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The Subsurface Soil Stratigraphy and Foundation Quality of Soils Underlying Uyo Town, Eastern Niger Delta, Nigeria

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Abstract

An investigation was carried out in Uyo town, Akwa Ibom state to determine the Subsurface Stratigraphy and engineering geological Properties of soils for construction purposes. Eleven boreholes were drilled in different locations across Uyo town to a maximum depth of 20m. Cone penetration tests and standard penetration tests were also carried out on the field and soil samples were obtained for moisture content, atterberg limits, particle size distribution, compaction and triaxial tests. The subsurface stratigraphic profile of Uyo consists from top to bottom of silty clays (0-3m), sandy clays (3-15m) and sand (10-20m) respectively. Engineering geological properties of the soils reveal that the low to intermediate plasticity clays are firm and expected to yield relatively high shear strengths. Standard penetration tests and pile bearing capacity analysis indicate that the sands are suitable foundation materials for construction. The design of a pile foundation using end bearing steel piles terminated within the sand substratum is recommended for the construction of civil engineering structures.

Keywords: Engineering properties, Subsurface Stratigraphy, Foundation, Pile Bearing Capacity.

1 Introduction

Akwa Ibom state is one of the fastest developing states in terms in of infrastructure in the Niger delta region, Nigeria. Through efforts of the state government to industrialize the state, the government has embarked on a massive construction of civil engineering structures in different parts of the state especially in Uyo, it’s capital city. Akwa Ibom state, like other states in the Niger delta region, is characterised by numerous rivers, creeks, swamps, gullies and the presence of structurally weak soils at the surface which often limit the availability of suitable sites for the construction of civil engineering structures. For the safety and durability of construction works in Uyo town, one or more of these problems must be somehow bypassed or improved. In recent times, the cases of building collapse in Nigeria, is on the increase. In the last three years, no fewer than four cases of building collapse have been reported. These include the Church building in Uyo, Akwa Ibom state in December 2016, a seven-storey building in Port Harcourt, Rivers State in November 2018, a three-storey building in Lagos Island on the 13th of March 2019 and another two-storey building in

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Ibadan on the 15th of March 2019 barely seven-two hours after the Lagos incidence. The suspected causes of failure among others include the excessive overloading of the structure and foundation failure. Therefore, in order to avert reoccurrence of this disaster, it is necessary to investigate the engineering geological properties of the sub soil prior to construction.

Although various researches on the engineering properties of soils in the Niger delta region have been documented by different authors such as (Tse and Akpokodje 2002 [1], Teme 2002 [2], Tse and Akpokodje 2010 [3], Nwankwoala and Warmate 2014 [4], Avwenegha 2014 [5], Tse and Ogunyemi 2016 [6], Abam 2016 [7]) etc, only few studies exist on the engineering properties of soils in Akwa Ibom state. (Ukpong and Aguwamba 2012 [8], Essien and Essien, 2013 [9] and Umoren et al., 2016 [10]).

This study therefore takes a holistic approach in tying and correlating the various delineated subsoil horizons and their engineering properties of soils across Uyo town, in order to ascertain their quality of foundation materials.

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2 Geology, Geomorhology and Hygrogeology

Uyo town is located at the center of Akwa Ibom State in the South Eastern part of the Niger Delta (Fig.1). It lies on the flat to gently undulating sandy plains, stone hills and ravines. This intensely dissected region consisits of gullies, ravines and V- shaped valleys. Uyo is drained by the Ikpa river that flows the North to the Southern part of the town

