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# Engineering Geological Properties of Soil for Design and Construction of Foundation from Kpansia in Yenagoa, Bayelsa State, Nigeria

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**Abstract:** *The geotechnical properties of soils influence the stability of construction materials and civil engineering structures. This study investigated the geotechnical properties of soil for design and construction of foundation from Kpansia in Yenagoa, Bayelsa State, Nigeria using standard techniques. Results obtained show that the Atterberg limit results reveal that the liquid limit ranges from 73.2% to 94.8%, the plastic limit ranges from 31.2% to 48.6% while the plasticity index values range from 34.8% to 50.1%. The cohesive soils(clays) are highly plastic (CH) in the Unified Soil Classification System (USCS) designation. The natural moisture content ranges from 63.5% to 87.9%. The particle size distribution analysis reveals that the sand is fine to medium to coarse grained and in a medium dense state of compaction and based on its coefficient of uniformity and gradation classifies as poorly graded (SP) by the USCS designation. The moisture content of the sand ranges from 12.6% to 19.2% while the bulk unit weight ranges from 19.6KN/m$^3$ to 20.3 KN/m$^3$. The angle of shearing resistance ranges from 26$^0$ to 33$^0$. The result of the undrained shear strength of the clay ranges from 16Kpa and 19Kpa. The clay is very soft to soft and exhibit medium to high moisture content. The strength test result indicates a material of low undrained shear strength, the coefficient of consolidation, Cv of the clay soil samples varies between 1.40m$^2$/year and 2.89 m$^2$/year. The coefficient of volume compressibility,Mv,for the same materials varies between 0.088 m$^2$/MN and 3.548 m$^2$/MN, generally indicating clay layers of high to very high compressibility. Raft foundation is best suited for these weak, soft foundation materials.*

**Keywords**: Geotechnical Properties; Atterberglimit; shearing resistance; Undrained shear strength.

## INTRODUCTION

The stability of civil engineering structures like building, bridge, highway, railway, runway, embankment etc.; that are erected below or on the surface of the earth required suitable foundation soil.The suitability of soil to be used as foundation or as construction materials requires a thorough and detail understanding of geotechnical properties of the soil which can be assessed by carrying out proper ground investigation (Oke et al. 2008).

Soils containing large quantities of silt and clay are the most troublesome in civil engineering construction. These materials exhibit tremendous changes in physical properties with change of moisture content. Hard dry clay may be suitable as a foundation material for heavy loads as long as it remains dry, but may turn into a weak, soft highly compressible clay when it becomes wet, and when the foundations of any structure are constructed on this compressible soil, it leads to settlement. Knowing the rate at which the compression of the soil takes place is essential for design consideration.

Geotechnical properties of subsoil are very important as relevant input data can be obtained for accurate interpretation as it assists the site engineers on the appropriate design and construction of foundations for the proposed structures. Some authors have argued that properly planned design and construction of civil engineering structures prevent structural failure or adverse environmental or post construction problems (Oghenero et al. 2014; Nwankwoala et al. 2014; Ngah et al 2013). Hence, the objective of this study is to investigate the geotechnical properties of soil for design and construction of foundation from Kpansia in Yenagoa, Bayelsa State, Nigeria using standard techniques.

**Description of the Study Area**

The study area is found within longitude $6^o\,15^l$ E and $6^o\,18^l$ E and latitude $4^o\,50^l$ N and $4^o\,55^l$ N (Fig. 1). The study area is in the Niger Delta tropical rain forest vegetation and basically accessible by a good road network. Although there are wooded valleys in the Southeast, the vegetation is mostly open grasslands which are used for grazing and farming. The study area is Kpansia in Yenagoa local government area. The terrain is lowland area, which is characterized by floodplains, with the highest elevation of about 15metres above sea level. The location falls within the Niger Delta (Miocene-Recent) which occurs at southern part of Nigeria bordering the Atlantic Ocean. Stratigraphically, the Niger Delta comprises of the lower marine unit, the Akata Formation, the middle continental unit, the Agbada Formation and the upper continental sequence, the Benin Formation. However, the study area falls within the Benin Formation which is characterized by clay, sand and sandstones that are coarse grained (commonly very granular) to very fine grained.(Reyment, 1965, Short and Stauble, 1967). The main deposit encountered at the site is organic peaty clays and sands. There is severe drainage problem with seasonal and temporary flooding due to heavy rainfall and rise in groundwater table.

