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Engineering Geological Properties of Subsurface Soils for Foundation Purposes in Parts of Bayelsa State, Niger Delta

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ABSTRACT: *The geotechnical properties of soil samples obtained from eight (8) boreholes from some parts of Bayelsa State were determined to assess their suitability as foundation materials. The geotechnical characteristics of the soils were determined from the laboratory and field works. The Atterberg limit results reveal that the liquid limit ranges from 46.5% to 98.3%, the plastic limit ranges from 23.5% to 56.3% while the plasticity Index values range from 17.1% to 51.3%. The clays are highly plastic (CH) in the USCS designation. The natural moisture content ranges from 35.9% to 91.3%, the moisture content is relatively high, this could be attributed to the wet season period of sampling. The particle size analysis disclosed that the cohesionless samples are predominantly fine to medium and medium dense sands. The triaxial test results shows that values of Cohesion (C) ranges between 16 – 40KN/m^2 and the friction angle (ϕ) ranges between 3 – 6^o. The result of the undrained shear strength of the clay ranges between 20Kpa and 24Kpa. The coefficient of consolidation (Cv) of the clay soil samples varies between 1.13 m^2/yr and 2.89 m^2/yr, the coefficient of volume compressibility, (Mv) for these same materials varies between 0.215 m^2/MN and 6.338 m^2/MN. Generally, indicating clay layers of high to very high compressibility. The calculated values for ultimate bearing capacity (q_u) and allowable bearing capacity (q_a) varies between 100.29KN/m^2 to 151.49 KN/m^2 and 33.42 KN/m^2 to 50.50 KN/m^2 respectively. The analyses showed that the values of ultimate bearing capacity increases with depth. The calculated settlement ranges between 69mm to 653mm with the thickness of clay of 7.5m and 30.0m respectively. Raft foundation is best suited for these weak, soft foundation materials for light structural loads but for heavy structural load, a pile foundation is recommended.*

KEYWORDS. Atterberg limit, cohesion, friction angle, coefficient of consolidation, coefficient of volume compressibility, shear strength

INTRODUCTION

Geotechnical properties of soils influence the stability of civil engineering structures. The civil engineering structures such as buildings, bridges, highway, etc. are founded below or on the surface of the earth. Not understanding the behaviour of the soil or lack of information as it concerns the soils engineering properties may result to structural failure or post construction problems which include cracks on building caused by differential settlement or total collapse of the structure.

(Nwankwoala et al, 2013; Teme, Oghenero et al, 2014). Geotechnical properties of the subsoils are necessary for generating relevant input data for design and construction of foundations for the proposed structures. (Laskar et al, 2012; Prakash and Jain, 2002; Ekpelu et al, 2018; Didei et al, 2016). In geotechnical investigation, different properties of soil are determined with the help of different tests and techniques. Determining soil behaviour and its properties is quite difficult as there isn't any method that can give exact behaviour of soil. All methods which are used to predict the behaviour of soil up to certain accuracy based on practices and experiences. Different geotechnical properties of soils such as moisture content, Atterberg limit, particle size analysis, shear strength, consolidation and permeability give almost every necessary information of soil for design of structures and for planning construction techniques. Some soils are simply not capable of supporting the weight or bearing pressure exerted by a building's foundation. Most settlement problems caused by weak bearing soils occur in residential construction, where the footings are designed base upon general guidelines and not site-specific soil information (Teme, 2000; Murthy,2008; Ngah and Nwankwoala, 2013; Oke and Amadi, 2008)