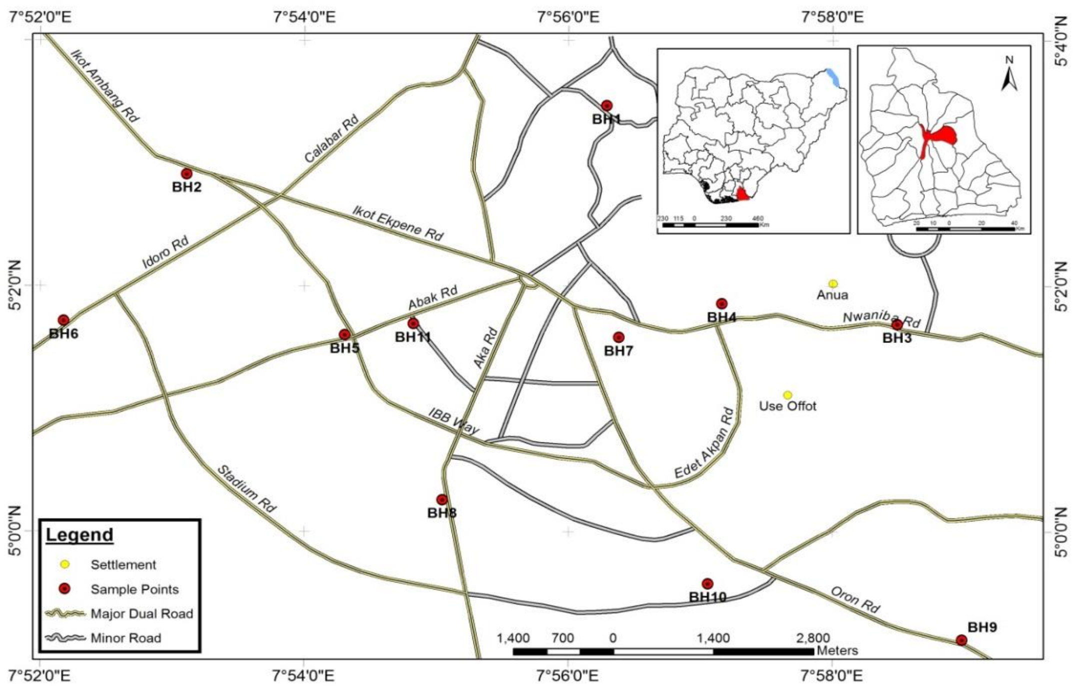

Figure 1: Map of Uyo town, Akwa Ibom state showing borehole locations

The Tertiary Niger Delta is a sedimentary basin, formed as a complex regressive offlap sequence of classic sediments, ranging in thickness from 9,000 to 12,000 meters (Etu-efeotor, 1997 [11]).The three main depositional environments typical of most deltaic environments (marine, mixed and continental) are observable in the Niger Delta and are represented by the Akata, Agbada and Benin formations respectively, they have been described in detail by

Short and Stauble (1967) [12] and Etu-Efeotor (1997) [11].The Akata formation forms the basal unit in the Niger Delta. It comprises mainly of dark grey uniform shales and an open marine facies which indicates shallow marine shelf depositional environment. The formation ranges in age from Paleocene to Holocene and has an approximate thickness of 0 to 6,000 meters. Overlying this formation is the Agbada formation, it consisits of a sequence of sandstone and shales and ranges from Eocene to Oligocene in age. The Agbada formation is over 3000, meters thick and is the main hydrocarbon bearing unit of the Niger Delta basin. The Benin formation overlies the Agbada formation. It is Oligocene to Pleistocene in age and ranges in thickness from 0 to 2,100 meters. It is composed predominantly of freshwater continental friable sands and gravel that have excellent acquifer properties with occasional intercalation of shales. The Benin formation is overlain by various types of quarternary alluvial deposits comprising mainly of recent sand, silt and clay of varying thickness. These deposits occur in five main geomorphic zones consisting of Coastal beach ridge, Mangrove/Saltwater swamps, Freshwater swamps, Sombreiro-Warri deltaic plain with abundant freshwater swamps and dry flat land plain. Geomorphologically, Akwa Ibom state is generally a flat, low lying terrain and riverine environment Usoro (2010) [13]. The land rises steadily northward from the sea-level at Eket in the south to 150m at Obotme in the north Beka and udom (2014) [14]. The Benin formation constitutes the regional acquifer in the Niger delta. Ground water conditions in the Niger Delta have been described by Etu-Efeotor and Akpokodje (1990) [15], Nwankwoala and Udom (2014)[16]etc. Etu-Efeotor and Akpokodje (1990) [15] delineated several irregular lenticular and lateral discontinuous layers of clay acquitard that regionally subdivide the regional acquifers into five units. All the acquifers in the other geomorphic units are generally overlain by sandy/silty clay or clay near the surface excluding the coastal beach islands which has a thin surficial sand layer, 0.5 – 3m thick directly overly a relatively thick clay, which in turn overlies the regional acquifer resulting in perched acquifers. The surface area of Akwa Ibom state is drained by the Cross River on the east, Qua Iboe river on the south Central parts and Imo River on the southwest (Beka and Udom, 2014) [14]. These rivers flow from the northern highlands of Obotme, Nkari, Itu, Ikono and Ibiono and drain into the Atlantic Ocean in the south bordering Eket, Oron, Ikot – Abasi, Eastern Obolo and Mbo. Uyo is drained by the Ikpa river that flows from the north to the southern part of the town through numerous tributaries that emerge from ravines of which the best known is the University of Uyo ravine.

3 Method of Study

This study utilizes engineering geological methods involving field studies and laboratory analysis. The field tests include drilling of eleven (11) boreholes, cone penetrometer test and standard penetration tests. The laboratory tests captured the moisture content, atterberg limits, particle size distribution, compaction and Quick unconsolidated undained triaxial test

3.1 Soil Borings

Boring using the shell and auger percussion drilling rig was used in the drilling operation. Boreholes were drilled to a maximum depth of 20m each. Both disturbed and undisturbed soil samples were collected. The disturbed soil samples were regularly collected at depths of 1m interval. All samples obtained from the borehole were identified and roughly classified on the field.