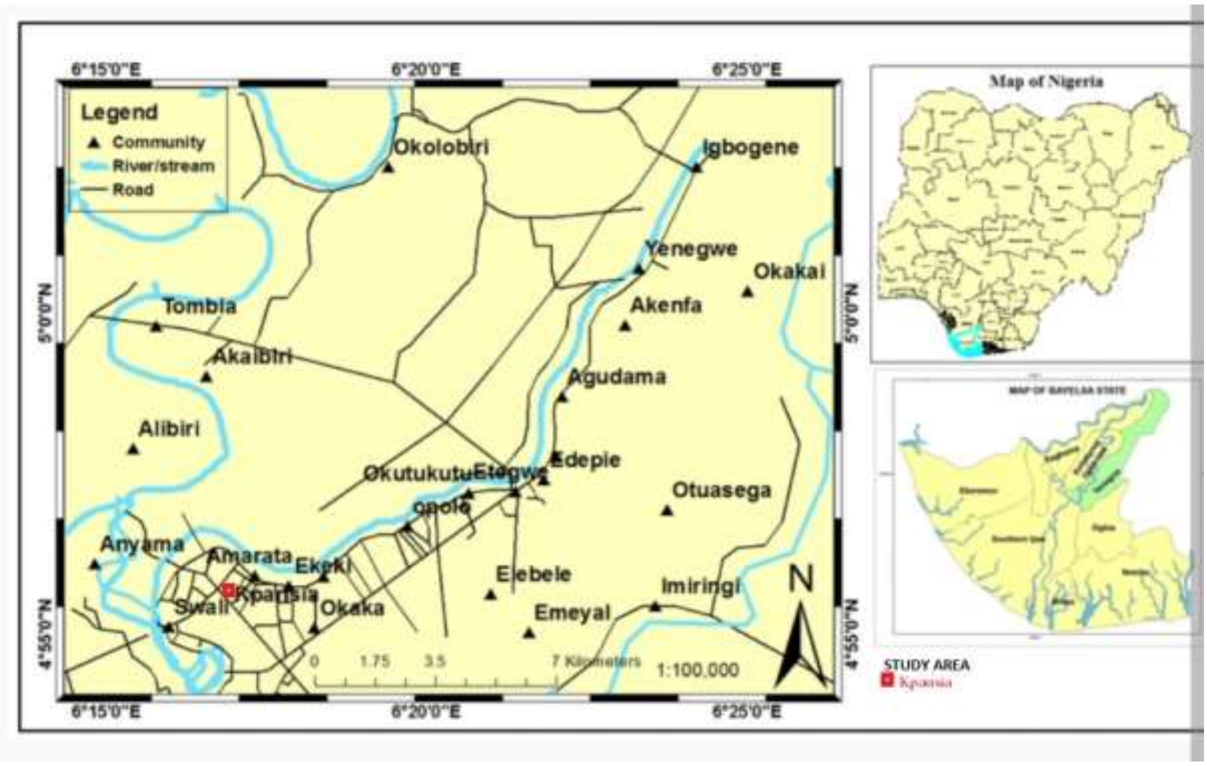


Fig. 1 Map of Yenagoa, Bayelsa State showing the study location.

## MATERIALS AND METHODS

### Sample Collection

The investigation comprised mainly the drilling of two (2) number geotechnical boreholesin Kpansia, Yenagoa, with soil sampling, measurement of water table and conducting standard penetration tests. The boreholes were drilled using the percussion boring rig. The disturbed samples were taken at regular intervals and at change in soil type. The samples were used for a detailed and systematic description of the soil in each stratum in terms of its visual and tactile properties and for laboratory tests. The soil sampling was carried out in accordance with BS1377, with a minimum requirement set out in ASTM. Field measurements of groundwater showed that groundwater levels stood at 1.0m. The water levels in boreholes are subject to seasonal fluctuations.

