ABUAD INTERNATIONAL JOURNAL OF NATURAL AND APPLIED SCIENCES
ISSN: 2955-1021
AIJNAS 2022, Volume 2, Issue 2, pp 116–122
https://doi.org/10.53982/aijnas.2022.0202.09-j

https://journals.abuad.edu.ng/index.php/aijnas
AIJNAS

Geotechnical Investigation of Subsoil Materials in a Typical Basement Terrain, Southwestern Nigeria- A Case study

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Abstract
Geotechnical investigation of the subsurface materials of a proposed Primary Health Center (PHC) in Modeke Oyo East Local Government Area (OELGA). of Oyo State has been conducted. The investigation is aimed to determine the suitability of the site for the proposed Bungalow building by assessing the subsoil strata that underlie the area. Three (3) points were tested to depth of 4.75m using a 2.5-ton DCPT equipment, while three (3) trial pits were dug to a depth of 1.5m with the aid of hand auger, and various lab analysis were conducted on selected samples from the trial pits. The result obtained from the DCPT indicates that subsurface is made up of stiff to very stiff sandy lateritic clay underlain by very stiff to hard sandy lateritic clay with hard pans layers. The allowable bearing pressure was observed to increase with depth to 4.75m further confirmed the subsurface lithologies. The Allowable Bearing Pressure (qa) in kN/m^2) with a range of values 81 – 256 kN/m^2, 54 – 155 kN/m^2 and 162 – 338 kN/m^2 for DCPT points 1, 2, and 3 respectively, indicate a Safe Bearing Pressure that can support load up to 45 kN/m with factor of safety of 2.5. Sieve analysis results revealed that the soil is well graded with dominant gravel which show a well-drained soil with good strength characteristics. Liquid limits ranged from 26.7% to 43.3%, plastic limits from 15% to 27% and plasticity index from 9.7% to 27.3%, thus indicating low to medium compressibility. The natural moisture contents values range between 4% and 15%, indicating lateritic clay of low to medium plasticity with low moisture content. Based on the above deductions, it can be concluded that, the factor of safety of 2.5 calculated from the allowable bearing pressure from the CPT, low to medium compressibility from Atterberg limits test and moisture content below 15% show that the investigated site is good and could safely support a bungalow building as proposed.
Keywords: *Safety, Compressibility and Plasticity, foundation.*

INTRODUCTION

Cases of building collapses have been on the increase in the recent time. These have been reported from various state all over Nigeria. The causes have been attributed to various factors ranging from poor planning, total lack/inadequate geotechnical investigation, substandard materials, poor construction among others (Falae 2014, Abija *et al*., 2018, Fajana 2021). Knowing the geotechnical properties of the subsurface is highly essential in sustaining any proposed structure that will pass integrity test. Often, these zones are usually neglected which however can pose various danger for the proposed structure. The heterogeneity of the subsurface materials can result to problem during construction and post construction phase of any structural project. Therefore, adequate and reliable information of the nature and variation of the subsurface lithologies is essential for the sustainability of structure (Ako *et al.* 2005, Oloruntola *et al.* 2017, Oyediran and Falae 2018Ademila 2022).

To this end, it is highly recommended that proper subsurface investigations should be carried out in determining the engineering properties of soil to ensure proper design and successful construction of any structure (Cosenza *et al*., 2006, Ebiegberi and Edirin 2020, Hussian *et al*., 2022). This problem is more pronounced in the sedimentary and coastal regions when compared with the basement complex, however, it is highly important to carry out proper subsurface investigation to delineate and characterize the materials upon which the structural foundation is to be laid. To achieve these various techniques can be employed such as geological, geotechnical and geophysical methods (Meshida and Ayolabi 2011, Oyedele and Olorede 2011, Kamal *et al*. 2015, Adeoti *et al*., 2016, Kirar *et al.* 2016, Egbeyale *et al*., 2019, Sanchez-Garndo *et al*., 2022).

In the present study, detail subsoil investigation has been carried out at the proposed bungalow building development for Oyo East Local Government Primary Health Centre in Modeke Asogo town, Oyo State. This is necessary to determine the suitability of the subsoil materials to support the proposed project as well as to help in determining suitable foundation type for the proposed structure.

The objective of this investigation is to determine the relevant Geotechnical/Engineering parameters of the subsoil strata that underlie the site and provision of information for the design of the site civil works, which will aid economic design of foundations for the proposed structure/development within the site. Presented herein are the results of our factual findings concerning the work carried out.

Study area

The proposed project site is situated within an open parcel of land within Modeke Asogo town in Oyo East L.G.A. of Oyo State. The site is accessible through a tarred road with no drainage channel within a mixed environment. The site is proxy to a canal (Figure 1).

