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Investigation of Suitable Foundation for Storey Building in Surcharged Swampy Soil (A Case Study of Lagos State)

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Abstract
In Lagos, Southwestern Nigeria, the land area has been developed such that there are insufficient land spaces for building construction. It therefore becomes imperative that construction of storey buildings is inevitable to accommodate buildings within the limited land spaces. The percentage of swampy – land is high, thus restricting people to build on the little available land with little or no convenience and to effectively utilize the available land, there is need to improve the large percentage of swampy–land for construction of storey building with suitable foundation. This study therefore focused on determination of soil properties for building foundations at 1.5km South of Lagos – Epe Expressway Oloja, Ibeju Lekki Local Government Area of Lagos State.Soil samples were collected from open pits in five different locations within the study area. The undisturbed samples were obtained at depths of 3m and were carefully transported by putting each of the samples in polythene bag and then kept in sealed container before being transported.The particle size distribution analysis of selected soil samples from the study area was carried out in accordance with the provision of BS1377: Part 2, 1990. Compaction test, Unconfined compression Strength (UCS) test and bearing capacity test were all carried out on the collected soil samples.The results of the tests carried out on the selected soil samples showed that the soil in the study area was largely made up of silty-clay material with OMC and MDD ranging from 9.60-12.5% and 1.82-1.91 g/cm^3 respectively; UCS values between 22.24 – 56.67 kN/m^2 and allowable soil bearing capacity ranging from 90.95 to 106.26 kN/m^2. It is recommended that Raft foundation be used for bungalows while beam/slab raft should be used for structures that have 2-5 storeys and pile foundation for structures above 5 storeys in order to cater for silt-clay nature of the soil and to prevent differential settlement in future.
Keywords: Swampy Soil, consolidation, foundation, storey building,

1.0 Introduction

The population of people living in Lagos southwestern Nigeria has increased tremendously and this has made the available land spaces close to good social amenities to be depleted. The little available land spaces are filled with highrise buildings. The condition of many highrise buildings in most places in Lagos is precarious and no more ideal or suitable for its intended purpose. There has been reported cases of loss of lives and properties resulting from collapse of public and private buildings due to poor construction method, inappropriate choice of foundation type and foundation failures. The soil conditions in the urban areas can be described as slum (Adedeji, 2013)

In Lagos the hectares of land available for building is far short of the population requirement and the percentage of swampy land is high, thus restricting people to build on the little available land with little or no convenience. Since the little available land has to be fully utilized, there is need study the capacity of soils in the study area with a view to improving them or make a suitable choice of foundation type for construction of storey building.

In surcharge swampy/marshy areas, the option of soil improvement may need to be employed considering the nature of soil on the study area (Bowlee, 1996) but in this study the option of suitable foundation type was explored.

2.0 Collection of Soil Sample and Tests

Samples were collected from open pits in five different locations. The pits were hand dug. The depth of obtaning the sample was about 3m. The samples were carefully transported by putting each of the samples in polythene bag and then kept in sealed container before being transported so that the samples will not be subjected to stresses since we want to test undisturbed samples. The principal aim of obataining undisturbed samples was to make sure that there is no change in the behaviour of the samples from the point of collection up to the laboratory where they were tested.

2.1 Sieve Analysis

The sieve analysis was carried out in accordance with the provision of BS1377: Part 2, 1990. The sample of the soil was oven dried for about three hours. After proper drying, the sample was pulverized by means of wooden mortal and rubber pestle. Suitable quantity of soil sample was taken and sieve through BS 4.75mm sieve. The soil retained on the 4.75mm sieve (+4.75mm fraction) was subjected to a coarse analysis consisting of the soil through the net of sieve of 20mm, 8mm, 4mm, and 2mm sieve. Each set of sieve was shaken continuously to ensure the passage of particle through the various sieves. The particle retained on each sieve was weighed and the percentage weight retained on each sieve determined for each sample.