3.2 Standard penetration tests (SPT) were performed at various depths in the sand horizon. The main objective of this test is to assses the relative densities of cohesionless soils penetrated. In this test, a 50mm diameter split spoon sampler was driven 450mm into the soil with a 63kg hammer falling freely from a distance of 760mm. The number of blows for the

first 150mm of penetration is not counted, while those required to drive the spoon 300mm into the soil provides an indication of the relative density of the cohesionless soil stratum and is recorded as the penetration resistance of the soil. This is also referred to as the N-value.
3.3 Cone penetration testing (CPT)
In situ cone penetration test to estimate the soil bearing capacity were conducted using a 2.5 ton CPT machine. The test involved advancing a 60^0 steel cone with base area of $10cm^2$ into the ground with the view to ascertain the resistance of the soil. This was achieved by securing a winch frame to the ground by means of anchors. These anchors provide the necessary power to push the cone into the ground at the rate of 2cm/sec and the resistance to the penetration registered on a pressure guage connected to the pressure capsule was recorded. At the end, series of cone resistance and sleeve friction readings were plotted against the depth and the bearing capacities of the subsoil horizons calculated.

4 Results and Discussion

4.1 Sub-surface soil Stratigraphy and engineering properties

4.1.1 Sub-surface soil Stratigraphy

A combination of data from the borehole logs, laboratory tests, in-situ cone penetration and standard penetration tests reveal that the subsoil profile (Fig.2) beneath Uyo town consists of silty clay, sandy clay and sand moving from top to bottom.

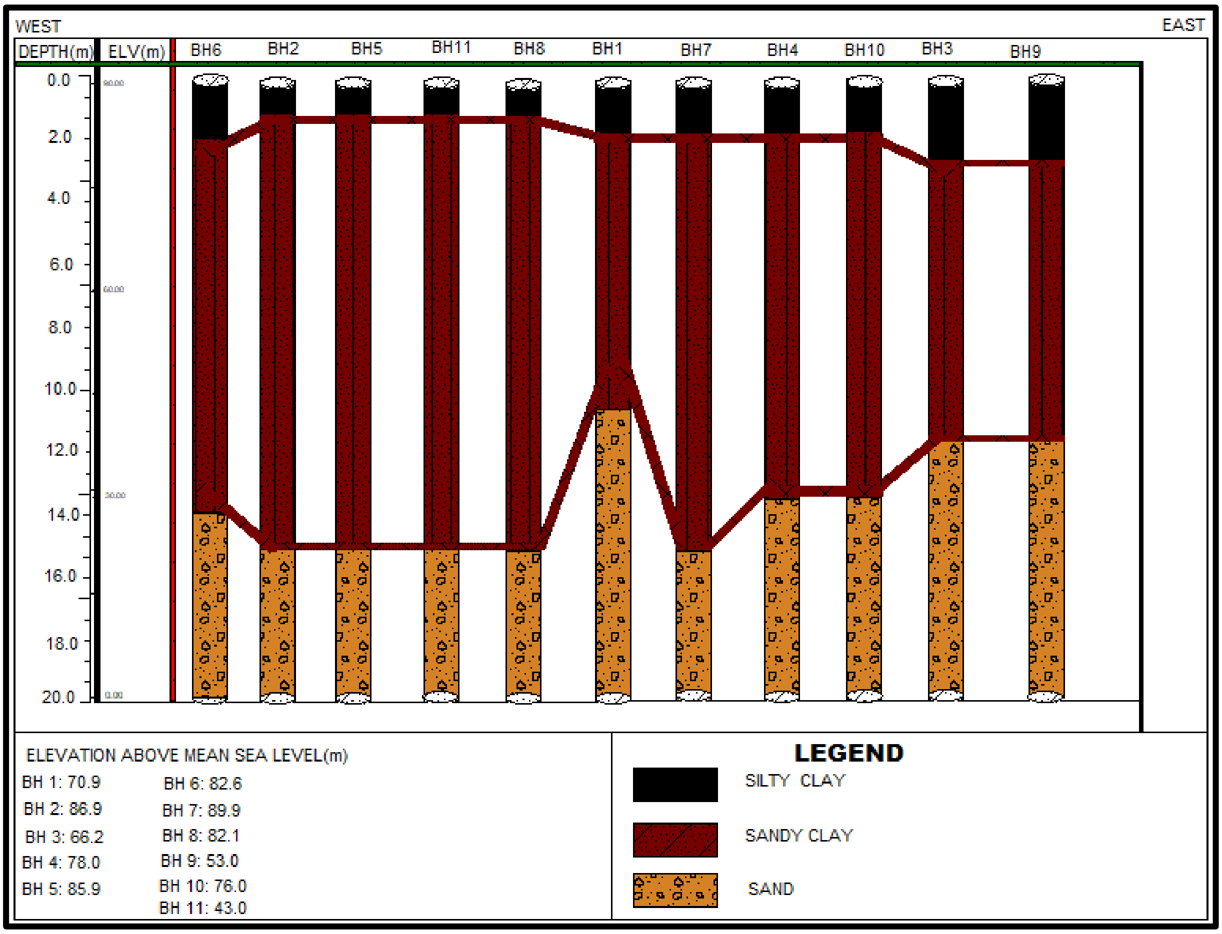

Figure 2: Sub surface Soil stratigraphy of Uyo town.

