BEARING CAPACITY ANALYSIS OF SUBSOILS, FOR SHALLOW AND DEEP FOUNDATION IN UYO TOWN, EASTERN NIGER DELTA, NIGERIA

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ABSTRACT

The Geotechnical properties of soils in Uyo town were analyzed to determine the bearing capacity and generate maps for shallow and deep foundation designs. Eleven geotechnical boreholes were drilled to a maximum depth of 20 meters each across Uyo town. Standard penetration tests and cone penetration tests were also carried out on the field. Soil samples were retrieved during the field investigation for various laboratory tests including liquid limits, plastic limit, bulk density, shear strength and particle size distribution. The general soil profile consists of silty clays, sandy clays, and sand from top to bottom. The silty clays are firm, low compressibility clays with liquid limit and plastic limit percentages between 32%-45% and 10%-45% respectively, cohesion averages of 4˚ to 12˚ and angles of internal friction between 48KN/m2-68KN/m2. Ultimate bearing capacities of this horizon range from 354.6kN/m2 to 866.7kN/m2. The sandy clays are also firm, low to intermediate plasticity clays with liquid limit and plasticity indexes of 29% - 42% and 9%-15% respectively. Their cohesion averages range between 50KN/m2-65KN/m2 and angles of internal friction between 6˚-12˚. The ultimate bearing capacities of this clay range from 482.5KN/m2 to 906.2KN/m2. The sand is a poorly graded, medium dense sand with standard penetration test N-values between 8 to 23. Pile bearing capacities of the sand gave ultimate and allowable bearing capacities between 10262.9KN-11510.2KN and 4105.2KN-4604.1KN respectively. The sand substratum is a suitable termination depth for piles.

Keywords: Bearing Capacity Analysis, Shallow Foundation, Deep Foundation, Bearing Capacity Maps, Geotechnical Maps

1. INTRODUCTION

Engineering structures consist of a super-structure and substructure. The substructure (foundation) transmits the weight of the structure and the superimposed loads to the underlying foundation material which may be a soil or rock Krynine and Judd (2003) The type and quality of foundation material underlying a structure is very important because it determines to a large extent, the safety of the structure. The underlying earth material supporting the structure must not be over-stressed; this is the main concern in the design of foundations, in order to prevent the failure of the foundation Akpokodje (2001) Although, the exact cause of foundation failure which may vary from overloading of soils, poor construction practices and poor choice of construction materials still remains unknown, the ultimate goal in foundation analysis is the design of a safe and economic foundation for structures. Sub surface knowledge that assist in the proper design of structures are usually provided via foundation studies Warmate and Nwankwoala (2018). Thus, the geotechnical index and mechanical properties of earth materials, as well as the bearing capacity of the soil must be understood for an appropriate design of foundations. Several studies on foundation properties of soils in the Niger delta include among others, Teme (2002) Tse and Akpokodje (2010) Atat et al. (2013) Ngah and Nwankwoala (2013) Warmate and Nwankwoala (2018) Abija et al. (2018) Ehibor et al. (2019) and Abija et al. (2018) This study therefore determines the bearing capacity of sub soils in Uyo town and develops maps for shallow and deep foundations designs. The benefits derivable from this study include an understanding of the bearing capacity of subsoils in Ayo town and the design of bearing capacity maps and other geotechnical maps which may serve as field models for foundation purposes.

1.1. DESCRIPTION OF STUDY AREA

Uyo town is located in the central part of Akwa Ibom state, southeastern Niger Delta. (Figure 1). It lies on the flat to gently undulating sandy plains, stone hills, and ravines. This intensely dissected region contains gullies, ravines, and valleys. Geomorphologically, Akwa Ibom state is generally a flat, low-lying terrain and riverine the environment that is divided into two major geomorphic regions, these are the North and North-Easternly intensely dissected regions and the Southern plain coastal regions. The major relief can be further divided into six sub-geomorphic units as follows: the Atlantic Ocean shoreline and beach, Mangrove swamps and flood plains with recent alluvial sediments, Beach ridge sands, Flat to gently undulating sandy plains, Sandstone hills, ridges, steep sided valley, and ravines and finally, the Obotme upland areas. Usoro (2010) The land rises steadily upwards from the sea level at Eket in the south to 150m at Obotme in the north Beka and Udom (2014) Uyo town is drained by the Ikpa river that flows from the North to the Southern part of the town through many tributaries that emerge from ravines. Four main stratigraphic units ranging from Maastrichian to Pleistocene in age are recognised in Akwa Ibom state namely: the Shale-Limestone facies (late cretaceous and early Eocene) which is the oldest geological facie in Akwa Ibom state, the Sand-Gravel facies (Oligocene-Pleistocene), the younger Benin formation Coastal plain sand (Pliocene-Pleistocene) and the Beach ridge complex and Alluvial deposits (recent). The younger Benin coastal plain sand underlies the flat lying plains of Uyo, Ikot Ekpene, Etinan, Ikot Abasi and terminates in the coastal brackish water, swamp zone with fringing Beach ridge complexes lying southwards Peters (1989)