2.2 Compaction test

An air dried sample of the soil was pretreated and passed through the 20mm BS sieve with the particle retained being discarded and those passing collected for the compaction. The empty weight of the mould was taken using a balance readable to 1g and recorded. A quantity of the collected soil was weighed and mixed with a measured volume of water. The volume of water used was not fixed but based on the soil texture and for subsequent trials. The soil mixing was done manually using a scoop and trowel and three layers of the soil were introduced into the mould whose base plate was already covered with filter paper to prevent adherence. The quantity of the soil for each layer was such that three of it filled the mould. 27blows of 2.5kg metal rammer from a height of 300mm were applied to each layer. After compacting the three layers, the collar was removed and excess soil was scrapped with a straight edge. The mould and compacted soil was then weighed to determine the wet bulk density. A sample of the soil was collected for moisture content determination from both the top and bottom of the mould.

This procedure was repeated four times. Maximum dry density and optimum moisture content was determined. Compaction curves were obtained by plotting dry density against moisture content for each of the five samples on the same axes for easy comparison of results. The maximum dry density and optimum moisture content were determined from the graph.

Where
p = Bulk density
w = moisture content

2.3 Unconfined Compression Test

The unconfined compression test is a quick, relatively inexpensive means of obtaining an estimation of the undrained shear strength of cohesive specimens. In this test, a cylindrical specimen of the soil is loaded axially as shown in Figure 1 without any lateral confinement to the specimen, at a sufficiently high rate to prevent drainage.

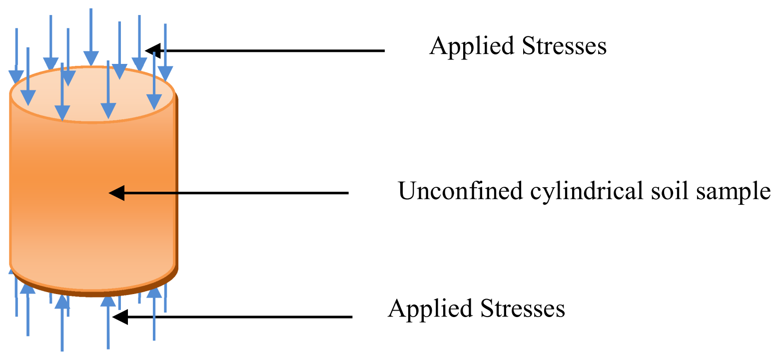

Figure 1: Schematic diagram of an unconfined compression test

According to the ASTM D 2166 standard, the unconfined compressive strength (qu) is defined as the compressive stress at which an unconfined cylindrical specimen of soil (Figure 2) will fail in a simple compression test. Since there were no confinements, the residual negative pore pressures that may exist in the sample following sample preparation generally controlled the state of effective stress in the sample. The shear stresses induced in the specimen by the axial load resulted in a shear failure. The magnitude of the shear stress at the moment of failure represents the shear strength of the soil under these conditions of loading and drainage. Therefore, the shear strength obtained from this test is called the undrained shear strength (su). In most cases, the value of undrained shear strength obtained from an unconfined compression test is conservative. The maximum axial compressive stress measured at failure represents the compressive strength of the soil under these conditions of loading, drainage, and confinement. Therefore, the compressive strength obtained from this test is called the unconfined compressive strength (qu).