### Laboratory investigation.

A series of classification, strength and compressibility tests were carried out in the laboratory. These tests were performed in accordance with British and ASTM standards.Details of the different tests are given below.

### Moisture Content

Moisture content test was carried out in accordance with BS1377, on samples recovered from the boreholes. The moisture content was determined by drying selected moist/wet soil materials for at least 18 hours to a constant mass in a 110$^{o}$c drying oven. The difference in mass before and after drying was used as the mass of the water in the test material. The mass of material remaining after drying was used as the mass of the solid particles. The ratio of the mass of water to the measured mass of solid particles was the moisture content of the material.

**Atterberg Limits**

Atterberg limits were determined on soil specimens with a particle size less than 0.425mm. The Atterberg limit refers to arbitrary defined boundaries between the liquid limit and plastic states (liquid limit, $W_L$) and between the plastic and the brittle states (plastic limit, $W_P$) of fine-grained soils. The **liquid limit** is the water content at which a part of soil placed in a standard cup and cut by a groove of standard dimensions flow together at the base of the groove when the cup is subjected to 25 standard shocks. The one-point liquid test was carried out. Distilled water was added during soil mixing to achieve the required consistency. **Plastic limit** is thewater content at which a soil can no longer be deformed by rolling into 3mm diameter threads without crumbling. The difference between the liquid limit and the plastic limit is the plasticity index, $I_P$.

**Particle Size Analysis**

Particle size analyses were performed by means of sieving. Sieving was carried out for particles that would be retained on a 0.075mm sieve, dry sieving was carried out by passing the soil sample over a set of standard sieve sizes and then shakes the entire units for few minutes with sieve shaker (machine).

Particle size is presented on a logarithmic scale so that two soils having the same degree of uniformity are represented by curves of the same shape regardless of their positions on the particle size distribution plot. The general slope of the distribution curve may be described by the coefficient of uniformity Cu, where $Cu=D_{60}/D_{10}$ and the coefficient of curvature Cc, where $Cc= (D_{30})^2/ D_{60}.D_{10}$. $D_{60}$, $D_{30}$ and $D_{10}$ are effective particle sizes indicating that 60%, 30% and 10% respectively of the particles (by weight) are smaller than the given effective size.Reference test standard, BS1377, Part2, 1990.

**Unit Weight**

The unit weights were determined from measurement of mass and volume of the soil. The unit weight ($KN/m^3$)refers to the unit weight of the soil at the sampled water content, The dry unit was determined from the mass of oven-dried soil and the initial volume. . Reference test standard, BS1377, Part2, 1990.

**Unconsolidated undrainedTriaxial**

Unconsolidated undrained triaxial compression tests were performed on cohesive samples, relatively undisturbed samples obtained from the open boreholes, with the objective of determining their undrained strength parameters, in accordance with BS1377, Part2, 1990

**Direct Shear Test**

The soil specimen is loaded into the shear box which split into two halves along a horizontal plane at its middle. The box is square with 60mm sides and 50mm high. It is made up of brass metal. It is placed inside a larger box-container and mounted on the loading frame. A proving ring is fitted to the upper halve of the box to measure the shear force. The proving ring which butts against a fixed support records the shear force as the box moves and the shear displacement is measured with a dial gauge fitted to the container. Another dial gauge fitted to the top of the pressure pad measures the change in the thickness of the specimen. . Reference test standard, BS1377, Part1-2016.

**Oedometer Consolidation**

Laboratory consolidation tests were carried out on cohesive soil specimens, relatively undisturbed sample with object of determining the compressibility properties of the soils, in accordance with BS 1377. The plot of void ratio (e) against effective pressure (P) for the samples tested presented in tables 1 and figure 4 together with calculated values of the coefficients of consolidation, (Cv) and coefficient of compressibility (Mv). Test results show that the samples are of predominantly high compressibility.