Figure 1

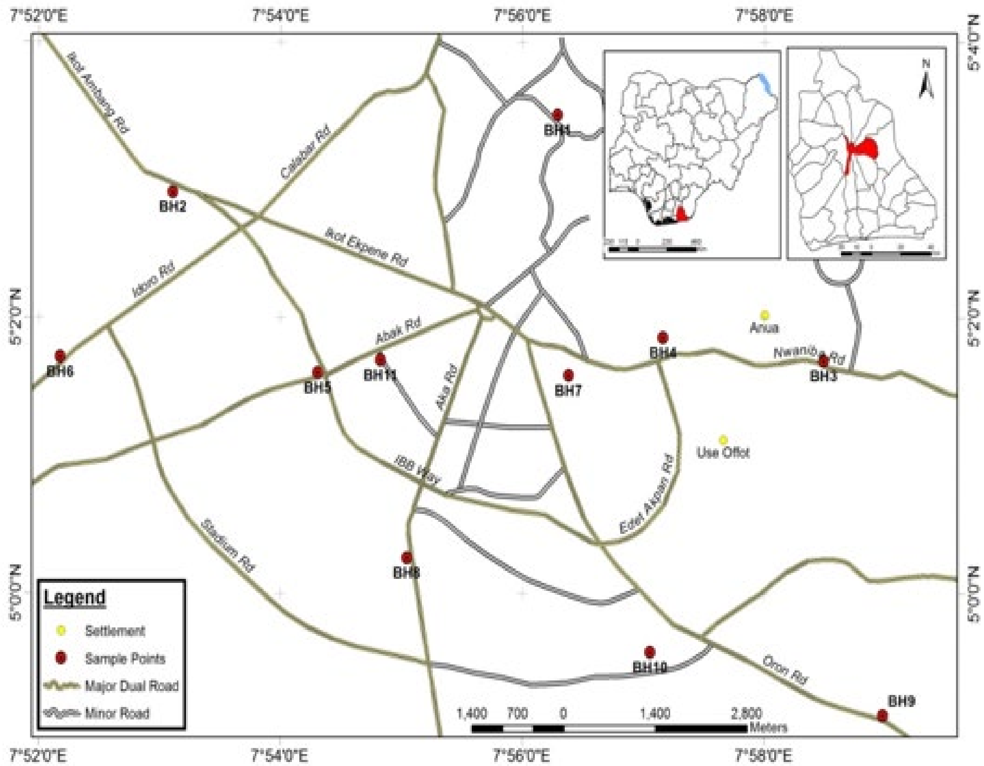

Figure 1 Borehole Locations, Uyo Town, Akwa Ibom State

2. METHOD

2.1. FIELD STUDY

A total of eleven boreholes were drilled in different locations across Uyo town to depths of 20 meters each, using the shell and auger percussion drilling rig. The percussion drilling method was used because of the lithology of the study area which consisted mainly of clay, sand and the presence of few gravels, the depth to which the soil samples were taken and the ease of the soil returning to its original state once the casings have been removed. Disturbed soil samples were collected at regular intervals of 1metres each, while Undisturbed soil samples were retrieved from the cohesive soil strata in the borehole. The soil samples collected were classified on the field before transporting them to the laboratory for further analysis.

2.1.1. STANDARD PENETRATION TEST

Standard penetration tests were performed at 18 meters depth on the cohesionless soils to determine the penetration resistance (N-Value) of the soil. The field standard penetration test N-values were corrected to account for the overburden pressure and dilatancy in saturated fine sands and silts.

2.1.2. CONE PENETRATION TESTS

The cone penetration test was performed using a 2.5-ton CPT machine, in order to ascertain the resistance of the soil, thus estimating its bearing capacity.

2.2. LABORATORY STUDY

Each of the soil samples taken from the field were subjected to various engineering geological tests in accordance with procedures specified by British Standard BS 1377 (1990). The tests include natural moisture content, atterberg limits, undrained Shear strength, particle Size distribution analysis (dry sieve method), bulk density and consolidation (oedometer) test.

3. DATA ANALYSIS

To calculate the bearing capacity of the subsoil, the results of the following properties of the soil were analysed:

1) The Standard Penetration Test N ^{1}-value
2) The Bulk density
3) The unit cohesion

Bearing Capacity Analysis for deep foundation design (SPT method)

Field standard penetration test N-values were corrected using the formula

$$N1 = 15 + ½ (N – 15) \qquad (1)$$

N1 – corrected field standard penetration Test N-value

N – Field standard penetration test N-value from 300mm penetration.

The bulk density and standard penetration Test N1 –values were used to determine the bearing capacities for deep foundation designs.

3.1. PILE CAPACITY ANALYSIS

The bearing capacity of piles for deep foundation was determined using the methods of Peck, Hanson and Thornburn (1974), Teezaghi (1960) and Berezantev (1961). The general equation for the total load on the pile Q can be expressed as:

$$Qult (KN) = Qb + Qs \qquad (2)$$

Where;

Qult (KN) = Ultimate bearing capacity of soil

Qb (KN) = Base resistance (offered by the soil)

Qs (KN) = Shaft resistance (offered by the shear stresses between the soil and the shaft)

For the ultimate base resistance in sand:

$$Qb (KN) = Abase + q0\ Nq \qquad (3)$$

Where;

A_{base} (m^2) = Base area of pile (πdl2/4)

d(mm) = Diameter of pile (306mm steel piles)

q_0 (KN/m^2) = Effective overburden pressure (γ x h) (4)

h(m) = Thickness of strata

γ (KN/m3) = Unit weight (pwet x g)/100 (5)

ρ_{wet} (Kg/m^3) =Bulk density

g(m/s2) = Acceleration due to gravity (9.81)

Nq = A bearing capacity coefficient which depends on the angle of internal friction (Ø)

For the ultimate shaft resistance in sand.

Qs (KN) = Ashaft. Ks. q0/2. tan δ (6)

Where;

A_{shaft} (m^2) = Area of Shaft (πdl) (7)

π = 3.142

d(mm) = Diameter of pile (306 for steel piles)

L(m) = Length of pile

Ks (N/m2) = Earth pressure coefficient which depends on the type of pile used (0.75 for steel piles)

$q_0/2$ (KN/m^2) = Average effective overburden pressure over soil layer (γ x h)/2 (8)

Tan δ = Angle of pile friction (200 for steel piles)

For the safe Axial pile capacity of the soil:

Qallow. (KN) = Qb +Qs/F. S (9)

Qallow. = Safe Axial pile capacity of soil

Qb = Base resistance

Qs = Shaft resistance

F.S = Factor of safety (2.5)

Terzaghi (1943) bearing capacity equation for shallow foundation (Strip footing)

$$q_d = cN_c + \gamma D_f N_q + \tfrac{1}{2}(\gamma B N_\gamma) \quad (10)$$

q_d (kN/m^2) = ultimate bearing capacity

c= unit cohesion

γ (KN/m^3) = effective unit weight of soil

B= width of footing (600mm for concrete strip foundation)

D_f (m) = depth of foundation

N_c, N_q and $N\gamma$ = bearing capacity factors which are a function of Ø

4. RESULTS AND DISCUSSIONS

4.1. SOIL STRATIFICATION

The general soil profile in Uyo town, may be categorized into three recognizable subsoil layers; the layers are composed of a dark brown, Silty-Clay, a light brown Sandy-Clay, and a light brown fine to medium to coarse Sand. These three layers of soil types occur in varying proportions, as shown in Figure 2 .