4.2. Engineering Properties

The discussion of the engineering geological properties of the various soil layers will be based on three major horizons, namely: upper clay, lower clay and sand. Two horizons of clay were encountered during this study. They are termed as Upper and Lower clay horizons on the basis of their relative positions in the soil profile.

4.2.1 Upper Clay horizon

This layer consists of a dark brown, soft to firm silty clay, with an average thickness of 3m. It occurs as the top soil in all the boreholes where it extend from the ground surface to 1m in boreholes (2,5,8 and 11); 2m in boreholes (1, 4, 6,7 and 10) and 3m in boreholes (3 and 9). Engineering properties of the Upper clay horizon are summarised in Table 1. The fines content range from 22 to 40% and the natural moisture content fall between 22 and 26%. Moisture content values vary greatly with season, clay and organic content, Akpokodje (1986) [17]. The range of values of the liquid limit and plasticity index are 32 to 45% with an average of 36% and 12 to 20% with an average of 16% respectively. These values imply low compressibility according to BS 5930 (1999) [18]. Also, all the clays plot above the A-line in the region of low to intermediate plasticity (CL - CI) on the Cassagrande plasticity chart (Fig.3). The ranges of the undrained cohesion and angle of internal friction are 48 to 68KN/m^2 with an average of 59.3KN/m^2 and 4 to 12^0 with an average of 8^0 respectively. The high cohesion value and low angle of internal friction of the clays, are characteristic of firm clays according to Vickers (1983) [19]. A typical plot of the Mohr cycles and Envelope is presented in figure 4.Optimum moisture content and maximum dry density values range between 8.5 to 16.8% (average of 12.7%) and 1.67 to 1.85 g/cm^2 (average of 1.76g/cm^2). The percentage of fines influences the compaction characteristics of clays in the Niger delta as shown by Akpokodje, 1986 [17], Avwenegha et.al., 2014[5] and Tse and Ogunyemi ,2016 [6]. Borehole 8 with the highest percentage of fines, has the highest optimum moisture content and lowest maximum dry density, while borehole 6 with the lowest percentage of fines, have the lowest optimum moisture content and highest maximum dry density. The higher the percentage of fines, the greater the pore spaces in a soil, resulting in a decrease in the density of the soil. The strength of any earth material is related to the density; thus, the higher the density of a soil, the higher shear strength of the soil.

