Original Research Article

Evaluation of Subsoil Competence for Foundation Design Design in Rumuokwuta, Port Harcourt, Eastern Niger Delta

ABSTRACT

Aim: A subsurface geotechnical investigation was carried out for the purpose of establishing the depth of competent soil for foundation design and construction of a one-storey building.

Study Design: The study was aimed at assessing the subsoil competence for a foundation design in the Eastern Niger Delta using engineering geology and geotechnics.

Place and Duration of Study: The research was conducted in three locations along the Rumuokwuta axis of Port Harcourt (the eastern Niger Delta) between April and September 2019.

Method: The study involved both field sampling and laboratory analysis. This involved soil boring for the retrieval of disturbed and relatively undisturbed samples for analysis, which involves grain size analysis, the Atterberg limits, moisture content, and unit weights. Also, Oedometer consolidation Oedometer and undrained, unconsolidated triaxial tests were carried out.

Results: The study revealed two main stratigraphic layers that are mostly fine within the shallow foundation level (0.0–3.0 m). From the results, the soil exhibited the following geotechnical properties: liquid limit (41-46%), plastic limit (21-23%), plasticity index (18-24%), and moisture content range (20.6-24.7%). The undrained cohesion value is 55 kPa, and the average frictional angle is 5^{o}. The coefficients of compression (Mv) and consolidation (Cv) were 0.20 m^2 /MN and 40.7 m^2/yr, respectively.

Conclusion: With the moderate bearing and settlement values within the shallow foundation level, the feasibility of adopting a shallow foundation for the purposed structure is tolerable. A shallow foundation (1.4 m minimum) with an allowable bearing pressure of 100 kPa is therefore recommended.

Keywords: Subsoil Competence, Allowable Bearing Pressure, Settlement, Shallow Foundation level.

Introduction

The desire of every property developer is to build a sustainable structure. Building a sustainable civil engineering structure is only possible if such a structure is designed and constructed in accordance with prevailing environmental conditions such as soil, air, and water. Inadequate knowledge of the subsoil condition has led to the failure of some infrastructure (Ademila, 2017). For a building to be sustainable, its foundation must be designed and constructed based on the engineering properties of the subsoil; contrary to this, the sustainability of the structure cannot be assured. This is because the condition of the subsoil plays a critical role in the stability of foundations [Adebisi and Adeyemi, 2018]. Many structures have been designed incorrectly and constructed inefficiently due to a lack of adequate knowledge of soil behavior and the application of geotechnical parameters of soil [Uyanga-Ehibor and Akpokoje, 2019].

It is in line with this that this investigation was carried out to evaluate the geotechnical properties of a subsoil at Rumuokwuta, Eastern Niger Delta, for the purpose of designing an appropriate foundation for a storey building in a land area of approximately 1082.1m^2.

Site Location and Geology

The project is located in the Rumuokwuta community, in Obio Akpor Local Government Area in Port Harcourt, east of the Niger Delta. There are some newly built buildings in the area that are already occupied and show no signs of cracks or structural failure. There are signs of vegetation cover for economic trees at different locations.

Geologically, the area is overlain by a dark brown, soft to firm clayey silty sand that is lateritic in nature and belongs to the Pleistocene (Morrison and Esonanjor, 2022). The superficial sediments, within our depth of investigation, are characterized by an upper layer of dark brown silty sand on top of a sandy silty clay.

