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Geotechnical Considerations for Foundation Design in Parts of Yenagoa, Bayelsa State, Niger Delta Nigeria

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ABSTRACT: *This research was to determine geotechnical properties of the subsoils in some part of Yenagoa and environs to obtain proper foundation design parameters, six towns in Yenagoa local government area, Bayelsa state was investigated. Six geotechnical boreholes was drilled and laboratory studies of soils samples were obtained from 0-20.25m deep. Subsurface 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. The general soil profile consists of (from top to bottom), , upper Silty clay horizon (0.0-5.25m thickness) 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 and medium coarse appear in all the boreholes in Yenagoa. Yenagoa sub-soil show clay of high plasticity, silt of intermediate to high plasticity (CH, MI and MH) according to unified soil classification system from the results it shows that pad foundation is more economical in the study areas. 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/m^2 In view of the significant variations in the stratification and engineering geological index properties of the soil in the six towns in Yenagoa while geotechnical data of one location cannot be used as a basis for design of foundation in a nearby land. Axial load carrying capacity for 305, 306mm, 356, 360mm, 406mm, 600and 610mm diameter for bore pile and tubular driven steel cased piles respectively were calculated for all the studies areas. Where high rise building is required in the various study areas. The study shows that the frequent causes of building collapse in Yenagoa are as a result of inadequate geotechnical investigations of the subsoil, poor quality materials, and poor work supervision.*

KEYWORDS: geotechnical consideration, foundation design, Yenagoa, Bayelsa state, Niger delta

INTRODUCTION

Background to the Study

Some parts of the Niger Delta are marginal land with challenge of building sustainable civil infrastructure, therefore there is need for proper geotechnical investigation for suitable Foundation. 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. The stability of a structure always depends on the suitability of foundation. Since the foundation is very important part of structure, it should be designed properly. Foundation design requires two different parameters which are (1) ultimate bearing capacity of the soil below the foundation and (2) the settlement which the footing can experience without any adverse effect on the structure. The design of any foundation depends on geotechnical index properties of the subsoil. A good foundation ensures absence of shear failure upon loading and settlement of super structure within allowable limit. Geotechnical properties of some coastal cities communities in parts of rivers state was carried out by (Dickenson *et al, 2023*). Geotechnical parameters have become a major issue, since the parameters are used in the design of suitable and stable foundation before civil engineering construction is carried out. Efforts have been made in studying the geotechnical properties of soils in the area under study because of building collapse and foundation design. This research was carried out to investigate geotechnical properties of subsoil in Yenagoa as a result of frequent structural failures in the cities. Some parts of the Niger Delta have experienced frequent cases of building collapse, which have resulted in loss of lives and properties. Building collapse could be attributed to natural disasters such as floods, hurricanes and earthquakes or man-made errors such as poor design or inadequate geotechnical investigation of the soil where the building is to be erected (Ayeni & Adedeji, 2015). In 2018, a seven-storey building belonging to Swiss Spirit Hotel at Woji Road, New GRA Port Harcourt collapsed killing 5 persons and trapping an additional 36 persons in the rubbles (Youdeowei & Rowland, 2019). The cause may have been due to foundation failure, inadequate design of the structure or poor quality control and supervision. There is need to investigate the geotechnical properties of subsoils in these areas for proper foundation design to ensure stability of civil engineering structure, Provide data for construction purposes in the area, The data so provided will be useful in foundation design of engineering structures, If proper design is given for structures in the area stability of those structures is guaranteed.

Geology of the Niger Delta

The study areas are situated within the central Niger Delta, underlain by sedimentary rocks. Generally, the geology of the Niger Delta is obtained from the works of several researchers including among others, those of (Reyment, 1965; Short and Stauble, 1967; Murat, 1970; Merki, 1970), Ekweozor and Dakoru (1994). Akpokodje (1986), stated that the superficial soils of the Niger Delta can be classified based on geotechnical properties, geology, geomorphology and drainage condition into four major groups namely: Reddish brown sandy loamy soil of low medium plasticity, Brown sandy clay of medium to high plasticity, Light gray, slightly organic fine sand and silty clay, Dark organic/ peaty clay of high to extremely high plasticity. He concluded that each of these groups have characteristic engineering properties and foundation potential. Akpokodje (1989), contended that the general sub-soil foundation engineering condition of the Niger Delta can be divided into three major zones. Clayey / sandy subsoil strata, Two-layer subsoil strata, Three- layer subsoil strata situations that are combinations of two or all the three typical conditions are very common.

