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Geotechnical Investigation of a Swampy Soil for Foundation Design and Construction in Buguma City, Rivers State, Nigeria

Joseph Chukwuka Okah
Department of Building Technology, Port Harcourt Polytechnic, Rumuola,
Port Harcourt, Rivers State, Nigeria

Abstract: Buguma City, in Asari Toru LGA of Rivers State had witnessed population upsurge on account of O&G, fishing and trading activities in the city, exerting pressure on lands available for buildings and driving development into swampy areas causing frequent building collapses that needed urgent attention. To this end, geotechnical investigation was conducted to determine the engineering properties of the soil for foundation design and future construction. In doing this, 4 boreholes; BH_1, BH_1, BH_3 and BH_4 were drilled at a landed space located at 4.7133170N and 6.863660E in Buguma City using cable percussion equipment to the depth of 25m and soil samples were collected for laboratory tests (Particle size analysis, consolidation etc) according to BS 1377 (1990). The Soil stratigraphy revealed near surface dark brown compressible silty clay from 0-750mm and grey to light silty clay of high plasticity from 0.6-8m depth for BH_1, BH_2 and BH_3 while BH_4 contains a grey to light silty clay of medium compressibility. Below the 8m is brown medium-grained loose sand to 13m depth which increases in density to a coarse-dense sand beneath. The Atterberge limit test result shows that the L.L, 49% and P.L, 26% sufficiently indicate relatively compressible silty clay. Result also revealed a Bulk unit weight γ, MDD and OMC of 18KN/m^3, 1.73g/cm^3 and 13.20% respectively. The soil produced a coefficient of compressibility mv of 0.687m^2/MN and Cc of 0.29, while the shear strength parameters were; c = 38KN/m^2 and Ø = 3.00 which produced bearing capacities (BC) of 98.25KN/m^2 and 104.9KN/m^2 and settlements of 63.76mm and 42.5mm for shallow foundation at depths 1m and 3m respectively under a water level of 1.8m. Finally, it was concluded that the soil is weak silty clay which is unsuitable for strip and pad foundations. However, it is recommended that a raft and beam/slab-raft foundation be adopted for bungalows and 1-storey buildings respectively otherwise pile foundation to the stratum of 25m depth should be adopted for more than 2 storey buildings

KEY WORDS: Soil stratigraphy, swamp, consolidation, compressibility, settlement, cohesion, shear strength, Allowable Bearing capacity

1.0 Introduction

Building collapse though a common phenomenon all over the world is alarming in developing countries like Nigeria (Folagbade, 2001) Rivers state inclusive. There is population upsurge in Urban coastal areas such as Port Harcourt and Buguma City of Niger Delta, Nigeria, on account of Oil & Gas activities, causing the depletion of the available land spaces and movement of development to swamps and marshy lands close to the river which pose serious challenge to property development (Haddou *et al.*, 2013; Youdeowei & Nwankwoala, 2010). A swamp is a wetland often partially or intermittently covered with water especially one dominated by woody vegetation. Niger-Delta region is where debris and sediments of River Niger are deposited in Nigeria. Geotechnical investigations of Niger-Delta soils have shown that the soil undergo excessive leaching which is detrimental to soil compactibility (Alayaki et al, 2015). Many of the soils here comprise large formation of compressible clays which lack gravels and sandy fractions causing excessive swelling and shrinkage resulting in low bearing capacities (Otoko and Karibo, 2014, Youdeowei and Nwankwoala, 2010).

