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ABSTRACT

The study was carried out with the aims of determining the stratification and geotechnical characteristics of foundation sub-soils underlying in six parts in Yenagoa local Government Area, Bayelsa state. Six boreholes were drilled in the six locations to a maximum depth of 20.25m. Laboratory tests and analysis were carried out on representative soil samples. Soil profiles were delineated followed by determination of their index and mechanical properties, including Atterberg limits, particle sizes distribution, undrained shear strength, shear box test and consolidation coefficient. Upper Silty clay horizon (0.0-5.25m thickness) very soft to firm for Yenagoa study areas, Medium silty clay horizon (0.75 to 1.5m thickness) soft to firm Yenagoa study areas, low clayey sand horizon (0.75 to 1.5m thickness) soft Yenagoa study areas, peaty clay (1.0m thickness between 3.0-4.0m) soft Igbogene Yenagoa, upper sand horizon (3.0m thickness) silty sand Etegwe town Yenagoa, lower sand horizon (13.5 to 18.0m) silty sand to fine to medium appear in all the boreholes in Yenagoa. Yenagoa sub-soil show low to high plasticity (CL-MH) according to unified soil classification system. From the results it shows that raft foundation is more economical in the six towns study areas of Yenagoa with Allowable bearing capacity of the upper clay layer ranges from 23-128KN/m². In view of the significant variations in the stratification and engineering geological index properties of the soil in the six towns in Yenagoa. However, the 1.0m thick peat embedded between 3.0m and 4.0m will great increase the compressibility of this clay. Pile foundation is recommended, considering the anticipated load and the very high compressibility of peat under imposed load. Piles should be straight-shaft, closed-ended steel pipe piles and driven into the medium dense sand. Straight shaft closed pipe piles were calculated for all the studies areas with diameter 305, 356, 406 and 610mm for the deep foundation for various study areas. Pile load test should be carried out on all piles to confirm working load and estimated settlements.

Keyword: Geotechnical index properties, Stratification, Allowable bearing capacities, pile foundation, Yenagoa

1. INTRODUCTION

Foundation is the lower hidden part of the structure, which carry large amount of load from the superstructure and distribute it to the soil. The foundation should be sound enough to carry the load of the superstructure. Geotechnical investigation is undertaken to obtain information on the physical properties of soil and rock underlying a site to design a proposed structure and for repair of distress caused by subsurface condition. The need for accurate information and adequate understanding of the geotechnical properties of the foundation of sub-soil cannot be over emphasized. Geotechnical information are useful in ensuring that the effect of projects on the environment and natural resource are properly evaluated and mitigated where necessary (Nwankwoala et al., 2009).

For the purpose of generating relevant data inputs for the design of foundations for proposed structures, it is on this basis that this study was undertaken to ascertain the engineering characteristic of the sub-soil in Etegwe, Akenfa-Agudama, Igbogene, Yenegue, Opolo Epie and Ovom in Yenagoa Local Government Area of Bayelsa state Nigeria.

Description of study area/geology

The study area (Figure 1), Etegwe, Akenfa-Agudama, Igbogene, Yenegue, Opolo Epie and Ovom are located in Yenagoa local Government area of Bayelsa state, is within the Niger Delta region of Nigeria. The local geology of the locations is composed of sediments which are characteristic of several depositional environments. Deposits are geologically young, ranging from the Eocene to the recent Pliocene. They include river mouth bar, delta front platform, delta slope and open shelf sediments. The detailed geology of the area has been described by Reyment, (1965) and Short and Stauble, (1967).

Litho- stratigraphically, the rocks are divided into the oldest Akata Formation (Paleoceone), the Agbada Formation (Eocene) and the youngest Benin Formation (Miocene to Recent). The wells and boreholes tap water from the overlaying Benin Formation (Coastal Plain Sands). This formation comprises of lacustrine and fluvial deposits whose thicknesses are variable but basically exceeds 1970 meters. The Benin Formation has lithologies consisting of sands, silts, gravel and clayey intercalations. The area is within the coastal zone. The coastal zone which comprises the beach ridges and mangrove swamps is underlain by an alternating sequence of sand and clay with a high frequency of occurrence of clay within 10m below the ground surface. Because of the nearness of these compressible clays to the surface, the influence of imposed loads results to consolidation settlement.

Study Location Coordinate

The study area coordinates for the various boring as in (Table 1).

Table 1 Show the Coordinates of the study locations in Yenagoa

Location	Northing	Easting
BH7	4º00’62.0”	6º24’30.8”
BH8	4º56’98.4”	6º20’20.3”
BH9	4º57’24.6”	6º21’15.5”
BH10	4º00’33.6”	6º23’11.5”
BH11	4º02’28.9”	6º24’28.7”
BH12	4º02’81,9”	6º24’89,7”

