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Geotechnical Properties of Clay Soilsin Uyo Town, Eastern Niger Delta, Nigeria.

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Abstract: *This study investigates, the geotechnical and mineralogical properties of clay soils in Uyo town, for construction purposes. On the basis of the field and laboratory investigations, the general subsurface profile of Uyo town consists of silty clays from 0-3m, sandy clays (3-15m) and sand from 10-20m.The silty clays are firm with a low to intermediate plasticity and high cohesion values, while the sandy clays, are also of low to intermediate plasticity, with high consolidation and cohesion values, that are expected to yield relatively higher shear strength than the silty clays. X-raydifraction analysis of the clays reveal the presence of kaolinite, quartz and trace amounts of goethite in the silty clays. Analysis of the foundation potentials using CPT results show that the silty clays have low potentials while the underlying sandy clay horizon may be suitable for small and medium civil engineering structures.*

Key words :*Gotechnical properties, mineralogy,s clay soils, .X-ray diffraction, Kaolinite, Foundation*

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I. Introduction

Clays are fine grained soils with particle sizes below 2µm .Chemically, they are hydrous aluminium silicates characterised by sheet silicate structures of composite layers stacked along the c-axis (Grim 1968). Clays are formed either as a product of thechemical weathering of pre-existing granitic rocks and feldspar minerals particularly in warm tropical and subtropical regions of the world or as a result of the hydrothermal alteration of granitic rocks Akhirevbulu et al., 2010. According to Akpokodje 1986, the superficial soils of the Niger Delta are essentially clays with varying proportions of sand, silt and organic matter. These quarternary deposits which have low swelling potentials (silty/clayey sand) to extremely high swelling potentials (organic clays) overlie the Benin formation at depths less than 5m from the ground surface and constitute the foundation material for most civil engineering structures in the Niger Delta region.

With increased construction activities taking place in different areas of the Niger Delta region over the last decade, various researches on the engineering properties of soils have been carried out. (Tse and Akpokodje 2010, Nwankwoala and Warmate 2014, Avwenegha 2014, Abam 2016) etc, However only few studies on the mineralogical composition and geotechnicalproperties of clay soils in the Niger Delta exist (Tse 2006, Onyebuolise 2009, Okunola and Egbulem 2015, Udofia et al., 2017 and Donatus et.al., 2018) . This study therefore investigates the mineralogical composition and geotechnical properties of clays soils in Uyo town for construction purposes.

Geology, Geomorphology And Hydrogeology

Uyo town is located at the center of AkwaIbom 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.