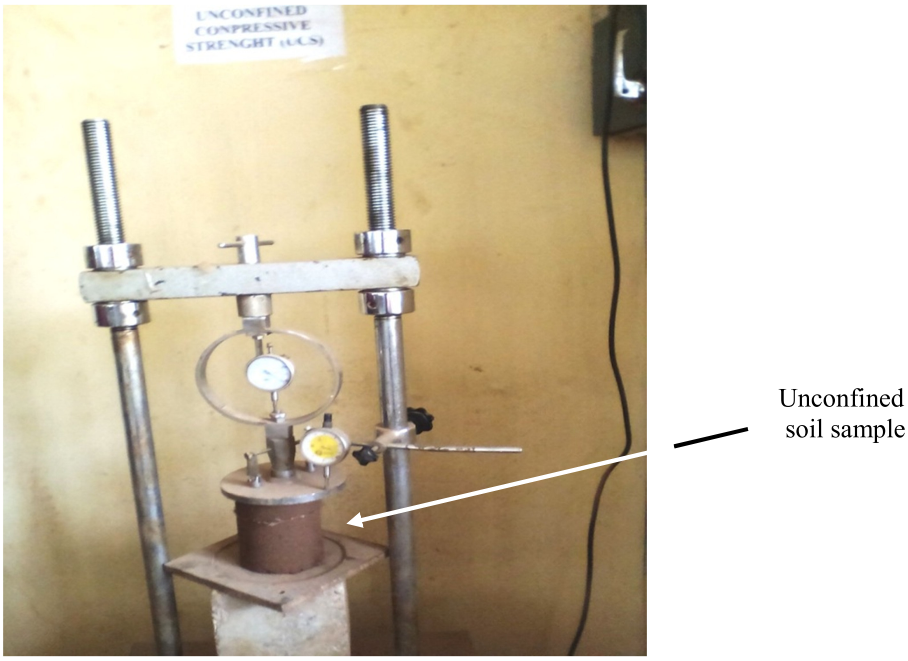

Figure 2: Unconfined Compression test machine

The soil sample was extruded from Shelby tube sampler and the soil specimen was cut so that the ratio (L/d) is approximately between 2 and 2.5 where L and d are the length and diameter of soil specimen respectively. The exact diameter of the top of the specimen was measured at three locations 120° apart, and the same measurements were made on the bottom of the specimen. Average of the measurements was taken and recorded as the diameter on the data sheet. The exact length of the specimen at three locations 120° apart was measured and the average was taken and recorded as the length on the data sheet. The weight of the sample was taken and the mass was recorded on the data sheet. The deformation (DL) corresponding to 15% strain (e) was calculated.

a. Strain (e) = Lo/DL
b. Where Lo = Original specimen length (as measured in step 3).

The specimen was carefully placed on the compression device and centered on the bottom plate, adjusting the device so that the upper plate made contact with the specimen and the load and deformation dials was set to zero. The load was applied such that the device produced an axial strain at a rate of 0.5% per minute, and the load and deformation dial readings was then recorded on the data sheet at every 20 divisions on deformation the dial. The load was applied until

(i) The load (load dial) decreased on the specimen significantly,
(ii) The load remained constant for at least four deformation dial readings, or
(iii) The deformation significantly past the 15% strain that was determined in step 5.

The sample from the compression device was removed and a sample for water content determination was obtained.

2.4 Atterbergs' Limit Test

About 200g of the soil sample passing through BS sieve number 36 (425um BS sieve) was measured and taken into a porcelain dish. Some quantity of distilled water was added to it and thoroughly mixed to form a soil paste of uniform colour. Some of the paste was put inside the cup of the Cassangrande twice and leveled with palette knife or spatula. The cup was given blows by manual operation of handle or by electrically operated motorized system, the rotation of handle being at the rate of 2rev/sec. the number of blows required close to close the groove for a distance of 13mm was noted down. Part of this paste was collected in the moisture content can and number of blows at that point was recorded.

The whole process was repeated four times with the original dry sample while the quantity of distilled water added varies. The moisture content values were plotted against the corresponding number of blows and linear graph was obtained. The moisture content at the 25th blow was read and this was the value of the liquid limit. About 20g of material passing the 0.425mm (No 40) sieve was obtained. The soil was mixed with water until the mass becomes plastic enough to be easily shaped into a ball. An approximately 8g of the soil was obtained to run the plastic limit test.

