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Geotechnical Properties of Foundation Subsoils in Parts of Port Harcourt City, Obio/Akpor and Ikwerre Local Government Area, Rivers State, Nigeria

[1]Udom, G.J, [2]John, P.N
Department of Geology, University of Port Harcourt, Nigeria

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ABSTRACT: *The study was carried out with the objectives of determining the stratification, geotechnical index properties of the soils in part of Port Harcourt city and Obio/Akpor local Government Area, Rivers state. Field Exploration 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. Results reveal an overlying light brown sandy clay, soft to firm consistency, clay thickness vary from 9.0 to 13.5m. Beneath this overburden lie yellowish brown to light grey fine to medium to coarse grained sand, loose to medium dense to dense consistency and poorly graded sand, thickness vary from 6.75 to 11.25m. The clays show low to intermediate clay plasticity (CL-CI). The shear strength parameters of these c- soil gave values range of 40-60KN/m^2 . Allowable bearing capacities for the shallow foundation and bored pile foundation analysis was also carried out for the soil profiles with diameter 306, 406, 460 and 600mm for the deep foundation for various study areas were calculated.*

KEY WORD: geotechnical index properties, stratification, allowable bearing capacities, pile foundation, Port Harcourt city, Obio/Akpor and Ikwerre Local Government Area

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.

The reason for most collapse building is ascribed to poor quality building material, while thus may be true, less attention is paid on the sub-surface soil condition that bears the foundation (Youdeowei etal., 2019). 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 (Nwankwoale etal., 2009).

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It is on this basis that this study was undertaken to ascertain the engineering characteristic of the sub-soil.

DESCRIPTION OF STUDY AREA/ GEOLOGY

The study area (Fig 1) are located within Port Harcourt city, Obio/Akpor and Ikwerre local Government area of Rivers state, Nigeria.

It lies within a sub-horizontal geomorphologic train with a measure of undulations among from uneven surface area erosion. Ground elevation range between 5 to 15 meters above mean sea level. The geology of the Niger delta is obtained from the works of several writers, including among other, those of (Rey merit, 1965, Short and Stauble (1967), Murat, (1970), Merki, (1970) Ekweozor and Dakoru, (1994).

There are drainage problems with seasonal and temporary flooding due to heavy rainfall and rise in ground water table at okilton drive NTA /Mgbuoba road, Obio/Akpor local government area.

Study Location Coordinate

The study locations coordinate for the various boring as shown in Table 1.1

Table 1.1: Showing the Coordinates of the studied locations in Rivers state.

Location	Northing	Easting
BH1	04º81’48.43”	006º98’43.536”
BH2	04º84’39.718”	006º98’26.0118”
BH3	04º46’63.4”	006º58’49.451”
BH4	04º57’53.4”	006º58’10.0”
BH5	04º57’43.1”	006º58’14.2”
BH6	04º57’49.9”	006º58’14.2”