Technically speaking, building failure occurs when the service load/stress exceeds the bearing resistance of the soil. Youdeowei et al (2019) writes that the collapse of a 7-storey building still under construction in 2018 at the GRA phase 2, Port Harcourt, which led to the loss of over 25 lives and 22 persons injured was as a result of poor foundation design and poor geotechnical investigation. Chendo and Obi (2015), reported the collapse of a building under construction in Benjamin Okpara Street, Port Harcourt in 2006. Teme et al, (2008) write that the soil at Tombia street extension, GRA phase III is marshy consisting of silty clays down to 2m underlain by silty sands and sand gravels beneath the building site. The investigation carried out by Ajamu et al (2015) on a swampy soil showed that the the allowable bearing capacity of the soil ranges from 91kN/m2 and 108kN/m2 and the UCS ranges from 22.235-56.67KN/m^2 which reveals that the soil in the study area is generally weak. Nwankwoala et al (2014) writes that the safe bearing capacity of a swampy soil in Akenfa, Bayelsa state, is 129KN/m^2 and 432 KN/m^2 at 10m and 25m foundation depth for a pile diameter of 305mm and the coefficient of compressibility (M_v) is 0.38 m^2/MN implying high compressibility and weakness of the soil.

Reliable geotechnical information of soil is important because the impact of the imposed load is dependent on the consistency of the compressible layer and its bearing resistance (Oke and Amadi, 2008). Therefore, this study was carried out to determine the geotechnical properties of the swampy soil in Buguma City, make recommendations for proper foundation design and construction to guide property developers and forestall future occurrences of building collapse.

1.1 Study Area

Buguma is the headquarters of Asari Toru LGA and the ancient base of the Kalabari Kingdom. An Island surrounded by The Buguma Sea leading to the Cawthorne channels and the Amanyanabo Okolo creek connecting the Buguma fish farm site. It is engulfed with predominant mangrove vegetation and tropical rain forest. The site is along Tena-Buguma Road down King Amachree Road, after the Baptist Church Cathedral, Buguma City, Asari Toru LGA in Rivers State. The geographical coordinates are; 4.73348ºN and 6.8637^{0}E

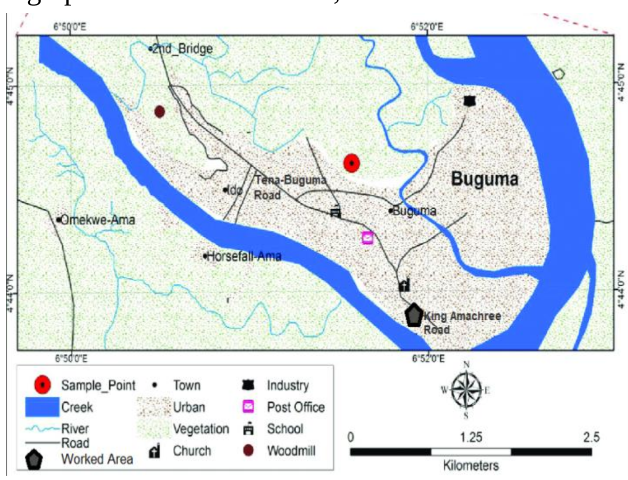

Fig 1.0: Buguma City, Asari Toru, Rivers State

Fig 2.0: Building Collapse in Buguma City

Table 1.0: The coordinates of the BH points

S/No	BH Point	Latitude (^{0}N)	Longitude (^{0}E)
1	BH_1	4.73317	6.86366
2	BH_2	4.73318	6.86379
3	BH_3	4.73307	6.86362
4	BH_4	4.73305	6.86381

2.0 Methodology

2.1 Methods of Data Collection

Four boreholes were sunk at specified positions; BH_1, BH_2, BH_3 and BH_4 using manual conventional light cable percussion equipment of size 75mm in diameter to the depth of 20m. Auger tool was used in retrieving the soil samples. The sampler is driven into the soil by dynamic means which cuts through the soil using a rotating handle. On withdrawal, the non-return valve assists in retaining the sample in the tube. During boring, undisturbed and disturbed soil samples were collected at regular intervals of 0.2m (200mm) and when a change of soil physical characteristics is observed. In the cohesive layer, undisturbed samples were collected. The borehole is lined with plastic casings to prevent collapse of the walls. The samples were well packaged in small cellophane bags and labeled as BH_1, BH_2, BH_3 or BH_4 indicating the borehole point. This was carefully transported to the laboratory in containers without subjection to any form of stress for laboratory analysis. The essence is to keep the samples undisturbed to maintain its behavior. The coordinates of the borehole points are shown in table 1.0 while the site is shown in table 1.0. Ground water level stood at 1.8m below the existing ground level at the time of this investigation in April, 2022 even if this is subject to fluctuations at different times of the year. The permeable layers are recharged with underground water from the adjoining river.

