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Exploring Subsoil Geotechnical Properties for Foundation Design of a Proposed Modern Market in Port Harcourt, Rivers State, Southern Nigeria

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Abstract
A geotechnical soil investigation was performed to determine the subsoil conditions at the proposed site to provide parameters for the design of foundation for a proposed modern market in Port Harcourt. Both field study and laboratory analysis of samples were done. Field works included five (5) number boreholes drilled to 20.3m by the use of Shell and Auger manually operated rig, six (6) number 10Tm CPT tests conducted to refused depth ranging from 12.00 to 21.00m and SPT-N values determinations. Disturbed and undisturbed soil samples were collected for analysis. The disturbed samples were analyzed according to BS standard for index properties such as grain size analysis, Atterberg limits, moisture content, and bulk density, while relatively undisturbed samples were analyzed for strength properties and parameters. From the results, the subsoil in the area consists of a thick layer of lateritic clayey/sandy clay with a plasticity index of 40%, coefficient of volume compressibility (mv) 0.278m^2/KN and cohesion 40KN/m^2 at the top followed by a larger of 9.75m thick medium dense five to coarse sand with frictional angle 28 to 350^0. Safe bearing capacities were computed for pad footings and raft foundation in the range of 122 to 173kPa and 122 to 151kPa respectively at various foundation width and LB rations. Groundwater was encountered between 5.64m and 6.10m below ground level.

Keywords: *Geotechnical soil investigation, Index properties, SPT-N values, CPT, Safe bearing capacities.*

Introduction

One of the greatest causes of structural collapse is foundation failure, and one of the greatest causes of foundation failure is insufficient knowledge of ground conditions (Abam, 2017). It is therefore necessary to have adequate knowledge of subsoil geotechnical conditions for sustainable foundation design and construction. For a sustainable foundation design accurate information about the ground conditions based on adequate soil sampling, correct interpretation and application of test results are paramount. Based on the above observation, a proposed development project in Port Harcourt necessitated the conduct of geotechnical subsoil investigation.

This study is carried out to determine the geotechnical properties of subsurface geomaterials of the study area, evaluatebearing capacity parameters for different foundation types, assess potential settlement characteristics and provide recommendations for foundation design.

A detailed soil investigation was carried outin the study area to determine the subsurface conditions at the proposed site and hence determine engineering parameters to enable foundation designs and recommendations..

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Site Location

The site location is Diobu, Port Harcourt, Nigeria. The area was sparsely vegetated with collapsed structures at the time of investigation. Access to the location is through a major road. A site vicinity map is presented as figure 1.

Geologically, the area is within the Niger Delta sedimentary basin which is believed to have resulted from the rifting during the drifting apart of the African and South African and South American plates in the late Jurassic (Okiwelu & Ude, 2012). The delta was formed by the deposition of terrigenous sediments brought by in-land Rivers, while the sediments within the delta were as a result of alternate transgression and regression. Three formations have been identified as lying unconformably over the basement complex within the Niger Delta: The Akata, Agbada and Benin Formations. The Akata is the oldest and is overlain by the Agbada formation which underlies the Benin formation (Okiwelu & Ude, 2012). The sediments in the Niger Delta are of 10,000km and range in age from late Cretaceous to Quaternary (Allen, 1965). In terms of composition, the Akata formation is composed of silts and sands that are overlain by shales which are extensive at the delta (Lambert & Shaw, 1982). This is the major

Fig. 1: Site Vicinity map

source rock for oil in the delta (Tuttle *et al.,* 1999). The Agba formation has an alternating layer of sands and clays, getting sandier towards the surface. It is the major reservoir rock for crude in the delta. The youngest – Benin formation was deposited during the late Tertiary to earl Quaternary period and it is the main aquifer in the Niger Delta basin (Ehirim & Nwakwo, 2010). It is up to 20,100m thick. In figure 2 is the geological map of Port Harcourt.

Materials and Methods

The investigation was carried out in three parts as follows:

- Field work
- Laboratory work
- Analysis of test results and compilation of geotechnical report.