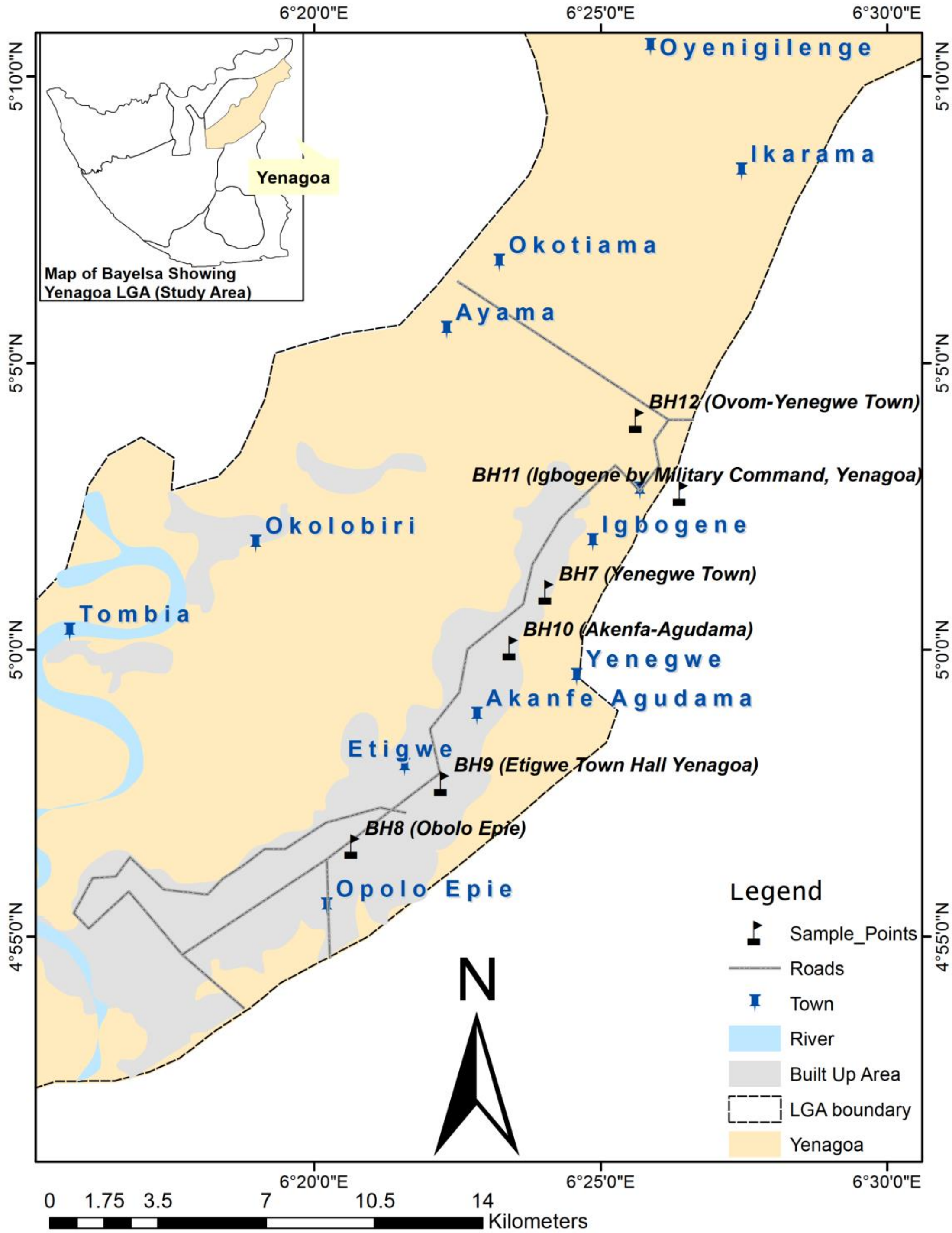


Figure 1 Map of Yenagoa, Bayelsa state, showing the six-study area

2. METHODOLOGY

Field Exploration

Information on subsurface conditions at the six (6) study areas was studied through ground borings to a maximum depth of 20.25m each using a percussion boring rig. Both disturbed and undisturbed representative samples were collected at the change of strata for visual examination. Standard penetration tests (SPT) were conducted to determine the penetration resistance values of cohesionless soils at specific depths within the boreholes as the boring progresses.

Laboratory Testing

Series of classification and mechanical property tests were conducted on representative soil samples. They include Atterberg limit tests, particle size analysis test, natural moisture content test, unit weight test, unconsolidated undrained triaxial test and consolidation test etc. All tests were carried out in accordance with British Standard Institute, (1990), standard procedures of testing soils for civil engineering purpose, equivalent to the American society for testing and materials standard.

Bearing capacity analysis for shallow foundation

The ultimate bearing capacity, Qu, for raft foundation on cohesive soils encountered at the study area using Terzaghi, (1943) equation as modified for shape factor is given below as:

$$Q_u = cNc(1+0.3*B/L)+\gamma.D_f.Nq+0.5\gamma.B.N_\gamma(1-0.2B/L) \quad (1)$$

Where:

Q_u = Ultimate bearing capacity

C = Soil cohesion at the studied depth

D_f = Depth of foundation

B = Foundation width

L = Length of foundation footing

γ = Unit weight of soil at the depth

NC, $N\gamma$, Nq = Bearing Capacity factors

Bearing capacity analysis of shallow foundations for layered soils (dense sand over soft clay) by Meyerhof, (1976) are as follows:

$$q_u = 5.14C_2\left[1+0.2\left(\frac{B}{L}\right)\right]+\left(1+\frac{B}{L}\right)\gamma_1 H^2\left(1+\frac{2D_f}{H}\right)\frac{K_s \tan\phi_1}{B}\lambda_S+\gamma_1 D_f \le q_t \quad (2)$$

$$N_{q(1)}\tan^2(45+\varphi o/2)e^{(\pi\tan\varphi)} \quad (3)$$

$$N_{\gamma(1)} = (N_q-1)\tan(1.4\varphi) \quad (4)$$

$$q_2 = 5.14C_2 \quad (5)$$

$$q_1 = 0.5\gamma_1 BN_{\gamma(1)} \quad (6)$$

$$q_2/q_1$$

$$q_t = \gamma_1 D_f N_{q(1)}\left[1+0.1\left(\frac{B}{L}\right)\tan^2\left(45+\frac{\phi_1}{2}\right)\right]+\frac{1}{2}\gamma_1 BN_{\gamma(1)}\left[1+0.1\left(\frac{B}{L}\right)\tan^2\left(45+\frac{\phi_1}{2}\right)\right] \quad (7)$$

Where

q_u = Ultimate bearing capacity Kpa

C_2 = Cohesion of bottom (weaker) layer kPa

γ_2 = Unit weight of bottom (weaker) layer KN/m^3

Ks = Punching shear coefficient, depending on q_2/q_1 and θ_1

B = Diameter or width of foundation m

L = Length of foundation m

Θ_1 = Internal angle of friction of the upper dense sand

λs = Shape factor = 1.1 to 1.27 for circular or square footings

D_f = Depth of Foundation

H = Depth below footing base to soft clay

q_t = Ultimate bearing capacity of upper dense sand kPa

Bearing capacity analysis for deep foundation

The pile bearing capacity, Q_u of bored piles is determined by the equation below derived from American Petroleum Institute (API).

$$Q_u = Q_s + Q_b \quad (8)$$

$Q_u = fs.As. + f_b.Ab$ (9)

$Q_u = \delta_v'.K_s.\tan Ø.A_s + \delta_{vb}'N_q.A_b$ (For sand layers) (10)

$Q_u = \alpha.ć_u.A_s + C_u.N_c.A_b$ (For clay layer) (11)

Where:

Qu = Ultimate axial pile capacity

Qs = Ultimate shaft resistance

Qb = Ultimate base resistance

fs = Unit shaft resistance

f_b = Unit base resistance

δ_v = Average effective overburden pressure over soil layer

Ks = Coefficient of lateral earth pressure against shaft wall

α = Pile wall adhesion factor

$ć_u$ = Average undrained shear strength of the clay over the pile penetration depth considered

δ_{vb}' = Effective overburden pressure at the pile base

Cu = Undrained shear strength of the clay at the pile base

Ab = Cross-sectional area of pile base

Nc, Nq = Bearing capacity factors

As = Exposed area of pile shaft in the soil layer

δ = Effective interaction angle between pile wall and the soil (Ø*0.75)

Settlement of the upper clay layer

Immediate settlement

Immediate foundation settlement of the different soil was calculated from the expression of Tomlinson, (2001)

$S_i = \frac{Bq_n}{E}(1-\mu_s^2)\, I_p$ (12)

Where

S_i = Immediate settlement

B= Breadth of foundation

q_n = Net foundation pressure

E = Modulus elasticity

μ = Poisson ratio

I_p = Influence factor

I_f = Influence factor is used.

E/cu = 400

Consolidation Settlement on Upper Clay Layer

Consolidation settlement (ϱ_c) in the cohesive layer was computed based on the foundation breadth (B) subjected to a bearing pressure of the soil. The induced vertical stress (Δσ) at the center of the consolidating was used in computing ϱc. The settlement value was computed from the expression given by Skempton and Bjerrum, (1957) as follows:

$\varrho c = \mu_g \varrho_{oed}$ (13)

$= m_v\, \Delta\sigma_z H$ (14)

$= m_v\, 0.55 q_n H$

Where

μg = Coefficient which depends on the type of clay

ϱ_{oed} = Settlement as calculated from oedometer tests

m_v = Coefficient of volume compressibility

q_n = Net foundation pressure

H = Thickness of the considering layer (1.5B)

B = Breadth of foundation.

3. RESULTS AND DISCUSSION

Soil stratigraphy

The soil stratigraphy encountered on the six study areas as obtained from the explored boreholes and laboratory tests were used to determine the soil profiles as in (Figure 2, 3) (Table 2). The study areas reveal light brown, light grey to dark grey silty clay and sandy clay of various thicknesses formation underlain by light brown to light grey sand of various thicknesses (Figure 4) to the final depth of 20.25m.