2.2 Laboratory tests

2.2.1 Soil Classification: Atterberg limits Test (BS 1377: Part 2: 1990)

Plastic limit (P.L): Atterberg limit test was conducted for plasticity classification of silty clay. About 180g of soil sample passing through 0.42mm on BS sieve was thoroughly mixed with water and left overnight in a porcelain dish to form a paste enough to be moulded with fingers. Then about 8g of soil was moulded to form a ball by rolling between fingers and glass plate until a thread of 3mm diameter of the plastic soil crumbles. Then the moisture content was determined.

Liquid limit (L.L): About 120g out of the 180g above passing through 0.42mm was mixed with water to form a paste placed in brass cup and leveled with a spatula. A grove is made with casangrande grooving tool and the cup is subjected to a uniform blows at 2blows/sec. The number of blows required to close the groove in 10mm was recorded and the paste immediately removed from the cup. The moisture content was determined. The test was repeated with different water contents for 4 times and the moisture content (W_L) was plotted against the number of blows from where the W_L at 25th blow was read as the liquid limit (L.L)

2.2.2 Particle Size Analysis (BS 1377: Part 2: 1990) - soil classification

Particle size analysis was carried out on the representative soil samples as an aid to soil classification. Generally, the method adopted included dry sieving for cohesionless soil. Sieve analysis of cohesionless soils particularly involved oven-drying samples for 3hrs and pulverized with mortar and pestle. About 500g of soil was sieved through +4.75mm BS sieve, the retained is subjected to coarse-grain analysis by shaking the mass of soil for 10mins and the mass retained on each sieve measured while the proportion passing +4.75mm is wet-sieved, washed, oven-dried and sieved mechanically in 0.075mm BS sieve for fine-grained analysis for greater accuracy. The mass retained on each sieve is measured.

2.2.3 Compaction Test (BS 1377: Part 4: 1990) OMC and MDD

The mass of the empty mould was measured and a weighed dry soil sample was thoroughly mixed with measured quantity water and left for 10mins. The mass was filled in the mould in 3 equal layers with the collar attached and base plate covered with paper and each compacted by 25 blows of 2.5kg BS standard rammer dropped from a height of 300mm at each blow. The soil was trimmed level with the top using a straight edge after removing the collar. The mould containing the compacted soil was weighed and the mass of the compacted soil determined for wet soil density (d_w). The soil was removed and small sample collected from the top, middle and bottom for moisture content (W_c) determination. The procedure was repeated for 4 times and the graph of dry density is plotted against moisture content to determine the maximum dry density (MDD) and optimum moisture content (OMC) of the soil.

2.2.4 Undrained Triaxial Test (BS 1377: Part 7: 1990) ASTMD285O-7U: Shear strength

Undrained triaxial tests were carried out on the remolded clay specimens that measured 38mm in diameter and 76mm in height. In the test, the soil specimen was encased in a thin plastic cylindrical chamber filled with water. The sample was subjected to confining pressure, and deviator stress was applied, axially, until shear failure occurred without drainage. The results of the tests were analyzed using Mohr — Coulomb criteria to determine the shear strength parameter C-Ø of the soil which is used to determine the bearing capacity (BC) of the soil.