There are existing foundations on the site with a dug pit for soak away. Buildings within the site vicinity are mainly bungalows with few storey buildings. Geologically, the area belongs to the basement complex of Nigeria.

Modeke Asogo town is entirely made up of Basement complex rocks. The rocks of the study area lie within the Precambrian Basement Complex of south-western Nigeria, which constitute of migmatite, biotite garnet-schist and quartzite). There are also minor occurrences of doleritic dykes, quartz and pegmatite veins that intruded into the main rock bodies.

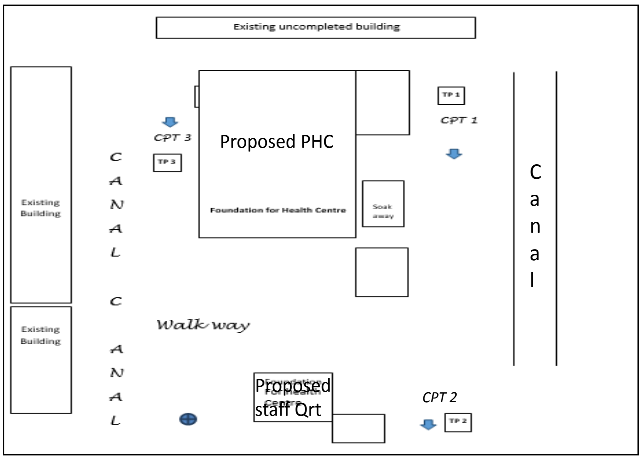

Figure 1: The sketch map of the study area indicating the site condition (Not to scale)

Methodology

In the present research, both field and laboratory approaches has been employed for the subsurface characterization of the proposed bungalow building development for Oyo East Local Government Primary Health Centre in Modeke Asogo town, Oyo State. The field investigation entails detail geotechnical investigation to unveil the subsurface lithology and condition and its ability to support the proposed project (Figure 2).

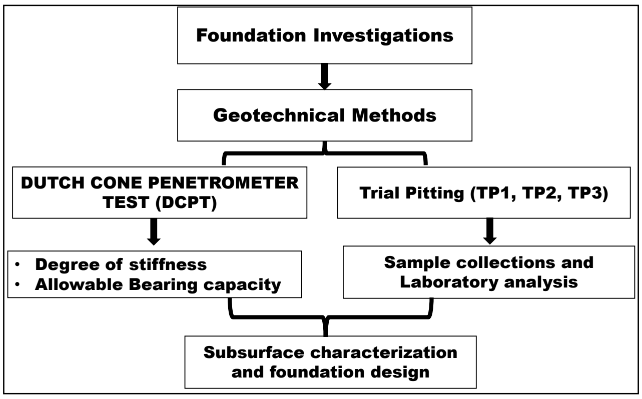

Figure 2: Investigation flow chart

Geotechnical Investigation

Trial Pits.

The procedure is carried out manually to show the soil stratigraphy with depth. A total of three (3) trial pits were dug close to the CPT points to access the subsurface strata below (Plate 1). The depth of each of the trial pits is up to 1.5m, while samples were collected at 0.5, 1.0 and 1.5 m depth respectively. These samples were later taken to the laboratory for necessary laboratory analyses. The following analysis were carried out grain size analysis and consistency limit. All the experimental work were carried out according to BS standard.

Plate 1: Picture showing CPT operator and dug trial pit during the site investigation work

THE DUTCH CONE PENETROMETER TEST (CPT)

The Dutch cone penetrometer test consists of forcing a hardened steel cone continuously into the ground and measuring its resistance to penetration (Lazcano *et al,* 2020). The standard cone used has an apex angle of 60º and a based area of 10cm². The penetrometer machine consists of a steel frame carrying a driving head which houses a hydraulic pressure capsule. The driving head can be raised or lowered by a manually operated winch or a motor drive hydraulic raw. The cone assembly is pushed into the ground by means of steel rods connected to the driving head (Plate 2). These rods are protected from friction with the soil by hollow outer rods. The cone driving rods and outer rods are pushed together into the ground for a distance of 250mm (200mm in the case of test with 2.5 tone machines). The driving pressure is then applied to the inner rods only and the cone is advanced independently of the outer rods for a distance of about 40mm at a rate of approximately 100mm/sec. The pressure required to advance the cone is transmitted through the capsule in the driving head to a gauge and the penetration resistance is registered on the gauge is recorded.

The larger penetration machines are capable of recording a skin friction value of the material by advancing a friction jacket or sleeve behind the cone. The outer tube is then advanced and the whole assembly is driven a further 250mm where the operation is repeated.