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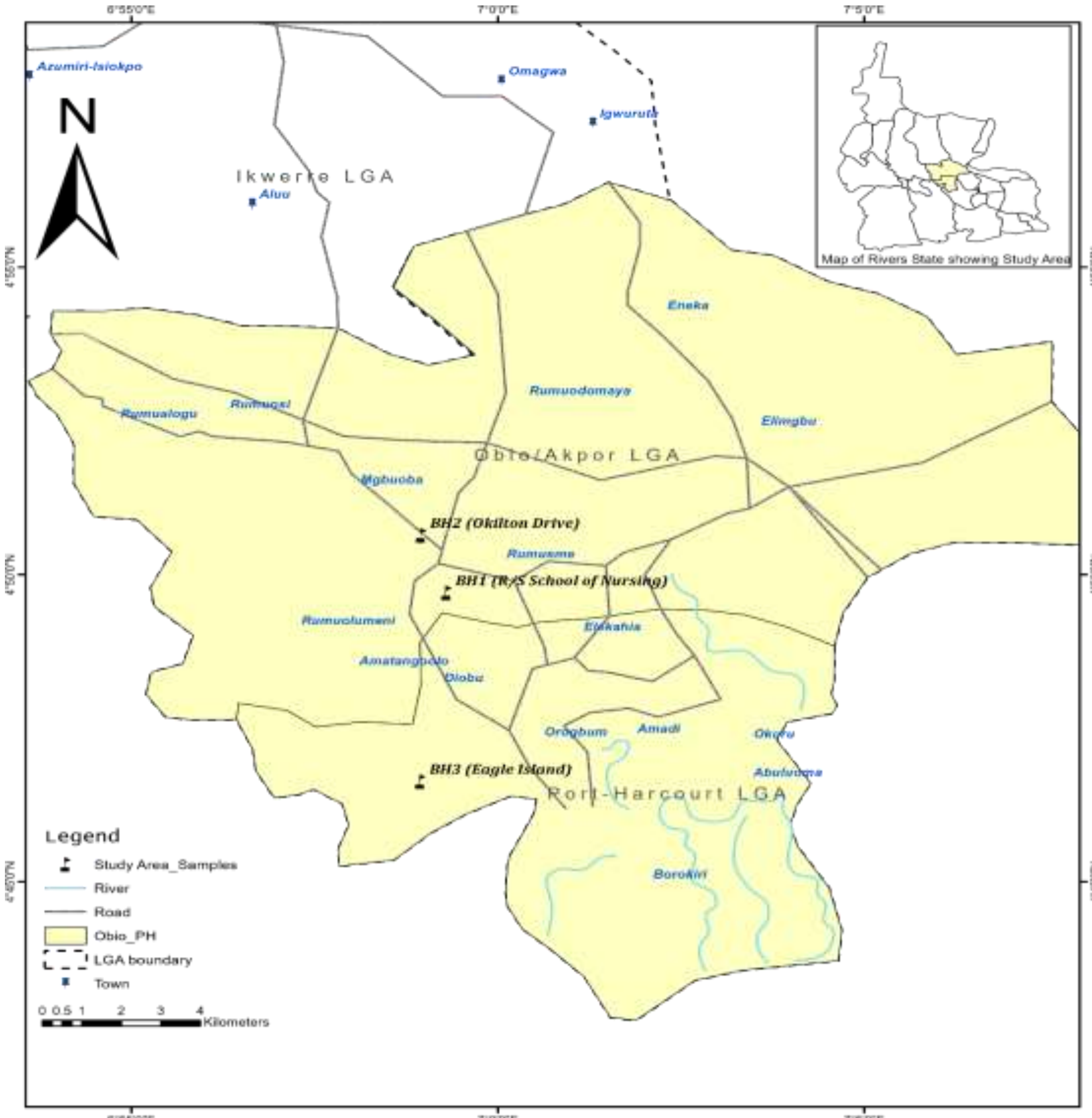

Figure 1.1 Map of the study area in Rivers state

METHODOLOGY

Field Exploration / Laboratory analysis

Subsurface data from three (6) locations: comprising of one from Andoni junction, Port Harcourt city and one (1) each from Okilton drive NTA/Mgbuoba road and formal school of nursing all within Obio/Akpor and (3) from Ikwerre local government area, Rivers state. The study area were studied through ground borings to depths of 20.25m each using a light cable percussion boring rig. Both disturbed and undisturbed soil samples were collected for visual examination, laboratory testing and classification. Also, standard penetration tests (SPT) was carried out to determine the penetration resistance of cohesionless strata at specific depths within the boreholes as the boring progresses. 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 the tests followed standard procedures of testing soils for civil engineering purpose.

BEARING CAPACITY ANALYSIS FOR SHALLOW FOUNDATION

The ultimate bearing capacity, Qu, for shallow square footing on cohesive soils encountered at the study area using Terzaghi's equation (1954) as modified for shape factor is given below as:

$$Q_u = 0.867cNc + \gamma.D_f.Nq + 0.4\,\gamma.B.N_y \qquad (1)$$

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,Nγ, Nq = Bearing Capacity factors

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 (1998).

$$Q_u = Q_s + Q_b \qquad (2)$$

$$\mathbf{Q_u} = fs.As. + f_b.Ab \qquad (3)$$

$$\mathbf{Q_u} = \delta_v'.K_s.\tan\varnothing.A_s + \delta_{vb}'N_q.A_b \text{ (For sand layers)} \qquad (4)$$

$$\mathbf{Q_u} = \alpha.\acute{c}_u.A_s + C_u.N_c.A_b \text{ (For clay layer)} \qquad (5)$$

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

$\acute{c}_u$ = 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*75)

SETTLEMENT OF THE UPPER CLAY LAYER

Immediate settlement

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

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$$S_i = \frac{Bq_n}{E}(1-\mu_s^2)\, I_p \qquad (6)$$

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 proposed by Bowles (1988).