**Soil Stratigraphy**

The strata show that the site is predominantly clay both in boreholes BH1 and BH2. In BH1, the strata reveal a formation of loose fine silty sand from the ground surface to 7.50m depth. The sity sand is greyish in colour. Beneath the silty sand was soft greyish silty peaty clay to the depth of 15.0m. In BH2, peaty clay is observed from ground surface to a depth of 3.0m. Underneath the peaty clay, loose greyish silty fine sand was encountered to a depth of 6.0m. Between 6.0m and 7.5m, another layer of peaty clay is observed. Below 7.5m to the depth of 12.0m, fine sand is encountered. The sand is loose to medium dense in compaction and grey in colour. Beneath the sand stratum to the final 30.0m depth of the investigation, peaty clay is again encountered. The clay is soft in consistency and grey in colour.

## RESULTS AND DISCUSSION

**Soft Clays**

The engineering properties and behaviour of clay is of significant because of the dominant influence of the fines. The higher the liquid limit of clays and silts, the more compressible they become. The engineering properties of soil samples obtained from the laboratory analysis are presented in tables 1-5 and figures 2-6.

**Table 1 Geotechnical properties of soil samples**

| Soil type | Soil parameters | Min. | Max. | Mean |
|---|---|---|---|---|
| **Clay** | Moisture Content (%) | 63.5 | 87.9 | 75.7 |
| | Bulk unit weight (KN/m$^3$) | 14.1 | 14.8 | 14.45 |
| | Dry unit weight (KN/m$^3$) | 7.6 | 8.9 | 8.25 |
| | Undrained shear strength (Kpa) | 15 | 18 | 16.5 |
| | Cohesion, C (KN/m$^2$) | 16 | 23 | 19.5 |
| | Angle of shearing resistance (Degree) | 3 | 6 | 4.5 |
| | Liquid limit (%) | 73.2 | 94.8 | 84.0 |
| | Plastic limit (%) | 31.2 | 48.6 | 39.9 |
| | Plasticity Index (%) | 34.8 | 50.1 | 42.45 |
| | **Classification USCS** | **CH** | **CH** | **CH** |
| | Coefficient of consolidation (m$^2$/Yr.) | 1.40 | 2.82 | 1.95 |
| | Coefficient of compressible (m$^2$/MN) | 0.088 | 3.545 | 1.82 |
| | Poisson's ratio | 0.40 | 0.43 | 0.42 |
| | Coefficient of earth pressure at rest, Ko | 0.81 | 0.90 | 0.86 |

**Table 2 Results of the Atterberg limit test**

| Location/ Borehole No. | Depth of sample (m) | Moisture content (%) | Liquid Limit (%) | Plastic Limit (%) | Plasticity index (%) | Liquidity index | Coefficient of Earth pressure at Rest, Ko | Casagrande classification |
|---|---|---|---|---|---|---|---|---|
| **Kpansia** | 8.0 | 67.5 | 73.2 | 38.4 | 34.8 | 0.84 | 0.81 | CH |
| **1** | 11.0 | 68.1 | 76.5 | 38.7 | 37.8 | 0.78 | 0.84 | CH |
| | 14.0 | 87.9 | 92.1 | 48.6 | 43.5 | 0.90 | 0.90 | CH |
| | | | | | | | | |
| **2** | 1.0 | 86.5 | 94.8 | 44.7 | 50.1 | 0.83 | 0.81 | CH |
| | 3.0 | 78.3 | 84.6 | 40.5 | 44.1 | 0.86 | 0.84 | CH |
| | 8.0 | 65.7 | 76.7 | 31.2 | 45.5 | 0.76 | 0.87 | CH |
| | 15.0 | 63.5 | 75.2 | 31.5 | 43.7 | 0.73 | 0.90 | CH |
| | 20.0 | 72.5 | 82.3 | 39.8 | 42.5 | 0.77 | 0.81 | CH |
| | 22.0 | 71.3 | 81.2 | 39.7 | 41.5 | 0.76 | 0.81 | CH |
| | 28.0 | 79.5 | 88.6 | 39.9 | 48.7 | 0.81 | 0.87 | CH |