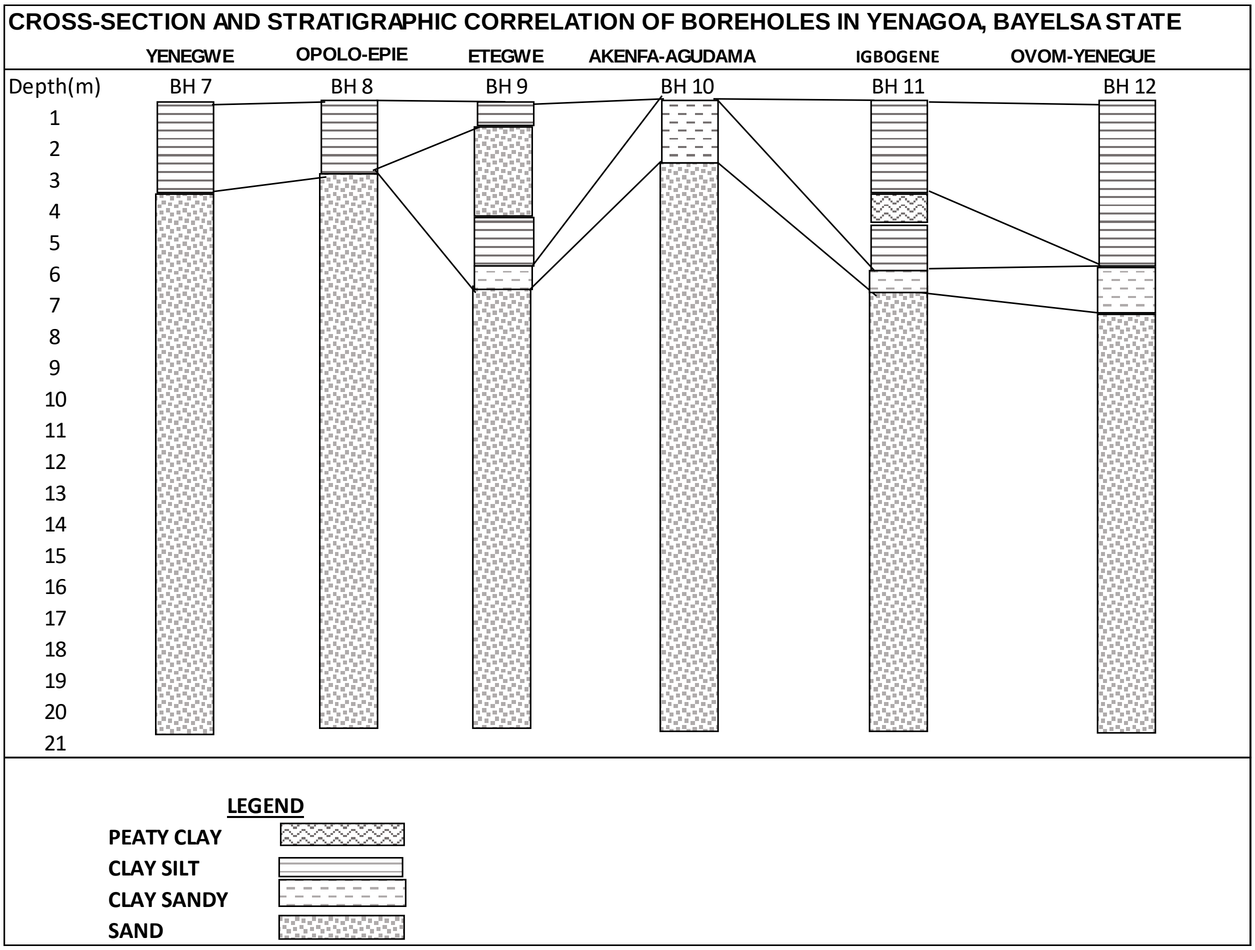
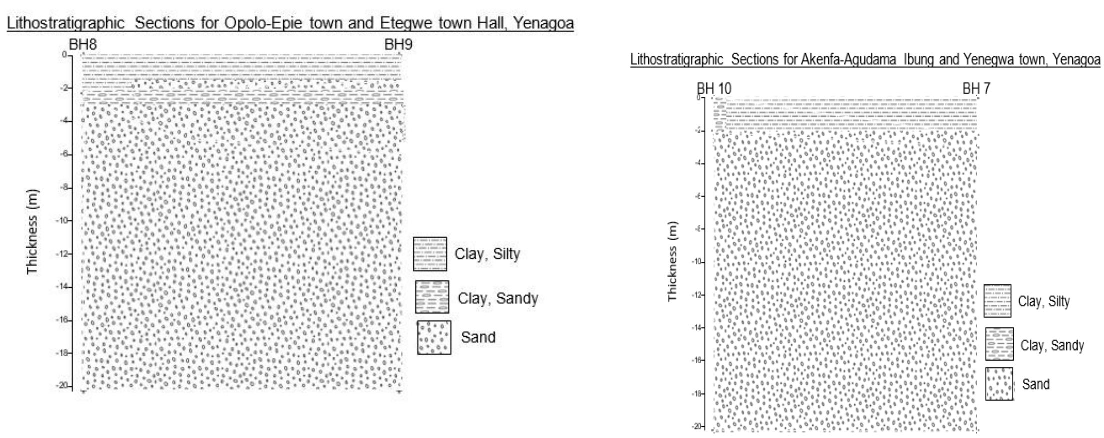
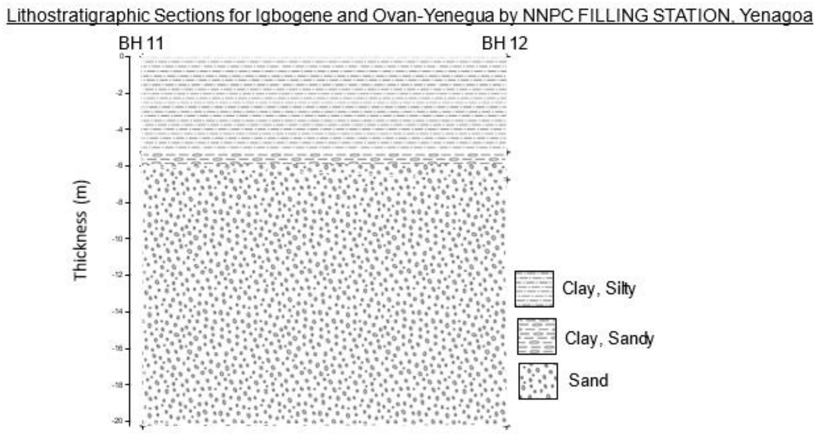