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 centre of the consolidating was used in computing ρc. The settlement value was computed from the expression given by Skempton and Bjerrum (1957) as follows:

$$\rho c = \mu_g \rho_{oed} \qquad (7)$$

$$= m_v\, \Delta\sigma_z H \qquad (8)$$

$$= m_v\, 0.55 q_n H$$

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

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H = thickness of the considering layer (1.5B)

B = Breadth of foundation.

RESULTS AND DISCUSSION

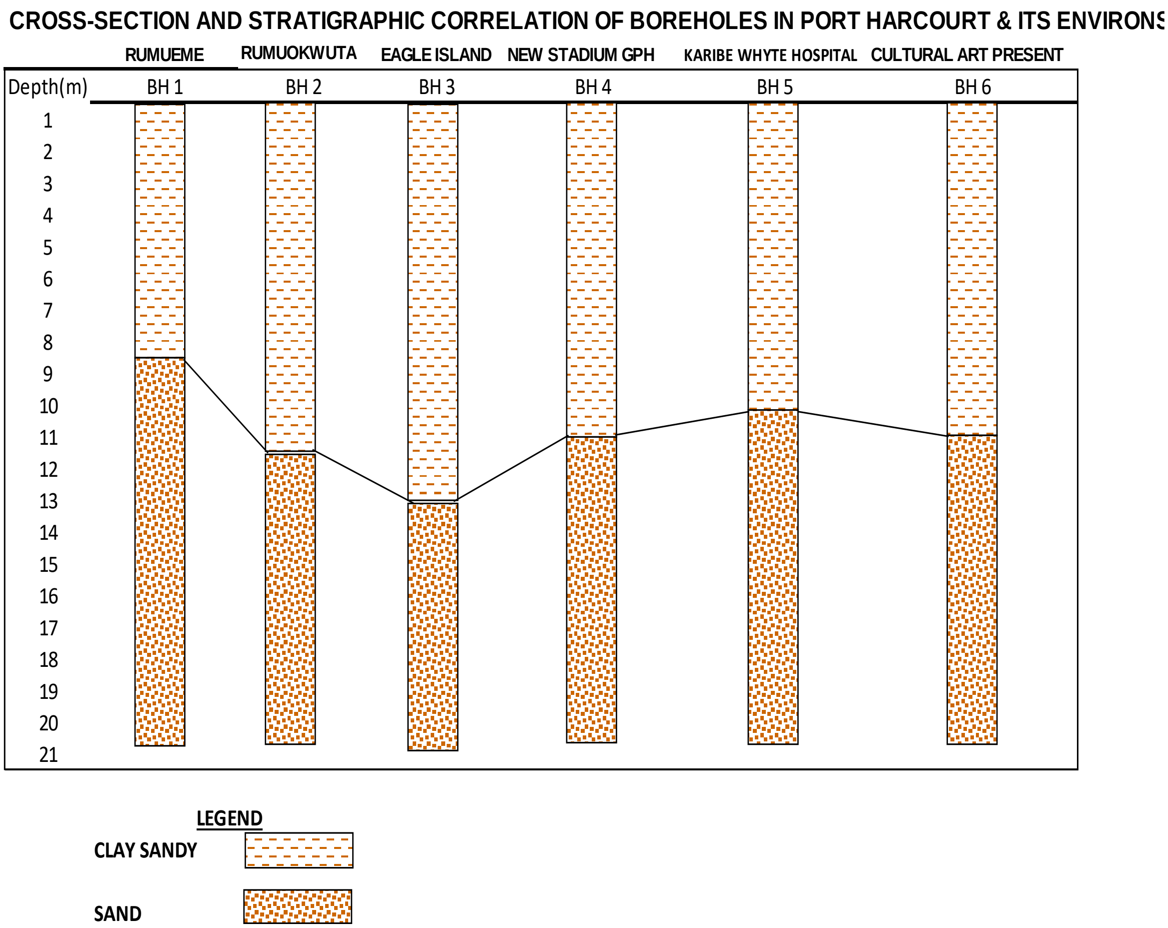

Fig 1.2: Cross section and Stratigraphic of the study Areas.

Engineering Properties of the Soil

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 summarized below in Table 2.0.