Description of the study Area

The study area is found within longitude $5^o\,40^l$ E and $6^o\,15^1$ E and latitude $4^o\,30^l$ N and $5^o\,05^l$ N (Fig.1). The study area is located in the Niger Delta rain forest vegetation and basically accessible by a good road network and river system. Bayelsa State shares a boundary with Delta State on the North, Rivers State on the East and the Atlantic Ocean on the West and South. It has a total area of $10{,}773km^2$, and comprises eight local government areas namely; Ekeremor, Kolokuma/Opokuma, Yenagoa, Nembe, Ogbia, Sagbama, Brass and Southern Ijaw. The study area cuts across four (4) local government areas which is Kpansia in Yenagoa local government area, Amassoma in Southern Ijaw, Ekeremor in Ekeremor and Elebele in Ogbia local government area. The terrain is flat, low, sloping very gently seawards (usually does not exceed 20m above sea level) and is drained and crisscrossed by network of distributaries characterized by the freshwater ecology of the upper reaches of the River Nun within the Niger Delta. 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 & Stauble, 1967). The main deposit encountered at the site is organic peaty clays and sands. Akpokodje, (1989), identified six major geomorphic units that comprise the Niger Delta, they are Barrier Island, mangrove swamps, coastal plain sands, Warri – Sombreiro delta plain, lower Niger flood plain and Niger flood zone. The study area is associated with freshwater swamps, backswamps and meander belts of flat to sub-horizontal elevation. There is severe drainage problem with seasonal and temporary flooding due to heavy rainfall and rise in groundwater table.