Figure 2

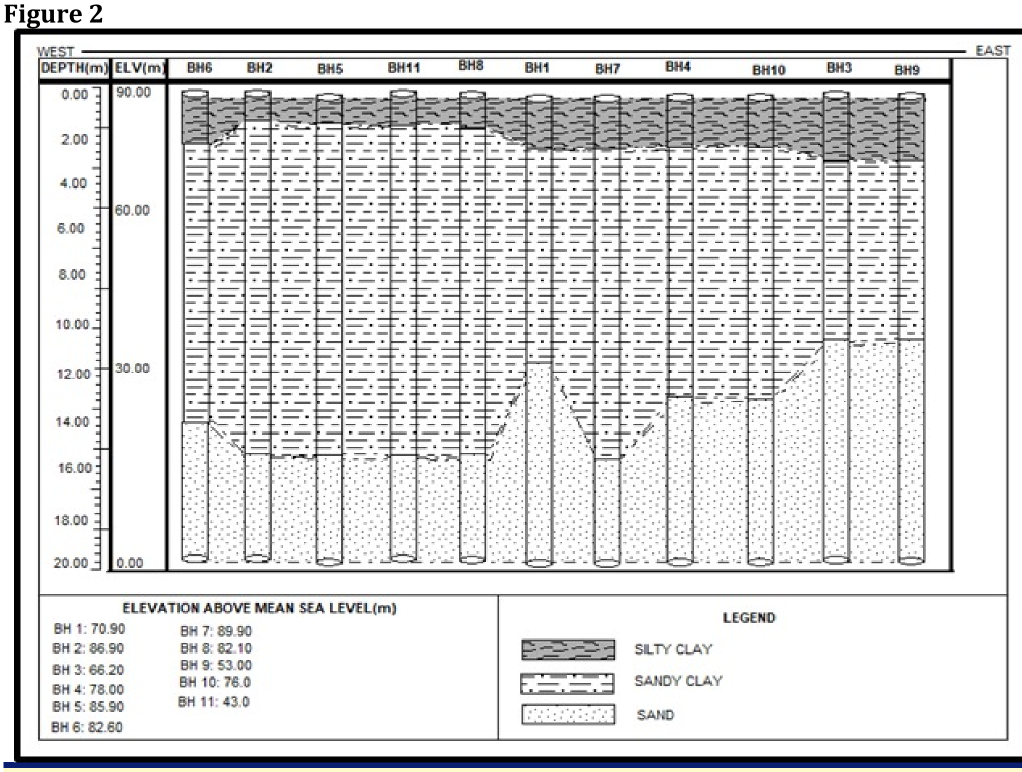

Figure 2 General Soil Profile in Uyo Town, Akwa Ibom State

4.2. ENGINEERING PROPERTIES

4.2.1 CLAY HORIZON I

This upper clay horizon, which is made up of a dark brown, soft to firm silty clay, with an average thickness of 3m forms the topsoil in all the boreholes. Engineering properties of this horizon are presented in Table 1. All the clay are of low compressibility, firm and low to intermediate plasticity (CL - CI), (Figure 3) Ehibor et al. (2019). The mineralogical composition of the clay reveal, kaolinite constitutes an average of 13.25% of the whole rock mineral, quartz 86.6% and goethite 0.1% Ehibor et al. (2019) Bearing capacity analysis of this clay layer at a depth of 1.5meters using the method of Terzaghi (1943) for shallow foundation design (Strip footing) gave ultimate bearing capacity values ranging between 354.6 kN/m2 in borehole 11 to 866.7 kN/m2 in borehole 8 as shown on the bearing capacity map in Figure 7.

Figure 3

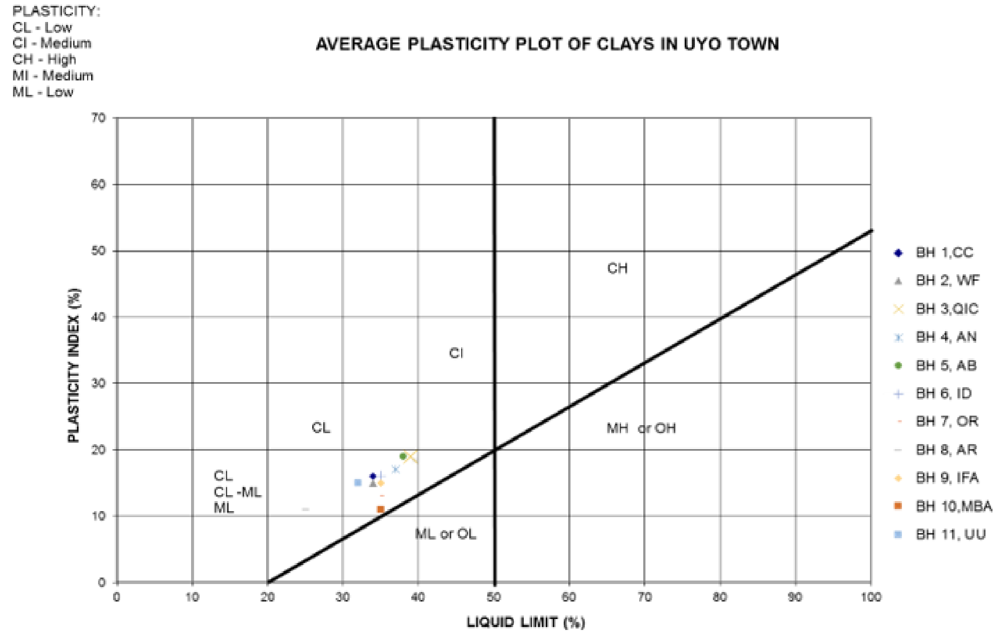

Figure 3 Typical Plasticity Plot of Clay in Uyo Town

Figure 4

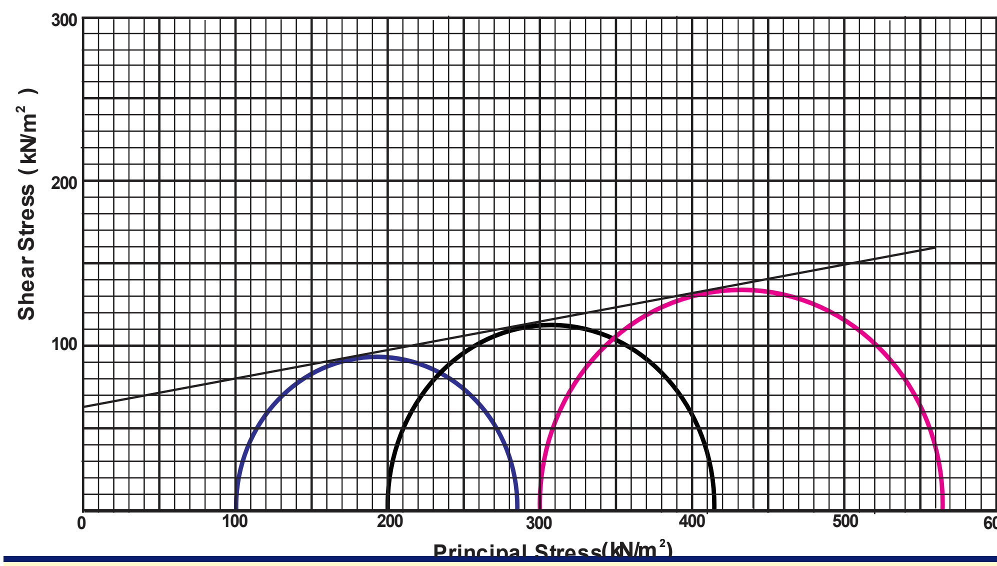

Figure 4 Mohr Circle and Envelope, Upper Clays

Table 1

Table 1 Engineering properties of the upper clay horizon Ehibor et al. (2019)