Table 1.2: Geotechnical Index Properties of Sandy clay in Port Harcourt city and Obio/Akpor

LOCATIONS	**BH1**			**BH2**			**BH3**			**BH4**			**BH5**			**BH6**		
Parameter	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**
Wn %	19.6	25.0	22	22.8	25.4	24.0	20.7	22.8	21.8	18.4	23.6	21	17.5	20.3	19.0	14.2	23.1	16.4
LL %	32.0	37.0	34	47	50	49	38	41	40	45	48	47	49	52	51	45	47	46
PL %	19.0	23.0	21	26	29	28	23	23	23	23	25	24	27	28	28	24	24	24
PI %	14.0	15.0	15	21	22	22	15	18	17	22	23	23	22	24	23	21	23	22
Cu (KN/m^2)	40	60	50	40	50	45	40	47	44	44	75	60	45	85	65	35	79	57
Ø (º)	4	7	6	3	4	4	3	5	4	5	10	8	4	8	6	3	8	6
Unit Weight (KN/m^3)	20.1	20.5	20.3	18.9	19.8	19.4	20.1	20.6	20.3	19.0	20.5	20	19.4	20.3	19.9	18.6	19.7	19.2
Cv (m^2/yr)	52.35	52.35	52.4	2.4	42.4	42.4	34.7	34.7	34.7	66.5	66.5	66.5	52.6	52.6	52.6	52.8	52.8	52.8
Mv (m^2/MN)	0.21	0.21	0.21	0.23	0.23	0.23	0.20	0.30	0.30	0.20	0.20	0.20	0.20	0.20	0.20	0.19	0.19	0.19

BH1- School of Nursing Rumueme, BH2- NTA-Rumuokwuta, BH3- Eagle Island, BH4- Great Port Harcourt new stadium

BH5 – Justice Adolphus karibe whyte hospital, BH6- Cultural art prescient

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 1.3: Geotechnical Index Properties of Sandy soil in Port Harcourt and Environs

LOCATIONS	BH1			BH2			BH3			BH4			BH5			BH6		
Parameter	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**	**Min**	**Max**	**Avg.**
d_{10} (mm)	0.20	0.23	0.22	0.20	0.23	0.17	0.22	0.32	0.27	0.17	0.22	0.20	0.20	0.32	0.26	0.14	0.21	0.18
d_{30} (mm)	0.26	0.33	0.30	0.27	0.30	0.29	0.31	0.44	0.38	0.25	0.37	0.31	0.30	0.50	0.40	0.23	0.35	0.29
d_{60} (mm)	0.34	0.50	0.42	0.36	0.44	0.40	0.46	0.59	0.53	0.36	0.48	0.42	0.48	0.90	0.69	0.35	0.49	0.42
$C_u = \frac{d_{60}}{d_{10}}$	1.7	2.2	1.95	1.8	1.9	1.9	1.8	2.1	1.95	2.1	2.5	2.3	2.4	2.8	2.6	1.6	3.0	2.3
$C_c = \frac{d_{30}}{d_{10} d_{30}}$	0.9	1.0	0.95	0.9	1.0	0.95	0.9	1.0	0.95	1.0	1.3	1.2	0.9	1.0	0.95	0.9	1.2	1.05
Unit weight KN/m3	19.6	20.2	19.9	18.5	20.8	19.7	20.4	20.9	20.7	19.2	19.5	19.4	19.2	19.9	19.6	18.6	19.4	19.0
Dry Unit weight KN/m^3	16.8	17.5	17.2	16.0	17.5	16.8	17.6	17.8	17.7	16.2	16.5	16.4	16.7	16.9	16.8	16.4	16.7	16.6
MC %	16.6	18.5	17.6	15.2	18.7	17.0	16.3	17.4	16.9	15.2	18.5	16.7	15.1	17.9	16.5	13.6	15.8	14.7
Ø (°)	29	33	31	30	30	30	30	31	31	30	31	31	30	30	30	29	30	30
N value	7	45	26	18	33	26	15	19	17	18	22	20	21	25	23	18	30	24

BH1- School of Nursing Rumueme, BH2-NTA-Rumuokwuta, BH3- Eagle Island, BH4- Great Port Harcourt new stadium

BH5 – Justice Adolphus karibe whyte hospital, BH6- Cultural art prescient,

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 (°), SPT, value (blow/0.30m) = N value