From the sample a 1.5g to 2g mass was pulled and squeezed and formed the test samples into an ellipsoidal-shape mass. The mass was rolled between the palm and the rolling surface with just sufficient pressure to roll the mass into a thread of uniform diameter along its length. Between 80 and 90 strokes per minute were rolled out, counting a stroke as one back and forth motion. The sample was rolled into the 3mm (1/8in) thread in no longer than two minutes. The thread was then broken into eight pieces when the diameter of the thread reached 3mm (1/8in). The pieces were squeezed together between the thumbs and fingers of both hands into an ellipsoidal shape mass and rerolled. The process was continued alternately rolling to a thread 3mm (1/8in) in diameter, cutting into pieces gathering together, kneading and rolling until the thread crumbles under the pressure required for rolling and the soil can no longer be rolled into a thread. The portions of the crumbled soils were gathered and placed in a container and covered. These steps were repeated until 8g of sample have been tested and placed in the covered container. The moisture content of the sample were determined.

3.0 Results and Discussion

3.1 Sieve Analysis

The sieve analysis results for all the 5 samples are as presented in Tables 1- 5 while particle size distribution curves for the 5 samples are as shown in Figure 3.

Table 1: Sieve Analysis for Sample 1

DATA RECORDING			SIEVE ANALYSIS		
Sieve: Alt Designation	Siev Dia. (mm)	Mass retained (g)	Percentage retained (%)	Cum. Percentage Ret (%)	Percentage Passing (%)
¾ in	20.000	0.00	0.00	0.00	100
$^5/_6$ in	8.000	0.00	0.00	0.00	100
No 5	4.000	0.00	0.00	0.00	100
No 10	2.000	13.00	3.25	3.25	96.75
No 18	1.000	17.00	4.25	7.25	92.75
No 35	0.500	20.60	5.15	12.65	87.35
No 40	0.425	46.80	11.70	24.35	75.65
No 60	0.250	24.00	6.00	30.35	69.65
No 80	0.180	22.70	5.68	36.03	63.97
No 120	0.125	31.50	7.88	43.91	56.09
No 200	0.075	6.90	1.73	45.64	54.36
No 200	0.075	217.5	54.38	100.00	0.00

Table 2: Sieve Analysis for Sample 2

DATA RECORDING			SIEVE ANALYSIS		
Sieve: Alt Designation	Siev Dia. (mm)	Mass retained (g)	Percentage retained (%)	Cum. Percentage Ret (%)	Percentage Passing (%)
¾ in	20.000	0.00	0.00	0.00	100
$^5/_6$ in	8.000	0.00	0.00	0.00	100
No 5	4.000	0.00	0.00	0.00	100
No 10	2.000	0.80	0.20	0.20	99.80
No 18	1.000	12.00	3.00	3.20	96.80
No 35	0.500	32.40	8.10	11.30	88.70
No 40	0.425	18.00	4.50	15.80	84.70
No 60	0.250	24.20	6.05	21.85	78.15
No 80	0.180	29.90	7.48	29.33	70.67
No 120	0.125	38.00	9.50	38.83	61.17
No 200	0.075	4.50	1.13	39.96	60.05
No 200	0.075	240.20	60.05	100.00	0.00

Table 3: Sieve Analysis for Sample 3

DATA RECORDING			**SIEVE ANALYSIS**		
Sieve: Alt Designation	Siev Dia. (mm)	Mass retained (g)	Percentage retained (%)	Cum. Percentage Ret (%)	Percentage Passing (%)
¾ in	20.000	0.00	0.00	0.00	100
$^5/_6$ in	8.000	0.00	0.00	0.00	100
No 5	4.000	0.00	0.00	0.00	100
No 10	2.000	4.20	1.05	1.05	98.95
No 18	1.000	19.00	4.75	5.80	94.20
No 35	0.500	33.60	8.40	14.20	85.80
No 40	0.425	74.40	18.60	32.80	67.20
No 60	0.250	18.90	4.73	37.53	62.47
No 80	0.180	21.00	5.25	42.78	57.22
No 120	0.125	40.80	10.20	52.98	47.02
No 200	0.075	9.20	2.30	55.29	44.72
No 200	0.075	178.90	44.73	100.00	0.00

