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Determination of the Settlement Characteristics and Degree of Earth Movement of Soils for the Construction of Building - A Case Study of Eastern Nigeria

P. O. Dike
Department of Civil and Environmental Engineering, Imperial College London, United Kingdom
(osunna.dike18@imperial.ac.uk)

Abstract-Settlement of soil is often inevitable. Soil settlement is amongst the major causes of building failure. It is on this note that this project work was carried out. The sole purpose of this work is to investigate the settlement characteristics of soils for the construction of buildings in Southeastern parts of Nigeria, a case study at the FUTO workshop arena and Umuakpu central area, other objectives are the classification of the soil, determination of the strength properties of theses soils and making of sundry recommendations about the type of foundation most suitable for the construction of buildings on these soils. Physical classification tests were also carried out to determine the nature of the soils present at FUTO workshop arena and Umuakpu central area. These tests are bulk and dry density test, sieve analysis test, and Atterberg limit tests, these tests were conducted in accordance to BS1377. The classification indicated that soils from FUTO workshop arena are lateritic in nature while those from Umuakpu central area are clayey in nature. Soils from FUTO area has shear strength parameters of, Cu= 30 KN $/m^2$ at a depth of about 2m, while those from Umuakpu area had strength parameters of, Cu= 40 KN$/m^2$ at a depth of about 2m. Consolidation test was also carried out and the settlement of the soil was obtained from data obtained from this test. Maximum settlement (short time) displacements of 0.35 mm and 5.29 mm were estimated for soils from FUTO and Umuakpu area respectively assuming a maximum foundation load of 200KN$/m^2$.

Keywords- *Atterberg Limit Tests, Borehole (Also Written as BH), Consolidation, FUTO (Federal University of Technology, Owerri) Lateritic, Settlement*

I. INTRODUCTION

In order to evaluate the suitability of a foundation or earth structure, it is necessary to design against both bearing capacity failure and excessive settlement. For foundations on cohesive soils, the principal design criterion is typically the latter; the control of expected settlements within the limits considered tolerable for the structure. As a result, once allowable foundation displacements have been established, the estimate of total settlement over the service life of the structure is a major factor in the choice of foundation design. According to Level (2011), thorough investigation and assessment of soil condition and settlement properties is essential in determining if a certain soil is suitable for the construction on.

Consolidation is the gradual reduction in the volume of a fully saturated soil of low permeability due to drainage of some of the pore water, while Consolidation settlement is the vertical displacement of the surface corresponding to the volume change at any stage of the consolidation process, Craig (2004).

Structures built on soil are subject to settlement. Some settlement is often inevitable and depending on the circumstances, some settlement is tolerable. For example, small uniform settlement of a building throughout the floor area might be tolerable whereas non-uniform settlement of the same building might not be. Or settlement of a garage or warehouse building might be tolerable, whereas the same settlement (especially differential settlement) of a luxury hotel building would not be because of settlement and a means of computing (or predicting) settlement quantitatively are important to the geotechnical engineer.

Although there are several possible causes of settlement (e.g. dynamic forces, changes in the groundwater table, adjacent excavation, etc.), probably the major cause is compressive deformation of soil beneath a structure, Cheng (2004). Compressive deformation generally results from reduction in void volume, accompanied by rearrangement of soil grains and compression of the material in the voids, Jack (2004).

This Project will help Civil Engineers, contractors and builders who are in the south-eastern Nigeria in the following ways;

i. To know the nature and type of the soil around the study area.

ii. To know the settlement characteristics of the soil within the study area.

iii. To have a better understanding of the type of foundation to be used for the construction of high-rise buildings around the Study area.

iv. Finally, this work is expected to contribute significantly to existing literature in the subject under investigation.

This work is limited to the establishment of data required to determine the Settlement Characteristic of soil for the construction of building. Study area is limited to FUTO workshop arena and Umuakpu central area only. Only materials considered relevant to this work are included.

This work is strongly grounded on Geotechnical specifications and Standards as various laboratory tests and field test are carried out. Laboratory test will be carried out on disturbed and undisturbed sample collected at a depth not more than 2.0 meters below the surface and all soil samples were collected from FUTO workshop arena and Umuakpu central area.