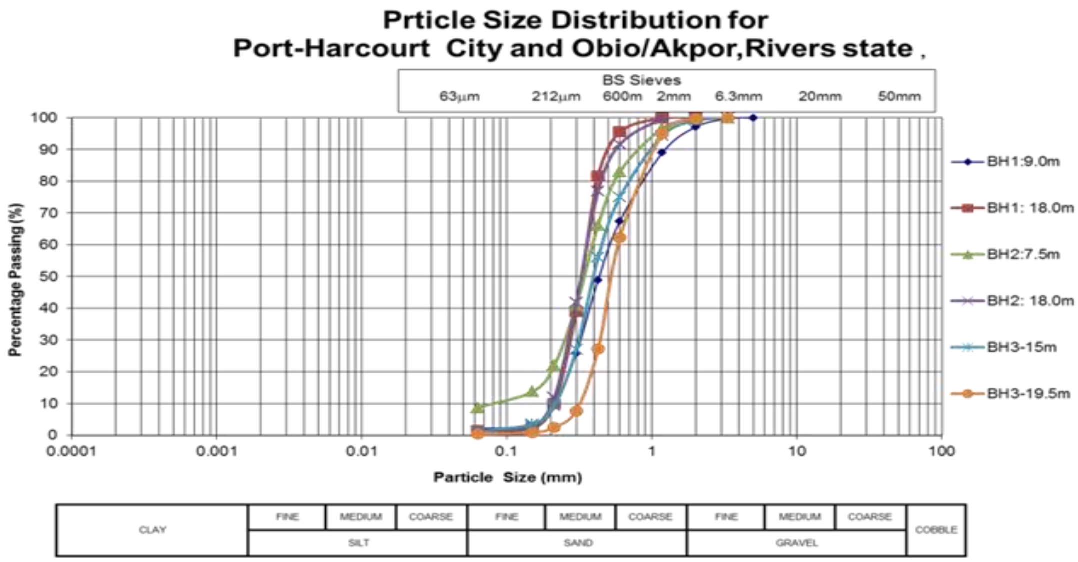

Fig 1.3: Particle Size Distribution of the study Areas.

Table 1.4: Bearing Capacity Values KN/m^2 for Square Foundation for School of Nursing Rumueme

Foundation Depth (m)	Ultimate Bearing Capacity	Allowable Bearing Capacity
1.0	218	73
2.0	218	73
3.0	302	101

Table 1.5: Total Settlement (mm) for Square Foundation : School of Nursing, Rumueme-BH1

Foundation Depth (m)	B= 1.0	B= 2.0	B= 3.0
1.0	16	32	47
2.0	16	32	47
3.0	20	40	59

Table 1.6: Bearing Resistance Values KN/m^2 for Square Foundation : Okilton Drive junction. NTA-Rumuokwuta BH2

Foundation Depth (m)	Ultimate Bearing Capacity	Allowable Bearing Capacity
1.0	207	69
2.0	216	72
3.0	275	92

Table 1.7: Total Settlement (mm) for Square Foundation: Okilton drive junction NTA-Rumuokwuta-BH2

Foundation Depth	B= 1.0	B= 2.0	B= 3.0
1.0	16	32	48
2.0	16	33	49
3.0	20	41	61

Table 1.8: Bearing Capacity Values KN/m^2 for Square Foundation: Adoni Junction, Eagle Island

Foundation Depth	Ultimate Bearing Capacity	Allowable Bearing Capacity
1.0	242	81
2.0	262	87
3.0	263	88

Table 1.9: Total Settlement (mm) for Square Foundation: Andoni Junction, Eagle Island-BH3

Foundation Depth (m)	B= 1.0	B= 2.0	B= 3.0
1.0	18	46	69
2.0	25	49	74
3.0	48	49	74

Table 1.10: Bearing Resistance Values KN/m^2 for Square Foundation: Great Port Harcourt New Stadium

Foundation Depth	Ultimate Bearing Capacity	Allowable Bearing Capacity
1.0	257	86
2.0	277	92
3.0	357	119

Table 1.11: Total Settlement (mm) for Square Foundation Greater Port Harcourt New Stadium BH4

Foundation Depth	B= 1.0	B= 2.0	B= 3.0
1.0	19	35	52
2.0	18	37	55
3.0	32	34	51

Table 1.12: Bearing Resistance Values KN/m^2 for Square Foundation: Adolphus Karibe Speciality Hospital BH5

Foundation Depth	Ultimate Bearing Capacity	Allowable Bearing Capacity
1.0	307	102
2.0	327	109
3.0	480	160