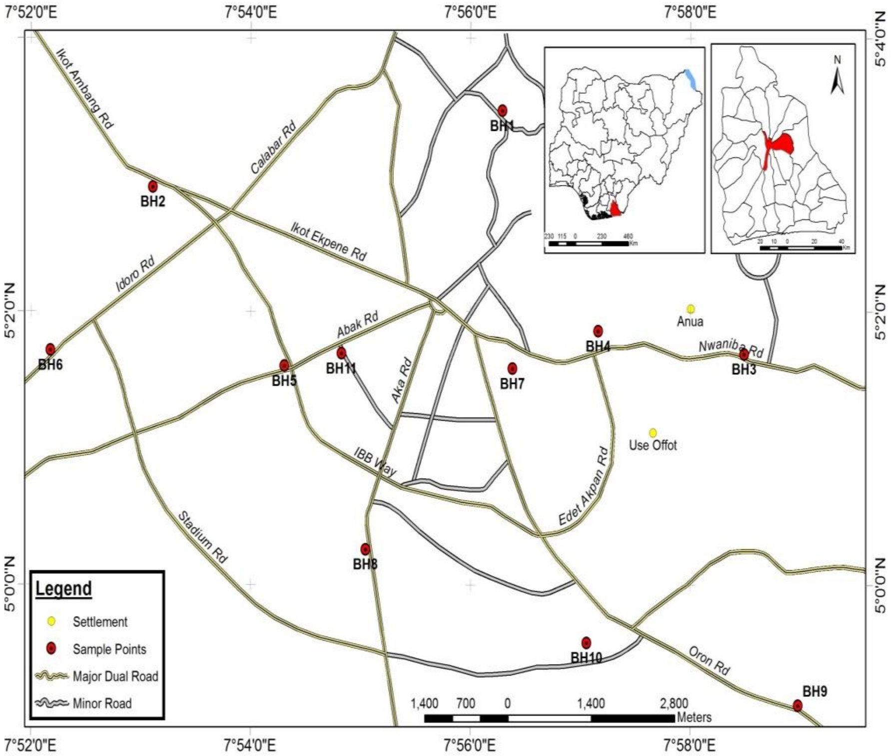

Figure 1: Map of Uyo town, Akwaibom state showing borehole locations

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).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 detaile by Short and Stauble (1967) and Etu-Efeotor (1997).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, AkwaIbom state is generally a flat, low lying terrain and riverine environment Usoro (2010). 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). 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),Nwankwoala and Udom (2011)etc. Etu-Efeotor and Akpokodje (1990) 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 AkwaIbom 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). 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 Ikpariver 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.

Method Of Study

This study utilizes engineering geological methods involving field study and laboratory analysis. The field tests include drilling of eleven (11) boreholes and cone penetrometer test. The laboratory tests captured the moisture content, atterberg limits, particle size distribution (wet sieve analysis),triaxial compression of the soils and X-ray diffraction analysis. The laboratory tests were carries out in accordance with British Standard 1377 of 1990.

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.

Cone Penetration Test (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.

X-Ray Diffraction Analysis

X-ray diffraction tests (quantitative and qualitative) were carried out on whole rock soil samples to determine the clay mineral species influencing the engineering properties.

After milling, the soil samples were prepared for XRD analysis using a back loading preparation method. X-ray diffraction tests were performed on the soil samples using a Malvern PanalyticalAerisdiffractometer with Pixcel detector and fixed slits with Fe filtered Co-Ka radiation. The phases were identified using X' Pert Highscore plus software. The relative phase amounts (weigh %) were estimated using the Rietveld method.

II. Results And Discussion

SUB-SURFACE SOIL STRATIGRAPHY

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

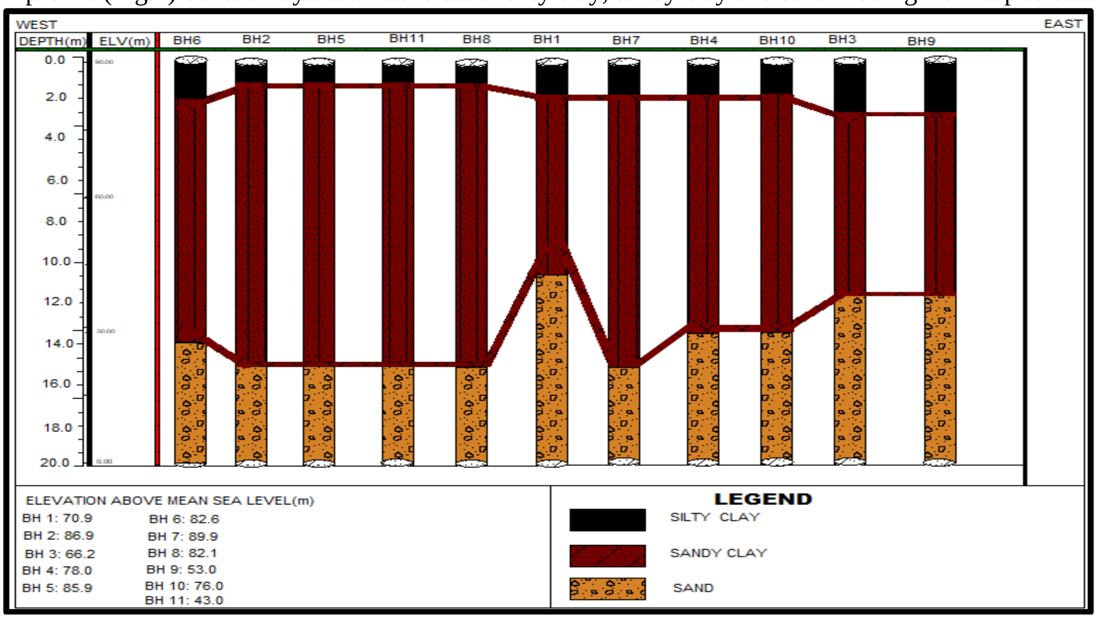

Figure 2: Sub surface Soil stratigraphy of Uyo town.

