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Bored Pile Designs Using Geotechnical Data in Parts of Port Harcourt and Environs, Rivers State, Nigeria

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ABSTRACT: *Assessment of ultimate pile carrying capacity (deep foundation) and its settlement in parts of Port Harcourt and environs Rivers State has become imperative due to moderate bearing pressure and poor subsoil nature found in the study area. Bored pile foundation analysis was carried out for the soil profiles with diameter 306, 406, 460 and 600mm for the deep foundation at various study area were calculated. The study shows that the higher the diameter and pile depth of the foundation, the higher the ultimate pile carrying capacity. The settlement of the piles fall within an acceptable criterion of one-tenth. Safe working load of Greater Port Harcourt New Stadium Precient (BH4) was found higher, when compared to other locations in parts of Port Harcourt and environs.*

KEYWORD: Pile, Bored piles. Settlement, safe working load, Port Harcourt, Rivers State.

INTRODUCTION

The reason for most collapse building are 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 et al., 2019). The need for deep foundation has become imperative in part of Port Harcourt and environs, due to moderate or poor bearing capacity which may not be suitable for high rise buildings. These necessitate the construction of high rise buildings using pile foundation. The need of deep foundation for heavy structures in the Niger delta has been recognized by several authors (Teme et al., 2008). Piles are columnar elements in a foundation which have the function of transferring load from the superstructure through weak compressible strata or through water onto stiffer or more compact and less-compressible soils or a stable stratum. The study aims at the design of bored piles within Port Harcourt city and environ.

This involves determining the safe work load for three different sizes of pile diameters and their anticipated settlement characteristic. Geotechnical information underlying the study areas to a depth of 20m was determined to enable appropriate pile foundation design. Pile diameter of 406 mm design by Akpila et al. (2006), observed 1070 kN as the allowable pile working load.

DESCRIPTION OF STUDY AREA / GEOLOGY

The study areas (Fig. 1) are located within Port Harcourt city, Obio/Akpor and Ikwerre local Government areas 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 ranges between 15 to 45 meters above mean sea level. The geology of the Niger delta is obtained from the works of several writers, including Reyment, 1965, Short and Stauble (1967), Murat, (1970), Merki, (1970) Ekweozor and Dakoru, (1994).

Study Location Coordinate

The study location coordinates for the various boring are as shown in Table 1

Table 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	04º46’63.4º	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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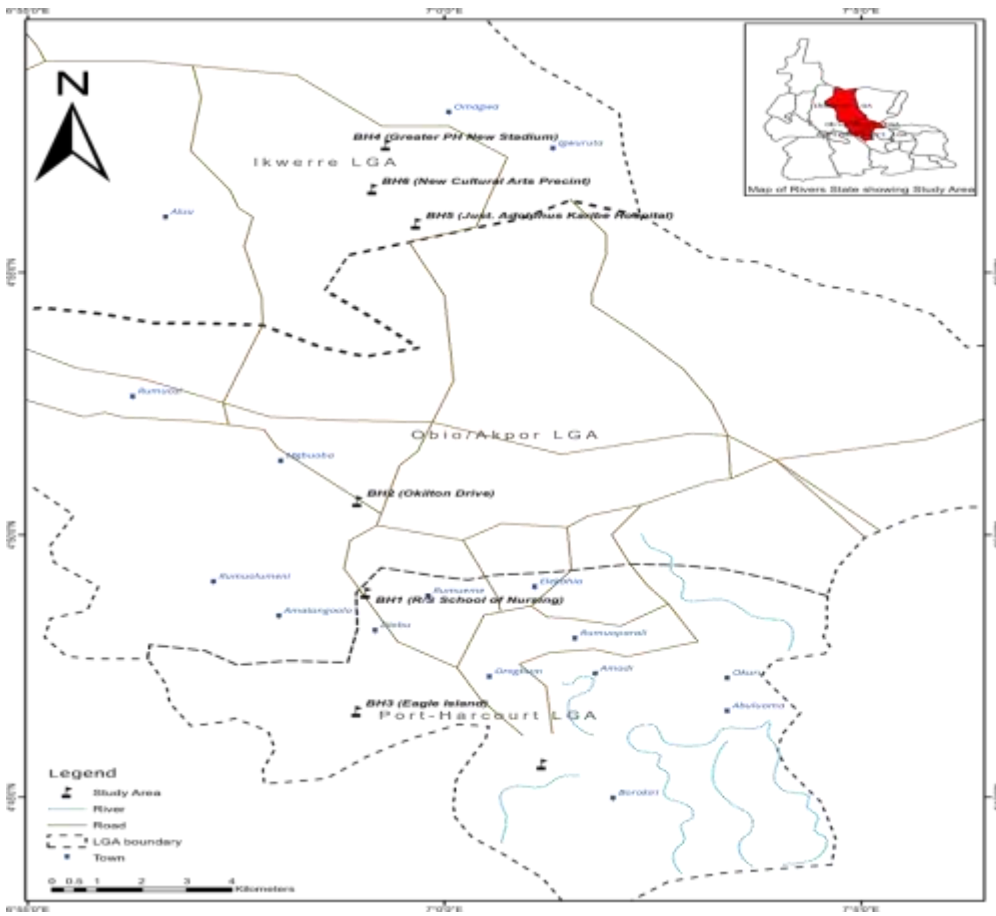