2.2.5 Consolidation Test (BS 1377: Part 6: 1990) -- Settlement and Compressibility

One dimensional consolidation test was performed on the remolded cylindrical samples measuring 25mm high and 90mm in diameter. The specimen was placed in an Oedometer that confines the specimen to zero lateral deformation during the test. Porous stones were placed at the upper and lower parts of the test specimen in order to permit the dissipation of water contained in the sample, thus allowing volume change. In the test, an increment of vertical stresses (4KN/m^2 initial trial setting load): 20, 50, 100, 200, 400 and 800KN/m^2 were applied and vertical displacements recorded for each of these increments. The relationship between changes in void ratio and applied pressure with the corresponding parameters are presented. The parameters obtained are used to determine the settlement rate of the soil. These parameters include compression index (Cc) and coefficient of compressibility (M_v)

3.0 Results and Discussion

3.1 Soil Stratigraphy

The soil stratigraphy encountered in the explored boreholes in the field as obtained from the field and laboratory tests revealed intercalations of near-surface dark brownish sandy clay of medium plasticity to the depth of 0.6m in BH_1, BH_2 and BH_4 and a 75cm thick dark silty clay of medium compressibility in BH_3. A very thick grey to light silty clay of high plasticity is underlain to the depth of 8m in BH_1, BH_2 and BH_3 while a grey to light silty clay of medium plasticity is found in and BH_4. However, in BH_2 and BH_3, 4m thick dirty brown medium-grained loose sand which gradually changed to a light grey medium-grained sand of medium plasticity is underlain the 8m-12m depth but this stretches to 13m in BH_1 and BH_4. Below 12m is whitish medium-grained sand which changes to coarse-grained

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dense sand in BH_1, BH_2, BH_3 and BH_4 down to 20m in BH_1 and BH_4. This is shown in table 2.0

Table 2.0: Soil profile of the borehole points in area of study

S/ No	Depth (m)	Description			
		BH_1	BH_2	BH_3	BH_4
1	0 - 0.6/0.75	dark brown medium plastic sandy clay	Same as BH_1	75cm medium compressible brown silty clay	Same as BH_1
2	0.6 - 8	Grey to light silty clay of high plasticity	Same as BH_1	light silty clay of high plasticity	Grey to light silty clay of medium compressibility
3	8-12/13	Light grey medium-grained loose sand	Brown to light grey medium-grained loose sand	Brown to light grey medium-grained loose sand	Same as BH_1
4	12/13-below	Medium dense/coarse-grained dense sand	Same with BH_1	Same as BH_1	Same with BH_1

3.2 The Engineering properties of the soil

3.2.1 Atterberg limits: Table 3.0 summarizes the engineering properties of the soil. The *L.L* and *P.L* are 49% and 26% respectively. The M_v is 0.687m^2/MN which is a measure of compressibility of the soil sufficiently indicates compressible silty clay.

Table 3.0: Engineering properties of the soil

Engineering Properties		Min	Max	Mean
Liquid Limit (%)		47	51	49
Plastic limit (%)		25	27	26
Plasticity Index (%)		22	24	23
Undrained Shear strength	Cu (KN/m^2)	38	38	38
	Φ(degree)	2.0	4.0	3.0
Initial void Index (e_o)		1.115		
Final porosity (%)		50		
Bulk Unit Weight (KN/m^3)		17.40	18.60	18.00
Dry unit weight (KN/m^3)		15.20	16.80	16.00
Optimum Moisture Content (OMC) (%)		12.50	13.80	13.20
Maximum Dry Density (MDD) (g/cm^3)		1.60	1.85	1.73
Coefficient of compressibility mv (m^2/MN)		1.36	0.013	0.687
Compressive index (cc)		0.29		

3.2.2 Particle size distribution – Classification of soil (BS sieve) for BH_2 and BH_4

Depth d sample	= 4m
Mass of dry wet soil sample used	= 500g
Mass retained on 0.075mm	= 249.90g
Mass passing through 0.075mm	= 250.10g

From the result in fig 3.0 and table 4.0, the soil contains 50.02% of silty clay (passed through 0.075mm sieve) while 35.11% of fine sand (passed through 0.42mm and retained in 0.075mm) indicating substantially silty clay soil.