Lithostratigraphy of the Niger Delta

The Tertiary Niger Delta covers an area of approximately 75,000 sq km and consists of a regressive clastic succession, which attains a maximum thickness of 12,000m (Orife and Avbovbo, 1982). The lithostratigraphy of the Tertiary Niger Delta (Figure 1.1 and 1.2). Akata, Agbada and Benin formations, in order of decreasing age with depositional environments ranging from marine, transitional and continental settings respectively. The Akata, Agbada and Benin Formations overlie stretched continental and oceanic crusts (Heinio and Davies, 2006). Their ages range from Eocene to Recent, but they transgress time boundaries. These prograding depositional facies can be distinguished mainly on the basis of their Lithology.

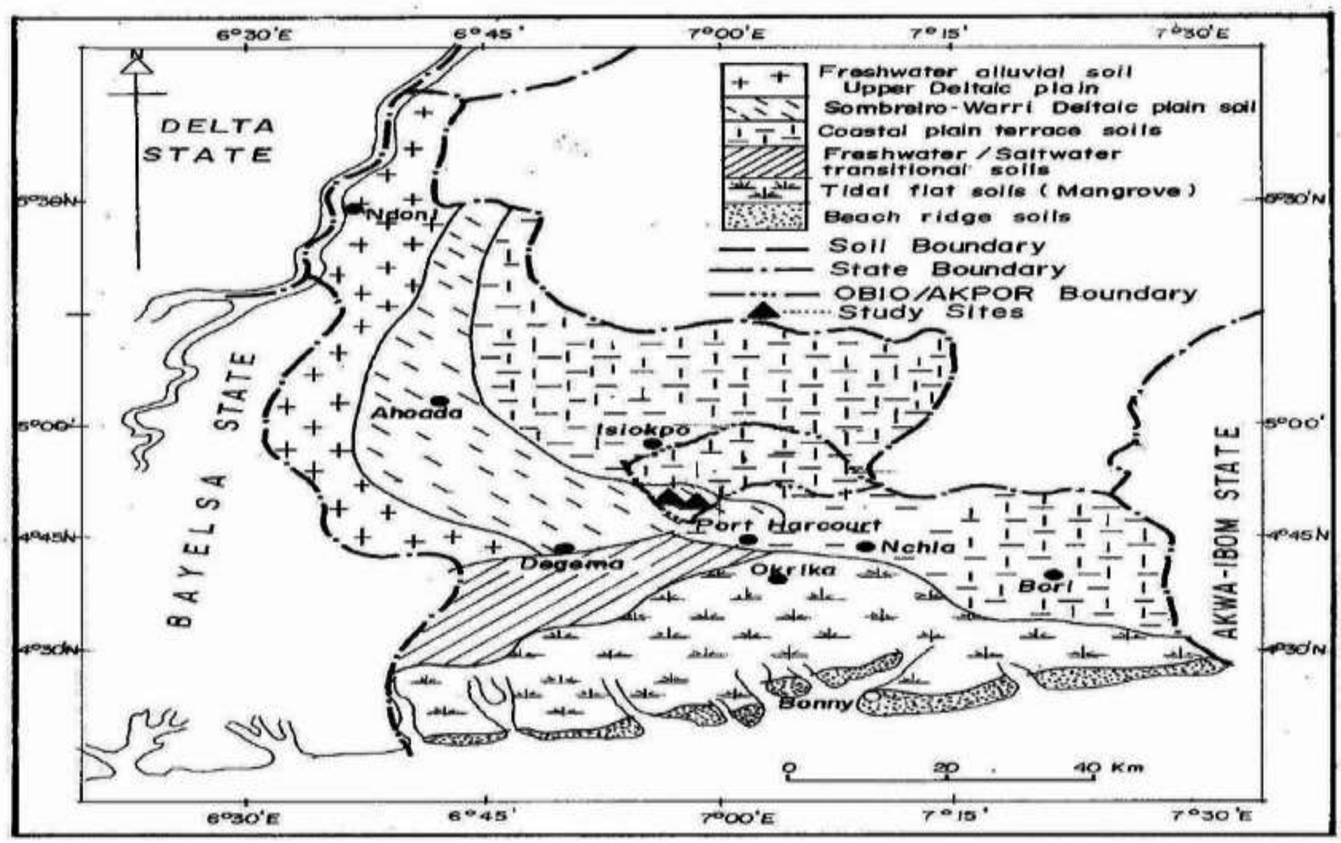

Fig 1.1: Geological Map of Niger Delta (Adapted from Ehirim et al., 2009)

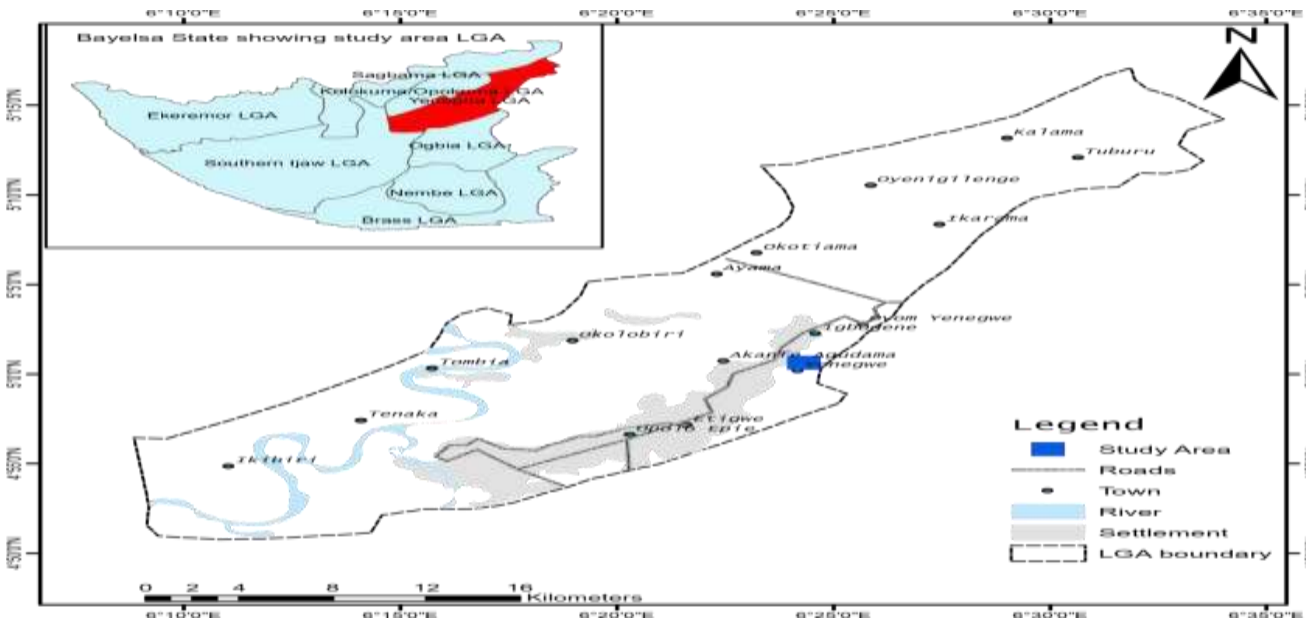

Fig 1.2: Map of Yenagoa showing the study areas in Six Town in Bayelsa state

METHODOLOGY

Percussion drilling method was used throughout the soil boring operation during the boring operation, disturbed samples were collected at interval of 0.75m and when change of soil type was noticed. Undisturbed cohesive soil samples were retrieved from the boreholes. Bayelsa state six towns was sampled namely: Etegwe, Akenfa-Agudama, Igbogene, Yenegwe, Opolo-Epie ,and Ovom town, with open-tube sampler which consists essentially of lower and upper end screwed into a drive head that is attached to a rod. The head has an overdrive space and incorporates a nonreturn valve to permit the escape of air or water as the sample enters the tube. The sampler is driven into the soil by means of a drop hammer. All samples recovered from the boreholes were examined, identified and described in the field.