Table 1.13: Total Settlement (mm) for Square Foundation Justice Adolphus Karibe Hospital BH5

Foundation Depth	B= 1.0	B= 2.0	B= 3.0
1.0	22	40	60
2.0	21	42	64
3.0	57	59	89

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Table 1.14: Bearing Resistance Values KN/m^2 for Square Foundation : Cultural Art Precient BH6

Foundation Depth	Ultimate Bearing Capacity	Allowable Bearing Capacity
1.0	266	89
2.0	285	95
3.0	447	149

Table 1.15: Total Settlement (mm) for Square Foundation Cultural Art Prescient BH6

Foundation Depth	B= 1.0	B= 2.0	B= 3.0
1.0	20	34	51
2.0	18	36	54
3.0	51	53	80

Table 1.16: Showing the Ultimate Pile Capacity and Pile Safe Working Load and Depth for School of Nursing, Rumueme BH 1

	Diameter (m)							
Pile Foundation	Pile Compressive Resistance (KN)							
Depth (mm)	306	306	360	360	406	406	600	600
10	428	171	534	214	631	253	1116	446
15	475	190	587	235	688	275	1183	473
20	966	386	1236	494	1490	596	2797	1119

Table 1.17: Showing the various Ultimate Pile capacity and Pile Safe Working Load and Depth for Okilton Drive junction. NTA-Rumuokwuta BH 2

	Diameter (m)							
Pile Foundation	Pile Compressive Resistance (KN)							
Depth (mm)	306	306	360	360	406	406	600	600
10	302	121	416	166	473	189	723	290
15	557	223	689	276	809	323	1394	557
20	913	365	1162	465	1397	559	2598	1039

Table 1.18: Showing the various Ultimate Pile bearing capacities and Pile safe Working Load and Depth for Andoni Junction, Eagle Island BH 3

	Diameter (m)							
Pile Foundation	Pile Compressive Resistance (KN)							
Depth (mm)	306	306	360	360	406	406	600	600
10	245	98	292	117	334	133	518	207
15	645	258	804	321	950	380	1796	718
20	927	371	1159	464	1372	549	2580	1032

Table 1.19: Showing the various Ultimate Pile Capacity and Pile safe Working Load and Depth for Greater Port Harcourt New stadium Precient BH 4

	Diameter (m)							
Pile Foundation	Pile Compressive Resistance (KN)							
Depth (mm)	306	306	360	360	406	406	600	600
10	396	158	472	189	538	215	831	333
15	1054	336	1054	422	1250	500	2435	974
20	1172	469	1460	584	1724	690	3296	1318

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Table 1.20: Showing the various Ultimate Pile Capacity and Pile safe Working Load and Depth for Justice Adolphus Karibe Speciality Hospital BH 5

	Diameter (m)							
Pile Foundation	Pile Compressive Resistance (KN)							
Depth (mm)	306	306	360	360	406	406	600	600
10	572	228	602	241	822	329	1483	593
15	834	334	859	344	1202	481	2158	863
20	1155	462	1175	470	1653	661	2914	1166

Table 1.21: Showing the various Pile safe Working Load and Depth for Cultural Art Precient BH6

	Diameter (m)							
Pile Foundation	Pile Compressive Resistance (KN)							
Depth (mm)	306	306	360	360	406	406	600	600
10	604	242	763	305	912	365	1664	666
15	850	340	1065	426	1264	506	2260	904
20	1232	493	1537	615	1818	727	3212	1285

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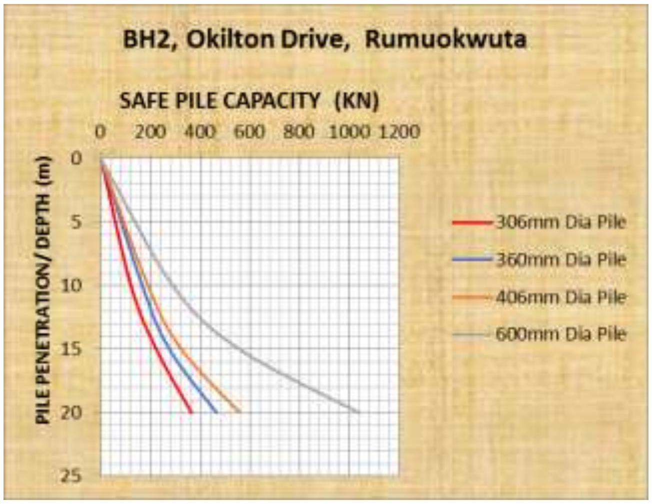