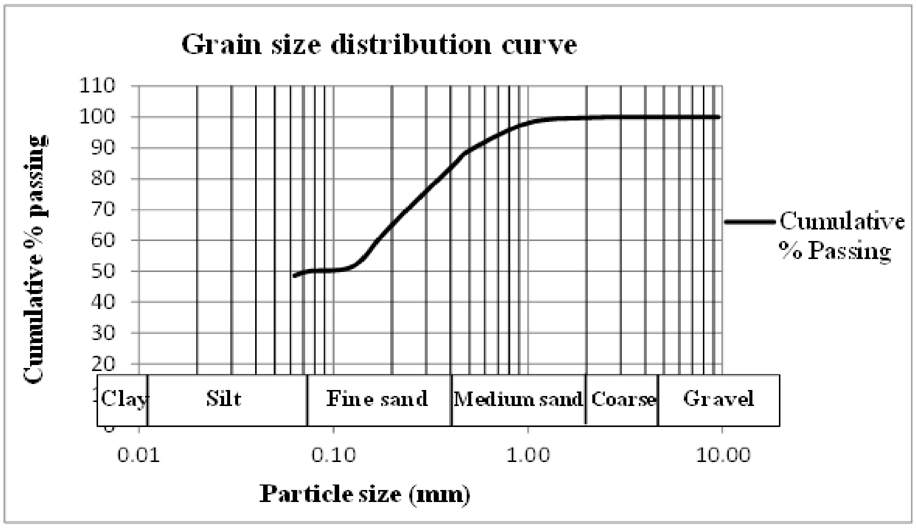

Fig 3.0: Soil Grain size distribution curve

Table 4.0: Sieve analysis

S/No	Sieve Aperture(mm)	Mass Retained (g)	% Mass Retained	Cum. % Mass Retained	Cum. % Mass Passing
1	9.500	0.00	0.00	0.00	100.00
2	4.760	0.00	0.00	0.00	100.00
3	2.000	0.80	0.20	0.20	99.80
4	1.000	6.80	1.70	1.90	98.10
5	0.500	35.50	8.88	10.78	89.23
6	0.420	16.38	4.10	14.87	85.13
7	0.250	55.82	13.96	28.83	71.18
8	0.180	36.54	9.14	37.96	62.04
9	0.125	42.25	10.56	48.52	51.48
10	0.075	5.82	1.46	49.98	50.02
11	0.063	5.82	1.46	51.43	48.57

3.2.3 Consolidation

From table 3.0, the **average coefficient of compressibility** (**m*v***) is 0.687m^2/MN indicating a moderate to high compressible soil**.** The result in fig 4.0 shows that at 3m depth, the initial void ratio of the soil is 1.115; the final settlement at the application of 800KN/m^2 is 5.0mm. The compression index, Cc which determines the recompression property of the soil is 0.310 and this is indicative of silty clay.

Table 5.0: Consolidation test result

<table>
<tr><td colspan="2">Geoaqua Nigeria Limited</td><td colspan="2">Project: Investigation of a Swampy soil for Foundation Design
Location: King Amachree Road, after the Baptist Church Cathedral, Buguma City, Asari Toru LGA, Rivers state</td></tr>
<tr><td colspan="4">CONSOLIDATION TEST RESULT</td></tr>
<tr><td>Borehole: BH$_1$</td><td colspan="2">Depth: 3m</td><td>Height of Solid Method</td></tr>
<tr><td colspan="2">Height of sample (thickness) H_0 = 25mm
Area of Ring= 6362mm^3
Diameter of Ring = 90mm
Specific gravity (G) = 2.7</td><td colspan="2">Initial Void ratio (e_0) = 1.115
Final void ratio (e_1) = 0.693
Dry mass of specimen after test = 203g
Height of solid specimen at the end = 11.82mm</td></tr>
</table>