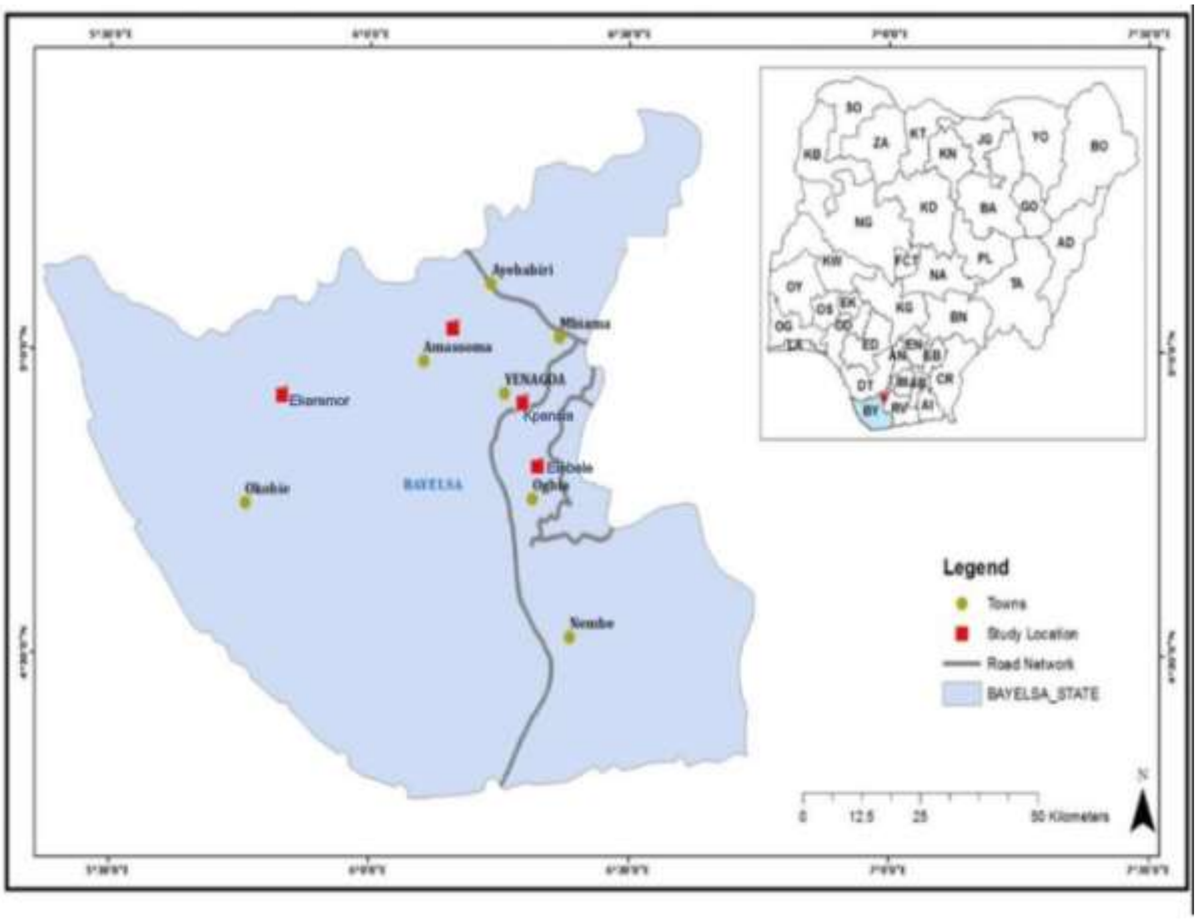

Fig. 1 Map of Bayelsa State showing the study area

MATERIALS AND METHODS

The investigation comprised mainly the drilling of eight (8) number geotechnical boreholes, two (2) each in Amassoma, Ekeremor, Elebele and Kpansia respectively, 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 BS 5930, with a minimum requirement set out in ASTM. Field measurements of groundwater showed that groundwater levels stood at between 1.0m and 3.0m. 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 limits 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 the water 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 analysis was 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 undrained Triaxial

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 5 and figure 7 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.

RESULTS AND DISCUSSION

Soft Clays: The engineering properties and behaviour of clay is of significant because of the dominant influence of the fines. The shear strength exhibited by the cohesive soil drops significantly when in contact with water. The characteristics values of the geotechnical parameters of soil samples as obtained from the laboratory analysis are presented in tables 1 to 5 and the various plots and curves are presented in Figures 1 to 7 respectively.

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Table 1. Characteristics values for soil samples

Strata layers	Soil parameters	Min.	Max.	Av.
	Water content (%)	35.9	91.3	63.6
	Bulk unit weight (KN/m^3)	14.1	18.8	16.5
	Effective unit weight (KN/m^3)	7.4	13.0	12.65
	Undrained shear strength (Kpa)	20	24	22
Clay	Cohesion, C (KN/m^2)	16	40	28
	Angle of shearing resistance (Degree)	3	6	4.5
	Liquid limit (%)	46.5	98.3	72.4
	Plastic limit (%)	23.5	56.3	39.9
	Plasticity index (%)	17.1	51.3	34.2
	Coefficient of consolidation (m^2/yr.)	1.13	2.89	2.01
	Coefficient of compressible (m^2/MN.)	0.215	6.338	3.277
	Poisson's ratio	0.40	0.43	0.42
Sand	Water content	8.9	19.2	14.1
	Bulk unit weight (KN/m^3)	18.4	21.0	19.7
	Effective unit weight (KN/m^3)	10.6	12.4	11.5
	Poisson's ratio	0.35	0.40	0.38
	Angle of shearing resistance (Degree)	25	37	31
	Coefficient of uniformity $Cu= d_{60}/d_{10}$	1.804	5.255	3.530
	Coefficient of curvature $Cc = d_{30}^2 / d_{60}.d_{10}$	0.926	1.380	1.153
	Standard Penetration Test (SPT) N value	8	37	22.5

Medium dense sand.

The sand is fine to medium grained, poorly graded, medium dense and greyish in colour. The layers are almost of uniform gradation. The ranges of variations in relevant engineering parameters of the sand are shown in tables 1 above.

Table 2: Summary Result of Atterberg Limits

Location/ borehole no.	Depth of sample range (m)	Liquid limit range (%)	Plastic limit range (%)	Plasticity index range (%)	Casagrande classification
Amassoma 1 2	1.5 – 29.0 2.0 – 31.0	50.1 – 98.3 46.5 – 98.2	26.7 – 49.8 23.5 – 49.5	19.0 – 48.5 20.7 – 48.7	CH CH
Ekeremor 1 2	1.0 – 12.0 8.0 – 26.0	69.5 – 78.4 54.3 – 95.8	35.6 – 42.5 28.4 – 56.3	28.4 – 35.9 17.1 – 39.5	CH CH
Elebele 1 2	1.5 – 14.0 1.0 – 28.0	76.4 – 96.5 64.3 – 94.2	28.9 – 45.2 28.9 – 45.6	41.3 – 57.3 33.7 – 48.6	CH CH
Kpansia 1 2	8.0 – 14.0 1.0 – 28.0	73.2 – 92.1 75.2 – 94.8	38.4 – 48.6 31.2 – 44.7	34.8 – 43.5 41.5 – 50.1	CH CH

