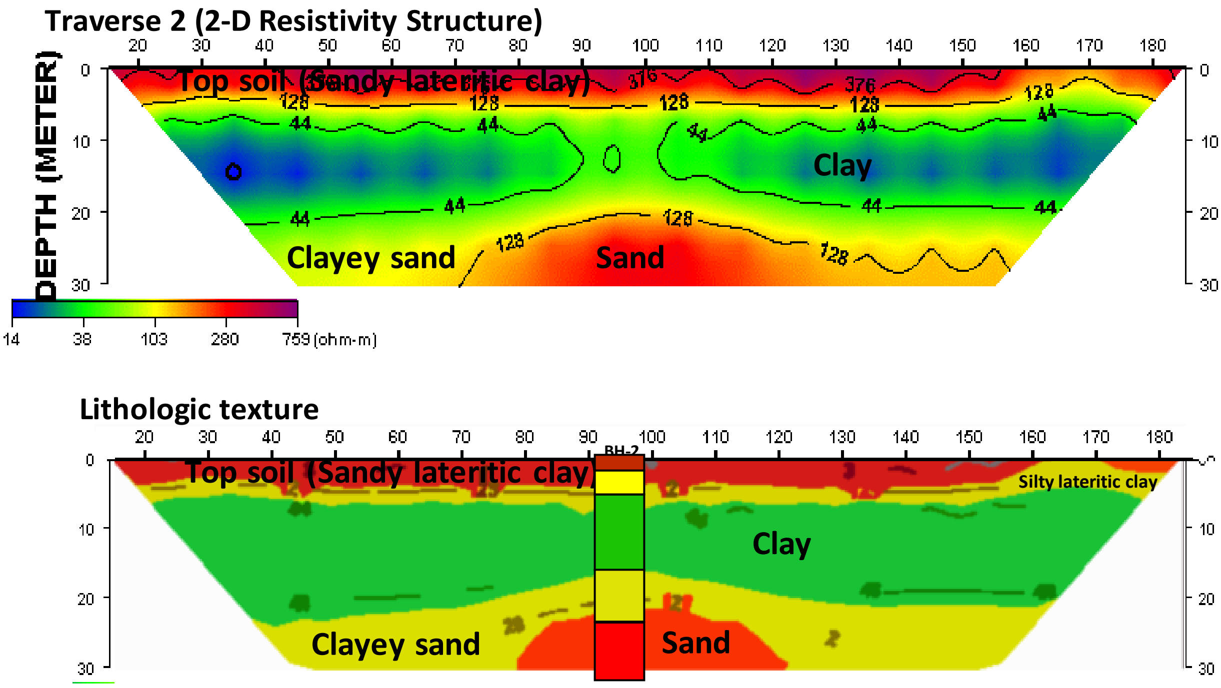

Figure 5: (a) 2-D resistivity structure along traverse 2 and (b) the corresponding filtered lithologic texture with borehole lithologic log superimposed.