Equipment and personnel were mobilized to site on the 26th of December, work commenced same day and field work was completed 31st of December.

Field Work

Field work started with the location of test points after mobilization to site. The detailed test points location map is presented in figure 2. Five (5) numbers borehole were drilled to depth of 20.3m by the use of shell and anger manually operated rig while 6nos 10Ton cone penetration test was conducted to refusal depth ranging from 12.00 to 20.00m.

Soil Boring

Drilling and sampling commenced simultaneously. It involved 5No boreholes up to depth 20.0m. The borings were done using a manually operated drilling rig (Shell and Auger technique). Sampling and insitu tests were done progressively for the advancement of the borehole through the cohesionless and cohesive soils encountered. The process was as follows; In cohesive materials, driven U4 (100mm) tube undisturbed samples were extracted at 1.50 intervals. In cohesionless materials Standard Penetration Tests (SPTs) were carried out at 1.50m and disturbed samples were retrieved from the SPT sampling tools. This SPT was conducted by driving a 50mm diameter split spoon

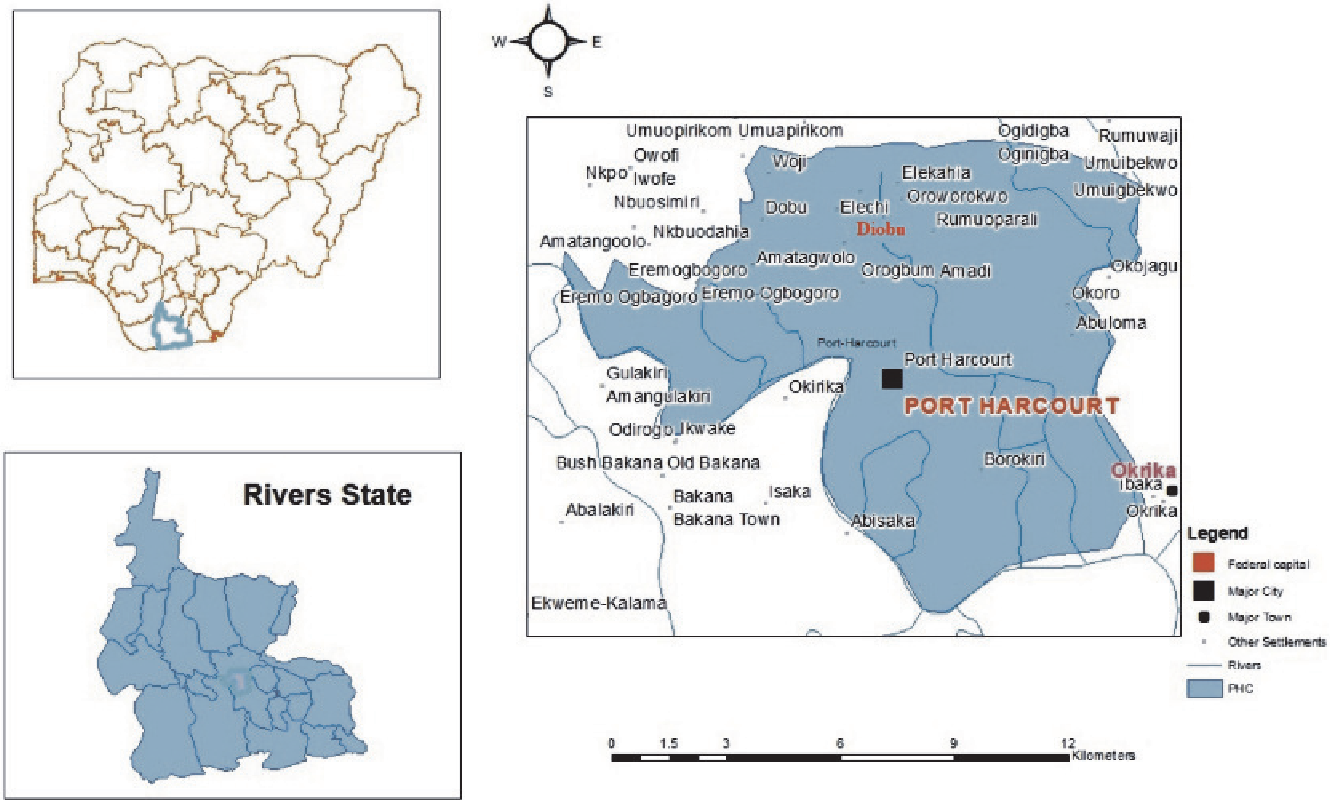


Fig. 2: Map of Port Harcourt

sampler into the soil using a 63.5kg hammer with a 760mm drop: The penetration resistance is expressed as the number of blows (N-value) required to obtain a 300mm penetration below an initial 150mm penetration. Disturbed samples as well as bulk samples were also recovered at depths between successive (U4) tube and SPT samples.

Cone Penetration Test (CPT)

6 Nos CPT tests were carried out using a 10Ton CPT machine to refusal depth ranging between 12.00m and 21.00m. The test was performed using the 10Ton piezocone CPT rig. This measures the tip resistance (qc), sleeve friction (fs) and pore pressure (U_2). The results are presented in Fig. 6.

Laboratory Tests

Laboratory tests were done on selected samples to determine geotechnical parameters relevant to the project. All tests were done in accordance with the BS 1377:1990 "Method of test of soils for Civil Engineering purposes". The three main areas covered by the tests include; soil classification test, shear strength and soil deformation tests.