The process is continued to the required depth or until one of the following occurs: -

1. The total resistance to penetration of the rods and cone reaches the capacity of the machine.
2. The anchors start to lift out of the ground, or
3. The rods start to bend due to insufficient lateral support in softer deposits.

Successive cone resistance and sleeve resistance readings are plotted against depth to form a resistance profile. Such profiles may be correlated with borehole data and used to provide information on the variation of strata and material strength across a site. Where both cone and sleeve resistance and measured, the relationship between the two values can be used to indicate the soil type as well as its strength or density.

If required, soil samples for identification purpose can be obtained by means of a special sampling tool, which is connected to the tubes in place of the cone. A piston seals the base of the sample while it is5 being driven to the ground. At the required sample depth, the tubes are turned and this releases the piston allowing the sampler be pushed into the soil.

Plate 2: The Dutch Cone Penetrometer Test (DCPT) ongoing on site

Results and Discussions

Soil Profile and Description

The results obtained from the trial pits, indicated that between 0-1.5 m depth of investigation various materials were encountered within the subsurface strata. TP 1 corresponding to the CP1 shows that the subsurface materials range from light brownish grey silty sand/clay with hard pans to dark/reddish brown very stiff to very stiff gravelly sandy lateritic clay with hard pan from 0.5 – 1.0 and Dark brownish grey silty, very stiff sandy lateritic clay with hard pan up to the end of the trial pit at 1.5 m depth (Figure 5). In TP 2, The upper layer up to 0.5 m depth is made up of dark brownish grey silty sand clay with hard pan beneath this a layer of dark reddish brown very silty, stiff to very stiff gravelly sandy lateritic clay with hard pans were encountered up to 1.0 m depth, from 1. 0 m depth up to the end of the trial pit at 1.5 m a dark brownish grey, silty, very stiff sandy lateritic clay with hard pans was observed (figure 6). In trial pit 3. A single layer of light brownish grey silty stiff to hard sandy clay with hard pan was encountered (Figure 7). Representative samples were collected at various depths in the trial pits i.e., 0.5, 1.0 and 1.5 m depth respectively for laboratory analysis.

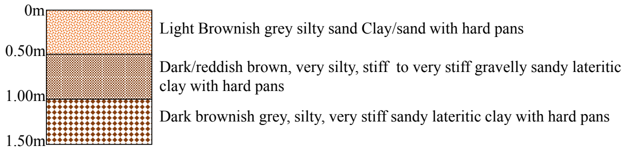

Figure 5: Litho-log of Trial pit 1

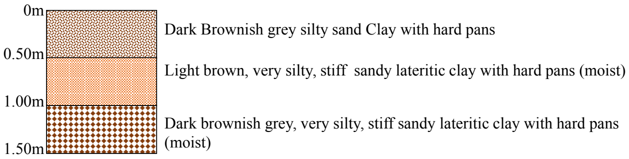

Figure 6: Litho-log of Trial pit 2

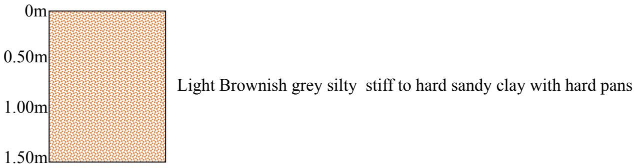

Figure 7: Litho-log of Trial pit 3

DCPT Results

The results obtained from the DCPT as presented in figure 8 (a-c) indicated that the competence of the subsoil increases with the depth. In CP 1, its resistance value increases progressively from 30 to 50 (kg/cm²) up to about 1.3 m depth and between 1.3 to about 2. 0 depth the resistance value decreases drastically to about 10 (kg/cm²) and the resistance increase after 2 m depth to about 120 (kg/cm²) below 3 m depth where the investigation was terminated. In CP2 similar trend to CP1 was observed as the resistance value gradually increase from 10 to 40 (kg/cm²) at about 1.6 m depth and the value decline at this point. At 3 m depth from the subsurface a continuous increase in the resistance was observed to about 114 (kg/cm²) before the CPT was terminated. In CPT 3, a continuous increase in the resistance value was observed from the beginning till the CPT was terminated at about 0.8 m where the resistance value was observed to be 125 (kg/cm²). Based on the obtained results as indicated on the Cone end Resistance Value (kg/cm²) (Table 1) for a granular soil, the soil within the study area can be classified as medium to dense.

Table1: GRANULAR SOILS (B.S. 5930: 2015 (Code of practice for site investigations).