Table 3: Summary Result of the Triaxial Test

Location/borehole no	Depth range (m)	Cohesion intercept (cu) range (KN/m^2)	Frictional angle (Φ) range (degree)	Soil type
Amassoma 1 2	1.5 – 29.0 2.0 – 31.0	16 – 39 16 – 40	3 – 6 3 – 6	Silty clay Silty clay
Ekeremor 1 2	2.0 – 12.0 8.0 – 26.0	16 – 39 18 – 39	3 – 6 3 – 6	Silty clay Silty clay
Elebele 1 2	1.5 – 14.0 1.0 – 28.0	19 – 24 16 – 22	3 – 6 3 – 6	Silty clay Silty clay
Kpansia 1 2	8.0 – 14.0 1.0 – 28.0	18 – 20 16 – 23	3 – 6 3 – 6	Silty clay Silty clay

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Table 4: Summary Result of Drained Direct Shear Test

Location/ borehole no	Depth sample range (m)	Water content range (%)	Bulk unit weight (KN/m³)	Bulk density range kg/m³	Angle of shearing resistance range (⁰)	Description of sample
Amassoma 1	4.0 31.0 – 43	9.7 – 12.3	18.4– 20.7	1.9 – 2.1	25 – 37	Sand
2	0.5 – 5.5, 33.0 – 4.30	9.2 – 12.8	18.9– 21.0	1.9 – 2.1	26 – 36	Sand
Ekeremor 1	12.5 – 15	9.7 – 12.3	18.4– 20.7	1.9 – 2.1	25 -37	Sand
2	2.0 – 4.0, 29.0 – 44.0	8.9 – 13.0	19.7– 20.9	2.0 – 21	27 – 37	Sand
Elebele 1	4.0	13.5	18.8	1.9	27	Sand
2	7 - 12.0	10.1-12.1	19.5– 20.3	2.0 – 2.1	29 – 34	Sand
Kpansia 1	2.0 – 6.0	12.6 – 18.9	19.8– 20.1	2.0	28 – 30	Sand
2	5.0 – 11.0	14.2 – 19.2	19.6 -20.3	20 -2.1	26 – 33	Sand

Table 5: Summary Results of Consolidation Test

			Coefficient of consolidation (cv) (m²/yr) Pressure				Coefficient of compressibility (MV) (m²/MN) Ranges KN/m²			
Location	Borehole	Depth (m)	25-50	50-100	100-200	200-400	25-50	50-100	100-200	200-400
Amassoma	1	1-5 6.0 25.0 29.0	2.69 2.58 2.54 2.10	2.35 2.02 2.13 1.94	1.61 1.72 1.39 1.27	1.52 1.44 1.20 1.13	0.782 0.597 0.833 0.461	0.611 0.441 0.628 0.326	0.558 0.288 0.548 0.279	0.402 0.219 0.434 0.226
	2	4.0 20.0 25.0 27.0	2.46 2.87 2.64 2.72	2.25 2.47 2.23 2.04	1.87 1.75 1.59 1.67	1.47 1.35 1.50 1.43	0.452 0.628 0.733 0.459	0.298 0.592 0.622 0.346	0.265 0.366 0.578 0.289	0.234 0.249 0.430 0.236
Ekeremor	1	4.0 8.0	2.46 2.69	2.25 2.01	1.87 1.73	1.47 1.73	0.452 0.657	0.298 0.401	0.265 0.382	0.234 0.215
	2	12.0 22.0 26.0	2.61 2.32 2.30	2.21 1.91 1.91	1.55 1.74 1.72	1.44 1.43 1.40	0.508 0.646 0.349	0.445 0.501 0.305	0.343 0.492 0.292	0.331 0.417 0.215
Elebe sle	1	1.5 9.0	2.32 2.21	2.12 2.11	1.79 1.65	1.48 1.46	2.00 0.660	0.667 6.330	0.600 0.265	0.401 0.237

	2	15.0 28.0	2.30 2.49	1.90 2.18	1.72 1.89	1.41 1.48	0.667 6.338	0.600 2.817	0.333 0.352	0.266 0.276
Kpansia	1	8.0 11.0	2.89 2.75	2.12 2.57	1.72 1.78	1.40 1.50	3.546 2.362	1.767 1.575	0.707 1.772	0.288 0.408
	2	1.0 21.0	2.84 2.75	2.10 2.57	1.52 1.78	1.47 1.50	1.329 4.698	1.661 1.342	1.329 0.587	0.249 0.483