Figure 1.4: Typical Chart for the Safe Load Capacity of Pile for BH2

DISCUSSION

Soil Classification / Stratification

This is obtained from the boring data and laboratory tests. Classification tests revealed the plastic soils as generally consisting of soft to firm to stiff, light brown, sandy CLAY of low to intermediate plasticity, underlain by loose to dense, fine to medium to coarse grained SAND for BH1, soft to firm to firm, light brown, sandy CLAY of intermediate plasticity, underlain by medium dense to dense, fine to medium to coarse grained SAND for BH2 and firm to soft to firm, light brown, sandy CLAY of intermediate plasticity, underlain by medium dense, fine to medium to coarse grained SAND for BH3 as illustrated in Figure 1.2 above. Underneath the sandy clay is a continuous layer of relatively clean sand which is poorly graded in all the study area as shown on Table 1.3 and figure 1.3.

BH 4 Revealed two layer sub-soil types underlain by a yellowish brown soft to stiff sandy clay (about 10.5m) thick, overlaying medium-dense fine to coarse sand , brownish grey colour of (about 9.75m).

BH5 revealed two layer sub-soil profile types underlain by a yellowish brown firm to stiff, firm, sandy clay of (about 9.75m) thick overlaying loose medium-dense, fine, fine to medium grained sand, of (about 10.5m) as presented in particle size distribution envelope in fig 3.2.

BH6 has a two layer sub-soil types yellowish brown firm to stiff, soft sandy clay (about 9.75m thick) overlying loose to medium-dense, fine to medium grained sand within light grey in colour and about 10.5m thick as presented in particle size distribution envelope in fig 3.2.

Bearing capacity

Both shallow square footing and deep pile foundation analysis for bored pile have been carried out for the study area within Port Harcourt city, Obio/Akpor and Ikwerre Local Government Area.

From the shallow foundation analysis, the allowable bearing capacities of the square footing with width of 1.0 to 3.0m and depth of 1.0 to 3.0m for the various study areas within Port Harcourt city and Obio/Akpor are as follow: for BH1 reveals allowable bearing capacity as shown in (Table 1.4) ranges from 73 to 101KN/m^2 with total settlement range of 16 to 59mm. For BH2 reveals allowable bearing capacity as shown in (Table 1.6) ranges from 69 to 92 KN/m^2 with total settlement values range of 16 to 61mm as shown in (Table1.7) and for BH3 reveals allowable bearing capacity as shown in (Table 1.8) ranges from 81 to 88 KN/m^2 with total settlement of 18 to 74mm as shown in (Table 1.9). while for BH4 allowable bearing capacity are shown in (Table 1.10) ranges from 86-119KN/m^2 with total settlement of 18-55mm. for BH5 reveals allowable bearing capacity as shown in (Table 1.12) ranges from 102-160KN/m^2 with total settlement values ranges from 21-89mm as shown in (Table 1.13) and BH6 reveals allowable bearing capacity as shown in (Table 1.14) ranges from 89-149KN/m^2 with total settle of 18-80mm as shown in (Table 1.15)

where the foundation footings are too close to each other in the various study area , the option of a raft foundation may be considered. The shallow foundation is guided by the allowable maximum settlement suggested by Skempton and Macdonald for isolated foundation 65mm, 65-100mm for raft on clay.

Pile foundation analysis was determined for the soil profile that was encountered on the study areas. Bored piles of diameters of 306,360,406 and 600mm within depth of 10, 15 and 20m were designed. Safe pile load capacity for the various study areas are presented in Table 1.16 to 1.21. The calculated safe load capacity of piles should be used where the bearing capacity is not adequate for the proposed structure or high rise building is to be built.

CONCLUSION

The following conclusion can be drawn from the study areas in Port Harcourt city, Obio/Akpor and Ikwerre Local Government Area.

i. The field investigation revealed that the study area comprise of two distinct soil layers soil types namely sandy CLAY and sand and there thickness vary from one study area to another.
ii. The subsoil in the study areas show low to immediate plasticity (CL-CI)
iii. The shear strength of study areas ranges from firm to soft to firm
iv. Evaluated bearing capacity values for (B) width equal 3.0m for Andoni junction Eagle Island did not satisfy the maximum allowable settlement for pad footing foundation.

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