Borehole (BH)	1	2	3	4	5	6	7	8	9	10	11
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 31^1	N05^0 25^1	N05^{0}1 41	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	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
PI (%)	12	15	18	17	18	18	13	12	15	13	17
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
CV(m^2/yr.)	56.1	52.7	47.8	45	42.5	51	64.2	59.3	44.2	51.2	58.4
MV (m^2/M	0.21	0.15	0.22	0.2	0.17	0.12	0.23	0.19	0.16	0.19	0.18
γ (KN/μ^2)	20.8	20.9	21.6	21.4	20.9	20.6	20.1	21	19.7	21.2	19.7
Ø (°)	10	11	11	10	9	7	12	12	4	11	5
q_d (kN/m^2)	715	708.5	706.2	680	592.3	535.6	677.3	866.7	354.6	760	388.9
q_a (KN/m^2)	286.0	283.4	282.5	272	236.9	214.2	271	346.7	141.8	304	154

Wn= Natural moisture content LL= Liquid limit PL= Plastic limit C=Cohesion Ø=Frictional angle γ (KN/m^2) = Unit weight q_d (kN/m^2) Ultimate bearing capacity

Figure 5

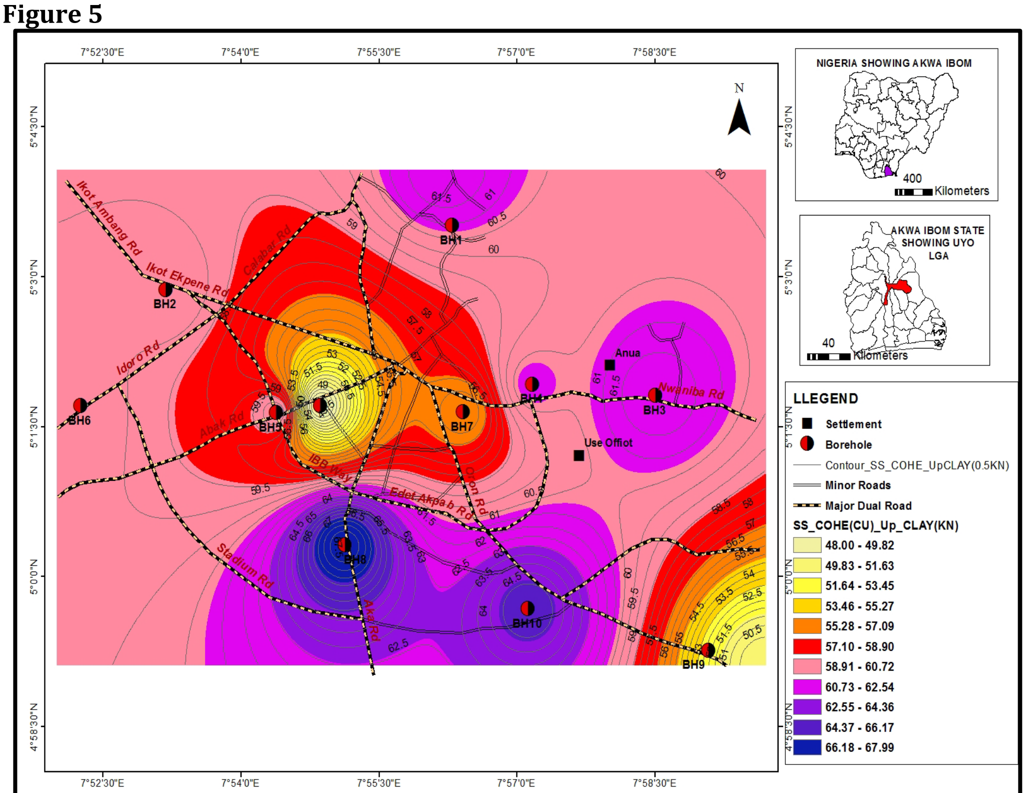

Figure 5 Shear Strength Map for Upper Clay Layer

Figure 6

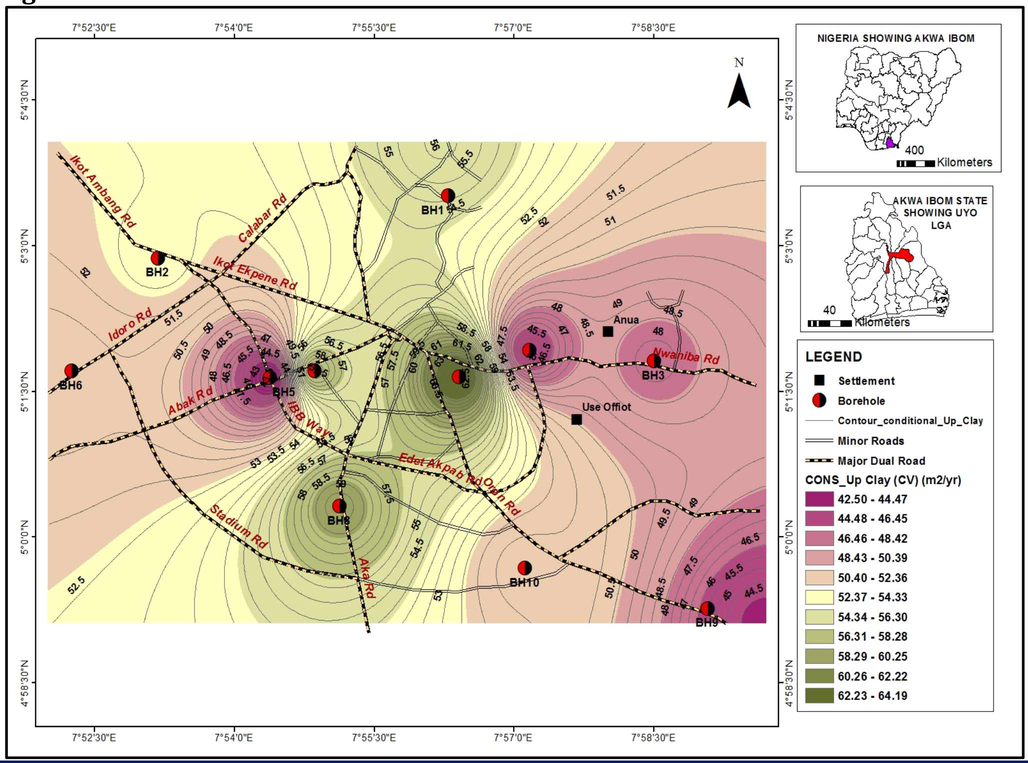

Figure 6 Consolidation Map for Upper Clay Layer

Figure 7

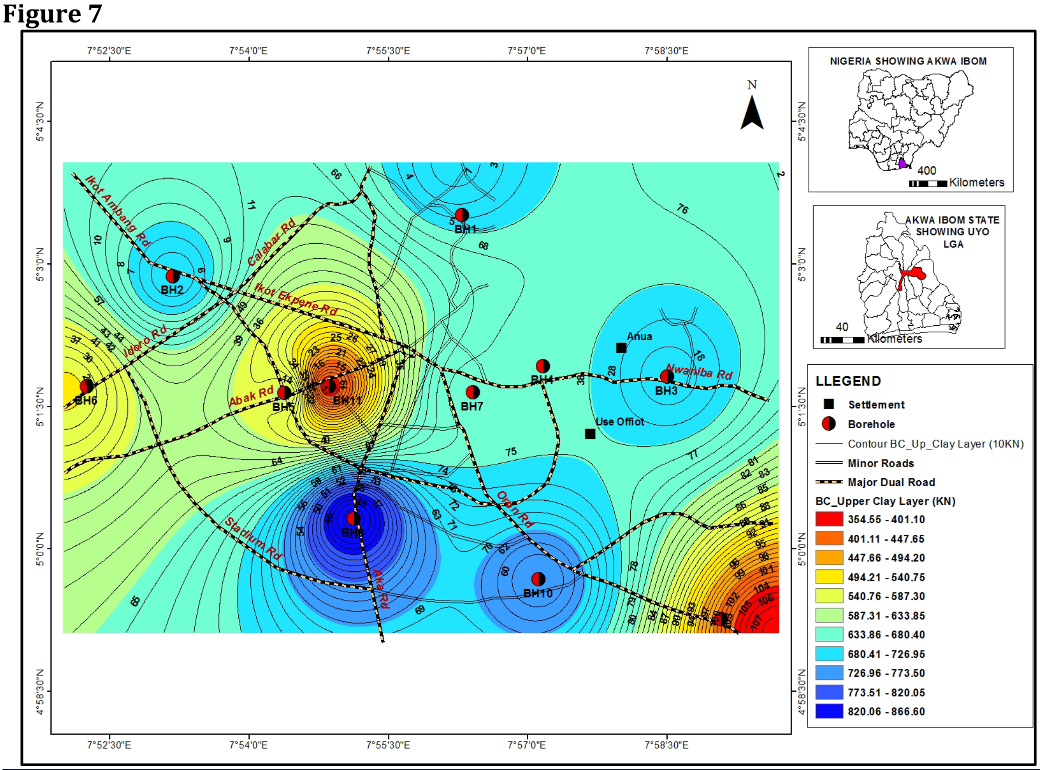

Figure 7 Bearing Capacity Map for Shallow Foundation Design in Upper Clay Layer, Uyo Town

4.2.2. CLAY HORIZON II