Figure 2 Cross section and Stratigraphic correlation of Six Boreholes in Yenagoa



A B



C

Figure 3 Lithostratigraphic section

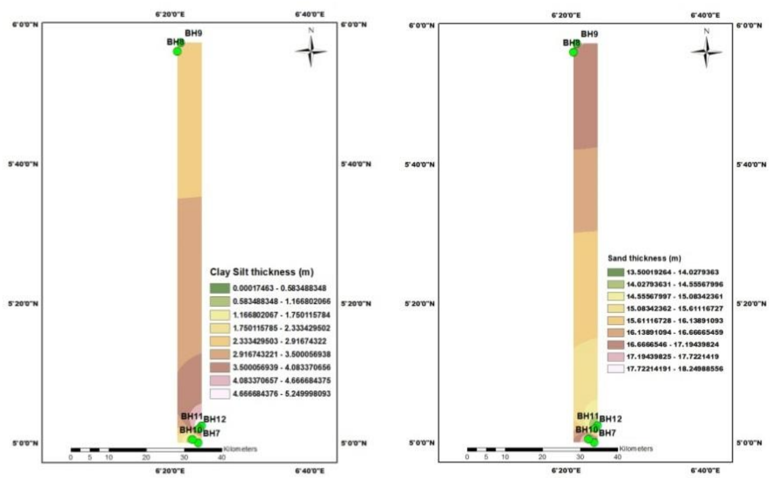


Figure 4 Shows Variation of Clay and Sand thickness in Yenagoa, Bayelsa state

Table 2 Soil Stratigraphy

Description Depth / Thickness (m)	BH7	BH8	BH9	BH10	BH11	BH12
Silty Clay	0.0-2.25	0.0-3.0	0.0-0.75		0.0-3.0	0.0-5.25
Peaty Clay			3.75-5.25		4.0-5.25	
Clay, Sandy					3.0-4.0	
Sand	2.25 -3.0		5.25-6.0	0.0-2.0	5.25-6.0	5.25-6.75
(Silty, fine, fine to medium grained)	3.0-20.25	3.0-20.25	6.0-20.25	2.0-20.25	6.0-20.25	6.75-20.25

Engineering properties

The geotechnical characteristics of the soil and the engineering attributes of the properties of the soil were determined from the laboratory and field work. The relevant index and engineering parameter of the soil are in (Table 3, 4).

Clay, very soft to firm

Upper layer predominately very soft to firm formation was encountered at the study areas and it is observed to possess medium to high moisture content and low to high plasticity with low to moderate undrained shear strength (British Standard Institute, 1981), the parameter of the clay formation (Table 3).

Loose and medium dense to dense

Underneath the silty clay and sandy clay is a continuous deposit of relatively clean sand, poorly graded in all the boreholes (Figure 5) (Table 4). The sand is predominantly light brown to light grey colour and silty to fine to medium coarse grained, loose to medium dense to dense in relative compaction.

Table 3 Geotechnical Index Properties of clay in Yenagoa

LOCATIONS	BH7			BH8			BH9			BH10			BH11			BH12		
Parameter	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**
Wn %	20.8	20.8	20.8	54.9	54.9	54.9	51.4	51.4	51.4	39.0	39.0	39.0	40	40	40	64.8	64.8	64.8
LL %	65	65	65	71	71	71	54	54	54	35	51	43	125	125	125	60	60	60
PL %	37	37	37	36	36	36	33	33	33	18	33	33	69	69	69	32	32	32
PI %	28	28	28	35	35	35	21	21	21	17	18	18	56	56	56	28	28	28
USCS			MH				MH			MH	CL		MH			MH		MH
Cu (KN/m^2)	42	42	42	28	28	28	17	17	17	47	47	47	41	53	47	35	35	35
Ø (°)	4	4	4	8	8	8	4	4	4	6	6	6	5	7	6	7	7	7
Unit Weight (KN/m^3)	18.1	18.1	18.1	14.9	14.9	14.9	17.8	17.8	17.8	18.7	18.7	18.7	18.2	19.4	18.8	14.5	14.6	14.6
Cv (m^2/yr)	18.38	18.38	18.38	3.26	3.26	3.26	3.24	3.24	3.24	10.5	10.5	10.5	10.5	10.5	10.5	4.34	4.34	4.34
Mv (m^2/MN)	0.38	0.38	0.38	0.59	0.59	0.59	0.65	0.65	0.65	0.30	0.30	0.30	0.32	0.32	0.32	0.80	0.80	0.80