Table 4: Sieve Analysis for Sample 4

DATA RECORDING			**SIEVE ANALYSIS**		
Sieve: Alt Designation	Siev Dia. (mm)	Mass retained (g)	Percentage retained (%)	Cum. Percentage Ret (%)	Percentage Passing (%)
¾ in	20.000	0.00	0.00	0.00	100
$^5/_6$ in	8.000	1.20	0.30	0.30	99.70
No 5	4.000	2.60	0.65	0.95	99.05
No 10	2.000	2.80	0.70	1.65	98.35
No 18	1.000	11.60	2.90	4.55	95.45
No 35	0.500	40.60	10.15	14.70	85.30
No 40	0.425	16.00	4.00	18.70	81.30
No 60	0.250	29.10	7.28	25.98	74.02
No 80	0.180	42.00	10.50	36.48	63.52
No 120	0.125	30.30	7.58	44.06	55.94
No 200	0.075	2.00	0.50	44.56	55.44
No 200	0.075	221.80	55.45	100.00	0.00

Table 5: Sieve Analysis for Sample 5

DATA RECORDING			SIEVE ANALYSIS		
Sieve: Alt Designation	Siev Dia. (mm)	Mass retained (g)	Percentage retained (%)	Cum. Percentage Ret (%)	Percentage Passing (%)
¾ in	20.000	0.00	0.00	0.00	100
$^5/_6$ in	8.000	0.00	0.00	0.00	100
No 5	4.000	2.40	0.60	0.60	99.40
No 10	2.000	11.00	2.75	3.35	96.65
No 18	1.000	30.40	7.60	10.95	89.05
No 35	0.500	82.80	20.70	31.65	68.35
No 40	0.425	12.10	3.03	34.68	65.32
No 60	0.250	14.70	3.68	38.36	61.64
No 80	0.180	39.50	9.88	48.24	57.76
No 120	0.125	52.30	13.08	61.32	38.68
No 200	0.075	6.40	1.60	62.92	37.08
No 200	0.075	148.40	37.10	100.00	0.00

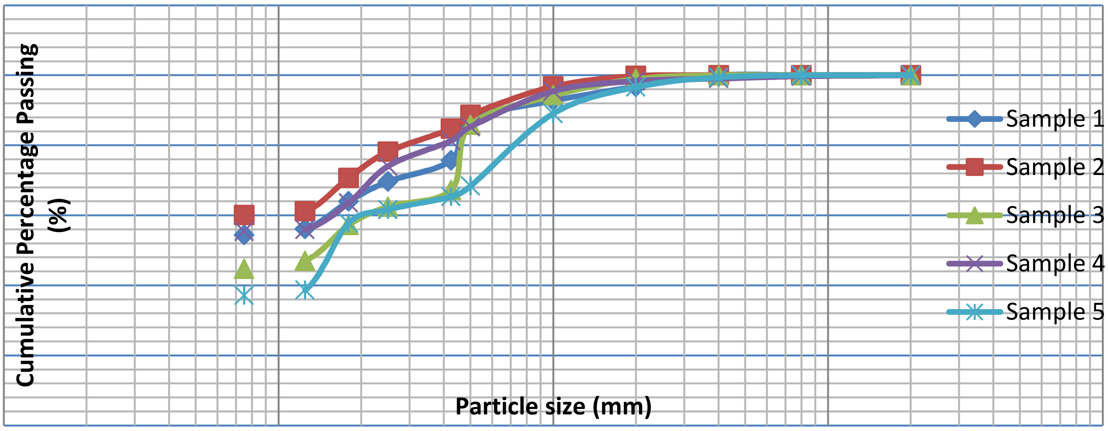

Figure 3: Particle size distribution curves for the 5 samples

The results of sieve analysis showed that all the soil smples fall withing the range of silty-clay soil particle