Under the classification test, particle size distribution and hydrometer analysis, natural moisture content and Atterberg limits test were carried out. Results are presented in various Tables and figures below.

The undrained shear strength of the relatively undisturbed cohesive samples was determined by means of the Unconsolidated Undrained Triaxial Compression Test. Shear strength values of between 31KN/m^2 and 46KN/m^2 were obtained with corresponding angles of friction.

Test were conducted in accordance = BS1377.1990.

The deformation characteristics of some clay samples were determined using Oedometer. The samples were obtained by pushing their walled Shelby tubes horizontally into the wall of the test pits. The Shelby tubes were then extended waxed and stored for the laboratory. The tests were done under pressure range of 50 to 400kPa, each held constant while dial gauge measurement of vertical deformation are taken, and until movement stop after 24hrs.

Results and Discussion

Subsoil Condition

Two main soil layers were encountered; the first layer is a soft to firm yellowish reddish brown to dark grey lateritic clayey sand/sandy clay of low to very high plasticity. This occurs between 0.0m to about 10.50m given an average thickness of 10.50m.

The second layer which directly underlies the first layer is a loose, medium dense to dense yellowish brown to

Table 1: Subsoil Characteristics

S/No	Strata Description	Depth Range (m)	Thickness (m)
1.	Soft to form yellowish brown to dark grey lateritic clayey sand/sandy clay of low to very high plasticity.	0.00 -10.50	10.50
2.	Loose, medium dense to dense brownish to brown fine to coarse sand	(9.75-10.50)	9.75-10.50

Table 2: Engineering Properties of the Soil

Layer	Depth Range (m)	Soil Description	Soil Parameters	Average Value	Remark
1.	0.00 - 10.50	Clay, soft to firm, sandy, latentic	Cu (KN/m^2)	40	
			PI (%)	40	
			Mv (m^2/MN)	0.27	
2.	10.50 – 13.50	Sand, looses fine to coarse	Ø (^{0})	28	Derived from SPT vs Angle of friction chart (Peck *et al.*)
			N	7	
			Y (KN/m^3)	19	
3.	13.10 – 20.0	Sand, medium dense, fine to coarse	Ø (^{0})	35	(Blow/0.3m)
			N	26	
			Y (KN/m^3)	20	

Sand Ø = Angle of shearing resistance
N = SPT penetration resistance
Y = (KN/m3) = unit wt. of soil compressibility

Clay PI (%) Plasticity Index
Cu (KPa) – Undrained cohesion
Mv(m2/MN) co-efficient of vol.