A light brown, firm sandy-clay with an average thickness of about 14m generally underlies the upper clay horizon in all the boreholes and is firmer in consistency The engineering properties in Table 2, reveal all the clay in this horizon are low to intermediate /plasticity clays (Figure 3) Ehibor and Akpokodje, 2019. Bearing capacity analysis of this clay layer at a depth of 6 meters using the method of Terzaghi (1943) for Strip footing gave ultimate bearing capacity values ranging between 482.5 kN/m2 in borehole 11 to 906.2 kN/m2 in borehole 2 as shown on the bearing capacity map in Figure 12

Figure 8

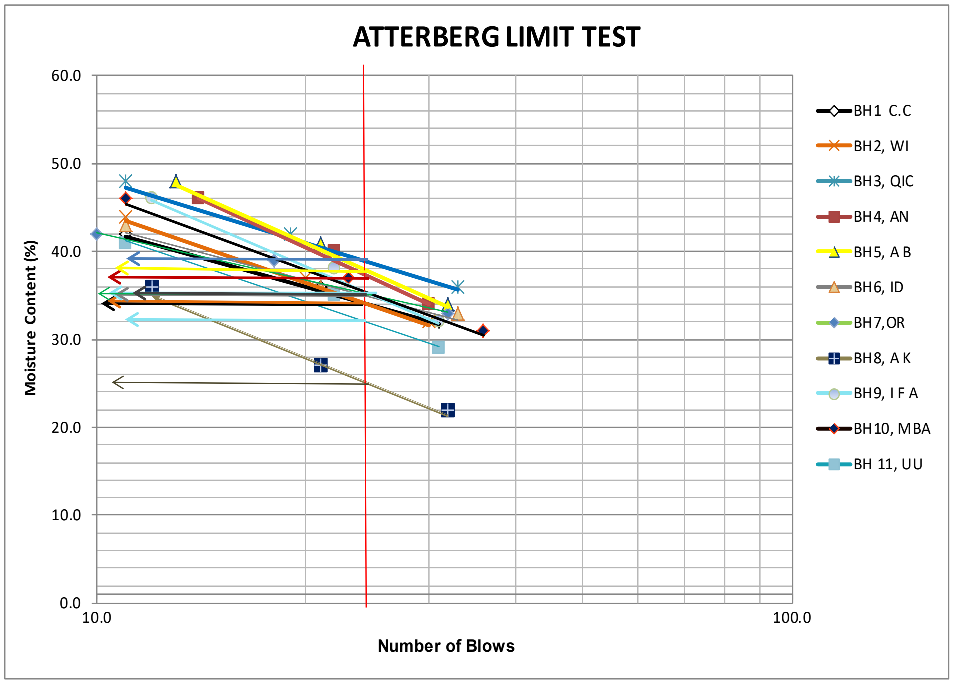

Figure 8 Typical Liquid limit plot of Clay in Uyo Town

Table 2

Table 2 Engineering properties of the Lower clay horizon Ehibor et al. (2019)

Borehole No	1	2	3	4	5	6	7	8	9	10	11
Depth (m)	10-Feb	15-Jan	11-Mar	15-Feb	15-Jan	14-Feb	15-Feb	15-Jan	11-Mar	13-Feb	15-Jan
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	13	9	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(KN/m^2)	60	60	62	62	59	55	52	62	65	62	50
CV(m^2/yr)	35.1	36.1	62.4	46	37.5	77.4	40	42.5	58.4	51.6	39.1
MV (m^2/M	0.23	0.21	0.18	0.21	0.19	0.09	0.17	0.17	0.18	0.55	0.11
γ (KN/μ^2)	20.2	20.7	21.1	21.2	20.4	20.3	19.4	21.1	20.6	20.6	19.9
Ø (°)	11	11	10	10	12	6	11	10	6	9	6

q_d (kN/m²)	898.8	906.2	830.1	831.8	817.1	531.2	677.3	830.7	598.7	745.5	482.5
q_a (kN/m²)	360.0	362.5	332	332.7	327	212.5	271	332.3	239.5	298.2	193