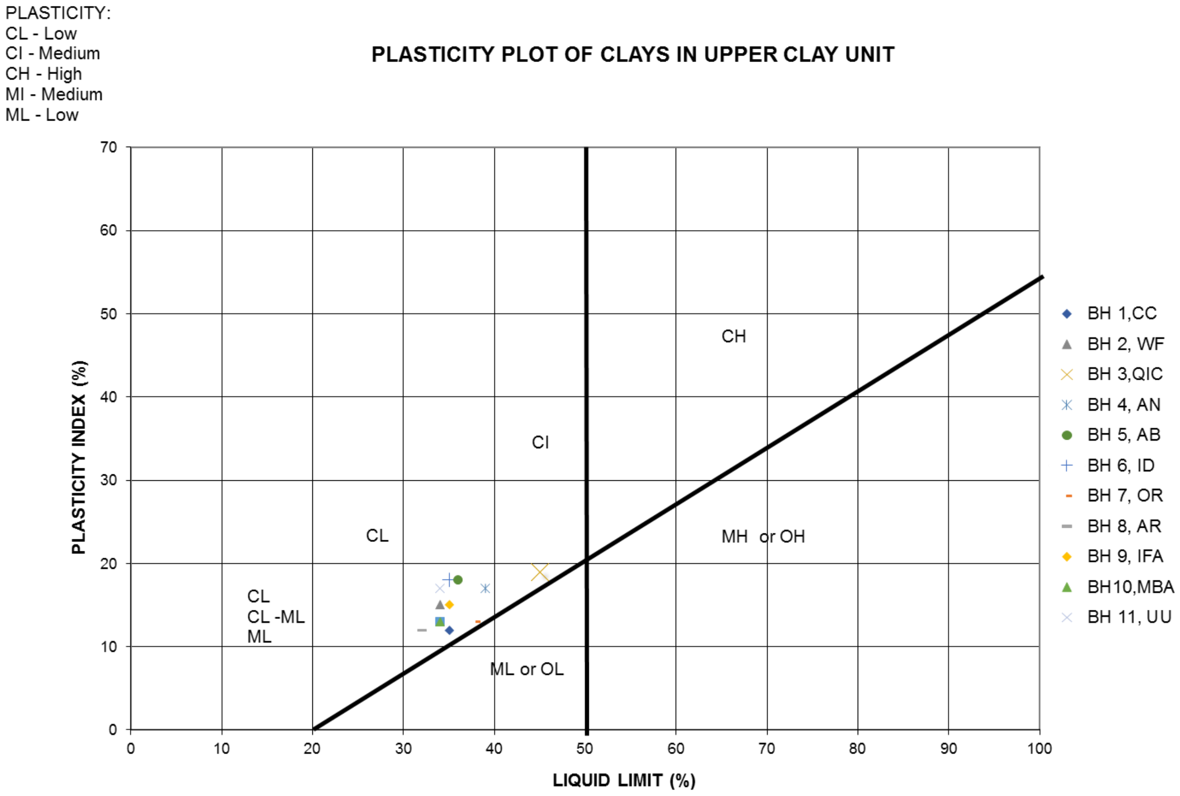

Figure 3: PLASTICITY PLOT OF UPPER CLAYS

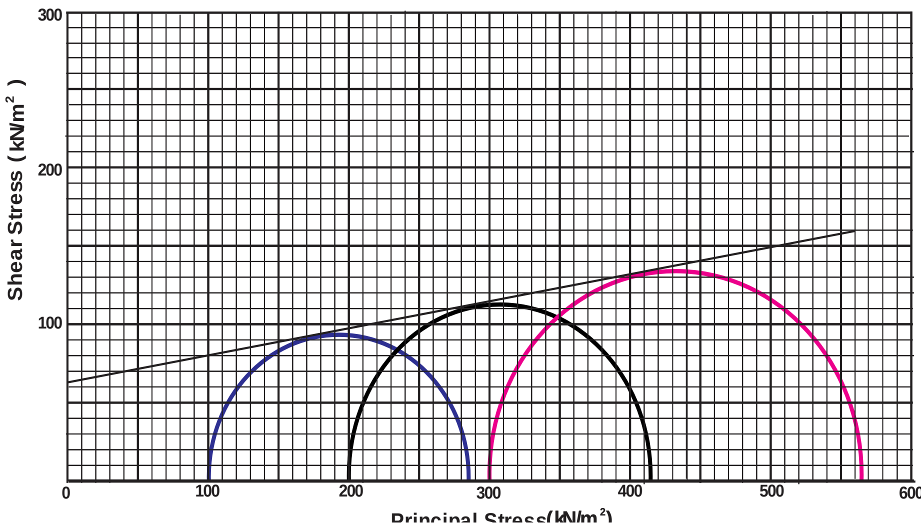

Figure 4: TYPICAL PLOT OF MOHR CIRCLES AND ENVELOP OF UPPER CLAYS

Table 1: Engineering properties of the upper clay horizon

Borehole No	BH1	BH2	BH3	BH4	BH5	BH6	BH7	BH8	BH9	BH10	BH11
Location	C.C.C Ikpa	West Itam	Q.I.C Church	Anua Road	Abak Road	Idoro Road	Oron Road	Aka Road	Ifa Atai	Mbab Anya	Udo Uman
Longitude	N05^0 31^1	N05^0 25^1	N05^0 14^1	N05^0 24^1	N05^0 14^1	N05^0 14^1	N05^0 12^1	N05^0 02^1	N05^0 59^1	N05^0 59^1	N05^0 01^1
Latitude	E007^0 56^1	E007^0 53^1	E007^0 58^1	E007^0 58^1	E007^0 54^1	E007^0 52^1	E007^0 56^1	E007^0 54^1	E007^0 59^1	E007^0 58^1	E007^0 55^1
WT (m)	12.8	16.7	13.6	13.0	15.4	16.6	16.9	16.6	15.8	15.5	15.3
Depth(m)	0-2	0-1	0-3	0-2	0-1	0-2	0-2	0-1	0-3	0-2	0-1
Wn (%)	24	25	25	25	24	26	23	26	26	22	26
LL (%)	35	34	45	39	36	35	38	32	35	34	34
PL (%)	18	18	27	26	18	16	25	10	19	25	16
USCS	CL	CL	CI	CI	CI	CI	CI	CL	CI	CL	CL
Fines (%)	40	40	40	32	32	22	30	42	30	36	28
C(KN/m^2)	62	60	62	61	60	60	56	68	50	65	48
Ø (^{0})	10	11	11	10	9.0	7.0	12	12	4.0	11	5.0
OMC(%)	11.8	11.0	12.3	14.0	10.9	8.5	11.6	16.8	10.0	11.5	9.4
MDD	1.74	1.78	1.73	1.72	1.76	1.85	1.74	1.67	1.80	1.74	1.83
CPT	25	25	15	14	11	11	18	15	8	7	8