The project is organized in chapters and not structured as a series of classroom lessons or lectures so as to make it adaptable to various teaching environments, including seminars, conferences etc. it does not deal with full details of ethics and principles for carrying out any soil investigation program.

The laboratory tests carried out are:

a. Bulk density and dry density test
b. Sieve analysis (i.e. particle size analysis)
c. Liquid limit test
d. Plastic limit test
e. Triaxial test
f. Consolidation test

II. RESEARCH METHOD

A. Materials and Methods

1) Materials

The major materials required for this study are water and soil. The choice of materials will depend solely on their abundance and proximity from lab and study area.

a) Soil sample

The Soil samples required for this study and laboratory tests were collected from FUTO workshop arena and Umuakpu central area. Both disturbed and undisturbed samples were collected for the laboratory testing. Disturbed samples were collected at 2.0m intervals while undisturbed were collected at 4.0m depth intervals.

b) Water

Good portable water sourced from a borehole tap in the Federal University of Technology Owerri was used for this research work.

B. Test, Procedures and Equipment

Several laboratory tests were carried out for the purpose of this research. Some of the tests include bulk and dry density tests, sieve analysis test, cone penetration test (CPT), triaxial test, consolidation test and Atterberg limit test (Plastic and Liquid limit tests).

1) Sieve analysis test

This laboratory work will be done in accordance to BS 1377 (1990).

a) Aim:

To determine quantitatively the proportions by mass of various sizes of particles present in the soil sample.

b) Equipment:

(1) Set of fine sieves, 2.36mm, 1.18mm, 0.6mm, 0.425mm, 0.300mm, 0.212mm, 0.150mm and 0.063mm (2) Weighing balance with an accuracy of 0.1% of the mass of sample (3) Oven (4) Mechanical shaker (5) Trays (6) Mortar with a rubber covered pestle (7) Brushes (8) Riffler.

c) Procedure:

a. A portion of the soil passing 4.75mm BS sieve was taken and oven dried at about 105° to 100°C. It was weighed to 0.1% of the total mass.
b. The soil was sieved through the nest of sieves. However, care was taken to ensure that no particle was pushed through the sieve.
c. The material retained on various sieves was taken in a mortar and rubbed gently with rubber pestle. 500g of the sample was collected from the pulverized sample. Each of the following set of sieves, 2.36mm, 1.18mm, 0.60mm, 0.425mm, 0.300mm, 0.212mm, 0.15mm and 0.063mm was weighed to the nearest 0.01 gram and recorded.
d. The sieves were then arranged in descending order and placed firmly on the sieve shaker.
e. The soil specimen was then poured into the top sieve; timer set for about 15minutes and the shaker then turned on. After shaking, each sieve was weighed with the content in them to the nearest 0.01gram and recorded.
f. Percentage retained, cumulative percentage retained, and the percentage finer are then obtained based on the initial weighed of the sample.

2) Bulk density and Dry density test (core cutter method)

The bulk density of a soil sample is the mass per unit volume, while the dry density is the mass of solids per unit total volume. The determination of the density and dry density of soil via the core cutter method is a field and laboratory exercise. The core cutter consists of an open cylindrical barrel with a hardened sharp cutting edge.

a) Aim:

To determine the bulk weight (density) and the dry weight (density) of the soil sample.

b) Equipment:

(1) Two cylindrical core cutters (2) steel rammer (3) weighing balance (4) steel dolly (5) palette knife (6) straight edge and steel rule.

c) Procedure:

a. Measure the internal diameter and height of the core cutter to the nearest 0.25mm. Then the masses M_1 of the core cutters are then measured to the nearest grams.

b. The core cutter is then pressed into the soil mass until it is filled with soil. The cutter is then retrieved, and the mass of the cutter and soil sample is then measured and recorded as M_2.

c. The core cutter is then oven dried and the mass of the core cutter with the dry sample was determined and recorded as M_3.

d. The calculation is then done as;

Bulk mass density, $\rho = \frac{M_2 - M_1}{V}$ (1)

Moisture content, $w = \frac{M_2 - M_3}{M_3 - M_1}$ (2)

Dry density, $\rho_d = \frac{\rho}{1-w}$ (3)

3) Liquid Limit Test

This test will be carried out in accordance to BS 1997 (1990).