Engineering Properties

The discussion of the engineering geological properties of the clay soils will be based on two major horizons, namely: upper clays and lower clays; 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.

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 (28 to 45%, avg.35%) and the natural moisture content fall between 22 and 26% with an average of 25%. Moisture content values vary greatly with season, clay and organic content, Akpokodje (1986). The range of values of the liquid limit and plasticity index are 32-45% with an average of (39%) and 12-20% with an average of (16%) respectively. All the clays plot below the A-line in the region of low to intermediate plasticity (CL - CI) on the Cassagrande plasticity chart (Fig.3).These values imply low compressibility according to BS 5930 (1999). 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. The moderate cohesion value and low angle of internal friction of the clays, are characteristic of firm clays according to BS 5930 (1981). CPT values in this horizon range between 7 to 25MN/m^2. The values of the coefficient of consolidation (CV) fall between 42.5 and 64.2m^2/year with an average of 52.0m^2/year, while the range of values of the coefficient of volume compressibility (Mv) are between 0.12 and 0.23m^2/MN with an average of 0.18m^2/MN. The shapes of the e-logp graphs from consolidation tests are indicative of soils that are over consolidated. This is collaborated by the values of the natural moisture content which are consistently lower than the liquid limits indicating pre consolidation.

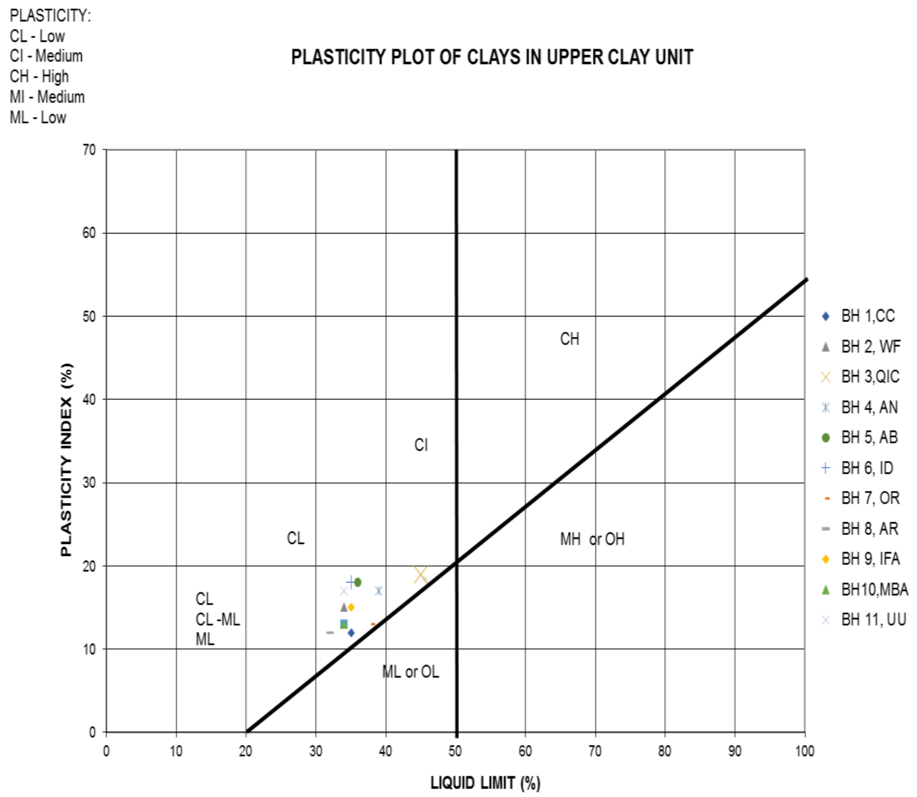

FIGURE 3. PLASTICITY PLOT OF UPPER CLAYS

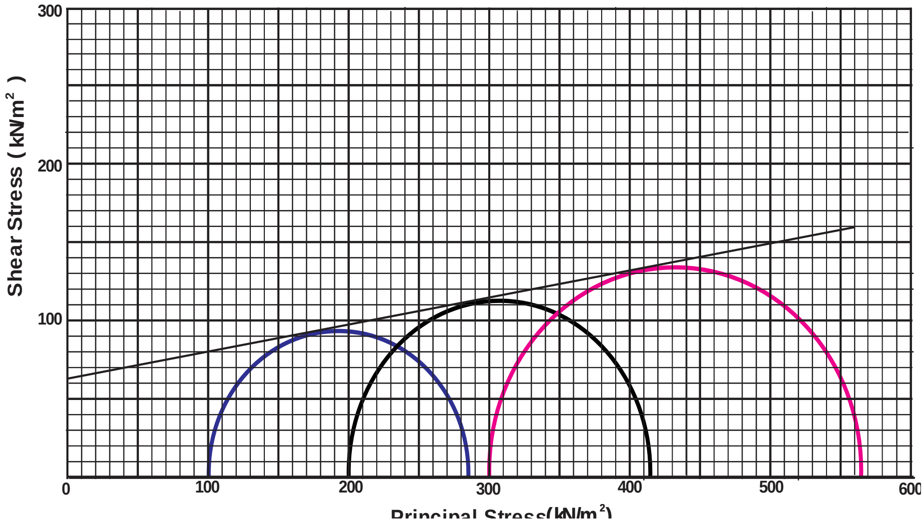

FIGURE 4. TYPICAL PLOT OF MOHR CIRCLES AND ENVELOPE OF UPPER CLAYS

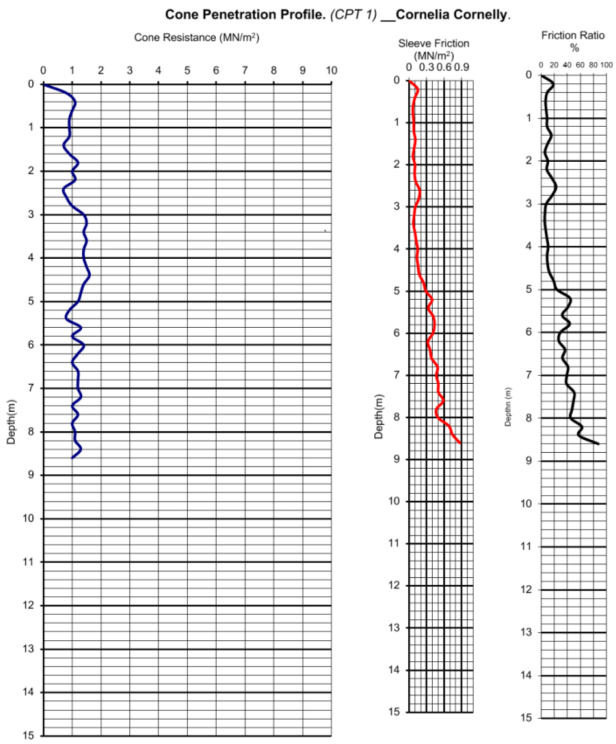

FIGURE 5. CONE PENETRATION PROFILE OF BOREHOLE 1

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	West	Q.I.C	Anua	Abak	Idoro	Oron	Aka	Ifa	Mbab	Udo
	Ikpa	Itam	Church	Road	Road	Road	Road	Road	Atai	Anya	Uman
Longitude	$N05^0$	$N05^0$	$N05^0$	$N05^0 24^1$	$N05^0 14^1$	$N05^0$	$N05^0$	$N05^0$	$N05^0$	$N05^0 59^1$	$N05^0 01^1$
	3^1	25^1	$14^1 67$	$E007^0$	$E007^0$	14^1	12^1	02^1	59^1	$E007^0$	$E007^0$
Latitude	$E007^0$	$E007^0$	$E007^0$	58^1	54^1	$E007^0$	$E007^0$	$E007^0$	$E007^0$	58^1	55^1
	56^1	53^1	58^1	13.0	15.4	52^1	56^1	54^1	59^1	15.5	15.3
WT (m)	12.8	16.7	13.6	0-2	0-1	16.6	16.9	16.6	15.8	0-2	0-1
Depth(m)	0-2	0-1	0-3	25	24	0-2	0-2	0-1	0-3	22	26
Wn (%)	24	25	25	39	36	26	23	26	26	34	34
LL (%)	35	34	45	26	18	35	38	32	35	25	16
PL (%)	18	18	27	17	18	16	25	10	19	13	17
PI (%)	12	15	20	-0.1	0.4	18	13	12	15	-0.2	1.0
IL (%)	0.6	0.5	-0.1	CI	CI	1.0	-0.1	1.4	1.0	CL	CL
USCS	CL	CL	CI	32	32	CI	CI	CL	CI	36	28
Fines (%)	40	40	40	61	60	22	30	42	30	65	48
C(KN/m^2)	62	60	62	10	9.0	60	56	68	50	11	5.0
Ø (^{0})	10	11	11	45.0	42.5	7.0	12	12	4.0	51.2	58.4
CV(m^2/yr)	56.1	52.7	47.8	0.20	0.17	51.0	64.2	59.3	44.2	0.19	0.18
MV	0.21	0.15	0.22	14	11	0.12	0.23	0.19	0.16	7	8