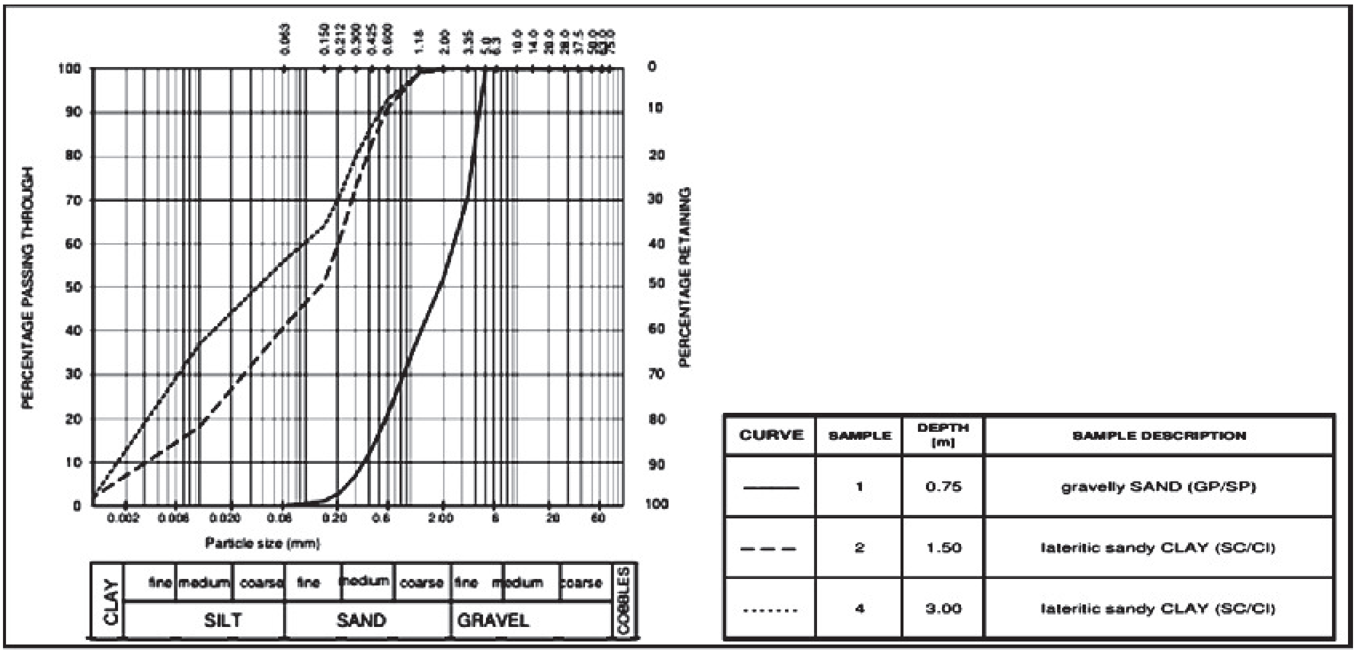
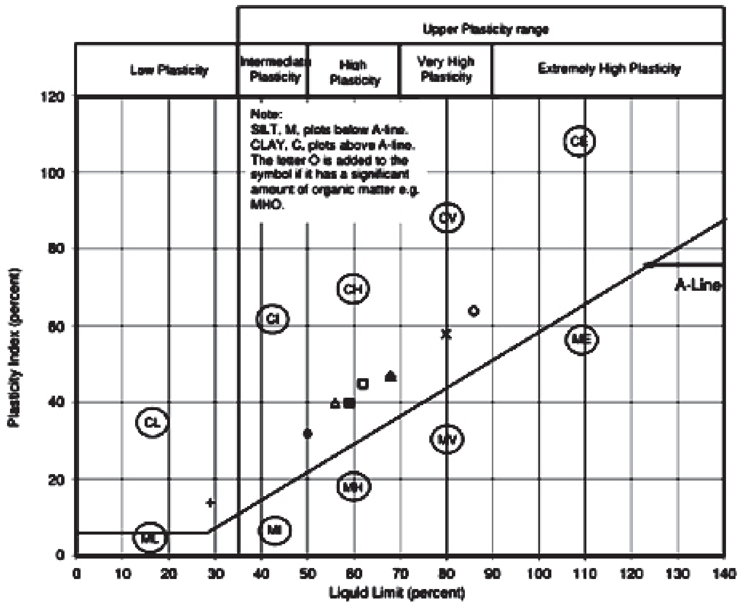
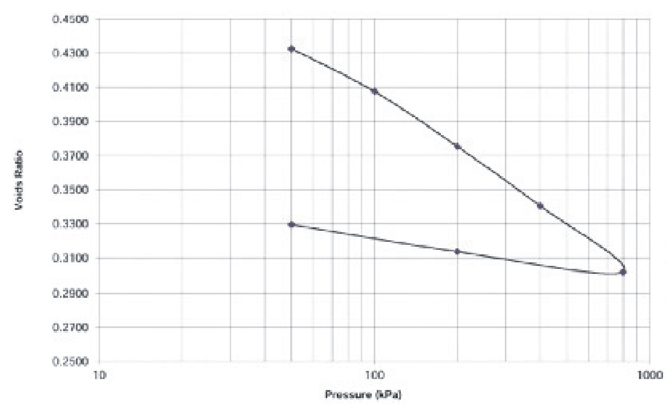