a) Aim:

To determine the moisture content at which the soil tends to behave like a liquid that flows by shearing.

b) Equipment:

(1) Casagrande's liquid limit device (2) Grooving tools of both standards and ASTM types (3) an Oven (4) Evaporating dish or glass sheet (5) Spatula (6) 0.425mm BS sieve (7) Weighing balance (8) wash bottle

c) Procedure:

a. The top of the liquid limit device should be adjusted by releasing the two screws at the top and by using the handle of the grooving tool. The drop should be exactly 1cm at the point of contact on the base. The screw is then tightened after adjustment.

b. Mix thoroughly an air-dried sample passing the 0.425mm BS sieve with distilled water in an evaporating dish to form a uniform paste, mixing should be done for a period of about 15minutes. Keep the paste in a humid environment to obtain a uniform moisture distribution.

c. Collect some of the paste and remix. Place the sample in the liquid limit device cup via a spatula and level it, using a straight edge until 1cm thick sample is obtained.

d. A groove is then cut in the sample inside the cup via groove tool. The grooving tool should be drawn along symmetrical axis, across the diameter through the center line. The tool should be held perpendicular to the cup.

e. The handle of the device is then rotated at a rate of about 2 revolutions per second. The number of blows is counted until the two halves of the soil specimen come in contact at the bottom of the groove along a distance of 12mm due to flow and by sliding.

f. A representative specimen of the soil is collected via a spatula and put in an air tight container and the moisture content is then obtained by oven drying method.

g. The remaining sample in the cup is removed and remixed with the other sample in the evaporating dish. The water content is then increased and the whole step is repeated in each case determining the number of blows (N) and the water content (w).

h. A curve of log N against w is then plotted. The liquid limit is the water content corresponding to N = 25.

4) Plastic Limit Test

This test will be carried out in accordance to BS 1997 (1990).

a) Aim:

To determine the water content of the soil below which the soil ceases to behave like a plastic.

b) Equipment:

(1) Porcelain evaporating dish about 120mm diameter or a flat glass plate, 450mm square and 10mm thick (2) Ground glass plate, about 200mm x 150mm (3) Metallic rod, 3mm diameter and 100mm long (4) Oven (5) Spatula and palette knife (6) Moisture content can.

c) Procedure:

a. 30 g of air-dried soil from a thorough mixed soil specimen passing the 0.425mm BS sieve will be mixed with distilled water in an evaporating dish and is made into a plastic. The sample is left for a period to cure and mature.

b. 8 g of the paste is taken and rolled on a glass plate using the finger. Rolling should be done at an approximate rate of about 90-80 strikes per minute until a thread, 3mm thick is formed.

c. The soil should be kneaded once a thread 3mm thick is formed to reduce the water content and rolling is then repeated.

d. The process is repeated on the soil sample until it crumbles or fails, and the soil can no longer be rolled into a thread.

e. Collect some of the crumble sample and determine its moisture content and the process repeated with a different sample.

f. The plastic limit is calculated thus;

$Plastic\ Limit = \frac{M_2 - M_3}{M_3 - M_1}$ (4)

Where;

M_1= Mass of empty container

M_2= Mass of container + wet soil

M_3= Mass of container + dry soil.

5) Consolidation (Oedometer) test

This test will be carried out in accordance to BS 1377-6 (1990)

a) Aim:

To determine the consolidation properties of disturbed or undisturbed soil by conducting a one-dimensional consolidation test using fixed ring type consolidometer.

b) Materials and Equipment:

1. Fixed ring type consolidometer consisting of: (a) specimen ring, with highly polished interior surface and top edge beveled (b) porous stone, 2nos of silicone carbide, aluminum or porous metal, the diameter of top stone should be about 0.2 to 0.5mm less than the internal diameter of the ring and the diameter of bottom stone should be equal to the external diameter of the ring. (c) Guide ring (d) outer ring (e) water jacket with base (f) pressure pad (g) steel ball (h) rubber gasket and bolts.

2. Suitable loading device for applying vertical loading to the soil specimen, loading being done either by a jack with weight of known magnitude.