CPT	25	25	15			11	18	15	8		

Wn= Natural moisture content LL= Liquid limit PL= Plastic limit
USCS= Unified soil classification scheme C= Cohesion Ø= Frictional angle
CV= Coefficient of consolidation MV (KN/m^2)= Coefficient of volume compressibility
CPT(MN/m^2)= Cone penetration Test PL(%)= Plastic Limit IL= Liquidity Index

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% with an average value of 21%. The liquid limit and plasticity index values range between 29 to 43% (avg.36%) and 9 to19% (avg.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 40% (avg. 31%). 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 (avg. 59kN/m^2) and 6 to 12^0 (avg. 9^0) respectively. The shear strengths of soils are controlled by both cohesive and internal friction forces. These values are therefore expected to yield relatively higher shear strengths in this horizon. This is corroborated by the CPT values which range between 38 to 101MN/m^2 with an average of 69.5MN/m^2. Again, the angle of internal friction is slightly higher in the lower clays compared with the upper clays. This friction may be due to the increase in the percentage of sand in this horizon. There is also a slight increase in the consolidation values of this horizon compared with the upper clay. The coefficient of consolidation range from 35.1 to 77.4m^2/year with an average of 56.3m^2/year while the coefficient of volume compressibility falls between 0.09 to 0.21m^2/MN with an average value of 0.15m^2/MN.