Figure 1.0 Map of the study area in Rivers state

METHODOLOGY

Field Exploration / Laboratory analysis

Subsurface data from six (6) locations: comprising of one (1) from Andoni junction (BH3) in Port Harcourt city local government and one (1) each from Okilton drive NTA/Mgbuoba road (BH2) and formal school of nursing (BH1) all in Obio/Akpor local government area and one (1) each from greater Port Harcourt new stadium prescient (BH4), Justice Adolphus Karibe hospital (BH5) and cultural Arts prescient (BH6) all in Ikwerre local government area of Rivers state. The study area was studied through ground borings to depths of 20.25m each using a light cable percussion boring rig. During the boring operations, disturbed samples were regularly collected at depth of 0.75m intervals and also when change of soil type is noticed. Undisturbed cohesive soil samples were retrieved from the boreholes with conventional open-tube sampler 70mm in diameter and 450mm in length. All collected soil samples were visually examinated, identified and roughly classified in the field. Standard penetration test (SPT) was carried out to determine the penetration

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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. These 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. Natural moisture content test, unit weight test, unconsolidated undrained triaxial test and consolidation test etc.

PILE LOAD CARRYING CAPACITY ANALYSIS FOR DEEP FOUNDATION

Pile load carrying capacity of non-displacement piles within the study area was carried out with the principles of soil mechanics approach. The choice of non- displacement pile is due to the economic consideration and effectiveness of installation within the study area. The carrying capacity in this study is obtained from the addition of the skin friction and Ending bearing. The ultimate bearing capacity is as follows.

$$Q_u = Q_s + Q_b + W_p \qquad (1)$$

Due to the insignificance component of W_p, in relations to Q_p this value is neglected in most scenarios. (Tomlinson, 2001). Work load for pile shaft for sand and clay are stated below.

$$\mathbf{Q_u} = fs.As. + f_b.Ab \qquad (2)$$

$$\mathbf{Q_u} = \delta_v'.K_s.\tan Ø.A_s + \delta_{vb}'N_q.A_b \text{ (For sand layers)} \qquad (3)$$

$$\mathbf{Q_u} = \alpha.ć_u.A_s + C_u.N_c.A_b \text{ (For clay layer)} \qquad (4)$$

Where:
Qu = Ultimate Bearing pile capacity of pile
Wp = weight of the pile
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*75)

Bearing capacity values (Nq) based on the works of Berenzantsev were adopted (Berezantsev, 1961). These values take into account the depth to width ratio and conform to field criteria of most pile failures (Tomlinson, 2001). The ultimate bearing capacity can be described as the load

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resulting in a settlement of one- tenth of the diameter of the pile (Vesic, 1973), though this rule excludes large diameter piles.
An average cu of less than 50kN/m^2 and average adhesion factor of 0.5 was considered in this study. The values corroborate with research values on bored piles by Skempton, 1959 and Nwankwoala et al., 2016.