3. Dial gauge accurate to 0.002mm.

4. Weight balance, sensitive to 0.01g.

5. Thermostatically controlled oven.

6. Moisture content can.

7. Mixer basin.

8. Soil trimming tools live fine wire saw and knife spatula.

9. Glass plate.

10. Filter paper.

11. Stop watch.

12. Water source

c) Test Procedure:

- Preparation of the soil specimen

The undisturbed soil sample from the field is to be prepared in a clean dish. The specimen ring will then be cleaned and weighed empty. The prepared sample will be filled in the ring with a slight compaction. About 3cm of the soil specimen from one end of the field sample is to be cut off.

The specimen ring will then be gradually inserted into the sample by pressing it with hands and carefully removing the material around the ring.

The soil specimen obtained will be projected about one cm from either side of the ring. The sample will be smoothly trimmed and flushed with the top and bottom of the ring by using glass plates. The ring will then be cleaned from outside and weighed. Specimens from the soil trimming will be collected for water content determination.

- Preparation of mould assembly and sample saturation

The porous stones are to be saturated by keeping them submerged in distilled water for about 5hours. Excess moist on the consolidometer will then be wiped off. The consolidometer will then be assembled with the soil specimen in the ring and porous stone at top and bottom of the specimen with a filter paper between the soil specimen and the porous stone. The pressure pad will then be centrally positioned on the top porous stone. The mould assembly is to be mounted on the loading frame and centered in such a way that the load applied acted axially.

The dial gauge will be positioned to measure the vertical compression of the specimen. The dial gauge holder should be set in such that the dial gauge was near the beginning of its release run, allowing sufficient margin for the swelling of the soil.

The mould assembly will then be connected to the water reservoir and the sample will be allowed to saturate. The level of water in the reservoir is to be maintained at the same level with the soil specimen.

An initial seating load will be applied to the assembly. The magnitude of the load will be chosen by trial such that there will not be swelling. The load should be allowed to stand until there was no change in dial gauge reading for two consecutive hours.

- Consolidation Process:

The final dial reading should be noted under the initial seating load. First load of intensity 10 KN/m^2should be applied and the stop watch was started simultaneously with the loading. The dial gauge readings should be recorded and tabulated at every 0.25minutes intervals. The dial gauge reading will be taken until 90% consolidation was achieved. The primary consolidation is expected to be reached within 24hours.

At the end of the above specified period, the dial gauges and stop watch reading will be recorded. The load intensity should be doubled, and the dial reading taken for 0.25minute intervals. The process should then be repeated for successive load increments. The usual loading intensities will be as follow, 10, 20, 50, 100, 200, 400 and 800 KN/m^2(Kpa).

After the last load is applied, the loading process will be then reduced to half of the last load and allowed to stand for 24 hours. The load should further be reduced in steps of one-fourth of the previous intensity till an intensity of 10 KN/m^2 is reached. The final reading of the dial gauge will be then taken.

The load will be reduced to the initial setting load and kept for 24 hours and the final dial readings will be taken.

The specimen assembly should be dismantled quickly and the excess surface water on the soil specimen removed by blotting. The ring weighed with the consolidation specimen. The soil specimen should be dried in oven and its dry weight can then be determined.

Calculations:

i. Height of solids is calculated as;

$$H_d = \frac{M_d}{G.A.P_w} \quad (5)$$

ii. Void ratio is given by;

$$e = \frac{H - H_s}{H_s} \quad (6)$$

iii. Coefficient of consolidation, Cv, is given by;

$$C_v = \frac{0.197d^2}{t_{50}} \quad \text{(Log fitting method)} \quad (7)$$

$$C_v = \frac{0.848d^2}{t_{90}} \quad \text{(Square root fitting method)} \quad (8)$$

6) Triaxial Test

This test will be carried out in accordance to BS 1377 (1990) part 7 and 8.

The aim of this test is to determine the compressive and shear strength parameters of the soil.

III. RESULTS AND DATA ANALYSIS

A. Data Presentation

1) Result of the Bulk Density and Dry Density Test

Tables 1-2 show the Data and results obtained from the bulk/dry density test of the soils obtained from FUTO workshop area.

2) Sieve Analysis Result

The results of the sieve analysis tests for the various samples are presented in tables 3-8.

3) Results of the Liquid Limit Tests

The results for these tests are represented in tables 9-14.