Wn= Natural moisture content LL= Liquid limit PL= Plastic limit
USCS= Unified soil classification scheme C= Cohesion Ø= Frictional angle
OMC= Optimum, moisture content MDD= Maximum, dry density
CPT(MN/m^2)= Cone penetration Test

4.2.2 Lower clay horizon

The lower clay horizon consists of a light brown, firm sandy-clay with an average thickness of about 14m.This layer which is firmer in consistency, generally underlies the upper clay horizon in all the boreholes where it extends from 1m to15m in borehole (2, 5, 8 and 11), 2m to10m in borehole (1) , 2m to 13m in boreholes (4 and 10), 2m to 14m in borehole (6) , 2m to 15m in borehole (7) and 3m to 11m in boreholes (3 and 9). As shown in table 2, the values of the natural moisture content which gives an indication of likely volume change, lies between 18 to 24%. The liquid limit and plasticity index values range between 29 to 43% with an average of 34% and 9 to19% with an average of 14% respectively. All the soil samples in this horizon also plot above the A-line on the Casagrande plasticity chart in the region of low to intermediate /plasticity clays (Fig. 6). The percentage of fines in this horizon ranges from 22 to 42%. The moisture content, liquid limit and plasticity index have lower values compared with the upper clay horizon. The decrease in these values may be attributed to the decrease in the percentage of fines in the lower clay horizon. Values of the undrained cohesion and angle of internal friction are between 50 to 65kN/m^2 (average of 59kN/m^2) and 6 to 12^0 (average of 9^0) respectively. The angle of internal friction is also slightly higher in these clays. This may be attributed to the increase in the percentage of sand in this horizon. Shear strengths of soils are controlled by both cohesive and internal friction forces. These values are therefore also expected to yield relatively high shear strengths in this horizon. This is corroborated by the CPT values in this horizon which range between 38 to 101MN/m^2.