SETTLEMENT ANALYSIS

The Single pile settlement is given by the sum of the elastic shortening of the shaft and the compression of the soil beneath the base as follows.

$$\rho = \frac{(W_s+2W_b)L}{2A_sE_p} + \frac{\pi.W_b}{4A_b} * \frac{B\,(1-v^2)I_p}{E_b} \qquad (5)$$

Where W_s and W_b are the loads on the pile shaft and base respectively
L = shaft length
A_s and A_b are the cross-sectional area of the shaft and base respectively
E_p is the elastic modulus of the pile material
B is the pile width
V is the poisson's ratio of the soil
I_p is an influence factor related to the ratio of
E_b deformation modulus of the soil beneath the pile bases
With v = 0.25 and L/B>5, I_p is taken as 0.5 A minimum value of 17000000kPa is assumed the elastic Modulus of the concrete material. Derivations of the deformation modulus of the soil beneath pile base were made from Das's assumption (Das, 1994).

RESULTS/ DISCUSSION

Soil Stratigraphy

The data from the field work and laboratory tests were used for stratification of the underlying soil in the various study location. Soil profiles characterizing the study area are described below in Table 3 and figure 2.

Table 2: Soil Stratigraphy

Description	Boreholes/ Thickness					
	(BH1)	BH2	BH3	BH4	BH5	BH6
CLAY, sandy	0.0-9.0	0.0-12.0	0.0-13.5	0.0-10.5	0.0-9.75	0.0-10.5
Sand	9.0-20.25	12.0-20.25	13.5-20.25	10.5-20.25	9.75-20.25	10.5-20.25

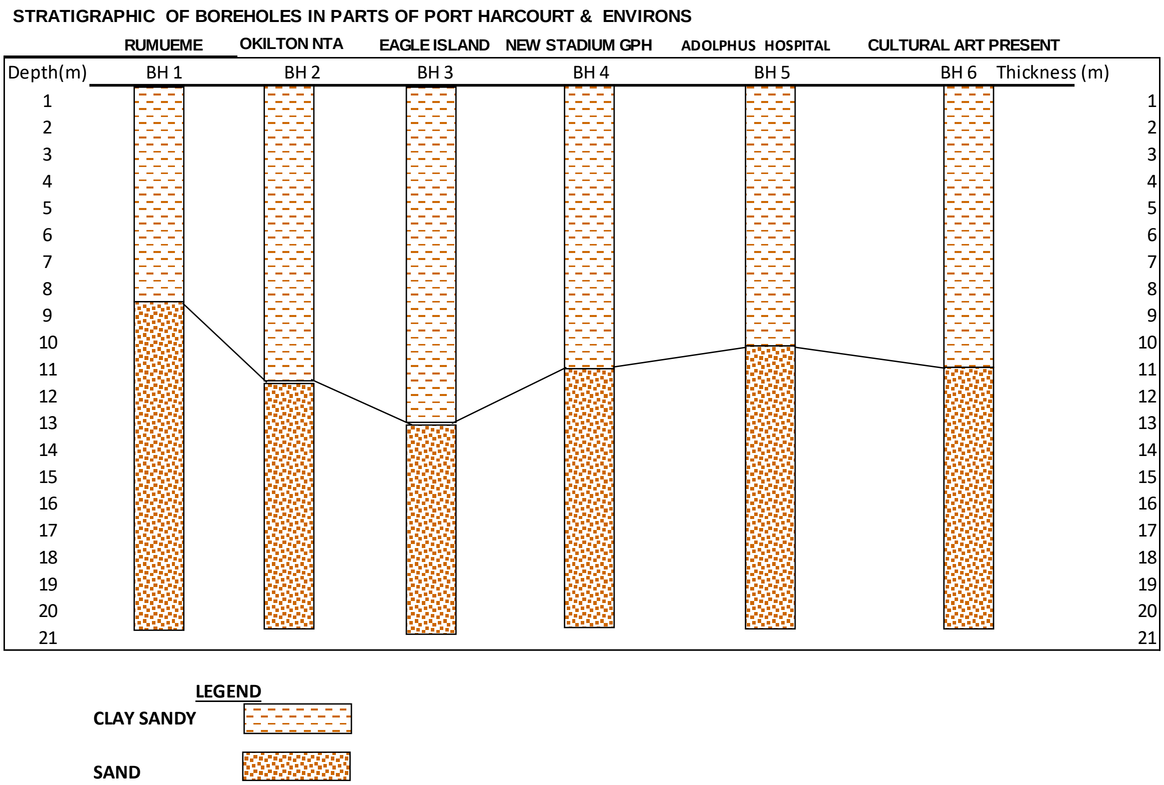

Fig 2: Stratigraphic of the study area.