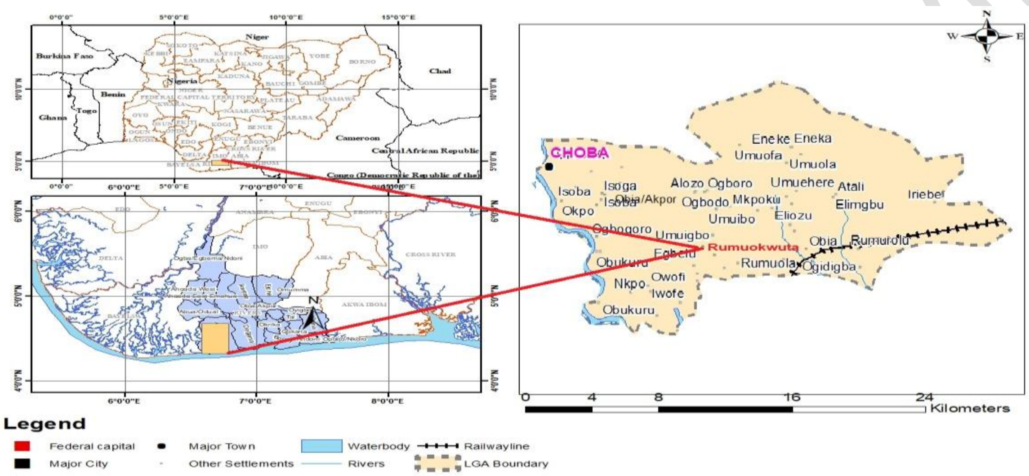


Figure 1: Study Location

Regional Geology

The regional geology of the area is basically the geology of the Niger Delta. The Niger Delta subregion, according to Teme (2017), is the arcuate structure situated at the southernmost section of the Nigerian coastline and lies between latitudes 4° 15' 00" and 6° 30' 00" north of the Equator and between longitudes 6° 37' 42" and 7° 30' 00" east of the Greenwich Meridian. Geologically, it comprises the Quaternary to recent sediments of sandy beaches, mangrove swamps, and the Niger floodplains that overlie and form part of the Benin Formation [Abam, 2018; Teme 2017]. The Agbada formation, made up mainly of sand and shales, is below the Benin formation. Beneath the Agbada formation is the Akata formation, which is believed to be the petroleum source rock in the region. It consists mainly of shales and is about 3300 meters thick [Abija et al, 2018].

Materials and Methods

The study involved both field and laboratory investigations. Field work involved the boring of three boreholes with a manually operated hand auger. The field work was done in accordance with Eurocode 7 [2007]. The shallow borehole points were all situated on land.

During boring, soil samples were collected at an interval of 1.0m. Boring was done up to 4.0 meters. The samples retrieved from boring were first inspected, described, and classified in the field before being sent to the laboratory for analysis.

The shallow boring provided the sample for the laboratory analysis. Boring was in compliance with the requirements given in B.S 5930 [2007 and Eurocode 7 (2017]. This method uses light, hand-operated equipment. The auger and drill rods were lifted out of the borehole without the aid of a tripod, and no borehole casing was needed. An open-tube sampler with a diameter of 63 mm and a length of 400 mm, driven into the ground by dynamic means for undisturbed samples, was used to collect a soil sample for laboratory testing.

Groundwater level was 3.6 m below ground surface; consequently, groundwater level within the area is expected to vary due to seasonal changes in relation to the climatic conditions and other environmental factors in the area [Uyanga-Ehibor and Akpokoje, 2019; Ige et al, 2018].

Laboratory Analysis

To verify and improve field identification and classification, a series of classification, strength, and compressibility tests were performed on the samples in the laboratory. Natural moisture content, unit weight, specific gravity, liquid, and plastic limits were all tested.

Soil Stratigraphy

The nature of the stratigraphy of the site was obtained from the soil boring. The data from soil sampling and laboratory tests were evaluated for the determination of the stratification of the underlying soils. The distinct soil layers were delineated as follows:

1. An upper clayey silty sand stratum with fine to medium gradation. It is dark brown in color, with a depth range of 0.0 to 0.3 m.
2. The second layer, within a depth range of 0.3 – 3.0m is a firm, lateriferous sandy silty clay. The sand within the clay has a size range of fine to medium grains. It is brownish in color. A typical soil profile characterizing the site is illustrated in figures 2 and 3.