CV= Coefficient of consolidation MV(m²/MN) = Coefficient of volume compressibility

q_d (kN/m²) Ultimate bearing capacity q_a (kN/m²) Allowable bearing capacity

Figure 9

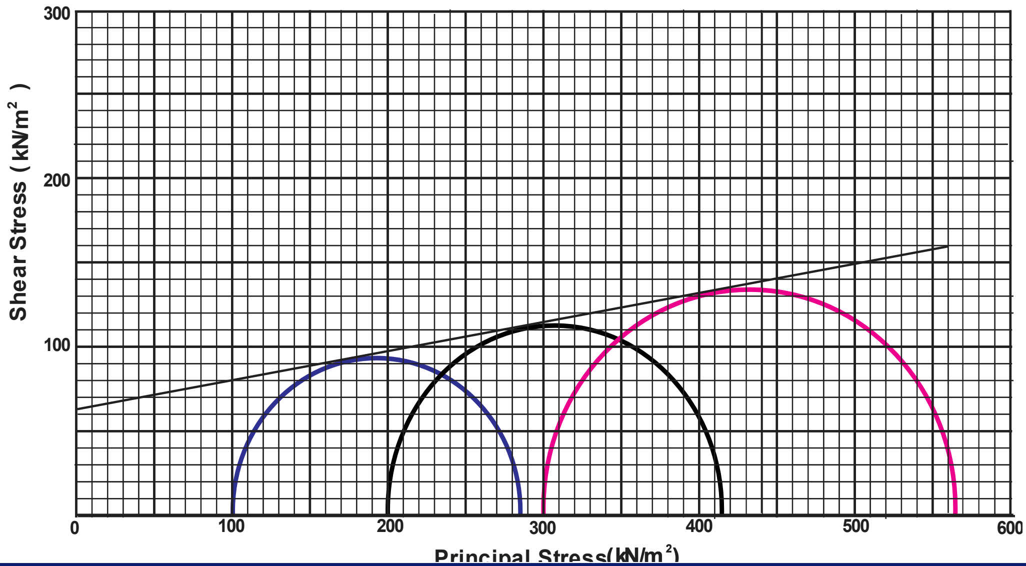

Figure 9 Mohr Circles and Envelope, Lower Clays

Figure 10

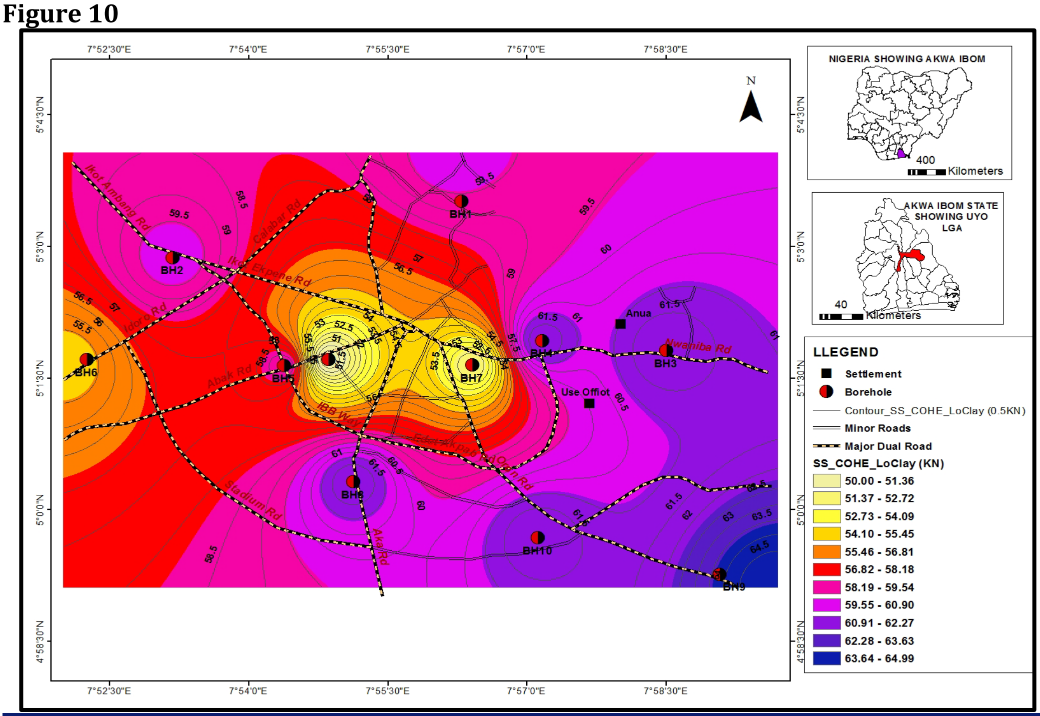

Figure 10 Shear Strength Map for Lower Clay Layer

Figure 11

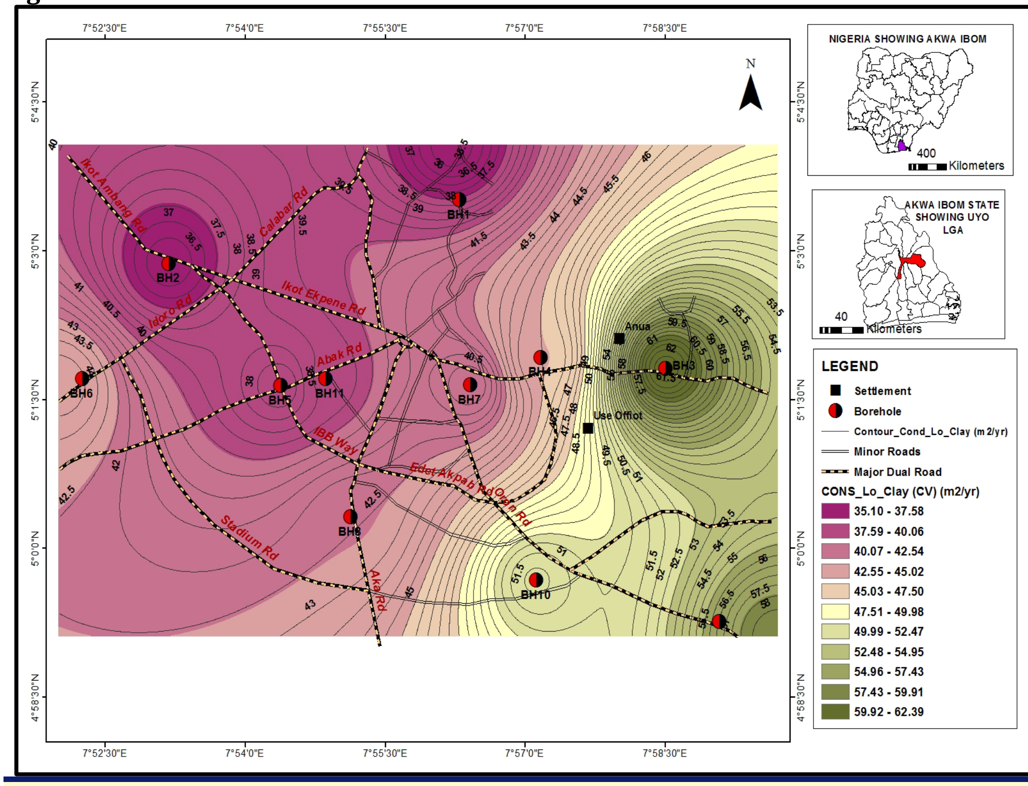

Figure 11 Variation of Coefficient of Consolidation Lower Clay Layer

Figure 12

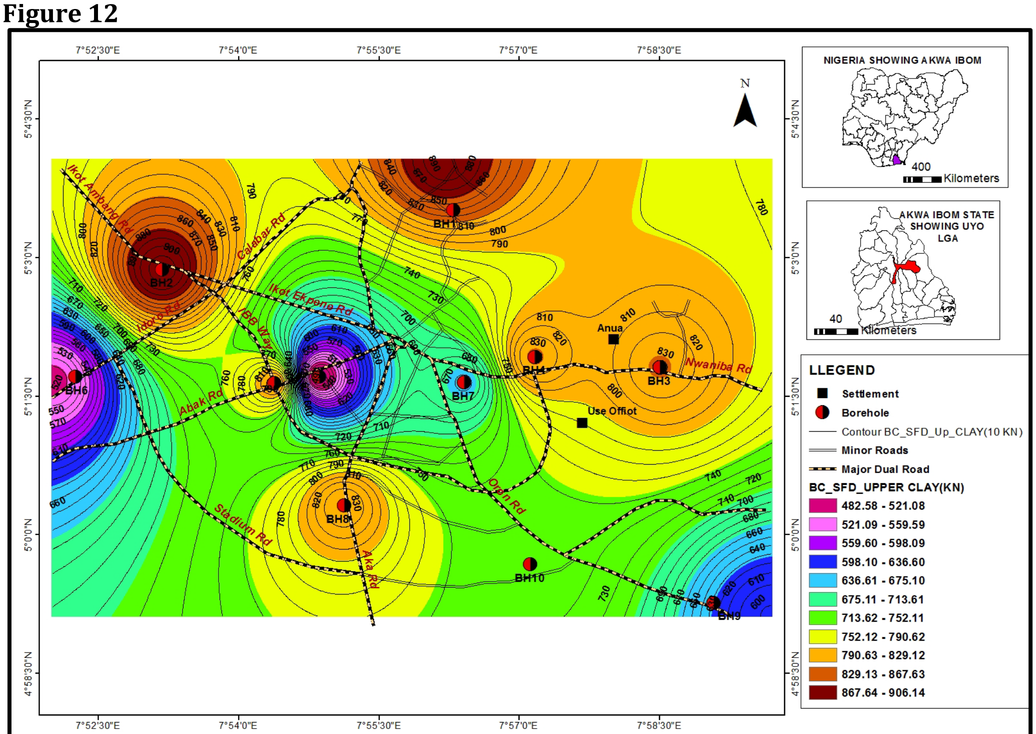

Figure 12 Bearing Capacity Map for Shallow Foundation Design in Lower Clay Layer, Uyo Town

4.2.3. SAND HORIZON

This horizon consists of a fine to medium to coarse, light brown, sand fraction Figure 13 about 10m thick generally underlying the silty sandy, light brown, clay. This poorly graded sand with a predominance of the medium sand fraction, is of medium density Table 3.