3.2 Compaction tests results

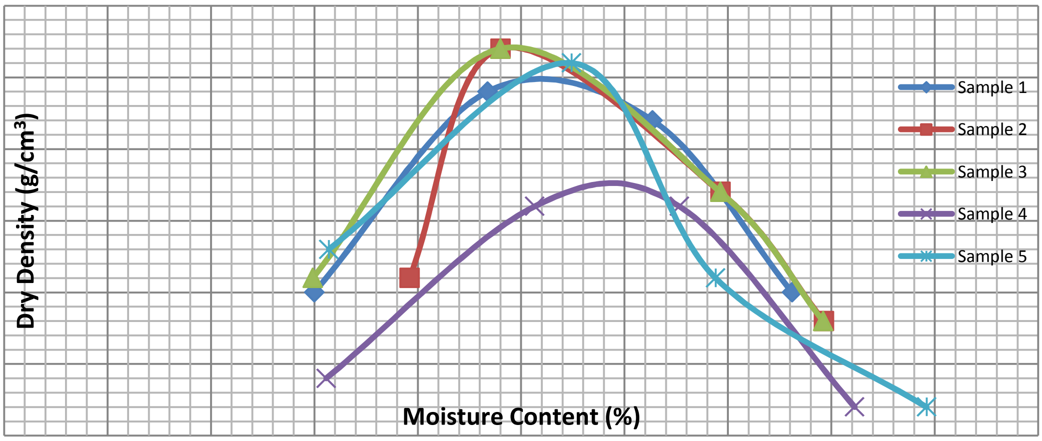

Figure 4: Result of compaction for sample 1

From the Figure 4, the MDD and OMC obtained from the compaction test on the five samples are as presented in Table 6.

Table 6: Summary of Result of Compaction Test

Sample No.	MDD (g/cm^3)	OMC (%)
1	1.89	10
2	1.83	12.5
3	1.92	9.6
4	1.82	11.5
5	1.91	11.0

3.3 Unconfined Compressive Strength (UCS) Test Results

The properties of each of the soil sample collected for the test are as presented in Table 7.

Table 7: Properties of the Soil Sample collected for test

Specimen Ref	Soil Type	Specimen Mass (g)		Moisture Content (%)	Specimen Size			Density (g/cm^3)	
		Wet (Mw)	Dry (Md)		Diam (mm)	Height L_0 (mm)	Volume (cm^3)	Bulk Pd = $Mw/\pi r^2 L_0$	Dry Pd = Pw/(1+w)
1	Disturbed	1940	1780	9.00	105	115	996	1.95	179
2	Disturbed	1920	1760	9.10	105	115	996	1.93	1.77
3	Disturbed	1980	1790	10.6	105	115	996	1.99	1.97
4	Disturbed	2100	1930	8.8	105	115	996	2.11	1.94
5	Disturbed	1940	1790	8.40	105	115	996	1.95	1.80

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The soil sample of diameter 10.5 cm, the cross-sectional area of the sample A_o is computed as
The corrected area is computed as:

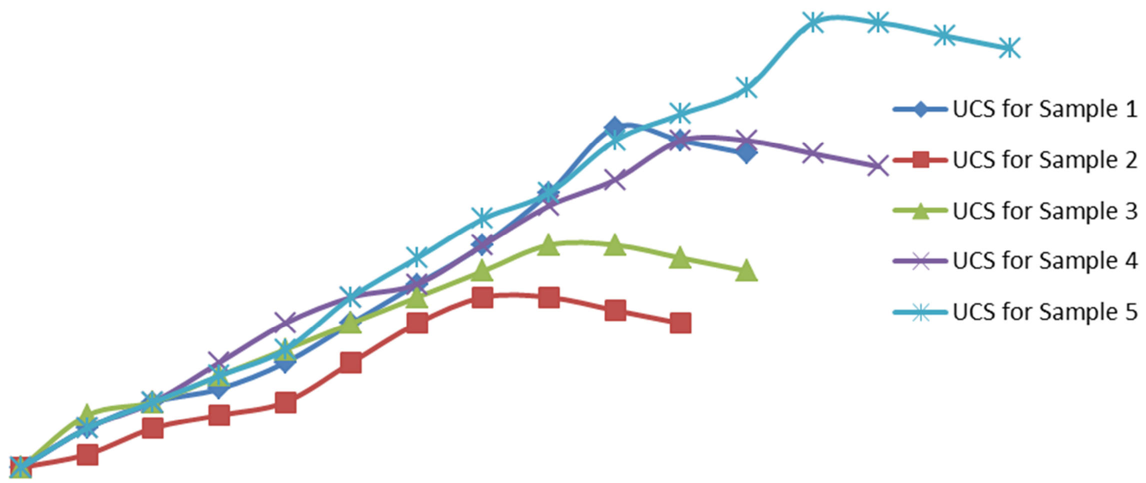

Figure 5: Unconfined Compressive Strength Test Results

3.3.1 Calculation of the UCS for each of the Tested Samples

The UCS for each of the tested sample is calculated based on the failure loads and the corresponding deformation only, these are obtained from Figure 5. Details of the calculation are as presented in Table 8.

Table 8: Stress calculation sheet for UCS of samples

Specimen Ref. Sample	Soil Type	STRAIN DIAL UNIT DEFLECTION (η) = 0.01mm LOAD RING (PRF) = $0.15kN/m^2$						
		FAILURE STRAIN			Corrected X – Sectional Area = $(A_0/1- \varepsilon)$ (m^2)	FAILURE LOAD		UCS (P/A) kN/m^2
		Reading (mm)	Change in Length (ΔL)	Strain (ε) $(\Delta L/L_o)$		Reading (N)	Load (P) (N.PRF)	
1	Disturbed	180	1.80	0.0160	0.00880	26	0.390	44.318
2	Disturbed	140	1.40	0.0120	0.00877	13	0.195	22.235
3	Disturbed	160	1.60	0.0140	0.00879	17	0.255	29.010
4	Disturbed	200	2.00	0.0174	0.00881	25	0.38	42.57
5	Disturbed	240	2.40	0.02087	0.00900	34	0.51	56.67

Summary of Results of UCS Tests

Unconfined Compressive Strength test was carried out on the five samples to provide value of the strength of the soils in term of total stress. The test results are as presented in Table 8 and the graphical presentation of the results are as shown in Figure 5 where load was plotted against the deformation strain. The load at failure for each sample was recorded with corresponding axial deformation. Maximum axial stress is reported as UCS for the sample as shown in Table 8.

3.4 Summary of Result of Allowable Bearing Capacity (qa)

The bearing capacity of the soil samples from five locations was determined using factor of safety of 3, values of the test results for the five soil samples range from 91 to $108kN/m^2$. Table 9 summarizes the results.

The ultimate Bearing Capacity is given by:

For square Footings: $qu = 1.3CNc + \gamma zNq + 0.4\gamma BN\gamma$

Allowable Bearing Capacity, $qa = {}^{qu}/_{3}$ factor of safety

Where:

γ_b= bulk density, γ_d = dry density, M = moisture content, H = depth, B = width, C_u = cohesion, Φ = angle of shearing resistance, and (N_c, N_q and N_γ) = bearing capacity factors

Table 9 Result of Bearing Capacity(q_a) Tests

Sample	γ_b (kN/m^3)	γ_d (kN/m^3)	M (%)	H (m)	B (m)	C_u (kN/m^2)	Φ	N_c	N_q	N_γ	q_u (kN/m^2)	q_a (kN/m^2)
1	11.92	9.94	19.96	1.20	0.80	0.00	-	-	17	13	292.76	97.59
2	12.98	10.77	20.57	1.20	0.80	0.00	-	-	17	13	318.79	106.26
3	11.11	9.35	18.83	1.20	0.80	0.00	-	-	17	13	272.86	90.95
4	13.21	11.03	19.80	1.20	0.80	0.00	-	-	17	13	324.44	108.15
5	12.75	10.68	19.42	1.20	0.80	0.00	-	-	17	13	313.14	104.38

3.5 Summary of results of Atterberg Limits tests

Figure 6 shows the plot of result of the Artterberg limit tests carried out on the soil samples while Table 10 shows the calculation of plasticity index based on the values of the liquid limits obtained from Figure 6. The moisture content which corresponds to the number of blows of 25 gives the liquid limit (LL) while the plastic limit (PL) is the air dry moisture content and the difference of LL and PL gives the plasticity index (PI).