DISCUSSION

The moisture content affects the engineering performance of clay deposits. The ability to expand when it absorbs water and shrink when it loses moisture. More so, the moisture content values range between 35.9 to 91.3%, this is relatively high because of the wet season period of sampling. Atterberg limit results reveal that the liquid limit ranges from 46.5- 98.3%, the plastic limit ranges from 23.5- 56.3% while the plasticity index ranges from 17.1- 51.3%, indicating that the clays are highly plastic (CH) on the bases of unified soil classification system (USCS). The bulk unit weight for the cohesive (clay) samples ranges 14.1KN/m^3 to 18.8KN/m^3. 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 sands (SP) by the USCS designation. The moisture content of the sand ranges between 8.9% to 19.2% while the bulk unit weight ranges from 18.4KN/m^3 to 21.0KN/m^3. The angle of shearing resistance ranges from 25^0 to 37^0. The result of the undrained shear strength of the clay ranges from 15Kpa and 18Kpa. 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 1.13m^2/year and 2.89 m^2/year. 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) varies between 0.215 and 6.338m^2/MN, exceeded the <0.05 which is classified as very low compressibility (Carter, 1983).

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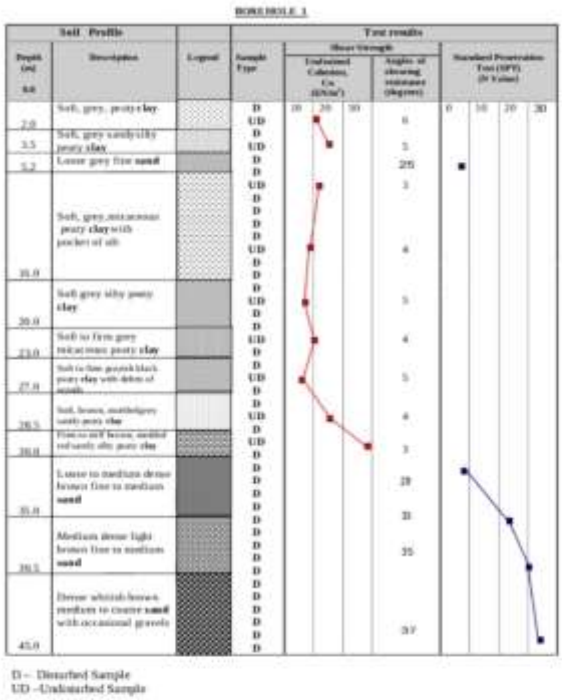