Analysis of the bearing capacity of the sand for pile design, at a depth of 18 meters using the methods of Peck, Hanson and Thornburn (1974), Teezaghi (1960) gave ultimate bearing capacities between 10262.9 KN and 11510.2 KN Figure 15 and allowable bearing capacities between 4105.2KN and 4604.1KN Table 4

Figure 13

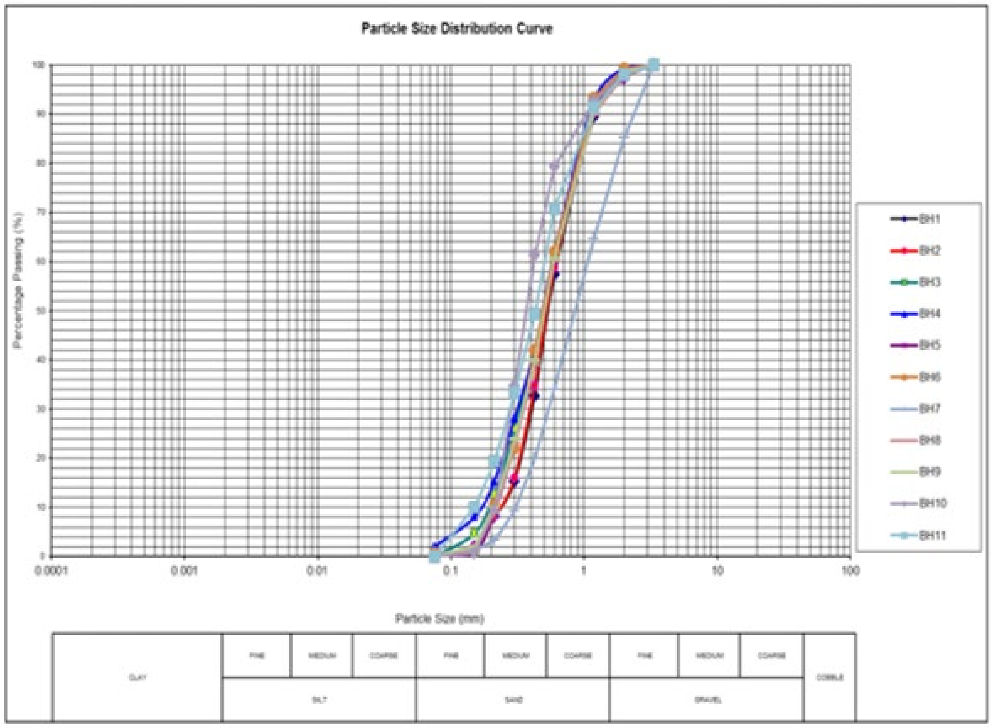

Figure 13 Typical Particle size distribution plots of the sand

Table 3

Table 3 Engineering properties of the sand horizon Ehibor et al. (2019)

Borehole No	1	2	3	4	5	6	7	8	9	10	11
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	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	2.5	1.5	2	0	1	0	2	2	2	2
D10	0.26	0.25	0.21	0.23	0.3	0.23	0.31	0.21	0.25	0.23	0.23
D50	0.51	0.52	0.49	0.51	0.89	0.39	0.85	0.36	0.6	0.37	0.52
D60	0.61	0.61	0.59	0.24	1.18	0.59	1.2	0.41	0.7	0.42	0.63
CU	2.4	2.5	1	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-Value	22	8	23	23	21	21	22	20	23	22	19
SPT NI-Value	19	12	19	19	18	18	19	18	19	19	17
Unit Weight	144.2	140.3	142.2	140.3	142.2	144.2	142.2	140.3	142.2	140.3	142.2