Fig. 3: Particle Size Distribution



Symbol	Sample	Depth [m]	Natural Moisture Content [%]	Liquid Limit [%]	Plastic Limit [%]	Plasticity Index [%]
●	1	0.75	25	50	18	32
■	2	1.50	22	59	19	40
▲	3	2.25	31	68	21	47
◆	5	3.75	29	68	21	47
x	6	4.50	20	80	22	58
+	9	6.75	21	29	15	14
○	10	7.50	21	86	22	64
□	12	9.00	17	62	17	45
△	23	16.72	28	56	16	40
◇						

Fig. 4: Atterberg Limit



Pressure (kPa)	m_v (m^2/MN)	c_v (m^2/year)
0	0.138	5.715
50	0.347	5.577
100	0.229	6.916
200	0.126	5.101
400	0.072	7.545
800		

Fig. 5: Oedometer Consolidation Plot

brown fine to coarse sand. It ranges from about 10.25 to 20.0m, giving an average thickness of 9.75 as shown in Table 1.

Groundwater was encountered in all the boreholes at depths ranging from 5.64 to 6.10m from the surface.

Bearing Capacity and Foundation Analysis

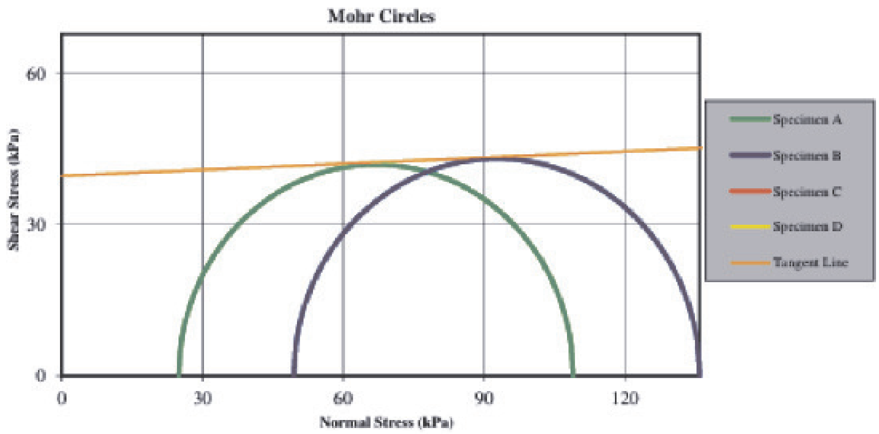
The thick layer of lateritic clayey sand/sandy clay provides adequate capacity for light to medium structures. Using the Meyerhof's (1963) equation below for bearing capacity, analysis of Pad footings with width 1.0m, 1.5m, 2.0m and 3.0m with foundation aspect ratio, L/B = 1, 1.5 and 2 at depth of 0.5m, 0.75m and 1.0m applying a Factor of Safety (FS) of 3 indicated Safe Bearing Capacity values ranging between 122kPa and 173kPa as shown in table 3.