4) Results of the Plastic Limit Tests

Tables 15-20 show the results of the Plastic Limit tests on both the clayey and lateritic soils.

5) Results for the triaxial test

Tables 21-26 show the results of the Triaxial tests on both the clayey and lateritic soils.

6) Results for the Consolidation (Oedometer) tests

Tables 27-28 show the results of the Consolidation tests on both the clayey and lateritic soils

Figure 1. Triaxial process and prepared soil sample for the triaxial test

TABLE I. BULK AND DRY DENSITY TEST DATA AND RESULT FUTO SOIL.

Observations	Lateritic Soil		
	BH-1, S10	BH-2, S10	BH-3, S10
Core cutter No.	No. 2	No. 2	No. 2
Internal diameter (mm)	45.00	45.00	45.00
Internal height (mm)	92.60	92.60	92.60
Mass of Core cutter, M_1 (g)	145.46	145.46	145.46
Mass of core cutter + Soil sample, M_2(g)	401.89	438.16	415.66
Mass of core cutter + Dry sample, M_3(g)	395.87	413.57	401.14
Mass of wet soil, M_4(g)	256.43	292.70	270.20
Mass of dry soil, M_5(g)	247.41	272.11	254.68
Internal Volume of core cutter, V (m³)	1.473x 10^{-7}	1.473x 10^{-7}	1.473x 10^{-7}
Water content, w (%)	8.85	16.26	14.21
Bulk density, ρ (Mg/m³)	1.74	1.98	1.83
Dry density, ρd (Mg/m³)	1.68	1.85	1.73

TABLE II. BULK AND DRY DENSITY TEST DATA AND RESULT FOR UMUAKPU SOIL.

Observations	Clayey Soil		
	BH-3, S8	BH-2, S10	BH-1, S6
Core cutter No.	No. 2	No. 2	No. 2
Internal diameter (mm)	45.00	45.00	45.00
Internal height (mm)	92.60	92.60	92.60
Mass of Core cutter, M_1 (g)	145.46	145.46	145.46
Mass of core cutter + Soil sample, M_2(g)	435.79	428.47	421.92
Mass of core cutter + Dry sample, M_3(g)	415.02	428.47	421.92
Mass of wet soil, M_4(g)	290.33	283.01	276.46
Mass of dry soil, M_5(g)	269.56	262.19	253.36
Internal Volume of core cutter, V (m³)	1.473x 10^{-7}	1.473x 10^{-7}	1.473x 10^{-7}
Water content, w (%)	7.71	7.94	9.12
Bulk density, ρ (Mg/m³)	1.97	1.92	1.88
Dry density, ρd (Mg/m³)	1.83	1.78	1.72

TABLE III. SIEVE ANALYSIS TEST FOR FUTO SOIL SAMPLE 9 AT BH-2

Location	FUTO Workshop Area					
PARTICLE SIZE DISTRIBUTION TABLE						
Borehole No. 2 (Sample 9)						
Weight of sample taken for analysis (g)						500
Weight retained on sieve No. 63μm (g)						496.81
Weight passing sieve No. 63μm (g)						3.19
Sieve size (mm)	Mass-of sieve (g)	Mass-of sieve + sample (g)	Mass-of sample retained (g)	Total mass retained (g)	Total mass passing (g)	Total percentage passing (%)
2.36	352.82	357.14	4.32	4.32	495.68	99.14
1.18	363.72	388.9	25.18	29.5	470.5	94.1
0.6	373.08	648.7	275.7	305.2	194.8	38.96
0.425	329.17	420.71	91.54	396.74	103.26	20.65
0.3	318.04	376.14	58.1	454.84	45.16	9.03
0.212	306.21	324.88	18.67	473.51	26.49	5.3
0.15	298.15	309.92	11.77	485.28	14.72	2.94
0.063	290.58	302.11	11.53	496.81	3.19	0.64
Pan	272.8	275.99	3.19	500	0	0