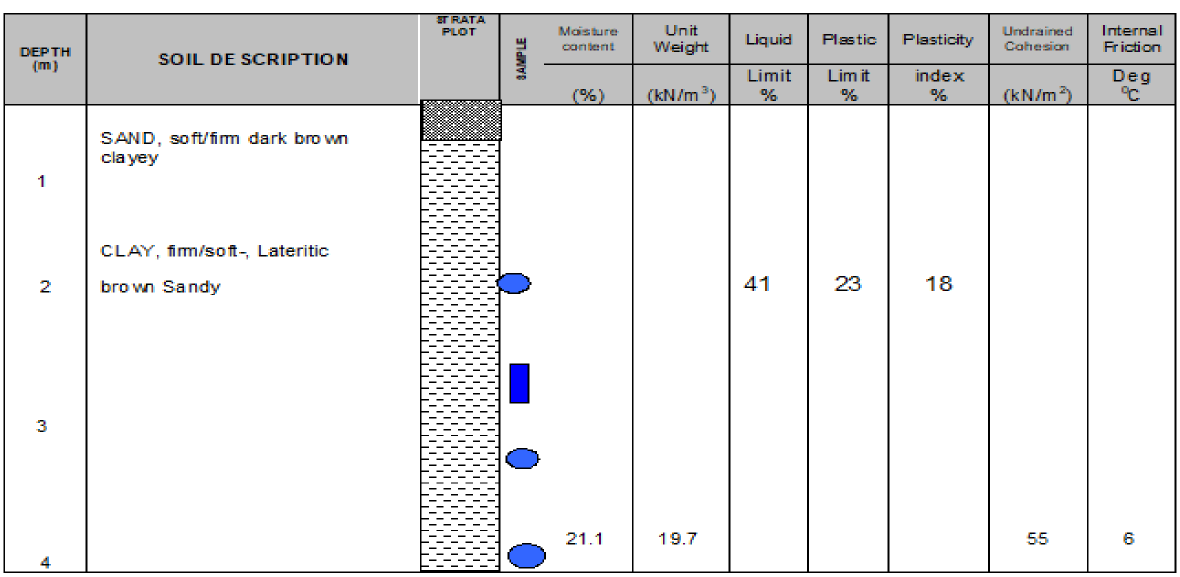


Figure 2: Borehole 1

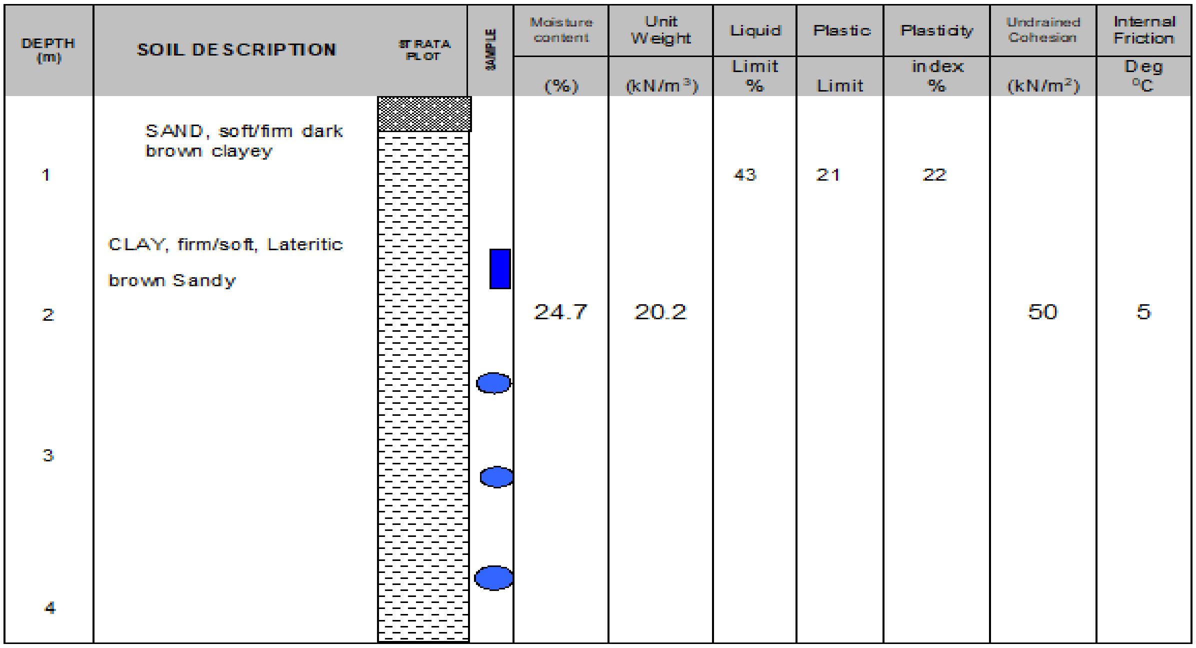


Figure 3: Borehole 2

For the strength test, undrained, unconsolidated triaxial shear strength tests were performed on clay specimens 38 mm and 76 mm high using standard triaxial equipment. During the test, the soil specimen was enclosed in a rubber membrane and placed in a triaxial cell. The cell was filled with water. A cell pressure was applied, which simulates the in-situ stress on the specimen. The specimen was then loaded to failure, with no drainage from the sample. 100, 200, and 300 kPa confining cell pressures were used during the test (see figure 5).

2. Engineering Properties of the Soils

A series of classification tests were conducted in the laboratory to determine the wider properties of the soil. The relevant index and engineering parameters of the soils are summarized in table 1.

Table 1: Some Geotechnical Parameters of the Soil

Natural Moisture Content (%)	Min	Max	Average
Natural moisture content (%)	19.9	22.9	21.4
Liquid limit (%)	41.0	46.0	43.5
Plastic limit (%)	21.0	23.0	22.0
Plasticity index (%)	18.0	24.0	21.0
Bulk unit weight ($^{KN}/m^3$)	19.7	20.2	19.5
Dry unit weight ($^{KN}/m^3$)	15.5	16.3	16.0
Specific gravity	2.57	2.58	2.58
Initial void ratio	0.548	0.595	0.572
Undrained cohesion	50	60	55

(kPa)			
Angle of internal friction (^{o})	5	6	6

Table 2 : Soil Classification (Atterberg Limits)- Rumuokwuta

Borehole No.	Depth of Sample (m)	Liquid Limit (%)	Plastic Limit	Plasticity Index (PI) %	Unified Soil Classification System (USCS)
1	2.0	41	23	18	CI
2	1.0	43	21	22	CI
3	3.0	46	22	24	CI

Table 3: Strength Test (Unconsolidated Undrained Triaxial Compression Test

Borehole No.	Depth of Sample	Natural Moisture Content %	Bulk Unit Weight (kn/m^3)	Dry Unit weight (kNm^3)	Undrained Cohesion (kPa)	Angle of Internal Friction (^{o})	Description of soil
1	4.0	21.1	19.7	16.3	55	6	Soft to firm Sandy Clay