Laboratory Testing

The basic geotechnical index and engineering properties, classification and strength tests were carried out in the laboratory according to procedures specified by the British Standards (BS 1377 1990), as well as American Society for Testing and Materials (ASTM 1975). The classification tests included: **Atterberg Limits, Liquid Limits, Plastic Limits, Plasticity Index, Particle Size Distribution Analysis, Triaxial Test, Compressibility Test,Shear Box Test**

Bearing Capacity Analysis: Shallow Foundation

Bearing capacity and settlement requirements are two basic criteria to be satisfied in the analysis and design of shallow foundations. The criterion on bearing capacity ensures that the foundation does not undergo shear failure under loading. A bearing capacity analysis of pad and raft foundation has been necessitated by the sub-soil stratigraphy at a site which generally consists of soft silty clay and firm clay.

The proposed formula by Terzaghi (1943) for net ultimate bearing capacity Qu, for shallow square foundations of the firm sandy clay, modified by Meyerhof for Square shape of footing is given below as:

$Q_u = 0.867cNc + \gamma.D_f.Nq + 0.4\,\gamma.B.N_y$ or (Equ 2.1)

$Q_u = cNc(1+0.3*B/L)+\gamma.D_f.Nq+0.5\gamma.B.N_y(1-0.2B/L)$ raft rectangular foundation (Equ 2.2)

Equation (2) is for raft or rectangular foundation.

Where: Q_u = Ultimate bearing capacity , C = soil cohesion at the studied depth, D_f = depth of foundation, B = Foundation width or diameter, L = length of foundation footing, γ = unit weight of soil at the depth, NC,Nγ, Nq = Bearing Capacity factors Bearing capacity analysis of shallow foundations for layered soils (dense sand over soft clay) by Meyerhof and Hanna's (1978) are as follows:

q_u □ 5.14C_2□□□1□ 0.2□□□BL□□□□□□□□□□□□1□ BL□□□□$_1H^2$□□□□1□ 2HD_f□□□□K_s tanB □1□s □□$_1D_f$□q_t (Equ2.3)

q_t = □$_1D_f N_q$□1□□1□ 0.1□□B□□tan2□□45□□1□□□□□ 12□$_1BN$□□1□□□□1□ 0. 1□□□BL□□□tan2□□□45□□21□□□□□□ (Equ2.4)
□ L□ □ 2 □□□□

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

Ultimate Bearing Capacity- Deep foundation (Pile)

Analysis of pile foundation for axial loads was performed for the different sites. The analysis was based on design criteria and specifications recommended by American Petroleum Institute API (1998). The ultimate static axial pile capacity is a combination of skin friction and end bearing. For determination of required allowable axial pile capacities, conservative factor of safety (FS) of 2.5 was applied to the ultimate axial pile capacity. The equation for the ultimate static axial capacity of the pile design used is expressed below:

$Q_u = Q_s + Q_b$ (Equ2.5)

$\mathbf{Q_u}$ = fs.As. + f_b.Ab (Equ2.6)

$\mathbf{Q_u}$ = δ_v'.K_s.tan ⌐ l.A $_s$ + δ_{vb}'N_q.A_b (For sand layers) (Equ2.7)

$\mathbf{Q_u}$ ⌐ ⌐ .ć $_u$.A_s + C_u.N_c.A_b (For clay layer) (Equ2.8)

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

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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

Table 2.1 API Design Parameter for Cohesionless soils

Soil Type	δ	Skin friction (Kpa)	N_q	Unit End Bearing q (Kpa)
Very loose sand	10	48	8	1900
Loose sand	15	67	12	2900
Medium dense sand	20	81	20	4800
Dense sand	25	96	40	9600
Very dense sand	30	116	50	12000

(Sources: American Petroleum Institute 1998)

RESULTS AND DISCUSSION

Results of the field and laboratory tests are presented and discussed in this chapter according to the subsoil type and distribution, geotechnical properties of the underlying subsoil, soils delineated horizons, vertical and horizontal distribution of the various subsoil, comparison of subsoils in parts of Yenegoa and its environs. The suitability of these subsoils both as foundation and construction materials are discussed. The work also recommends the most appropriate types of foundation for the various subsoils in the study areas.