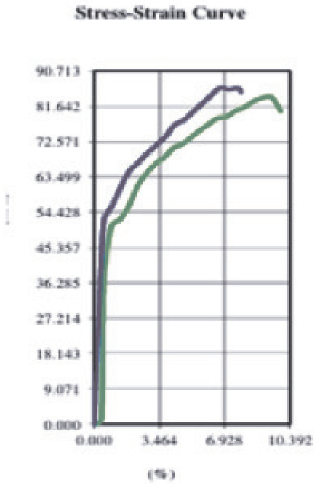
Analysis for raft foundation with width of 5.0m, 7.5m and 10.0 with L/B = 1, 1.5 and 2 at depth 0.5m, 0.75m and 1.0m applying FS of 3 also, revealed a safe bearing capacity of values ranging between 122kPa and 151kPa.

$$\mathbf{Qult = CNcdcSc + YDNqdqSq + 0.5YBN_Y\delta_Y S_Y} \quad \text{...... (1)}$$

Where;

C = undrained cohesion (kPa)
Y = unit wt of soil (KN/m^3)
D = foundation depth (m)
NcNqNy = bearing capacity factors
$d_c d_q d_Y$ = depth factors
ScSqSy = shape factors





Before Test	Specimen A	B	C	D
Water Content (%)	23.53	22.71	0.00	0.00
Dry Density (g/cm3)	1.54	1.50	0.00	0.00
Saturation (%)	86.37	78.99	0.00	0.00
Void Ratio	0.72	0.76	0.00	0.00
Diameter (mm)	38.000	38.000	0.000	0.000
Height (mm)	76.000	76.000	0.000	0.000
Liquid Limit				
Plastic Limit				
Specific Gravity	2.650	2.650	2.650	
After Test	**A**	**B**	**C**	**D**
Water Content (%)	23.53	22.71	0.00	0.00
Test Data	**A**	**B**	**C**	**D**
Strain Rate (mm/min)	50.80	50.80	0.00	0.00
Peak Deviator Stress (kPa)	83.960	86.394	0.000	0.000
Axial Strain @ Failure (%)	9.409	6.686	0.000	0.000
	Cell Pressure			
Cell (kPa)	25.0	49.5	0.0	0.0
Back (kPa)	n/a	n/a	n/a	n/a
	Principle Stresses at Failure			
σ1 (kPa)	109.0	135.9	0.0	0.0
σ3 (kPa)	25.0	49.5	0.0	0.0

Mohr-Coulomb Strength Parameters		Sample Description
C (kPa)	39.7	Soft yellowish brown sandy CLAY
Friction Angle Ø	2.34	