2	2.0	24.7	20.2	16.2	50	5	Soft to firm Sandy Clay
3	3.0	20.6	19.9	15.5	60	5	Soft to firm Sandy Clay

Table 3 shows the results of the unconsolidated undrained triaxial test. The result indicated that the undrained cohesion of the soil ranges from 50-60kPa with corresponding internal friction angel of between 5 to 6^{o}.

Compressibility and strength tests

Laboratory consolidation tests were conducted on selected cohesive samples to determine the compressibility characteristics of the cohesive soils using an Oedometer. The cylindrical test specimen was placed carefully in a standard single drainage fix-ring Oedometer that confines the material to zero lateral deformation during the test [Nwankoala, 2016]. Porous stone was placed at the lower part of the test specimen to allow gravitational water contained in the sample to dissipate, allowing volume change. Increments of vertical stress are applied, and the vertical displacement is recorded for each of the increments. Each load increment was maintained for about 24 hours or until the change in height of the specimen with time became negligible. Detailed results are presented in Figure 4.

Bearing Capacity Analysis

The conventional method of foundation design is based on the concept of the bearing capacity or safe bearing pressure of the soil [Abam, 2018; Ademila, 2017]. The bearing capacity is defined as the load or pressure developed under the foundation without introducing damaging movements in the foundation or in the superstructure supported by the foundation [Teme, 2017]. Damaging movements may result from foundation failure or excessive settlement. The two criteria often used are:

1. Determination of the bearing capacity of soil and the selection of an adequate factor of safety (usually between 1.5 and 3).
2. Estimating the settlement under the anticipated load and comparing it to the allowable settlement [Nwankoala, 2016)].