Fig. 2. Borehole log for Amassoma BH1 @ 45.0m

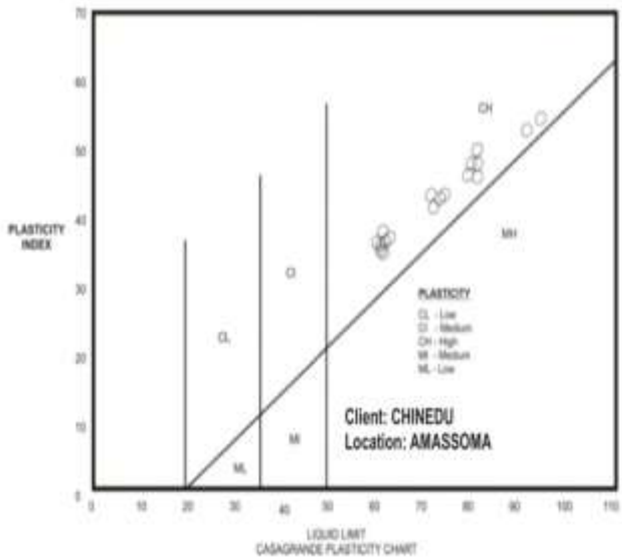

Fig. 3. Plasticity chart for Amassoma

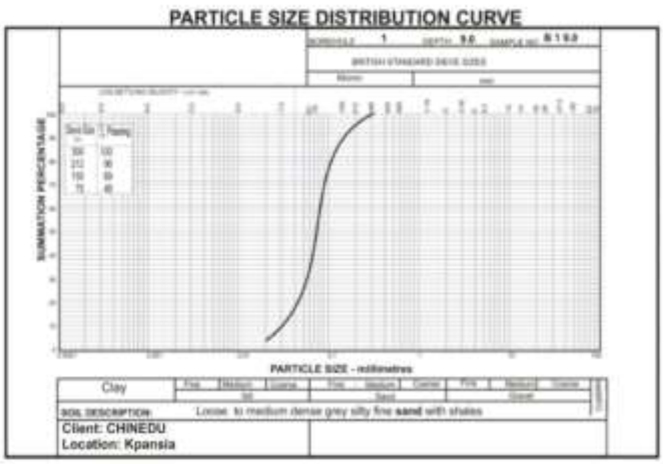

Fig. 4 Particle size distribution curve @ 9.0m

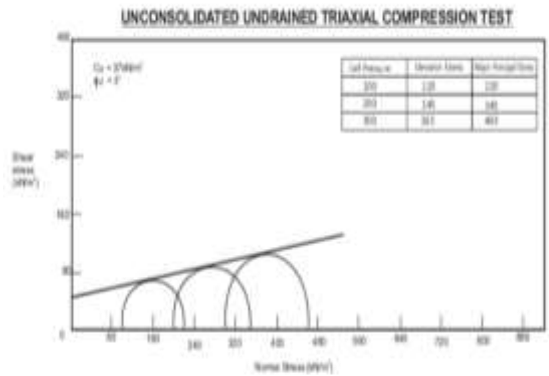

Fig.5. Mohr circle for Ekeremor BH2 @ 9.0m

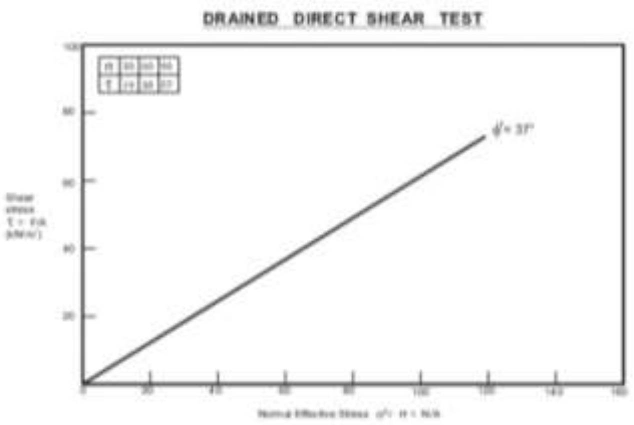

Fig. 6 Drained Direct Shear Test for Ekeremor BH2 @ 44.0m

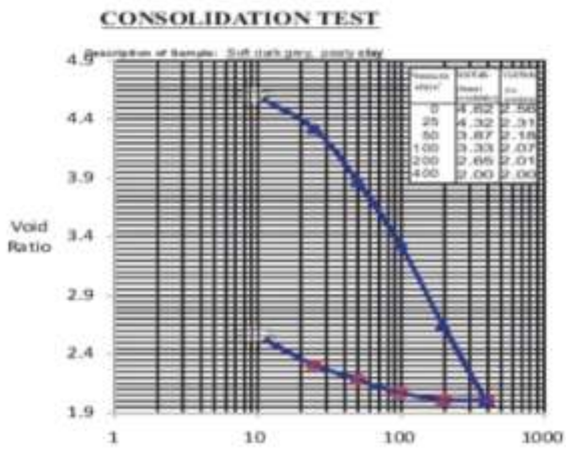

Fig.7. Consolidation Test for Elebele BH2 @ 1.5m

CONCLUSION

The importance of the study of the engineering properties of the soil on which engineering structures are to be built on cannot be overemphasized. Failure to carry out this study and proper design and constructions not strictly adhered to, may lead to settlement as the building begins to show cracks on the walls and finally, the collapse of the building. 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 to minimize the deleterious effects of moisture movements in cohesive soils, foundations should be placed at depths which are unaffected by seasonal fluctuation of moisture content. Finally, the raft foundation is the most suitable as it provides support in highly compressible, low strength foundation materials.

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