Cone end Resistance Value (kg/cm²)	Soil Type
0-40	Very loose to loose
40-120	Medium dense
120-200	Dense
Above 200	Very dense

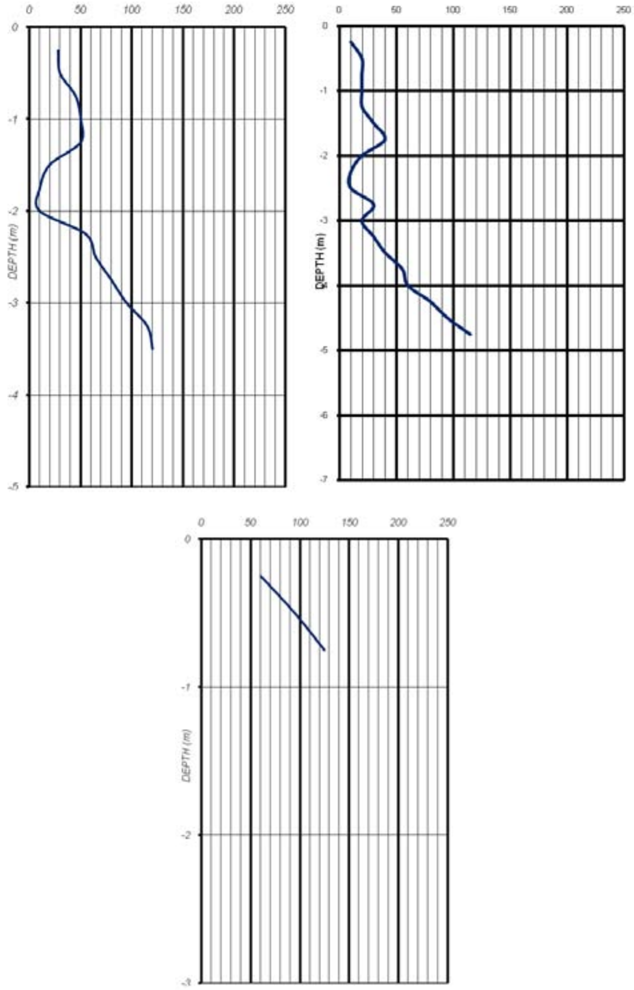

Figure 8 a-c: DCPT 3 GRAPH

Estimation of Allowable Bearing Pressure

The result of the investigation gave a general Safe Bearing Pressure value of not less than 45kN/m^2 with factor of safety of 2.5, for a Continuous strip footings at 0.40m depth below the existing ground level as recommended above (Table 2). The Engineer in charge of the project should ensure that the final ground floor level of the building is raised to a height of not less than +600mm above the present ground/ road level with consideration of the elevation of the site. The result of the investigation as calculated based on Meyerhof's formulae for Strips or Square/Circular foundations irrespective of the foundation width at various depths range gave the following: Allowable

Bearing Pressure values for the subsoil condition in its present natural state as follows:

$qa=2.7CkdkN/m^2 \sim \frac{Ckd}{40} kg/cm^2$

Where Ckd = cone resistance in kg/cm^2 and qa = allowable bearing pressure in kN/m^2

Table 2: Table showing Allowable Bearing Pressure for CPT 1, CPT 2 and CPT 3

Depth Range (m)	**Allowable Bearing Pressure(qa) in kN/m2**		
	CPT 1	**CPT 2**	**CPT 3**
0.50	81	54	162
1.00	135	54	256.5
1.50	54	81	337.5
2.00	27	54	-
2.50	175.5	27	-
3.00	256.5	54	-
3.50	162	54	-
4.00	-	81	-
4.50	-	128.25	-
4.75	-	155.25	-

From the aforementioned subsoil conditions and as described in section 4.2 and considering the nature of the propose building on this site i.e., one floor bungalow structure; Continuous strip footings to a depth of 0.40m could be adopted for the site.

Laboratory Analysis results

Various laboratory analysis was carried out on the obtained samples from the trial pits to examine the geotechnical properties of the subsurface materials. The results are presented in table 3.

The sieve analysis carried out on selected sand samples encountered between the existing ground level and 1.50m depth in the trial pit location revealed a well graded soil with dominant coarse sands to gravel, which show a well-drained soil with good strength characteristics and suitable for foundation (Figure 9).