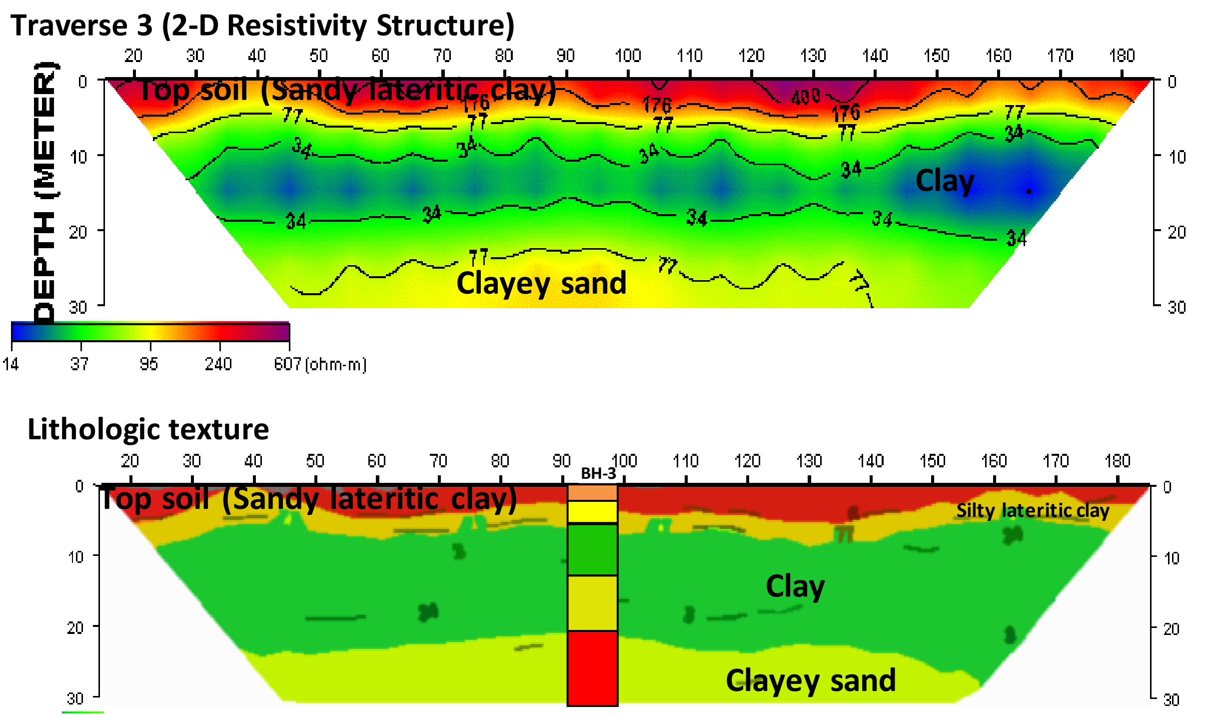

Figure 6: (a) 2-D resistivity structure along traverse 3 and (b) the corresponding filtered lithologic texture with borehole lithologic log superimposed.