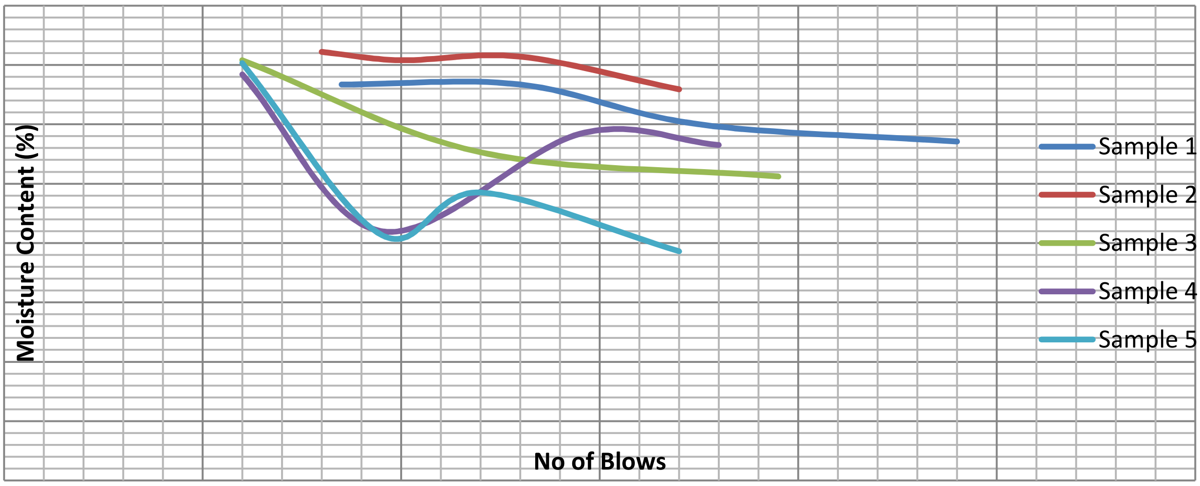

Figure 6: Plasticity Properties of Soil Samples

Table 10: PI Calculation from the test results

Test Result(s)	LL (%)	PL (%)	PI (%)
Sample 1	64	42	22
Sample 2	70	41	29
Sample 3	58	26	32
Sample 4	61	31	30
Sample 5	49	36	13

4.0 CONCLUSION

From the analysis of the results obtained from the laboratory test conducted on the Ibeju Lekki Local Government Area of Lagos state, Nigeria. The following conclusion can be drawn:

(i) Using AASHTO classification method, all samples 1 to 5 is classified as A-7 rated silt-clay materials, that is, more than 35% of total sample passing 75um (sieve No. 200).

(ii) The soil samples are made up silty-clay material with little fine gravels. The samples 1 to 5 have the highest percentage of silty- clay and sand, percentage of silty-clay ranges from 37 to 60% with sample 2 showing the highest percentage of silty-clay.

(iii) All the soils samples are majorly made up of silty-clay materials (silt and clayey soils).

(iv) The bearing capacity of soil in the study area ranges from 91kN/m^2 and 108kN/m^2 and the UCS results showed that the soil in the study area is generally weak.

5.0 Recommendation

Based on the various soil tests carried out on the study area it is recommended that raft foundation be used for bungalows while beam/slab raft should be used for structures that have 2-5storeys depending on the intended use and pile foundation for structures above 5 storeys building in order to cater for silt-clay nature of the soil and to prevent differential settlement in future.

Consolidation/settlement test should also be carried out on the study area so as to establish the settlement potential of the study area.

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