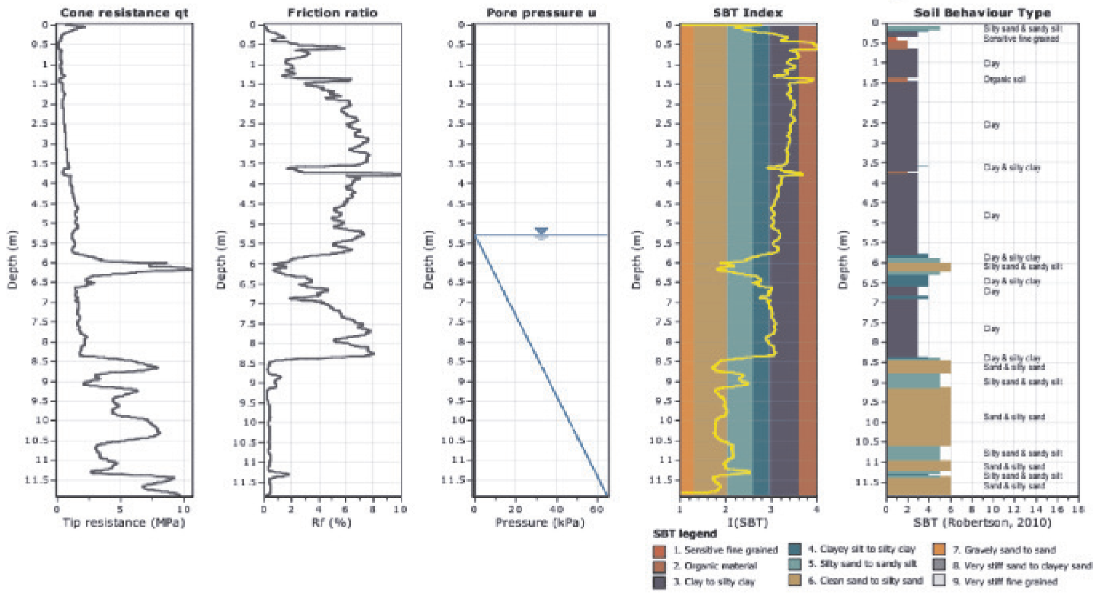


Fig. 6: CPT Plot

Table 3: Ultimate Bearing Capacity and Safe Bearing Capacity

Df (m)	B (m)	Ultimate Bearing Capacity (kNm^2)				Safe Bearing Capacity (kNm^2)			
		L/B =1	L/B =1.5	L/B =2	L/B =3	L/B =1	L/B =1.5	L/B =2.5	L/B =3
0.50	1	449	418	403	388	150	139	134	129
	1.5	435	406	391	376	145	135	130	125
	2	429	400	385	370	143	133	128	123
	3	423	395	380	366	141	132	127	122
0.75	1	483	450	434	418	161	150	145	139
	1.5	461	430	415	399	154	143	138	133
	2	451	421	405	390	150	140	135	130
	3	442	412	397	382	147	137	132	127
1.00	1	518	482	466	448	173	161	155	149
	1.5	488	455	439	423	163	152	146	141
	2	474	442	426	410	158	147	142	137
	3	460	430	414	399	153	143	138	133

Table 4: Ultimate Bearing Capacity and Safe Bearing Capacity for Raft Foundation

Df (m)	B (m)	Ultimate Bearing Capacity (kNm^2)				Safe Bearing Capacity (kNm^2)			
		L/B =1	L/B=1.5	L/B =2	L/B =3	L/B =1	L/B=1.5	L/B 2.5	L/B=3
	5	422	393	379	365	141	131	126	122
0.50	7.5	424	396	381	367	141	132	127	122
	10	428	399	385	371	143	133	128	124
	5	437	408	393	379	146	136	131	126
0.75	7.5	438	409	394	380	146	136	131	127
	10	441	412	397	382	147	137	132	127
1.00	5	452	422	407	392	151	141	136	131
	7.5	451	422	407	392	150	141	136	131
	10	454	424	409	394	151	141	136	131

Settlement Analysis

The settlement of the foundation is a governing criterion for adopting allowable bearing pressures. The long-term consolidation settlement of the pad footing and raft foundation were computed using Skempton (19) formula.

$\mathbf{S_m = Mv.\delta. H}$..(2)

Where;

H = thickness of the layer in consideration or 1.5B, whichever is smaller

δ = applied pressure on the layer in consideration (kPa)

Mv = co-efficient of vol. compressibility obtained from consolidation text.

Modulus of Subgrade Reaction

Modulus of Subgrade Reaction, Ks, is used in the structural analysis and design of mat/raft foundations. The equation for this is as follows:

$\mathbf{Ks = E/B(1-v^2)}$..(3)

Where;

E = Young modulus which can be derived by the relationship'

E = 600Cu

Where

Cu = undrained shear strength obtained from the Triaxial test

V = passion ratio, taken as 0.5 for clay soils

B = foundation width.