Engineering Properties of the Soils

The geotechnical investigation revealed that the soil deposits within the depths drilled are characterized by the following;

(BH1) consists of a light brown firm sandy clay overlying loose to medium-dense to dense, yellowish brown fine to medium to coarse grained sand.

(BH2) light brown firm sandy clay overlying medium-dense to dense, light brown fine to medium grained sand.

(BH3) light brown firm sandy clay overlying medium-dense, light grey fine to medium grained sand.

(BH4) light brown firm to stiff sandy clay overlying loose to medium-dense, light brown to grey fine to medium grained sand.

(BH5) yellowish brown firm to stiff sandy clay overlying loose to medium-dense , yellowish brown and light brown fine to medium grained sand

(BH6) yellowish brown firm to stiff sandy clay overlying loose to medium-dense , light brown to light grey fine to medium grained sand

Classification, strength and compressibility characteristics of the soils were determined from the laboratory. The relevant index and engineering parameters of the soils are summarized below.

Firm to Stiff Sandy Clay

Thickness of the deposit varies from 9m to 13.5m as presented on table 2. The sandy clay is mainly moderate compressibility. The ranges of variation in the relevant index and Engineering parameters of the sandy clay are summarized below.

Table 3: Geotechnical Index Properties of Sandy clay 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.**
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
USCS			CL			CI			CI			CI			CI			CI
Cu (KN/m^2)	40	60	50	40	50	45	40	47	44	44	75	60	45	85	65	35	79	57
Ø (°)	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	42.4	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 (°) – Frictional angle, Cv – coefficient of consolidation (m^2/yr), Mv – coefficient of volume compressibility

Loose to Medium Dense Sand layer

Beneath the clayey layer is a layer of predominantly poorly graded sand. Thickness ranges for variations in the relevant engineering parameter of the sand are given below.

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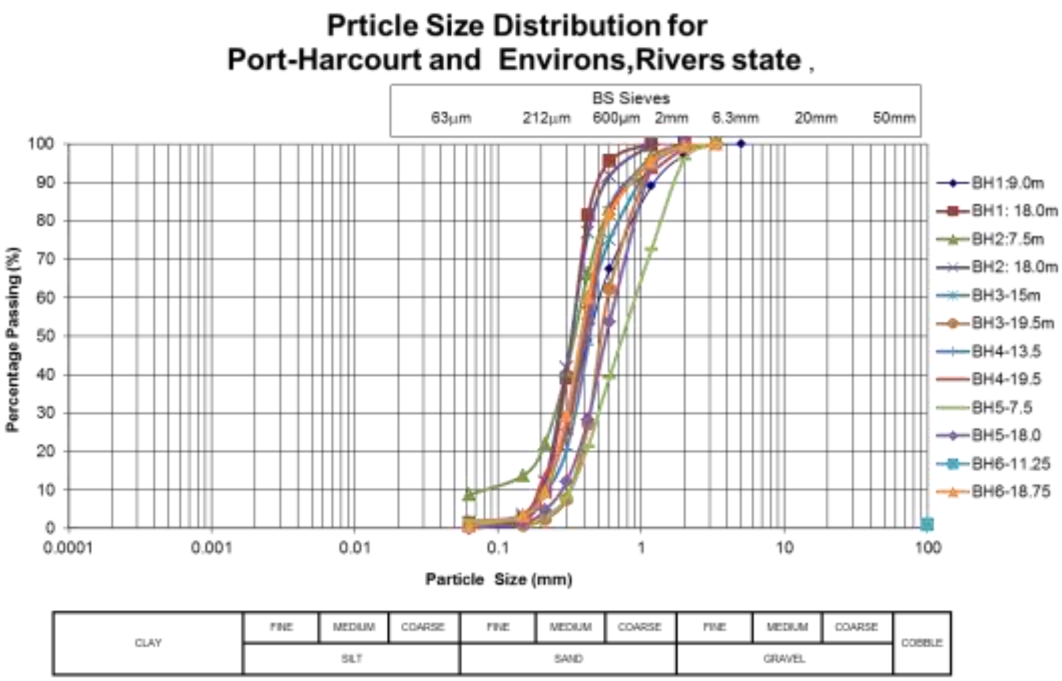

Fig 3.0: Particle Size Distribution of the study Areas.