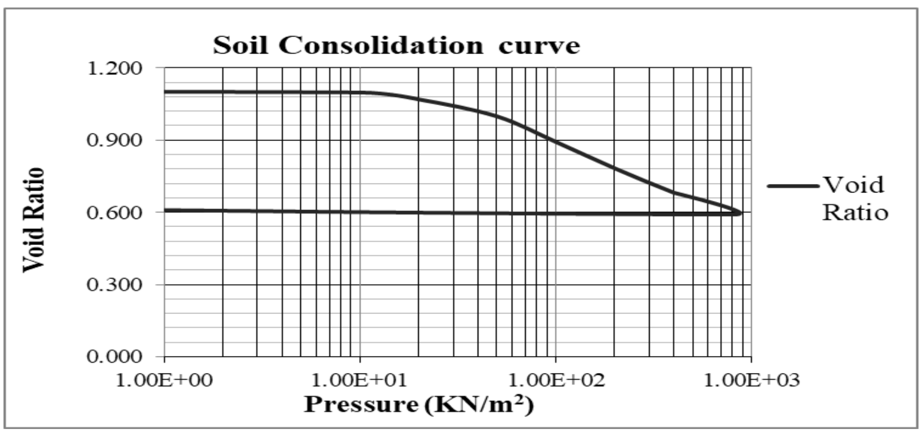

Fig 4.0: Soil Consolidation curve

Table 6.0: Compressibility of the soil

S/No	Pressure (KN/m^2)	Void Ratio	Av. Compression Index (C_c)	mv= $a_v/(1+e_0)$ (m^2/MN)
1	0.0	1.115	**0.29**	**0.687**
2	10	1.098		
3	20	1.069		
4	50	0.999		

5	100	0.893		
6	200	0.783		
7	400	0.682		
8	800	0.591		
9	0	0.693		

3.2.4 Undrained triaxial test

Unconsolidated triaxial tests were carried out at approximately 2m depth of BH_1 and BH_3. Three samples of the cohesive soil were subjected to undrained triaxial compression by loaded deviator stress in each case to failure with data obtained as represented in table 7.0.

Fig 5.0 illustrates the Mohr circle which was used to analyse the shear strength of the soil. It is clear from the diagram that the undrain cohesion of the soil is on c = 38KN/m^2, while the angle of friction Ø = 3.0^0.

This result shows that the soil is a cohesive soil but with low undrained shear strength of 38KN/m^2. The effect of this is that the bearing capacity of the soil will be low.

Table 7.0: Undrained Triaxial Test Result

Geoaqua Nigeria Limited	**Project:** Investigation of a Swampy soil for Foundation Design **Location:** King Amachree Road, after the Baptist Church Cathedral, Buguma City, Asari Toru LGA, Rivers state		
UNDRAINED TRIAXIAL TEST RESULT			
Borehole: BH_1 and BH_3	**Depth: 2m**		**Test without Drainage**
Dimensions of plastic chamber: Diameter: 38mm Height = 76mm	The shear strength parameters; Undrained cohesion, **C_u = 38KN/m^2** Undrained angle of friction, **Ø = 3.0^0** Analysis: Mohr - Coulomb circle		
Sample No.	**Major Principal Stress σ_1 (KN/m^2)**	**Minor Principal Stress σ_3 (KN/m^2)**	**Deviator Stress (KN/m^2)**
1	210	100	110
2	308	180	128
3	430	280	150