D10= Effective particle size   D50= Mean particle size   CU= Coefficient of uniformity

SPT N-Value = Standard Penetration test N-Value   Unit Weight □ (KN/m3)

SPT NI-Value = Standard Penetration test corrected N-Value

Table 4

Table 4 Pile Bearing Capacity of the sand horizon

BoreHole (BH) No	Depth (m)	Qult (KN)	Qallow (KN)	Qult (KN)	Qallow (KN)
1	18	11510.2	4604.1	11510.2	4604.1
2	18	10262.9	4105.2	10262.9	4105.2
3	18	11353.9	4541.6	11353.9	4541.6
4	18	11197.2	4478.9	9494.4	3797.8
5	18	11353.9	4541.6	11353.9	4541.6
6	18	11510.2	4604.1	11510.2	4604.1
7	18	11428.1	4571.2	11428.1	4571.2
8	18	11197.2	4478.9	11197.2	4478.9
9	18	11353.5	4541.4	11353.5	4541.4
I0	18	11197.2	4478.9	11197.2	4478.9
11	18	11353.5	4541.4	11353.5	4541.4

Figure 14

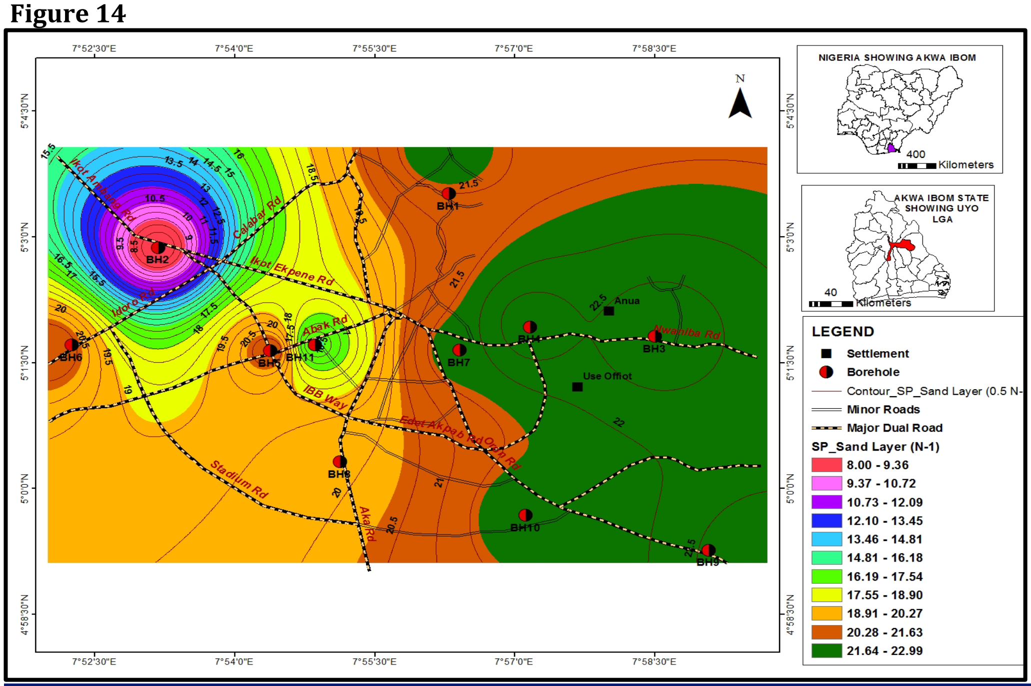

Figure 14 Standard Penetration Test Map for Sand Layers, Uyo Tow

Figure 15

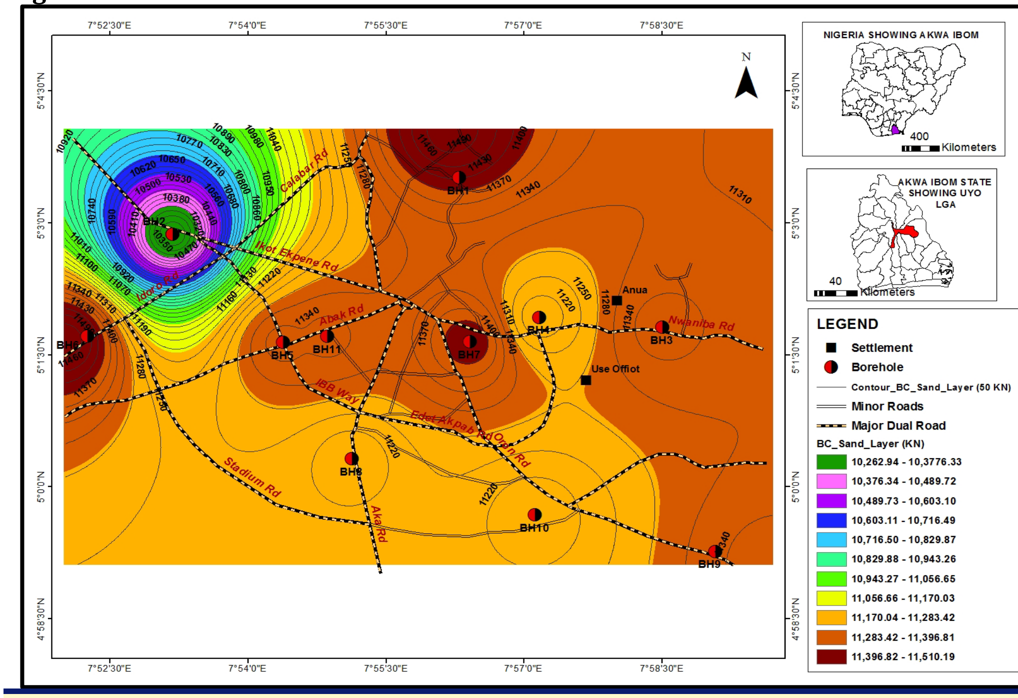

Figure 15 Bearing Capacity Map for Sand Layer in Uyo Town

5. CONCLUSION

The sub soils in Uyo town were analysed to determine their bearing capacity and generate maps for shallow and deep foundation designs. The general soil stratification of Uyo town is made up of silty clays, sandy clays, and sand. The ultimate bearing capacities of the silty clays are between 354.6 KN/m2 and 866.7KN/m2 and the sandy clays between 482.5 KN/m2 and 906.2KN/m2. The medium dense sands have ultimate and allowable pile bearing capacity averages of 10886.6KN and 4354.7kN respectively. The medium dense sand substratum is an adequate termination depth for piles and appropriate for engineering structures.

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