In our computation of the bearing capacity of the subsoils, the method proposed by Meyerhof (19) was adopted. This is given as:

$$q_u = C.N_C S_C d_C + qN_q S_q d_q + \nabla.5BYN_y S_y d_y \qquad \text{Eqn 1}$$

Where:

q_u = ultimate bearing capacity of the foundation soil

C = undrained cohesion

q = effective overburden pressure

B =width of foundation

N_c, N_q, N_y = Meyerhof's bearing capacity factors

S_c, S_q, S_y = Meyerhof's shape factors

d_c, d_q, d_y = Meyerhof's depth factors

Table 2 summarizes the results of the ultimate bearing capacities and the allowable bearing pressures at various shallow foundation depths (1.0m, 1.5m and 2.0m) using a factor of safety of 3.

Table 3 shows the results of the unconsolidated triaxial test. The result indicates that the undrained cohesion of the soil ranges from 50-60kpa with corresponding internal friction angle of between 5 to 6^o.

Table 4: Summary of Ultimate / Safe bearing pressure

Foundation	**Foundation**	**Ultimate Bearing Capacity**			**Allowable Bearing Pressure**		
Depth	**Width B**	**L/B -1**	**L/B-1.5**	**L/B-5**	**L/B -1**	**L/B-1.5**	**L/B-5**
1	1	354.60	354.55	354.47	118.20	118.18	118.16
	1.5	354.87	354.84	354.79	118.29	118.28	118.26
	2	355.14	355.13	355.12	118.38	118.38	118.37
	2.5	355.41	355.42	355.44	118.47	118.47	118.48

	5	356.76	356.89	357.06	118.92	118.96	119.02
	10	359.46	359.81	360.30	119.82	119.94	120.10
1.5	1	368.73	368.68	368.60	122.91	122.89	122.87
	1.5	369.00	368.97	368.92	123.00	122.99	122.97
	2	369.27	369.26	369.25	123.09	123.09	123.08
	2.5	369.54	369.55	369.57	123.18	123.18	123.19
	5	370.89	371.02	371.19	123.63	123.67	123.73
	10	373.59	373.94	374.43	124.53	124.65	124.81
2	1	382.86	382.81	382.73	127.62	127.60	127.58
	1.5	383.13	383.10	383.05	127.71	127.70	127.68
	2	383.40	383.39	383.38	127.80	127.80	127.79
	2.5	383.67	383.68	383.70	127.89	127.89	127.90
	5	385.02	385.15	385.32	128.34	128.38	128.44
	10	387.72	388.07	388.56	129.24	129.36	129.52

Table 5: Consolidated Settlement Calculation

Foundation Depth(m)	**Foundation Width B(m)**	**Settlement (mm)**		
		L/B -1.5	L/B -2	L/B - 5
1	1	17.2992	19.584	27.744
	2	34.5984	39.168	55.488
	3	51.8976	58.752	83.232
	4	69.1968	78.336	110.976
	5	86.496	97.92	138.72
	10	172.992	195.84	277.44
1.5	1	12.2112	13.824	19.584
	2	24.4224	27.648	39.168
	3	36.6336	41.472	58.752
	4	48.8448	55.296	78.336
	5	61.056	69.12	97.92
	10	122.112	138.24	195.84

Settlement Calculations

Settlement of shallow foundation was computed assuming a foundation pressure of 100Kpa for various foundation depths (1.0m and 1.5m) using the relationship is given as:

$S_C = Mv.\Delta P.H$

Where;

S_C = consolidation settlement

Mv = coefficient of volume compressibility

H = the thickness of consolidating layer

ΔP = average imposed pressure due to load on consolidating layer.