Table 4 Geotechnical Index Properties of Sand in Yenagoa

LOCATIONS	BH7			BH8			BH9			BH10			BH11			BH12		
Parameter	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**
d_{10} (mm)	0.16	0.22	0.19	0.18	0.20	19	0.20	0.22	0.21	0.18	0.22	0.20	0.17	0.22	0.20	0.20	0.23	0.22
d_{30} (mm)	0.23	0.30	0.27	0.26	0.28	0.27	0.30	0.30	0.30	0.29	0.30	0.30	0.23	0.30	0.27	0.30	0.30	0.30
d_{60} (mm)	0.35	0.46	0.41	0.39	0.49	0.44	0.42	0.50	0.46	0.42	0.50	0.46	0.35	0.47	0.41	0.41	0.50	0.46
$C_u = \frac{d_{60}}{d_{10}}$	1.9	4.6	3.3	2.0	2.7	2.4	1.9	2.4	2.2	1.9	2.4	2.2	1.9	2.4	2.15	1.9	2.2	2.05
$C_c = \frac{d_{30}}{d_{10} x d_{30}}$	0.8	2.0	1.4	0.7	1.0	0.8	0.8	1.0	0.9	0.8	1.1	0.95	0.9	1.0	0.95	0.8	1.0	0.9
Unit weight KN/m3	20.0	20.5	20.3	19.2	20.0	19.6	18.5	19.0	18.8	19.2	19.2	19.2	19.0	19.1	19.1	19.4	19.8	19.6
Dry Unit weight KN/m^3	17.3	17.6	17.5	16.3	17.6	17,0	16.0	16.0	16.0	16.6	16.9	16.8	16.7	16.9	16.8	16.8	17.3	17.1
MC %	14.5	15.1	14.8	13.7	17.5	15.6	15.6	18.6	17.1	13.6	15.8	14.7	19.0	19.1	19.1	14.2	15.6	
Ø (°)	28	30	29	29	30	30	30	30	30	29	30	30	30	31	31	30	32	31
N value	6	13	10	8	23	16	11	27	19	14	28	21	7	18	13	14	33	24

Bearing capacity for shallow foundation

From the shallow foundation analysis, Raft foundation of width 2, 5 and 15m at different depth of 1 and 2.0m respectively and rectangle footing foundation using layer soil analysis for Etegwe town have been calculated for the study areas (Table 5, 6, 7, 8, 9, 10).

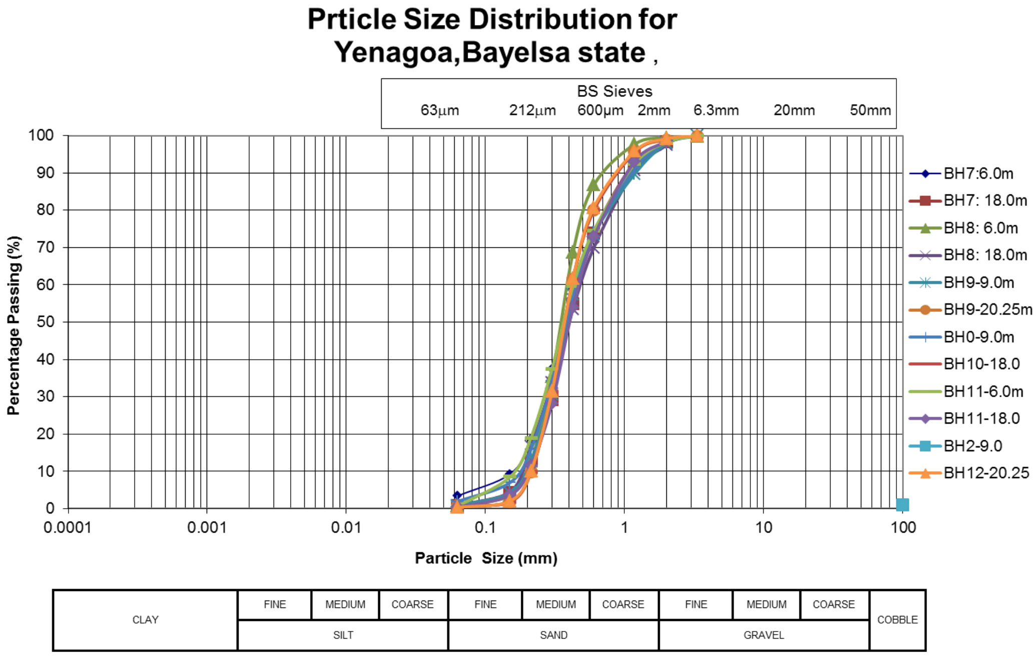


Figure 5 Particle Size Distribution of the study Areas

Table 5 Allowable Bearing Resistance Values KN/m² for Raft Foundation: Yenegwe BH7