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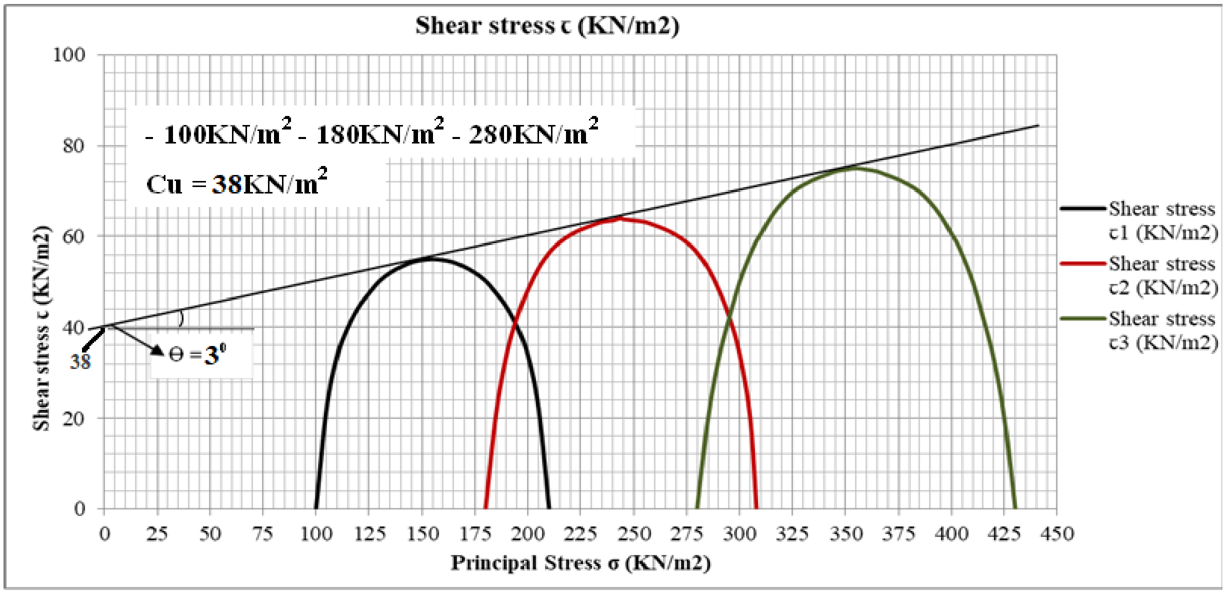

Fig 5.0: Shear strength of the soil - Mohr-circle

3.2.5 Compaction test Result

The compaction test conducted in section 2.2.3 at depth 2m for **BH_2** is summarized in **table 8.0**. From the foregoing, the OMC is indicative of silty clay soil which retains much water because of its higher water retaining capacity thus hindering compaction of the soil. Consequently, the MDD will be difficult to be achieved. OMC is 12.80%, while MDD is 1.6g/cm^3

Table 8.0: Compaction test Result – OMC and MDD

Tests	**OMC (%)**	**MDD p (g/cm^3)**	**Average OMC (%)**	**Average MDD (g/cm^3)**
1	12.50	1.65	13.20	1.73
2	13.80	1.85		
3	12.50	1.60		
4	13.20	1.70		

3.3 Allowable bearing capacity, q_a (ABC)

From Terzaghi's equation for Safe or Ultimate Bearing Capacity of soil:

$q_u = 1.3N_cC_u + \gamma D_f N_q + 0.4\gamma B N\gamma$ ---- (Square Footings)

$q_a = q_u/3$ Where q_a = allowable Bearing Capacity, factor of safety = 3

Table 9.0: Parameters of Terzaghi's equation for Bearing Capacity

S/No	Parameter	Value
1	Bulk unit weight, γ (KN/m^2)	18.00
2	Saturated unit weight, $\gamma_{(sub)}$ (KN/m^2)	8.20
3	Depth, D_f (m)	0-3.0
4	Square footing, (2mx2m) B = L = 2m	2.00
5	Undrained Cohesion, C_u (KN/m^2)	38.00
6	Undrained angle of friction, Ø	3.0^0
7	Underground water level (m)	1.80
8	Terzaghi (modified) BC factor, N_q	1.30
9	Terzaghi (modified) BC factor, N_c	5.72
10	Terzaghi (modified) BC factor, Nγ	0.03

Nc, Nq and Nγ were derived from Prandtl, Brinch and Hansen modifications of Terzaghi's equation.