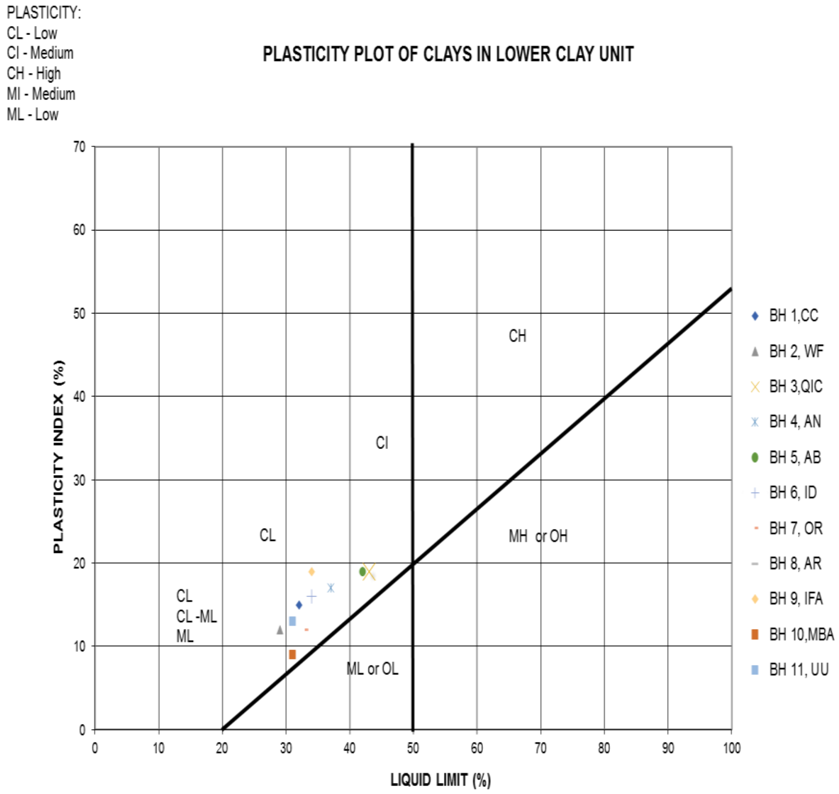

FIGURE 6. PLASTICITY PLOT OF LOWER CLAYS

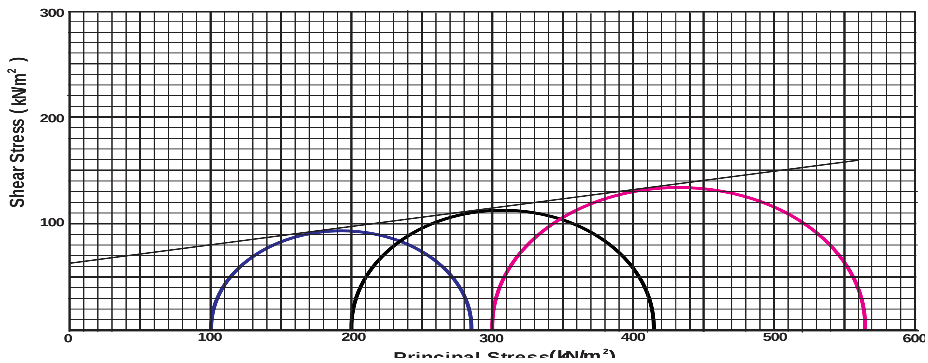

FIGURE 7. TYPICAL PLOT OF MOHR CIRCLES AND ENVELOPE OF LOWER CLAYS

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
IL(%)	0.4	0.5	-0.1	0.2	0.1	0.6	0	0.5	0.7	0.2	0.4
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
CV	35.1	36.1	62.4	46.0	37.5	77.4	40.0	42.5	58.4	51.6	39.1
(m^2/yr)	0.23	0.21	0.18	0.24	0.19	0.09	0.17	0.17	0.18	0.55	0.11
MV	83	83	43	85	83	77	101	81	38	41	38
CPT											

Soil Mineralogy

The mineralogical composition of the upper clays at a depth of 2m as determined by the X-ray diffraction method reveal kaolinite as the clay mineral present in the soil, while the non-clay mineral components consists of quartz as the major mineral and trace amounts of goethite. A typical example of the sample diffraction trace is shown in figure 8. A quantitative estimate of the mineralogical composition of the eleven samples in Appendix 1shows that Kaolinite constitutes 6.9 to 19.6% of the whole rock minerals with an average of 13.25%, quartz constitutes 80.2 to 93%, average of 86.8%, while goethite constitutes 0.1 to 0.4%. These values are similar to results obtained by Okunola and Egbulem (2015)and Donatus et al., (2018) whose studies on clay soils in IkotEkepene and Itulocal government areas of AkwaIbom staterespectively, reveal kaolinite as the major clay mineral with trace amounts of goethite. These results reflect the provenance of the clays from quartz rich basement rocks and sediments in the hinterland as shown and described by Etu-Efeotor (1984). Studies on the formation of clays (Buhman 1992; Velde 1985 and Weaver 1989) have shown that kaolinite is a mineral typical of continental weathering in the humid inter tropical zone where weathering is predominantly chemical in character, rainfall is high, pH is acidic and cations are absent. The conditions in the Niger Delta are more favourable for the formation of kaolinite as shown by Etu- Efeotor (1984) ,Emofurieta et al., (1994), Tse (2006) and Onyebuolise (2009).