LOCATION: **RUMUOKWUTA** DATE: **AUGUST, 2019**

BOREHOLE No.: **1**

DEPTH OF SAMPLE **4.0m**

Minor Principal Stress	Deviator Stress	Major Principal Stress
σ_3 (kN/m^2)	$\sigma_1 - \sigma_3$ (kN/m^2)	σ_1 (kN/m^2)
100	147	247
200	160	360
300	190	490

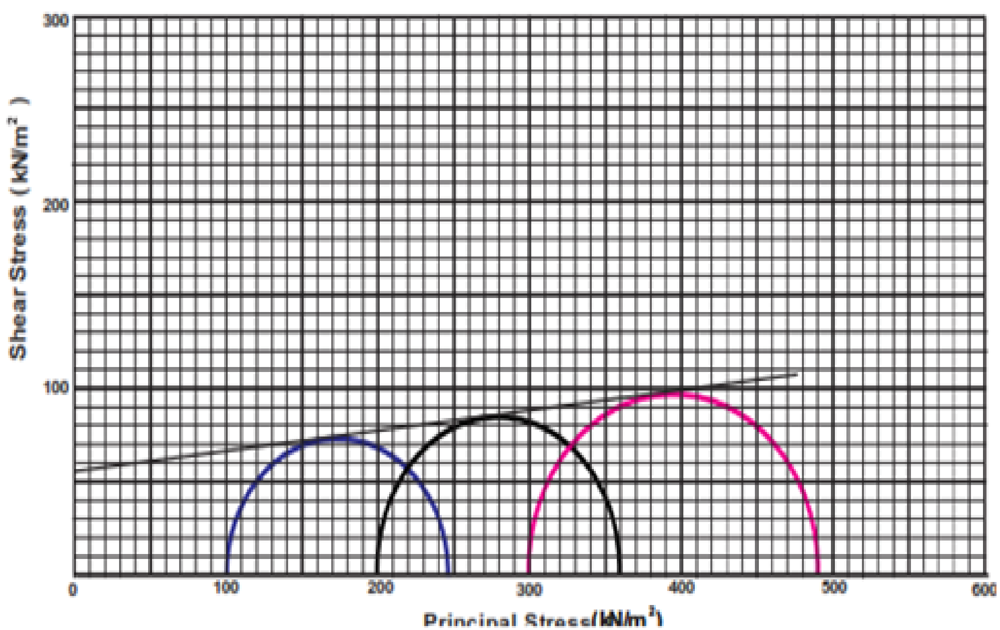


Figure 4 : Graphical presentation showing shear stress against principal stress at 4m depth

LOCATION:RUMUOKWUTA

BOREHOLE No.:2

DEPTH OF SAMPLE 2.0m

DATE: AUGUST, 2019

Minor Principal Stress	Deviator Stress	Major Principal Stress
σ_3 (kN/m²)	σ_1 - σ_3 (kN/m²)	σ_1 (kN/m²)
100	124	224
200	131	331
300	152	452