**Table3 Results of particle size distribution and drained direct shear test**

| Borehole No. | Depth of sample (m) | Moisture content (%) | Bulk Unit Wt .KN/m$^3$ | Angle of shearing Resistance (ϕ) Degree | Effective particle size $D_{10}$ (mm) | D30 (mm) | Mean particle size D50 | D60 (mm) | Coeff. of uniformity $Cu=D_{60}/D_{10}$ | Cc | USCS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2.0 | 12.6 | 19.8 | 28 | 0.019 | 0.038 | 0.062 | 0.071 | 3.737 | 1.070 | SP |
| | 6.0 | 18.9 | 20.1 | 30 | 0.046 | 0.092 | 0.108 | 0.135 | 2.935 | 1.363 | SP |
| 2 | 5.0 | 14.2 | 19.6 | 31 | 0.085 | 0.145 | 0.165 | 0.184 | 2.165 | 1.344 | SP |
| | 9.0 | 19.2 | 19.7 | 33 | 0.031 | 0.061 | 0.072 | 0.087 | 2.806 | 1.380 | SP |

**Table 4 Results of the Undrained Triaxial compression tests**

| BH No. | Depth (m) | Moisture content (%) | Bulk Unit Wt KN/m$^3$ | Dry Unit Wt. KN/m$^3$ | Undrained Cohesion Cu KN/m$^2$ | Angle of Shearing Resist. (ϕ) Degree | Shear Modul. MN/m$^2$ | Poisson's Ratio |
|---|---|---|---|---|---|---|---|---|
| | 8.0 | 67.5 | 14.5 | 8.7 | 20 | 6 | 7.5 | 0.40 |
| 1 | 11.0 | 68.1 | 14.7 | 8.7 | 21 | 5 | 7.8 | 0.40 |
| | 14.0 | 87.9 | 14.8 | 7.9 | 18 | 3 | 8.7 | 0.41 |
| 2 | 1.0 | 86.5 | 14.1 | 7.6 | 16 | 6 | 4.7 | 0.42 |
| | 3.0 | 78.3 | 14.3 | 8.0 | 18 | 5 | 4.6 | 0.43 |
| | 8.0 | 65.7 | 14.7 | 8.9 | 22 | 4 | 7.5 | 0.40 |
| | 15.0 | 63.5 | 14.8 | 8.9 | 23 | 3 | 9.7 | 0.40 |
| | 20.0 | 72.5 | 14.6 | 8.6 | 19 | 6 | 8.7 | 0.41 |
| | 22.0 | 71.3 | 14.6 | 8.5 | 18 | 6 | 8.6 | 0.41 |
| | 28.0 | 79.5 | 14.7 | 8.2 | 20 | 4 | 8.8 | 0.42 |

**Medium dense sand.**
The sand is fine to medium grained, poorly graded, medium dense and greyish to brown in colour. The layers are almost of uniform gradation. The ranges of variations in relevant engineering parameters of the sand are shown in table 5.

**Table5 Characteristics values for sand samples**

| Soil type | Soil Parameters | Min. | Max. | Mean |
|---|---|---|---|---|
| Sand | Moisture content (%) | 12.6 | 19.2 | 15.9 |
| | Bulk unit weight (KN/ $m^3$) | 19.6 | 20.3 | 19.95 |
| | Effective unit weight (KN/ $m^3$) | 8.31 | 9.09 | 8.7 |
| | Poisson's ratio | 0.40 | 0.43 | 0.42 |
| | Angle of shearing resistance (Degree) | 28 | 33 | 30.5 |
| | Effective particle size, $D_{10}$mm | 0.019 | 0.085 | 0.052 |
| | Effective particle size, $D_{30}$mm | 0.038 | 0.145 | 0.092 |
| | Mean particle size, $D_{50}$mm | 0.062 | 0.165 | 0.114 |
| | Effective particle size, $D_{60}$mm | 0.071 | 0.184 | 0.128 |
| | Coefficient of uniformity $Cu= D_{60}/D_{10}$ | 2.165 | 3.737 | 2.961 |
| | Coefficient of curvature $Cc = (D_{30})^2/ D_{60}.D_{10}$ | 0.972 | 1.380 | 1.176 |
| | Classification USCS | SP | SP | SP |