Subsoil Types and Distribution in Yenagoa and Environs,

BH7: Yenegwe town, Yenagoa

The study location shows a three layer sub-soil types of light brown silty clay (of about 2.25m thick),as upper layer, overlying light brown clayey sandy (of 0.75m thick) and lower the clayey sandy layer of loose to medium-dense silty, fine to medium grained sand which is in colour and light grey (about 17.25m thick),

BH8: Opolo Epie town, Yenagoa

The study location revealed three sub-soil types with upper layer as a dark brown, very soft silty clay of about 2.25m thick overlying a thin layer of light brown clayey silty sandy of about 0.75m thick on top of a loose to medium-dense silty, fine to medium grained sand which is light grey and about 17.25m thick.

BH9: Etegwe town, Yenagoa

The study location revealed three sub-soil types with upper layer consisting it a light brown soft silty clay of 0.75m thick overlying light brown loose fine grained sand of a 3.0m thick. This layer also overlies silty sand dark silty clay of 1.5m thick underlying a thin layer of sandy clay of 0.75m thick overlying a light grey medium-dense fine to medium grained sand of 14.25m thick.

BH10: Akenfa-Agudama by living faith church town, Yenagoa

The study location revealed two sub-soil types light brown firm clay and sand intercalation of a thickness 2.0m overlying light grey loose to medium-dense, fine to medium grained sand of 18.25m thick.

BH11: Igbogene Town by military command, Yenagoa

The study location revealed four sub-soil type of upper layer of dark grey firm silty clay of 3.0m thick beneath this layer is thin dark grey soft peaty clay of 1.0m thick overlying a third layer of light grey firm sandy clay of 1.25m thick, beneath silty clay is a thin layer of sandy clay underlie this layer is a light grey sand, medium dense, fine to medium, light grey of 14.25m thick.

BH12: Ovom –Yenegue town by NNPC filling station, Yenagoa

The study location revealed three sub-soil types of upper layer soil of light brown soft silty clay of 5.25m thick overlying a second layer of light grey clayey sand of 1.5m thick. The third layer is a light grey medium-dense to dense silty, fine to medium grained sand of 14.25m thick.

Upper Layer – Yenegwe and Opolo-Epie

The layer consists of light brown to dark brown, soft to firm silty clay, with thickness of 3.0m it occurs as upper layer in (BH7) Yenegwe and (BH8) Opolo-Epie.

Sand Horizons

A light grey and light brown, silty to fine medium grained sand with thickness of 17.25m and 18.0m respectively are encountered in the two boreholes. The correlation between (BH9) Etegwe and BH 11 Igbogene with 5 layers horizons are as presented in fig. 1.3.