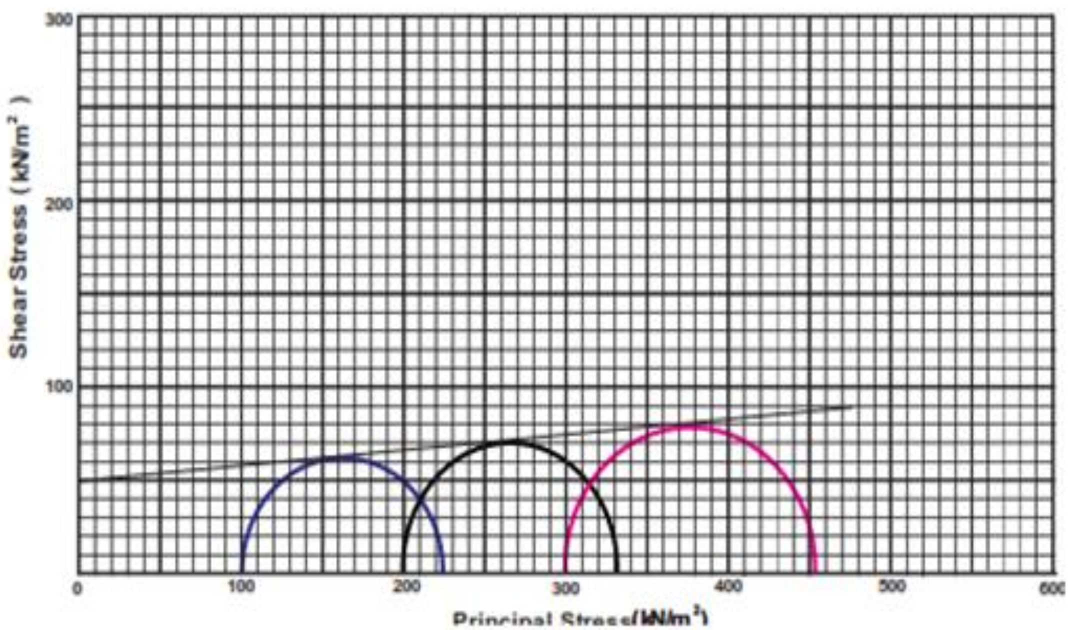
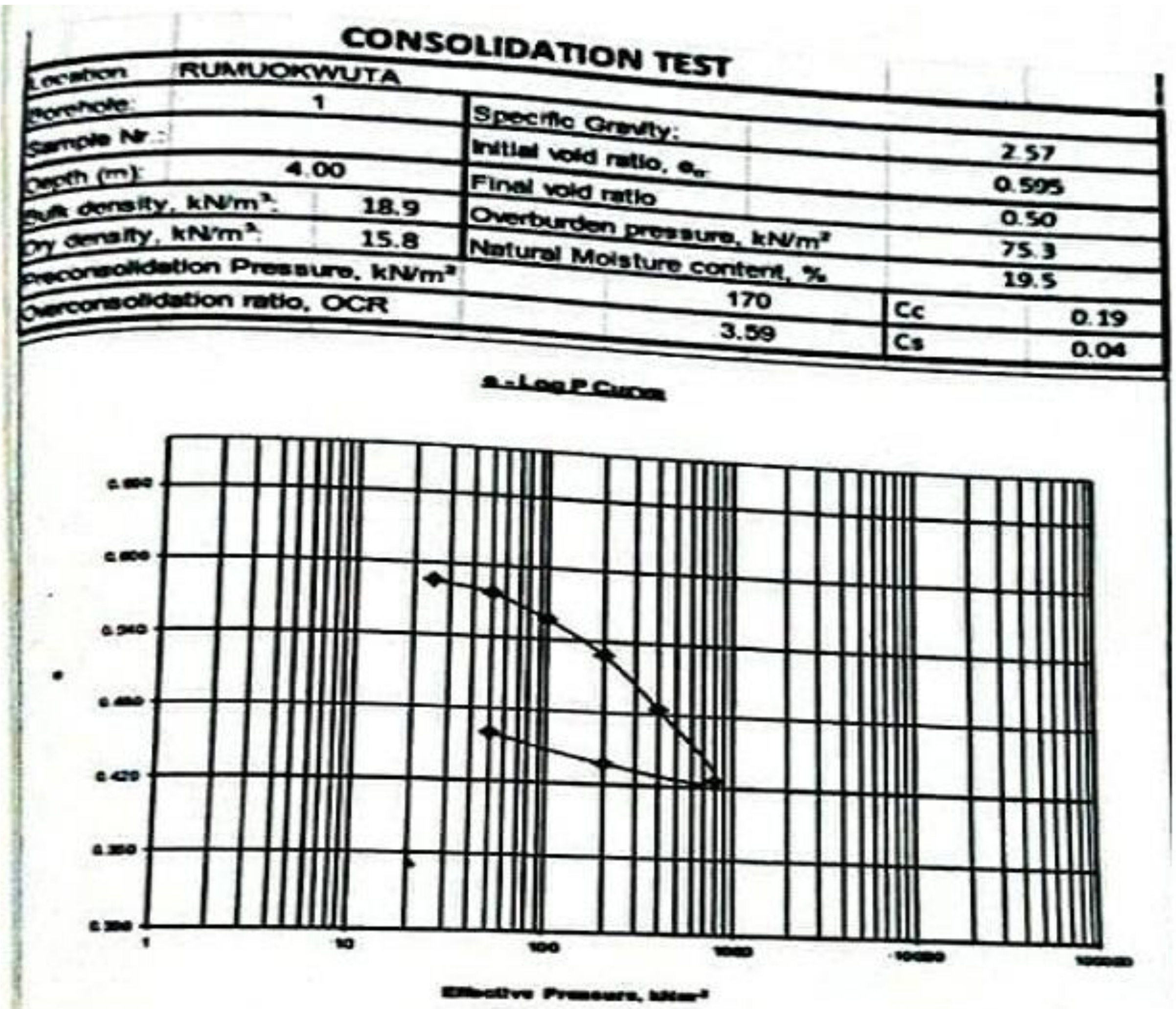