The moisture content affects the engineering performance of clay deposits. The ability to expand when it absorbs water and shrink when it loses moisture. Moreso, the moisture content values range between 63.5 to 87.9%, this is relatively high because of the wet season period of sampling. Atterberg limit results reveal that the liquid limit ranges from 73.2- 94.8%, the plastic limit ranges from 31.2- 48.6% while the plasticity index ranges from 34.8- 50.1%, indicating that the clays are highly plastic (CH) on the bases of unified soil classification system (USCS). The particle size distribution reveals that the cohesionless soil samples are predominantly fine to medium, medium dense poorly graded sand (SP). The cohesive soils are highly organic clays and peats that are very soft and very highly compressible as the values of coefficient of volume compressibility (Mv) vary between 0.088 and 3.548$m^2$/MN.

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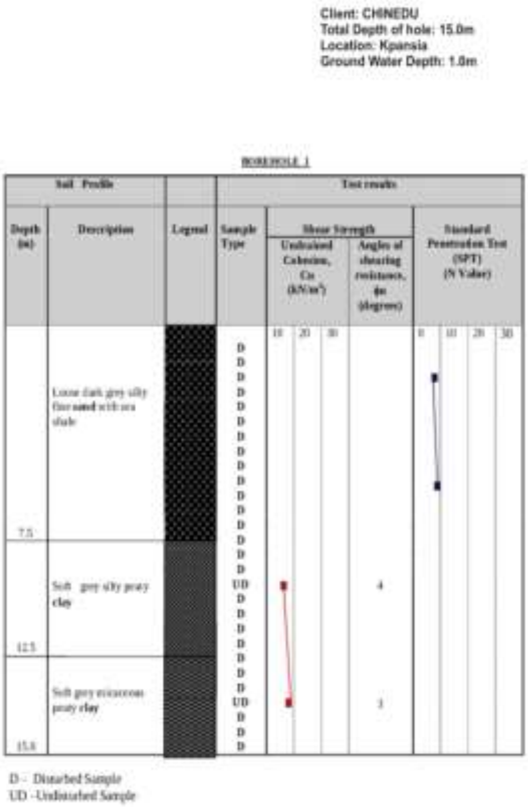


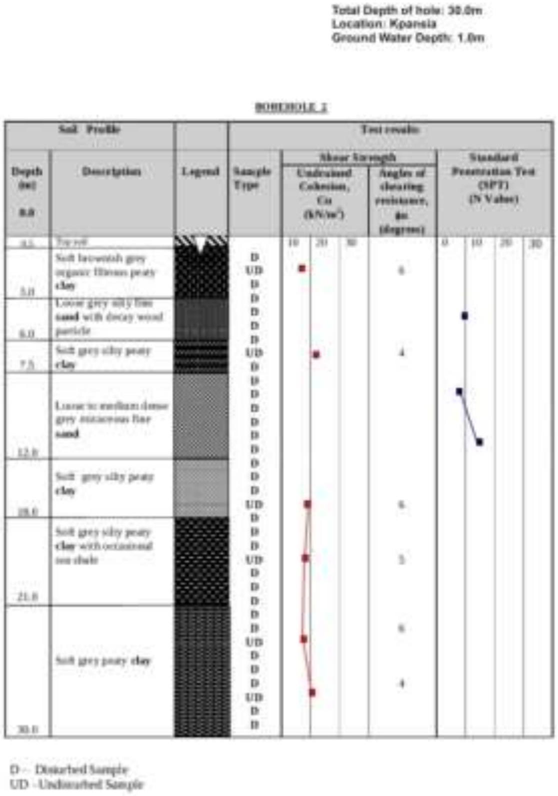
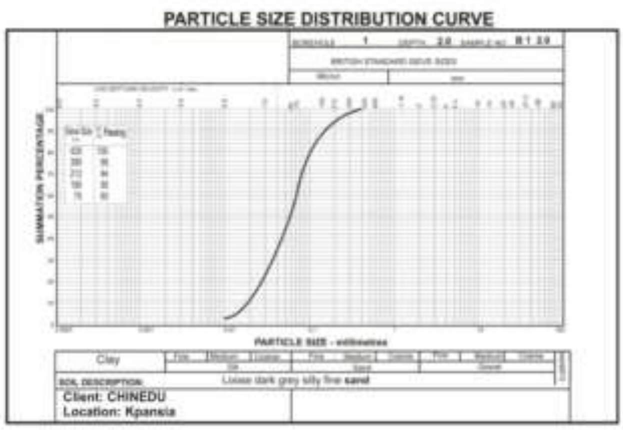