Table 5: Computed Settlement for Pad Footings

Mv (m^2 MN)	δ (kN/m)^2)	B(m) =1		B(m) =1.5		B(m) =2	
		H(m)	S(m)	H(m)	S(mm)	H(m)	S(mm)
0.278	50	1.5	21	2.25	31	3.0	42
	60	1.5	25	2.25	38	3.0	50
	70	1.5	29	2.25	44	3.0	58
	80	1.5	33	2.25	50	3.0	67
	90	1.5	38	2.25	56	3.0	75
	100	1.5	42	2.25	63	3.0	83
	110	1.5	46	2.25	69	3.0	92
	120	1.5	50	2.25	75	3.0	100
	130	1.5	54	2.25	81	3.0	108
	140	1.5	58	2.25	88	3.0	117

Table 6: Computed Settlement for Raft Foundation

Mv (m^2 MN)	ŏ (kN/m^2)	B(m) =5		B(m) =7.5		B(m) =10	
		H(m)	S(mm)	H(m)	S(mm)	H(m)	S(mm)
	50	7.5	104	9.5	132	9.5	132
	60	7.5	125	9.5	158	9.5	158
	70	7.5	146	9.5	185	9.5	185
	80	7.5	167	9.5	211	9.5	211
0.2780	90	7.5	188	9.5	238	9.5	238
	100	7.5	209	9.5	264	9.5	264
	110	7.5	229	9.5	291	9.5	291
	120	7.5	250	9.5	317	9.5	317
	130	7.5	271	9.5	343	9.5	343

Table 7: Ks at different widths

B(m)	Ks (KN/m^3)
5	6,400
7.5	4,267
10	3,200

Discussion of Results

The subsoil was investigated to determine the prevailing conditions at the site to provide soil parameters for design of foundations for the proposed structure. The investigation revealed within the depth explored the presence of a 9.75 – 10.50m thick layer of soft to firm yellowish reddish brown to dark grey lateritic clayey sand/sandy clay of low to high plasticity with average cohesion $40KN/m^2$. This layer is underlain by a 9.75 to 13.50m thick layer of loose to medium dense yellowish brown five to coarse sand with angle of internal friction of 28^0. The third stratum is the medium dense five to coarse sand with frictional angle of 35^0 and average SPT – N value of 26, unit weight $20KN/m^3$.

Settlement analysis reveals critical limitations for foundation design:

1. Pad Footings: 1.0m width foundations show acceptable settlements (<65mm) at 120kPa. 1.5m width foundations require load reduction to 100kPa to maintain acceptable settlements.
2. Raft Foundations: Computed settlements exceed the 100mm threshold for clayey soils
   - Load reduction or ground improvement measures may be necessary.
   - The high coefficient of volume compressibility (mv = $0.278m^2/MN$) indicates significant consolidation potential.

The relatively shallow groundwater table (5.64-6.10m) requires careful consideration in foundation design. - Long-term effects on soil strength parameters should be considered. The Atterberg test results as shown in fig.4 indicated that the top clay has moisture content (Wa), liquid limit LL (29-69%) and plastic limit (PL) (15-22%) which give a plasticity index (PI) of (14 – 47%) which is below the 55% limit cautioned by Ige *et al.,* (2018).

The sandy layer in the area can be divided into two distinct layers based on SPT-N value. The top loose fine to coarse sand with SPT value of between 7 – 11 and the medium dense fine to coarse sand below it with SPT-N value of 26. This indicates that they can withstand low to medium foundation pressure.

From the settlement table, it can be decided that allowable bearing capacity (with a limiting settlement of 65mm) of 120kPa can be adopted for pad footing of 1.0m width and 100kPa for 1.5 width. For raft foundation, the settlement exceeds 100mm allowed for clayey soils and thus there might be need to reduce the loads to accommodate this.

Conclusion

The superficial soil of the area has been investigated for their engineering properties. The study revealed a top soft to firm clay layer with average cohesion $40KN/m^2$, plasticity index 40% and average co-efficient of volume compressibility (Mv) $0.276m^2/MN$. This is followed by a loose to dense fine to coarse sand layer with frictional angle 28 - 35^0 SPT-N value 7 -26 and unit weight $20KN/m^3$. Bearing capacity values at various depths of foundation and widths have been computed and presented. Also, the expected settlements are indicated. The results of this study will be useful in the design and construction of a sustainable foundation for the proposed structure.

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