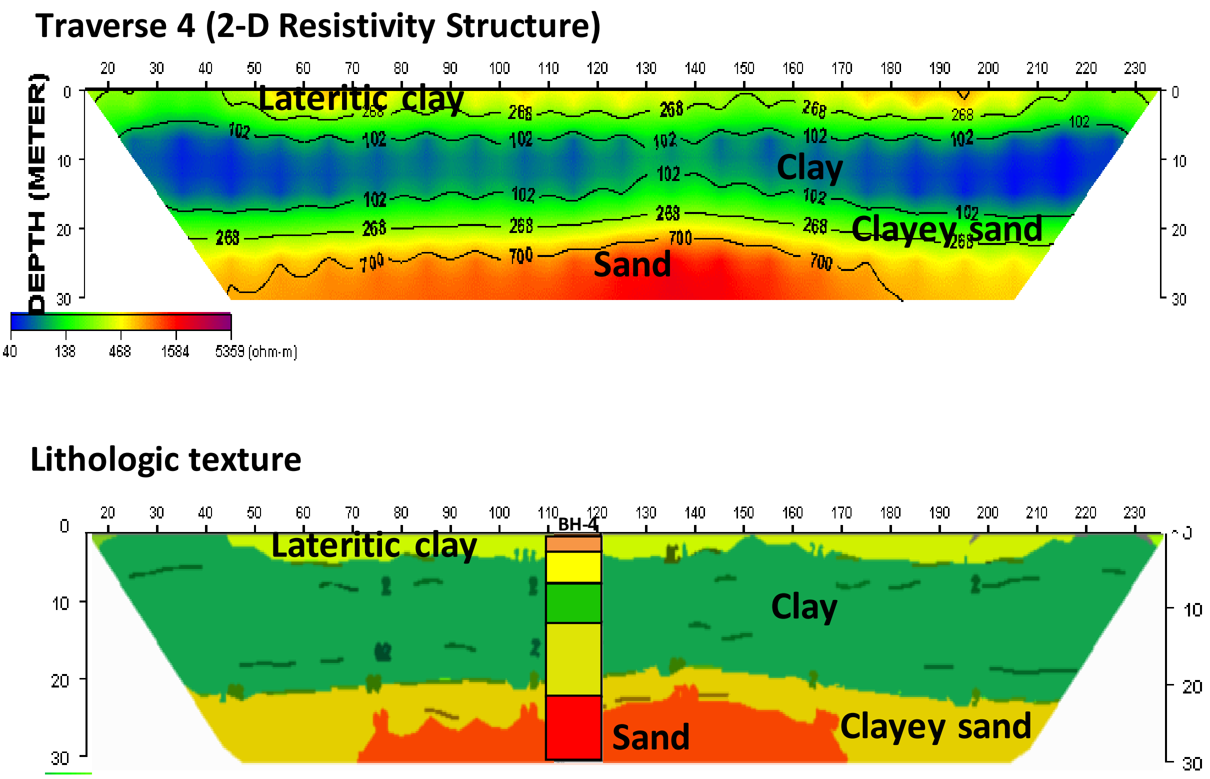

Figure 7: (a) 2-D resistivity structure along traverse 4 and (b) the corresponding filtered lithologic texture with borehole lithologic log superimposed.

The clayey nature and low competence values can be attributed to the high degree of saturation which may have reduce the strength of the soil in-situ. They are therefore viewed as inimical to the proposed engineering structure and are thus not suitable for foundation purpose. The third stratum revealed very low resistive clay formation considered unsuitable for the intended building because of the incompetence of the layer. Clay soil expands and contracts, mostly non-uniformly, as it goes through wet and dry periods

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respectively. This could result in differential foundation movement, thereby causing distress. Sand, characterized by high resistivity (415-5359 Ωm) and SPT blow counts (27 -37), is the most competent of the delineated lithologic units. Depth to the competent bed (sand) was determined to vary from 18 – 22 m for most parts of the area. The results have shown the capability of the SPT method to provide accurate point information on the competency of the subsurface strata in form of blow counts and the CPT to determine the strength of the near surface soft clay. But budgetary constraints often limited the number of boreholes that could be drilled; hence the site was sparsely covered by boreholes. Both SPT and CPT provided lithological control for the interpretation of HEP. The horizontal electrical profiling complemented the SPT and CPT by providing continuous coverage of the subsurface and continuation of borehole lithologic interpretation and soil properties to areas where no drilled holes exist, thereby enhancing the value of borehole data. However, in order to reduce the duration and cost of investigation, the cheap geophysical methods should be largely employed and small number of geotechnical tests is then employed to yield subsurface information that could serve as control on the geophysical interpretation. While discrete geotechnical information would permit determination of soil property and unambiguous interpretation of geophysical dataset, geophysics would enable extrapolation of geotechnical results into areas where little or no borehole information is available.

5 CONCLUSION

This study has revealed that the natural soil setting in the study area has many variables. Integration of geophysical and geotechnical methods has been used satisfactorily to investigate the engineering characteristics of the site with the aim of identifying geologic factors that might adversely affect any civil engineering structure founded on it. The geologic sequence beneath the study area was discovered to consist of the upper layer, lateritic clay, silty clay, clayey sand and sand. The three topmost clayey materials were viewed to be highly compressible and could cause possible foundation problems due to their soft – stiff nature, low resistivity and low SPT blow counts. The high resistivity cum high "N" value, dense sand was determined to be the competent geologic material for foundation purpose. Depth to the competent bed varies from 18 – 22 m for most parts of the area. The integrated geotechnical and geophysical investigation showed significant correlation and proved useful in subsurface exploration. This study concludes that a complementary use of geophysics and geotechnics showed significant correlation, proved useful in subsurface exploration and provided results that would not be possible by using any of the methods independently.

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