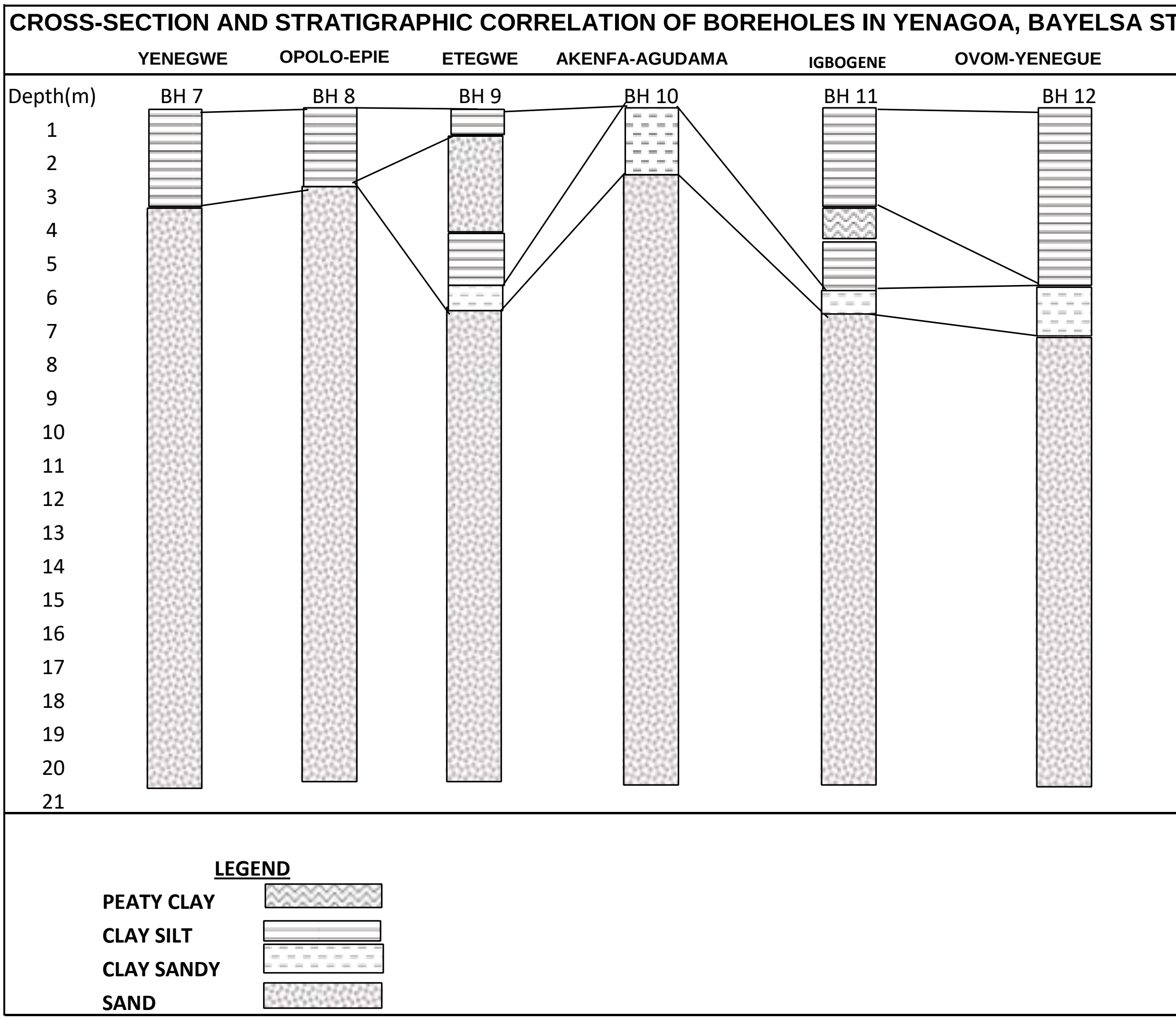

Fig 1.3: Cross-section Correlation of Six Boreholes Study area in Yenagoa

Upper Layer – Yenegwe and Opolo-Epie

The layer consists of light brown to dark brown, soft to firm silty clay, with thickness of 3.0m it occurs as upper layer in (BH7) Yenegwe and (BH8) Opolo-Epie.

Sand Horizons

A light grey and light brown, silty to fine medium grained sand with thickness of 17.25m and 18.0m respectively are encountered in the two boreholes. The correlation between (BH9) Etegwe and BH 11 Igbogene with 5 layers horizons are as presented in fig. 1.3

Upper Clay

This layer consists of light brown to dark grey, soft to firm silty clay, with thickness of 0.75m and 3.0m respectively. It occurs in the two boreholes BH9 and BH11.

Lower Layer
In this layer the various borehole profile differs from one another, in BH9 have a light brown fine grained sand of average thickness of 3.0m, while BH 11 have a thin layer of dark grey peaty clay of about 1.0m thickness.

Third Layer
In this layer, they both have dark grey soft to firm silty clay, with thickness of 1.5m and 1.25m respectively.

Fourth Layer
In this layer, they both have light grey soft sandy clay, with average thickness of 0.75m.

Bottom Layer
In this layer, they both have light grey silty to fine medium sand with average thickness of 14.25m.

The correlation of (BH10) Igbogene.
Akenfa have two-layer soil profile, upper layer with brownish grey firm silty clay intercalation with sand with average thickness of 2.0m overlaying silty to fine medium sand of average thickness of 18.25m.

The correlation of (BH12) Ovom
In this borehole, it has three-layer profile. Upper layer of light brown silty clay of average thickness of 5.25m overlaying lower layer of light grey soft sandy clay and beneath the sandy clay lies light grey silty to fine medium sand of average 13.5m.