Teng's water correction factors = RW_q and RW_y

Table 10.0: Bearing capacities at depths; 1-3.0m for BH_1 and BH_3 for square footing

Depth (m)	B/L Ratio	Bearing Capacity (BC) (KN/m^2) (q_u)	Allowable Bearing Capacity ($q_u/3$) (KN/m^2)
0.5	1.0	294.75	98.25
1.0	1.0	306.39	102.13
1.5	1.0	318.00	106.00
2.0	1.0	304.20	101.40
2.5	1.0	309.60	103.20
3.0	1.0	314.70	104.90

3.4 Settlement

From soil stratigraphy, Silty clay soil is found between 0-6m, while, the foundation is located at 6m below the ground surface for BH_1 and BH_3. Similar result was obtained for BH_2 and BH_4. The Correction factor, K_2 is based on **H/B** ratio (**H** = thickness of clay soil below the footing on which the footing is supported, while **B** = the width of the footing) as recommended by Skempton and Bjerrum (Garg, 2009)

Settlement $(\Delta H) = [C_c*H_0/(1+e_0)]\log[(\Delta p+p_0)/p_0]$

Consolidation Settlement $S_{SC} = K_2 * \Delta H$

Table 11.0: Settlement

Depth (m)	B/L Ratio	Allowable BC (q_a) (KN/m^2)	K_2	$S_{SC} = K_2*\Delta H$ (mm)
0.5	1.0	98.25	0.45	66.94
1.0	1.0	102.13	0.46	63.76
1.5	1.0	106.00	0.48	61.44
2.0	1.0	101.40	0.48	52.32
2.5	1.0	103.20	0.50	48.50
3.0	1.0	104.90	0.50	42.50

4.0 Conclusions

The main indices for determining the suitability of the soil for the foundation design are; **the type of soil, shear strength hence bearing capacity (BC) and settlement under stress, and compressibility of the soil**. In the light of the above, the major criteria for design of suitable foundation are therefore; (i) The bearing capacity of the soil under stress to sustain the ultimate stress from the building foundation and (ii) The settlement not to exceed the maximum tolerant limit of the sub and super structure. The soil is normally consolidated. The soil profile revealed near surface dark brown compressible silty clay of high compressibility from 0-750mm and grey to light silty clay of high plasticity from 0.6-8m depth for BH_1, BH_2 and BH_3 while BH_4 contain a grey to light silty clay of medium compressibility. Below the 8m is brown medium-grained loose sand to 13m depth which increases in density to a coarse-dense sand beneath to 30m. The Atterberge limit test result shows that the L.L (<35%L.L<50%) and P.L (26%) sufficiently indicate relatively high compressible silty clay (Garg, 2009). Similarly, the M_v (0.687m^2/MN) indicates compressible silty clay (Skempton, 2003). The shear strength parameter of the soil; c = 38KN/m^2 and Ø = 3.0^0 indicates a cohesive silty clay of bearing capacity (BC) 104.90KN/m^2 and settlement of 42.50mm for shallow foundation at the depth of 3.0m (Table 11.0)under a water level of 1.8m. Hence the soil is very weak plastic silty clay.

5.0 Recommendation

In order to ensure that maximum settlement does not exceed the permissible settlement of 65mm for isolated foundations and 65-100mm for raft foundations as recommended by Skempton and MacDonald on clay soil (Garg, 2009), it is recommended that allowable bearing pressure of 98.25KN/m^2 could be adopted for the shallow foundation (raft foundation) since design decision is made for the worst case scenario. Any allowable pressure from the footing that exceeds 104.90KN/m^2 at 3m depth (or according to table 11.0) will collapse. Therefore, strip foundation should never be contemplated; however, raft foundation and beam and slab-raft should be adopted for bungalows and 2 storey buildings respectively otherwise pile foundation to the stratum of 25m depth should be adopted for 3 or more storey buildings. Pile foundation is the most suitable for inconsistent compressible soils (Poulos et al, 2011).

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