Table 4: Geological Index Properties of Sand Layer 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
$C_c = \frac{d_{30}}{d_{10} x d_{30}}$	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 (º)	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

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PILE WORK LOAD

The pile work load was calculated using relevant equations stated above and the results are presented below.

Table 5 Ultimate Pile Capacity and Pile Safe Work Load and Depth for School of Nursing, Rumueme BH 1

Pile Foundation	Pile Compressive Resistance (KN) Diameter (m)							
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 6 Ultimate Pile capacity and Pile safe Working Load and Depth for Okilton Drive junction. NTA-Rumuokwuta BH 2

Pile Foundation	Pile Compressive Resistance (KN) Diameter (m)							
Depth (mm)	306	306	360	360	406	406	600	600
10	302	121	416	166	473	189	723	289
15	557	223	689	276	809	323	1394	558
20	913	365	1162	465	1397	559	2598	1039

Table 7 Ultimate Pile bearing capacities and Pile safe Working Load and Depth for Andoni Junction, Eagle Island BH 3

Pile Foundation	Pile Compressive Resistance (KN) Diameter (m)							
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

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Table 8 Ultimate Pile Capacity and Pile safe Working Load and Depth for Greater Port Harcourt New stadium Precient BH 4

Pile Foundation	Diameter (m) 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

Table 9 Ultimate Pile Capacity and Pile safe Working Load and Depth for Justice Adolphus Karibe Speciality Hospital BH 5

Pile Foundation	Diameter (m) Pile Compressive Resistance (KN)							
Depth (mm)	306	306	360	360	406	406	600	600
10	572	228	691	276	822	329	1483	593
15	834	334	1012	405	1202	481	2158	863
20	1155	462	1398	560	1653	661	2914	1166

Table 10: Ultimate Pile Capacity and Pile Safe Working Load and Depth for Cultural Art Precient BH 6

Pile Foundation	Diameter (m) 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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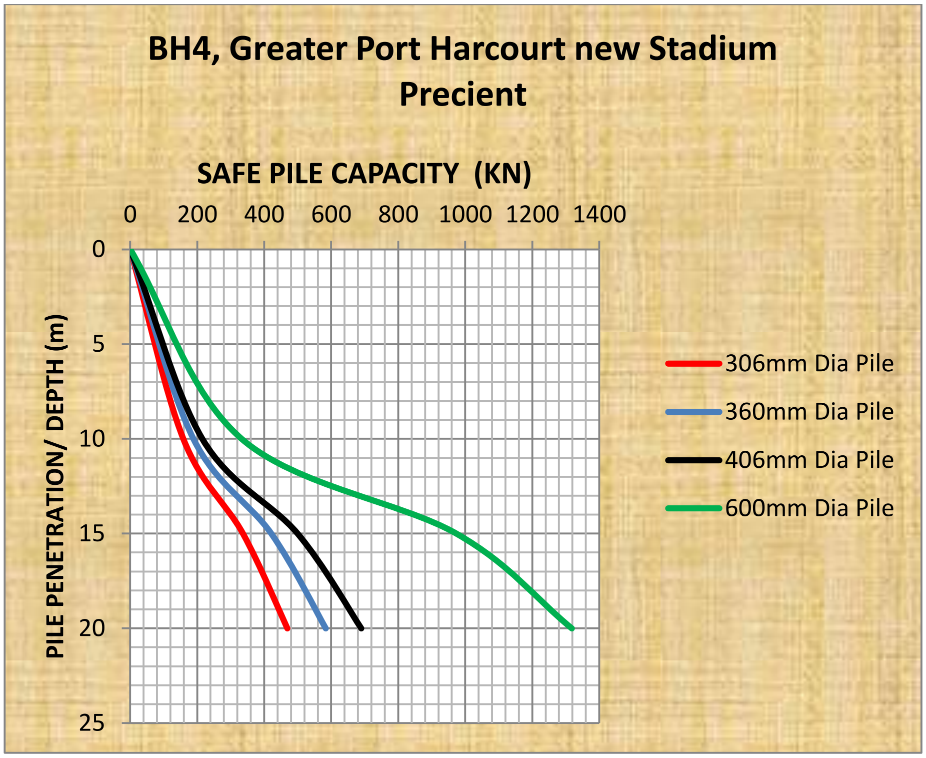