Figure 5 : Graphical presentation showing shear stress against principal stress at 2 m depth



Pressure kN/m^2	Void ratio (e)	M $_v$ (m^2/year)	C $_v$(m^2/year)	K $_v$(10^8)cm/s)
25	0.585	0.22	89.03	61.24
50	0.576	0.25	42.84	33.67
100	0.556	0.18	28.85	16.07
200	0.528	0.15	39.61	17.98
400	0.484	0.10	30.55	9.18
800	0.426			

Figure 6: Graphical Representatin of Consolidation Test

Discussion

The study delineated two stratigraphic units. Within a depth range of 0.0–0.3 m, the top soft/firm clayey sand is dark brown in color. It is fine to medium in grain size.

The second layer, which is beneath the top stratum, is the lateritic sandy silty clay, at a depth of 0.30–3.0m. It is fine-to coarse grained and brownish in color. It has the following geotechnical properties: moisture content (Wn) of 20.6–24.7%, a liquid limit (LL) range of 41–46%, plastic limit (PL) range of 21–23%, and a dry unit weight of 15.5–16.3%. The undrained cohesion and angle of internal friction are 50–60 kPa and 5-6^o respectively. This is summarized in Tables 2 and 3.

The moisture content and movement of water are determining factors of the foundation bearing capacity of the subsoils. The moisture content is an indicator of the shear strength of soils [Abam, 2018; Teme, 2017], as an increase in moisture content leads to a decrease in shear strength.

The high moisture content conforms to the general high porosity. Also, the values of the liquid limit are an indication of the intermediate plasticity of the soil [Abija et. al 2018]. Under the Unified Soil Classification Scheme (USCS), it belongs to the CL. This means it has good to fair compactor characteristics, medium compressibility, and impervious drainage [Ademila, 2017], and the result of the Oedometer consolidation test, as presented in Figure 4 and is indicative of the soil having a high compactive ability; its values range from 0.10 to $0.22m^2/y^r$.

Bearing Capacity

Both the ultimate bearing capacity and the allowable bearing pressures at various foundation depths (1.0 to 2.0 m) on a foundation (1.0 to 10.0 m) were computed, taking L/B ratios of 1 to 5m. At a depth of 1.5m (about the depth recommended), the allowable bearing pressures for 4B 1 and 1.5 are 123.00 kPa and 122.99 kPa, respectively. Other bearing capacity values as computed are presented in Table 5.

Settlement

A prediction of the settlement was made from the summation of the vertical strains caused by the foundation. The soil beneath the foundation was taken as a single layer, and the coefficient of volume compressibility (M_v) obtained. At foundation level 1.5 m, foundation width 3 m, and L/B = 1.5, the settlement value was 36.63 mm, while at L/B = 2, the settlement increased to 41.4 mm. However, an allowable bearing pressure of 100 kN/m^2.

Kpa is recommended in order to keep the total settlement within limits. Where the foundation footings are too close to each other, a raft foundation may be considered.

Foundation Recommendations

From the analysis of the data from various tests, the feasibility of adopting a shallow foundation for the proposed structure is tolerable. As a result, soil bearing characteristics within normal shallow foundation placement are moderate. However, settlement considerations often govern the allowable bearing pressure chosen for the design of a foundation, and this may be less than the safe bearing pressure obtained for the soil. It is recommended that a minimum shallow foundation depth of 1.4 m be adopted as an alternative to the deep foundation option.

Conclusion

Subsoil investigation was done for appropriate structural foundation design. The study revealed two soil types, with distinct geotechnical characteristics within the depth of the study. Based on the results of the study, recommendations have been given as regards foundation type. It is believed that the results of this investigation will be useful in designing and constructing the right foundation for the structure. This is the starting point for sustainable structural design and construction.

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