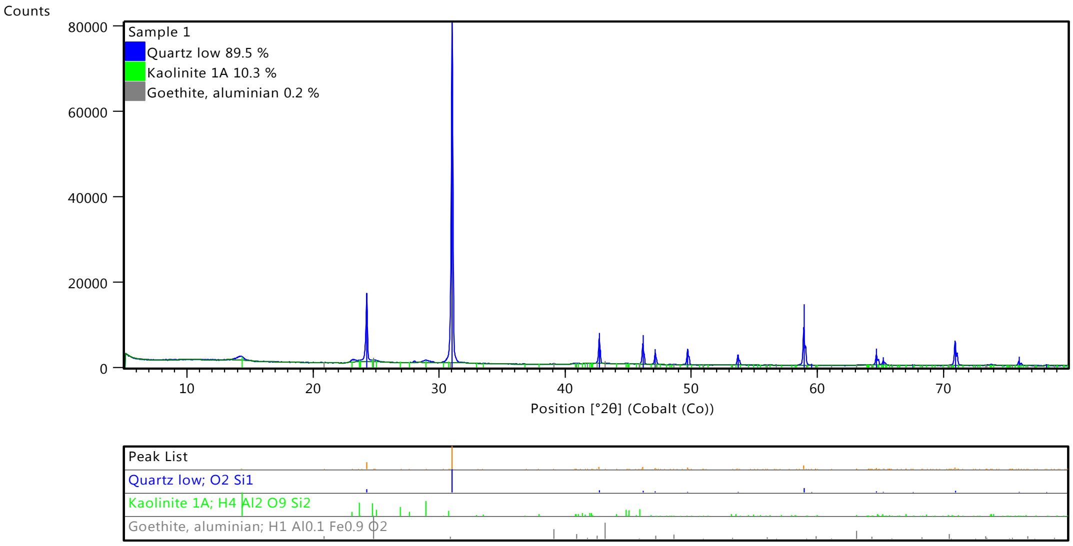

FIGURE8. Sample diffraction trace of clay minerals

III. Conclusion

In this study, the geotechnical and mineralogical properties of clay soils in Uyo town were investigated for construction purposes. On the basis of the field and laboratory investigations, the general subsurface profile of Uyo town consists of silty clays from 0-3m, sandy clays (3-15m) and sand from 10-20m.The upper clay and lower clay horizonsare firm with a low to intermediate plasticity and high cohesion values. Mineralogical analysis of the clays reveals that kaolinite constitutes 6.9 to 19.6% of the whole rock minerals. Analysis of the foundation potentials using CPT results show that the silty clays in the upper clay horizon have low potentials while the underlying sandy clay horizon may be suitable for small and medium civil engineering structures.From the above conclusions, the results of the geotechnical properties of the clay soils in Uyo town constitute useful a guide for the proper planning of site investigation programmes for foundation purposes.

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Appendix 1

Quantitative estimate of the Mineralogical composition of the upper clays

Sample Number/ Name	Borehole Number	% Quartz	% Kaolinte	% Goethite
1- Cornelia Conelly	BH1	80.2	19.6	0.2
2- West Itam	BH2	85.5	14.5	0.0
3- Q.I.C Nwaniba	BH3	93.0	6.9	0.1
4- Annua	BH4	85.3	14.3	0.4
5- Abak road	BH5	87.5	12.3	0.2
6- Idoro road	BH6	89.5	10.3	0.2
7-Oron road	BH7	90.3	9.8	0.2
8- Aka road	BH8	91.5	8.5	0.0
9- IfaAtai	BH9	85.6	14.1	0.3
10- Mbaobong	BH10	81.9	17.8	0.2
11- Udoumana	BH11	90.0	9.8	0.2

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