Figure 4.0: Typical Chart for the Safe Load Capacity of Pile for BH4

Table 11 Summary of Pile Characteristics

BH	Pile Depth (m)	Pile Diameter (m)	Ultimate Pile Capacity KN	Allowable Pile capacity KN	Expected Settlement mm	Allowable Settlement mm
1	15	0.306	475	190	3.50	30.6
1	15	0.360	587	235	4.11	30.6
1	15	0.406	688	275	4.64	40.6
1	15	0.600	1183	473	6.86	60
1	20	0.306	966	386	11.41	30.6
1	20	0.360	1236	494	13.42	36
1	20	0.406	1490	596	15.14	40.6
1	20	0.600	2797	1119	22.44	60
2	15	0.306	302	121	3.81	30.6
2	15	0.360	689	276	4.48	36
2	15	0.406	809	323	5.05	40.6
2	15	0.600	1394	557	7.47	60
2	20	0.306	913	365	10.22	30.6
2	20	0.360	1163	465	12.02	36

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2	20	0.406	1397	559	13.76	40.6
2	20	0.600	2598	1039	19.74	60
3	15	0.306	645	258	7.80	30.6
3	15	0.360	804	321	6.10	36
3	15	0.406	950	380	6.88	40.6
3	15	0.600	1796	718	10.86	60
3	20	0.306	927	371	7.80	30.6
3	20	0.360	1159	464	9.15	36
3	20	0.406	1372	549	10.32	40.6
3	20	0.600	2581	1032	16.03	60
4	15	0.306	841	337	7.33	30.6
4	15	0.360	1054	422	8.64	36
4	15	0.406	1250	500	11.09	40.6
4	15	0.600	2435	974	16.29	60
4	20	0.306	1172	469	9.31	30.6
4	20	0.360	1054	422	10.85	36
4	20	0.406	1725	690	12.48	40.6
4	20	0.600	3296	1318	20.15	60
5	15	0.306	835	334	7.48	30.6
5	15	0.360	1012	405	8.59	36
5	15	0.406	1202	481	9.68	40.6
5	15	0.600	2158	863	14.31	60
5	20	0.306	1156	462	9.20	30.6
5	20	0.360	1399	560	10.62	36
5	20	0.406	1653	661	11.98	40.6
5	20	0.600	2914	1166	17.70	60
6	15	0.306	850	340	7.51	30.6
6	15	0.360	1065	426	8.86	36
6	15	0.406	1264	506	9.96	40.6
6	20	0.306	1232	493	10.07	30.6
6	20	0.360	1537	615	11.84	36
6	20	0.406	1818	727	13.36	40.6
6	20	0.600	3212	1285	19.74	60

CONCLUSION

The objective of the study was to determine the subsoil conditions, ultimate carrying capacity of pile and the pile settlement that are prevalent at the different locations within parts of Port Harcourt and Environs. Information from the field and laboratory test was used in determining the soil stratigraphy and the calculation of the ultimate carrying capacity of the piles.

The following conclusion can be drawn from the study areas in parts of Port Harcourt and Environs

i. The different boreholes drilled have a near consistent uniform soil stratum but vary in clay thickness from 9.0 to 13.5m. the clays shows low to intermediate plasticity, which are underlain by fine to medium grained, loose to medium dense to dense sand
ii. Pile foundation analysis was determined from the soil stratigraphy 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 area are presented in Table 5 to 10.
iii. Settlement analysis of the various piles indicates values less than the acceptable criterion of one-tenth multiply by the diameter of the pile (Table 11).
iv. The pile settlement increases as the safe working load capacity and depth increases (Table 11).
v. Greater Port Harcourt new stadium prescient has the highest safe working load of pile between Port Harcourt and Environs.

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