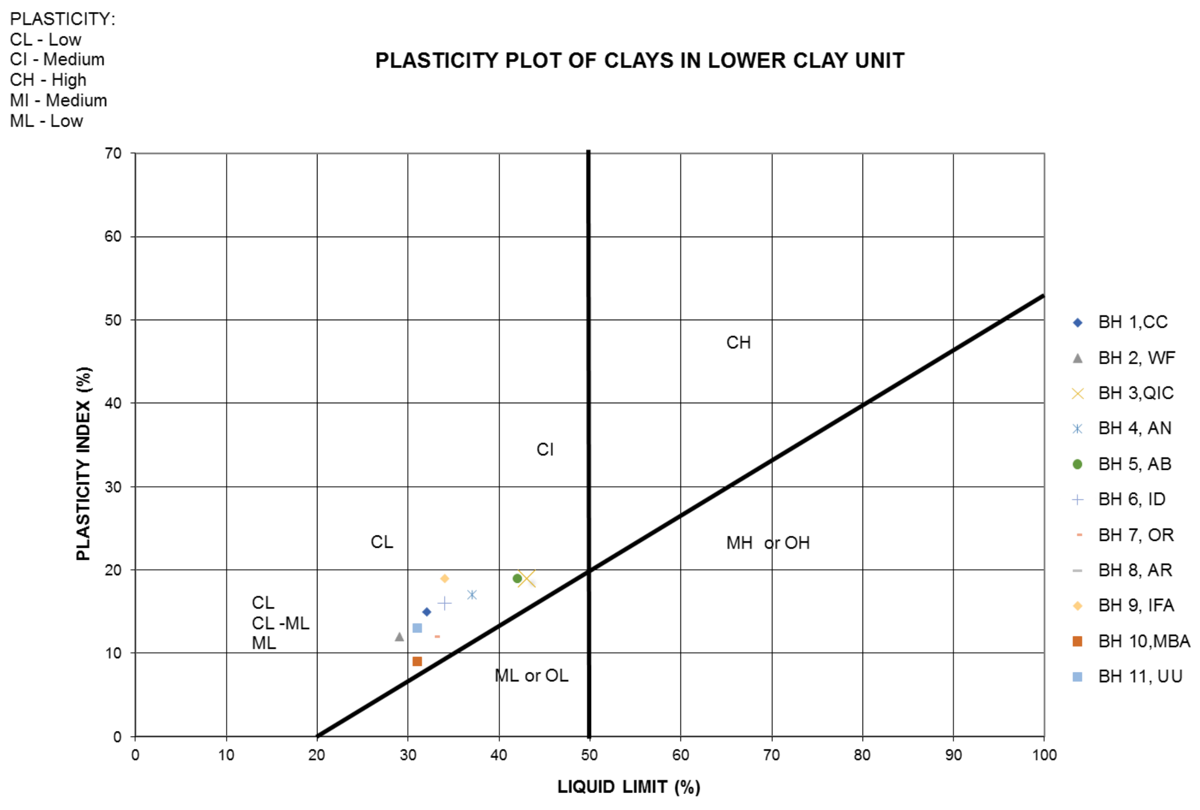

Figure 5: PLASTICITY PLOT OF LOWER CLAYS

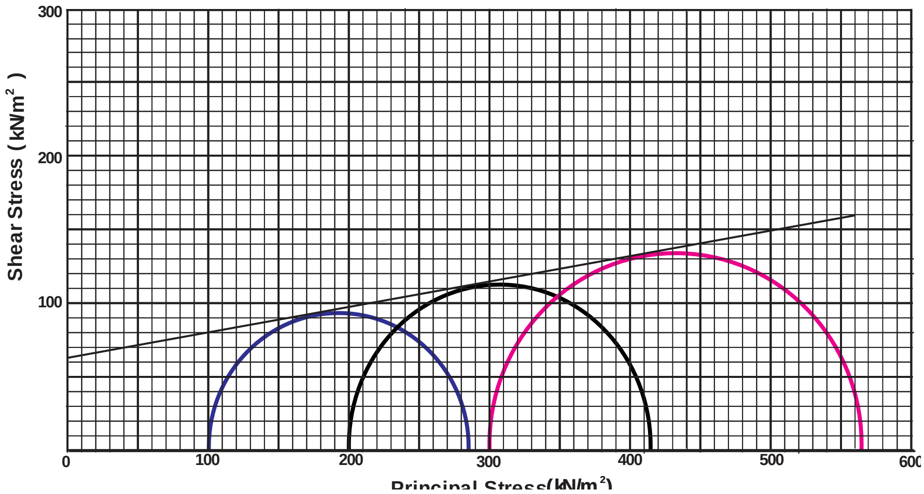

Figure 6: TYPICAL PLOT OF MOHR CIRCLES AND ENVELOPE OF LOWER CLAYS

Table 2: Engineering properties of the Lower clay horizon

Borehole No	BH1	BH2	BH3	BH4	BH5	BH6	BH7	BH8	BH9	BH10	BH11
Depth (m)	2-10	1-15	3-11	2-15	1-15	2-14	2-15	1-15	3-11	2-13	1-15
Wn (%)	22	23	24	23	24	23	18	24	23	23	20
LL (%)	35	29	43	37	42	34	33	31	34	31	31
PL (%)	15	17	25	20	23	15	18	20	16	22	15
PI (%)	15	12	19	17	19	16	12	9.0	13	9.0	15
USCS	CL	CL	CI	CI	CI	CL	CL	CL	CL	CL	CL
Fines (%)	40	35	40	38	42	24	32	36	27	40	22
C (m^2/yr)	60	60	62	62	59	55	52	62	65	62	50
Ø (^{0})	11	11	10	10	12	6.0	11	10	6.0	9.0	6.0
CPT	83	83	43	85	83	77	101	81	38	41	38

4.2.3. Sand horizon

A light brown fine to medium to coarse sand with an average thickness of about 10m generally underlies the light brown, silty sandy clay extending from 10m to 20m in borehole (1), 11m to 20m in boreholes (3 and 9), 14m to 20m in borehole (6) and 15m to 20m in boreholes (2, 5, 7, 8 and 11). This horizon consists of fine, medium and coarse sand fractions with a little percentage of gravel as shown in the particle size distribution graph (Fig. 7).The engineering properties in table 3 reveal that the medium sand fractions are the predominant fractions. Fine sand fractions have an average value of 6.8%, the medium and coarse sand fractions range between 17 to 72% with an average of 51% and 18 to 51% with an average of 37% respectively, while the average percentage of gravel is about 2%.The coefficients of uniformity values range from 1.0 to 3.9 classifying the sands as poorly graded (SP) according to the unified soil classification system. Standard penetration tests gave N-corrected values from 13 to 22 indicating medium density of the sand. This horizon constitutes a suitable foundation for medium engineering structures although, the use of pile is necessary in the design of the foundation.

Pile bearing capacity analysis of the sand using the methods of Peck, Hanson and Thornburn 1973[20], Terzaghi 1960[21] and Berezantsev 1961[22], gave allowable bearing capacities of 3797.6 to 4605.2kN with an average of 4201.4kN. This horizon therefore also constitutes is a good termination depth for piles.