Foundation Depth	B = 2.0	B = 5.0	B = 15.0
1.0	87	98	106
2.0	90	100	109

Table 6 Allowable Bearing Resistance Values KN/m² for Raft Foundation: Opolo- Epie BH8

Foundation Depth	B = 2.0	B = 5.0	B = 15.0
1.0	61	67	73
2.0	66	72	75

Table 7 Allowable Bearing Resistance Values KN/m² Rectangle Foundation: Etegwe BH9 using layer soil of strong soil over soft soil

Foundation Width	L/B = 1.0	L/B = 1.5	L/B = 5.0
1.0	98	97	73
2.0	68	57	45
3.0	58	44	35
4.0	53	37	30
5.0	50	33	27
6.0	48	30	25
7.0	47	28	24
8.0	45	27	23

Table 8 Allowable Bearing Resistance Values KN/m² for Raft Foundation: Akenfa- Agudama - BH10

Foundation Depth	B = 2.0	B = 5.0	B = 15.0
1.0	100	111	122
2.0	106	117	128

Table 9 Allowable Bearing Resistance Values KN/m² for Raft Foundation: Igbogene - BH11

Foundation Depth	B = 2.0	B = 5.0	B = 15.0
1.0	85	94	104
2.0	88	97	107

Table 10 Allowable Bearing Resistance Values KN/m² for Raft Foundation: Ovom - BH12

Foundation Depth	B = 2.0	B = 5.0	B = 15.0
1.0	71	80	87
2.0	73	81	89

Settlement analysis for shallow foundation

Table 11, 12, 13, 14 and 15 reveals the total settlement at different foundation depth 1 and 2m and different width of 2.5 and 15m.

Table 11 Total Settlement (mm) for Raft Foundation Yenegwe BH7

Foundation Depth (m)	Dimension: Length and Width (m)		
	B = 2.0 L = 10	B = 5.0 L = 8.0	B = 15.0 L = 15.0
1.0	20	34	51
2.0	18	36	54

Table 12 Total Settlement (mm) for Raft Foundation Opolo-Epie BH8

Foundation Depth (m)	Dimension: Length and Width (m)		
	B = 2.0 L = 10	B = 5.0 L = 8.0	B = 15.0 L = 15.0
1.0	32	50	98
2.0	43	62	103

Table 13 Total Settlement (mm) for Raft Foundation Akenfa-Agudama BH10

Foundation Depth	B = 2.0	B = 5.0	B = 15.0
1.0	35	55	112

Table 14 Total Settlement (mm) for Raft Foundation Igbogene BH11

Foundation Depth (m)	Dimension: Length and Width (m)		
	B = 2.0 L = 10	B= 5.0 L = 8.0	B = 15.0 L = 15.0
1.0	36	57	119
2.0	43	65	120

Table 15 Total Settlement (mm) for Raft Foundation Ovom BH12

Foundation Depth (m)	Dimension: Length and Width (m)		
	B = 2.0 L = 10	B = 5.0 L = 8.0	B = 15.0 L = 15.0
1.0	53	84	151
2.0	61	93	159

Bearing capacity deep foundation

Pile foundation analysis was carried out for the soil profile that was encountered on the study areas. Straight shaft closed pipe piles of diameter of 305. 356. 406 and 610mm were designed. Results of the pile compressive resistance is in (Table 16, 17, 18, 19, 20, 21).

Table 16 Showing the various Ultimate Pile Capacity and Pile safe Working Load and Depth for Yenegwe BH 7

Pile Foundation	Diameter (m)							
	Pile Compressive Resistance (KN)							
Depth (mm)	305	305	356	356	406	406	610	610
10	343	137	387	155	413	165	521	208
15	540	216	602	241	646	259	826	330
20	795	318	882	353	950	380	1228	491

Table 17 Showing the various Ultimate Pile Capacity and Pile safe Working Load and Depth for Opolo-Epie BH 8

Pile Foundation	Diameter (m)							
	Pile Compressive Resistance (KN)							
Depth (mm)	305	305	356	356	406	406	610	610
10	284	114	361	144	443	177	863	345
15	411	165	520	208	638	255	1234	494
20	592	237	745	298	911	364	1743	697

Table 18 Showing the various Ultimate Pile Capacity and Pile safe Working Load and Depth for Etegwe BH 9

Pile Foundation	Diameter (m)							
	Pile Compressive Resistance (KN)							
Depth (mm)	305	305	356	356	406	406	610	610
10	303	121	376	150	458	355	888	355
15	486	194	592	237	708	283	1293	517
20	749	300	910	364	1082	433	1940	776

Table 19 Showing the various Ultimate Pile Capacity and Pile safe Working Load and Depth for Akenfa-Agudama BH 10

Pile Foundation	Diameter (m)							
	Pile Compressive Resistance (KN)							
Depth (mm)	305	305	356	356	406	406	610	610
10	305	122	383	153	467	187	886	354
15	804	322	731	292	880	352	1608	643
20	1256	502	1184	473	1413	566	3837	1535