Geotechnical Index Properties of Soils in the Study Area.
The Geotechnical index properties of the clay soils in Yenagoa are shown in Table 3.1 and 3.2.

Table 3.1: Geotechnical Index Properties of Silty clay in Yenagoa, Bayelsa State

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	66.6	65.3
LL %	65	65	65	71	71	71	54	54	54	51	51	51	52	52	52	60	60	60
PL %	37	37	37	36	36	36	33	33	33	33	33	33	32	32	32	32	32	32
PI %	28	28	28	35	35	35	21	21	21	18	18	20	20	20	20	28	28	28
Cu (KN/m^2)	42	42	42	28	28	28	17	17	17	47	47	47	41	53	47	35	35	35
Ø (º)	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

BH7- Yenegwe, Yenagoa, BH8-Opolo Epie, BH9- Etegwe, BH10- Akenfa-Agudama, BH11- Igbogene, BH12 – Ovom
Wn- Natural moisture content, LL – Liquid limit, PL – Plastic limit, PI – Plastic index. Cu – Cohesion
Ø (º) – Frictional angle, Cv – coefficient of consolidation (m^2/yr), Mv – coefficient of volume compressibility

Table 3.2: Range of variations of Geological Index Properties of Sandy soil 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
$C_c = \frac{d_{30}}{d_{10} d_{60}}$	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 (º)	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

BH7- Yenegwe, Yenagoa, BH8-Opolo Epie, BH9- Etegwe, BH10- Akenfa-Agudama, BH11- Igbogene, BH12 – Ovom
Effective Particle Size d_{10} (mm) , Mean Particle Size d_{30} (mm), Particle Size d_{60} (mm)
Coefficient of Uniformity = Cu, Coefficient of Curvature = Cc
Natural moisture content = MC, Frictional angle = Ø (º), SPT end value SPT end value (blow/0.30m) = N value

CONCLUSIONS AND RECOMMENDATIONS

The major goal of this research is to determine the stratigraphy and geotechnical properties of the soils underlying the study area to a depth of 20m, and use the result to recommend appropriate shallow and pie foundation designs for various structures. The main result obtained can be summarized as follows:

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.

Yenagoa sub-soil show silt of intermediate to high plasticity (MI-MH) according to unified soil classification system, Yenagoa ranges from soft to firm silty clay in strength consistency also varies from one location to another. Yenagoa are mostly of silty sand.

Yenagoa top silty clay are low to medium bearing strength and it varies from one location to another. Yenagoa are more of raft foundation, because of the sub-soil nature.

In the entire study area in Yenagoa, only Igbogene has peaty clay at middle of the layer In view of the significant variations in the stratification and engineering geological properties of the soil in the six towns in Yenagoa local government area of Bayelsa state be supported by means of raft beam foundation within upper clay and sand layer.

The consolidation characteristic of the clay horizons are typical of overconsoldated clays.
Axial load carrying capacity for 305, 306mm, 356, 360mm, 406mm, 600 and 610 mm diameter for bore pile and tubular driven steel cased piles respectively were calculated for all the studies area.

Recommendation

Considering all the geological engineering parameter data and other datas already highlighted, the following recommendation are suggested.

1. Further investigation is necessary to examine more borehole data at Yenagoa, Bayelsa state due to the different layer soil overlaying the study area in other to ascertain an accuracy and consistency of the parameter of the locations.
2. To avoid collapse and failures of a building structure, proper design and implantation of structural element must be achieved. These include specification of materials (i.e. reinforcement steel, concrete aggregate, cement etc.) and adequate site supervision.
3. Adequate quality control should be carried out on the construction materials to avoid the usage of inferior materials.
4. The pile foundation design should be validated with a pile load test to provide qualitative confirmation of the design load adopted and pile settlement.
5. The design and construction of the foundation of a superstructure should be carried out in accordance with good engineering practice embodied in recognized codes of practice such as British standard institution: BS 8004:1986 code of practice for foundation.

6. Proper soil test and study of weather patterns in an area the building is to be situated need to be carried out and independently verified before permits are issued.
7. Geotechnical investigation should be supervised by competent personnel.
8. Government should set up a readily accessible data bank for soils in the Niger Delta where all subsurface soil investigation results must be deposited to enhance Regional, national planning and management, including academic studies.

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