Table 3: Engineering properties of the sand horizon

Borehole No	BH1	BH2	BH3	BH4	BH5	BH6	BH7	BH8	BH9	BH10	BH11
Depth(m) min	10	15	11	13	14	14	15	15	11	14	15
Depth(m) max	20	20	20	20	20	20	20	20	20	20	20
% Fine sand	3.5	4.5	8.5	5.5	4.5	8.5	1.5	7.5	12	8.0	11
%Med sand	54	52	52	53	30	61	17	72	44	72	51
% Coarse sand	41	41	39	40	51	28	51	19	44	72	58
% Gravel	2.0	2.5	1.5	2.0	0.0	1.0	0.0	2.0	2.0	2.0	2.0
D_{10}	0.26	0.25	0.21	0.23	0.30	0.23	0.31	0.21	0.25	0.23	0.23
D_{50}	0.51	0.52	0.49	0.51	0.89	0.39	0.85	0.36	0.60	0.37	0.52
D_{60}	0.61	0.61	0.59	0.24	1.18	0.59	1.2	0.41	0.70	0.42	0.63
CU	2.4	2.5	1.0	2.7	3.9	2.7	3.9	1.9	3.1	1.8	2.1
USCS	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP
SPT N^{1-}Value	22	13	21	21	21	20	20	20	21	20	20

D10=Effective particle size D_{50}=Mean particle size CU=Coefficient of uniformity
SPT N^1-Value= Standard Penetration test corrected N- Value

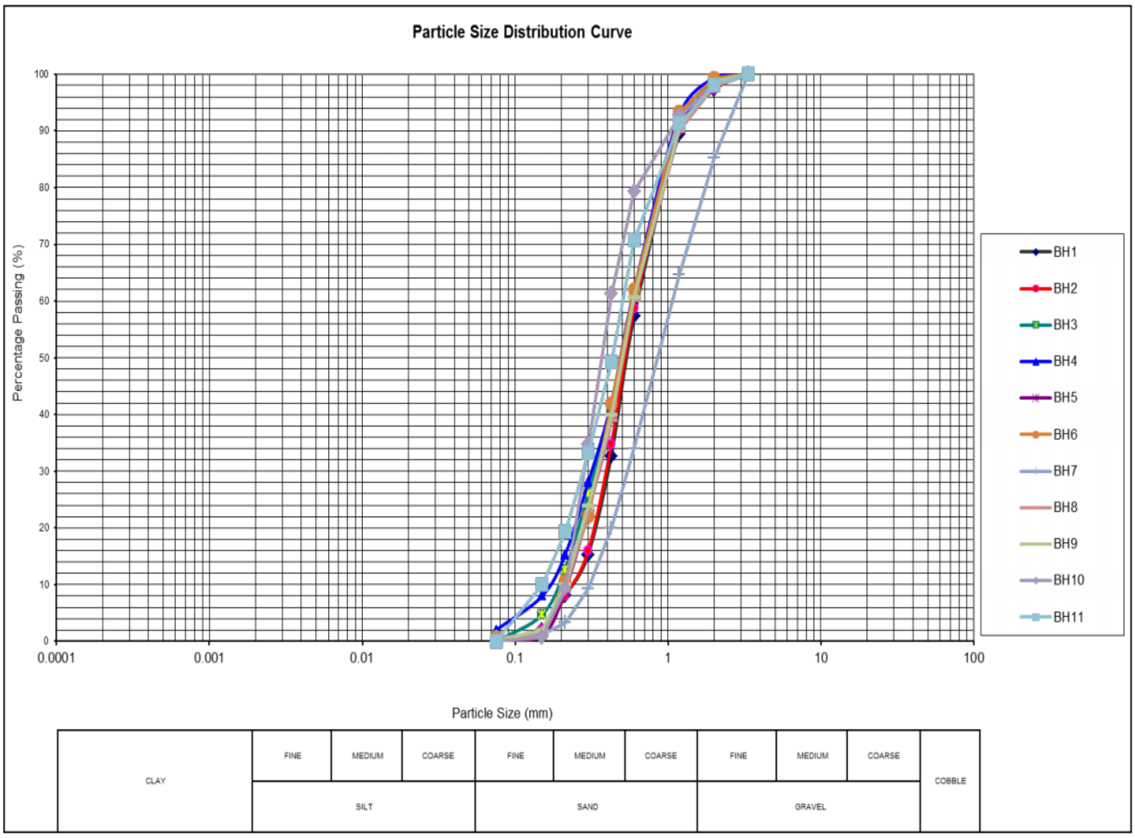

Figure 7: Particle size distribution plots of the sand

5 Conclusion

The Subsurface stratigraphic profile of Uyo town reveals from top to bottom: silty clays, sandy clays and sand. The low to intermediate plasticity clays are firm, with moderate cohesion values, low angles of internal friction and are expected to yield relatively high shear strengths. Standard penetration test values indicate medium density of the sand with an allowable pile bearing capacity average of 4201.4kN. Based on the standard penetration tests, particle size distribution and pile bearing capacity, this substratum constitutes a suitable foundation for the construction of medium engineering structures. Thus, the design of a pile foundation using end bearing steel piles terminated within the sand is recommended for medium engineering structures.

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