Fig.2a. Borehole log for BH1 Fig.2b Borehole log for BH2



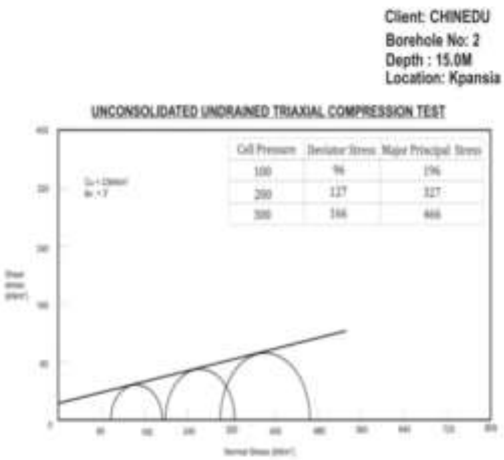
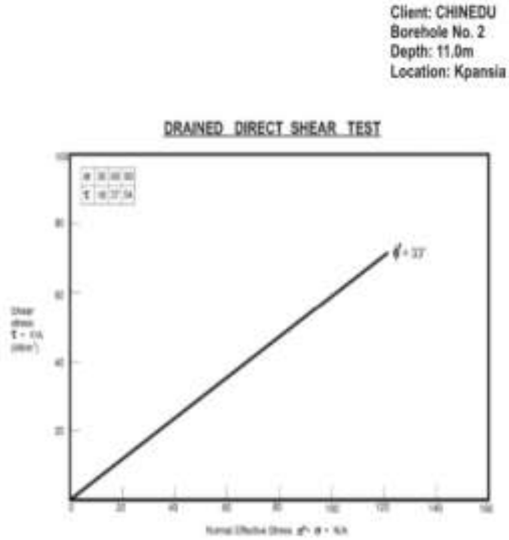




Fig.3 Particle size distribution curve BH1 @ 2.0m Fig.4 Mohr circle for BH2 @ 15.0m



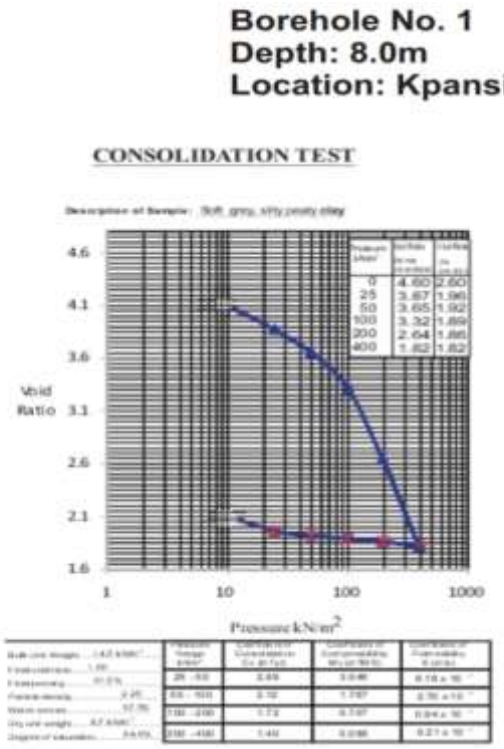




Fig.5 Direct shear test forBH2 @ 11.0m

Fig. 6 Consolidation curve for BH1 @ 8.0m

## CONCLUSION

The study has provided improved and detailed understanding of the geotechnical properties and characteristics of the underlying soils across the studied area. The very low water gradient in the Niger Delta, coupled with the flat topography, the soil properties and high rainfall of the wet season, it is important to check this engineering problem by constructing good drainage network. Finally, the raft foundation is the most suitable as it provides support in highly compressible, low strength foundation materials.

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