Table 20 Showing the various Ultimate Pile Capacity and Pile safe Working Load and Depth for Igbogene BH 11

Pile Foundation	Diameter (m)							
	Pile Compressive Resistance (KN)							
Depth (mm)	305	305	356	356	406	406	610	610
10	284	114	449	180	534	214	940	376
15	528	211	748	299	893	357	1580	632
20	1190	476	1153	462	1372	549	3421	1368

Table 21 Showing the various Ultimate Pile Capacity and Pile safe Working Load and Depth for Ovom-Yenegue BH 12

Pile Foundation	Diameter (m)							
	Pile Compressive Resistance (KN)							
Depth (mm)	305	305	356	356	406	406	610	610
10	329	132	410	164	497	199	925	370

15	543	217	674	270	814	326	1638	655
20	1349	540	1686	674	2047	819	3839	1536

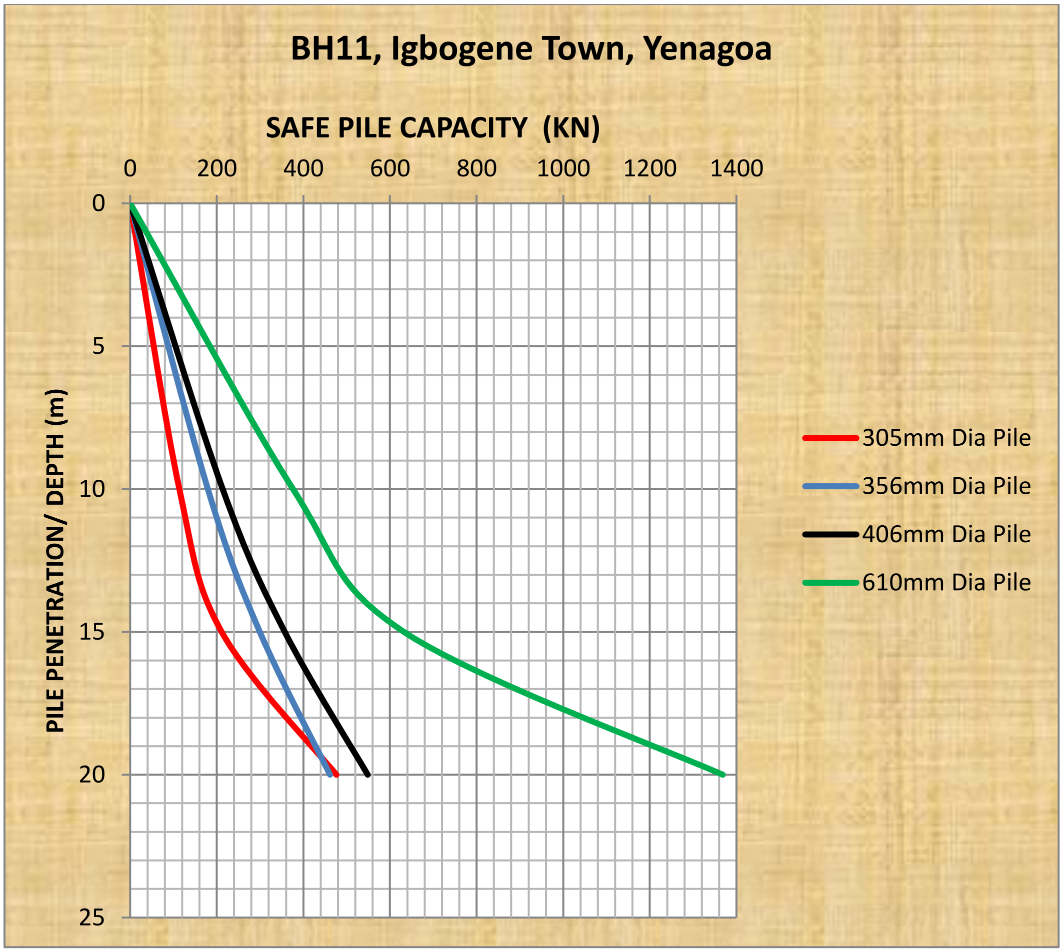


Figure 6 Typical Safe Bearing Capacity of Pile in Yenagoa

4. CONCLUSION

The following conclusion can be drawn from the six study areas in Yenagoa local government area.

The soil profile across the six study area in Yenagoa Bayelsa state are not uniform in layer, they varies from one location to another but silty clay and sand are found in all the location

The six study areas in Yenagoa sub-soil show low to high plasticity (CL-MH) according to unified soil classification system

From Yenegwe (BH7) and Opolo-Epie (BH8) shows similar soil profile of silty clay, intercalation of clay and sand and sand layer.

From Igbogene town is 1.0m thick peaty clay embedded in the clay between 3.0 and 4.0 depths, this will greatly increase the compressibility of the clay consisting the nature of the intended structure so pile foundation is recommended to take the imposed load beyond the soft clay layer to the underlying sand stratum.

Akenfa allowable bearing capacity was design using layer soil analysis due to the nature of the layer of soil in the area. Raft foundation should use to support the structure within the top sand layer.

Ethical issues

Not applicable.

Informed consent

Not applicable.

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Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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