Uniformity Coefficient (Cu)

The uniformity coefficient (Cu) is defined as the ratio of D60 to D10. A value of Cu greater than 4 to 6 classifies the soil as well graded. When Cu is less than 4, it is classified as poorly graded or uniformly graded soil. Uniformly graded soil has identical particles with Cu value approximately equal to 1. A uniformity coefficient value of 2 or 3 classifies the soil as poorly graded. Beach sand comes under this category. Higher value of Cu indicates that the soil mass consists of soil particles with different size ranges.

$$Cu=\frac{D60}{D10}$$

Cu= 3.10/ 0.58 = 5.34

Therefore, the soil can be classified as well graded soil.

Coefficient of Curvature (Cc)

The coefficient of curvature is a measure of gradation of particles. For the soil to be well graded, the value of Cc must range between 1 and 3.
This can be estimated using the formula below:

$$Cc=\frac{(D30)^2}{D60 \; x \; D10}$$

Cc = (1.25)2/ 3.10 x 0.58 = 1.25

The Atterberg Limit Tests values of Liquid and Plastic Limits gave 26.7% to 43.3% and 15% to 27% while Plasticity Index was 9.7% to 27.3% respectively for the lateritic Clay between the existing ground level and 1.50m the results indicate low to medium compressibility. The natural moisture contents values range between 4% and 15% for all the samples collected at different depth interval of the trial pits. These values indicate lateritic Clay of low to medium plasticity with low moisture content on Casagrande Plasticity Chart (Figure 10). The soil is in the A-6 group of AASHTO soil classification system and could safely support an engineering structure such as the proposed bungalow.

Table 3: The index properties of the Samples.

	TP 1			**TP 2**			**TP 3**		
Depth	0.5	1.0	1.5	0.5	1.0	1.5	0.5	1.0	1.5
Natural moisture content	4	14	14	13	14	15	15	15	14
Plastic Limit		16	17					15	
Liquid Limits		28.6	26.7					42.3	

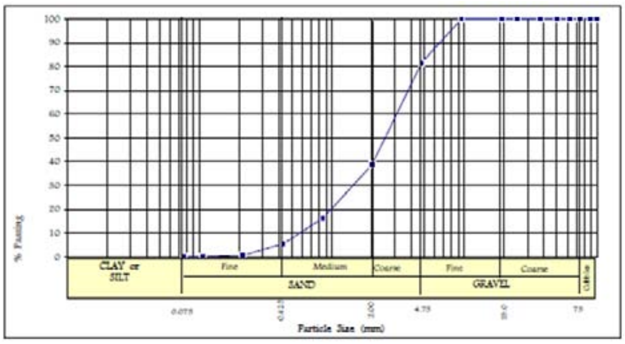

Figure 9: Grain size distributions of the selected sample

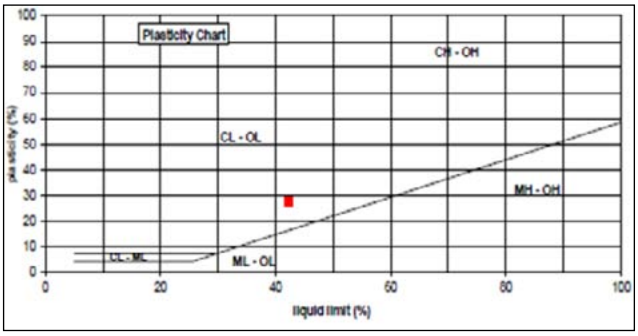

Figure 10: Casagrande Plasticity Chart

Conclusions

The geotechnical evaluation of the proposed bungalow building development for Oyo East Local Government Primary Health Centre in Modeke Asogo town, Oyo State has been carried out, to determine the suitability of the site for the proposed project. The results obtained from both the field investigations and the laboratory analysis indicated the DCPT shows that the area is underlain by stiff to very stiff Sandy lateritic Clay and finally by very stiff to hard sandy lateritic clay with hard pans. The soil is well graded with dominant gravel suggesting a well-drained soil that is suitable for foundation. The lateritic clay between the existing ground level and -1.50m the results indicate low to medium compressibility. The lateritic clay is of low to medium plasticity with low moisture content on Casagrande Plasticity Chart. The soil is in the A-6 group of AASHTO soil classification system.

Recommendation

Continuous strip footings at 0.40m depth below the existing ground level to be designed for the proposed building. The final ground floor level of the building should be raised to a height of not less than +600mm above the present ground level depending on the relief of the site. To stem the problem of flooding in the area, the final ground level of the building should take into account this natural controllable phenomenon and provision of a good and functional drainage system should be incorporated into the preliminary and final design of the project. The trial pit excavation and the CPT test locations represented a very small statistical sampling of the subsurface conditions. These subsurface conditions could vary substantially from those indicated by the soil test results. In such instance, adjustment to the design and construction of the proposed structure(s) may be necessary depending on the characteristics materials encountered.

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