TABLE IV. SIEVE ANALYSIS TEST FOR FUTO SOIL SAMPLE 9 AT BH-1

Location	FUTO Workshop Area					
PARTICLE SIZE DISTRIBUTION TABLE						
Borehole No. 1 (Sample 9)						
Weight of sample taken for analysis (g)						500
Weight retained on sieve No. 63μm (g)						32.31
Weight passing sieve No. 63μm (g)						465.56
Sieve size (mm)	Mass-of sieve (g)	Sieve size (mm)	Mass-of sieve (g)	Sieve size (mm)	Mass-of sieve (g)	Sieve size (mm)
	352.82	353.13	0.31	0.31	499.69	99.938
1.18	363.72	370.69	6.97	7.28	492.72	98.544
0.6	373.08	544.1	171.02	178.3	321.7	64.34
0.425	329.17	455.45	126.28	304.58	195.42	39.084
0.3	318.04	417.61	99.57	404.15	95.85	19.17
0.212	306.21	342.44	36.23	440.38	59.62	11.924
0.15	298.15	322.98	24.83	465.21	34.79	6.958
0.063	290.58	290.93	0.35	465.56	34.44	6.888
Pan	272.8	305.11	32.31	497.87	2.13	0.426

TABLE V. SIEVE ANALYSIS TEST FOR FUTO SOIL SAMPLE 9 AT BH-3

Location	FUTO Workshop Area					
PARTICLE SIZE DISTRIBUTION TABLE						
Borehole No. 3 (Sample 9)						
Weight of sample taken for analysis (g)						500
Weight retained on sieve No. 63μm (g)						18.45
Weight passing sieve No. 63μm (g)						469.67
Sieve size (mm)	Mass of sieve (g)	Sieve size (mm)	Mass of sieve (g)	Sieve size (mm)	Mass of sieve (g)	Sieve size (mm)
2.36	352.82	353.03	0.21	0.21	499.79	99.958
1.18	363.72	375.12	11.4	11.61	488.39	97.678
0.6	373.08	539.55	166.47	178.08	321.92	64.384
0.425	329.17	494.06	164.89	342.97	157.03	31.406
0.3	318.04	416.72	98.68	441.65	58.35	11.67
0.212	306.21	318.13	11.92	453.57	46.43	9.286
0.15	298.15	313.79	15.64	469.21	30.79	6.158
0.063	290.58	291.04	0.46	469.67	30.33	6.066
Pan	272.8	291.25	18.45	488.12	11.88	2.376

TABLE VI. SIEVE ANALYSIS TEST FOR UMUAKPU SOIL SAMPLE 9 AT BH-3

Location	Umuakpu Community School Ohaji, Umuakpu.					
PARTICLE SIZE DISTRIBUTION TABLE						
Borehole No. 3 (Sample 9)						
Weight of sample taken for analysis (g)						500
Weight retained on sieve No. 63µm (g)						41.12
Weight passing sieve No. 63µm (g)						458.6
Sieve size (mm)	Mass of sieve (g)	Sieve size (mm)	Mass of sieve (g)	Sieve size (mm)	Mass of sieve (g)	Sieve size (mm)
	352.82	352.85	0.03	0.31	499.69	99.938
1.18	363.72	370.08	6.36	6.67	493.33	98.666
0.6	373.08	502.43	129.35	136.02	363.98	72.796
0.425	329.17	466.21	137.04	273.06	226.94	45.388
0.3	318.04	435.92	117.88	390.94	109.06	21.812
0.212	306.21	338.02	31.81	422.75	77.25	15.45
0.15	298.15	332.92	34.77	457.52	42.48	8.496
0.063	290.58	291.66	1.08	458.6	41.4	8.28
Pan	272.8	313.92	41.12	499.72	0.28	0.056

TABLE VII. SIEVE ANALYSIS TEST FOR UMUAKPU SOIL SAMPLE 9 AT BH-2

Location	Umuakpu Community School Ohaji, Umuakpu.					
PARTICLE SIZE DISTRIBUTION TABLE						
Borehole No. 2 (Sample 9)						
Weight of sample taken for analysis (g)						500
Weight retained on sieve No. 63µm (g)						33.84
Weight passing sieve No. 63µm (g)						466.09
Sieve size (mm)	Mass of sieve (g)	Sieve size (mm)	Mass of sieve (g)	Sieve size (mm)	Mass of sieve (g)	Sieve size (mm)
2.36	352.82	353.36	0.54	0.54	499.46	99.892
1.18	363.72	370.76	7.04	7.58	492.42	98.484
0.6	373.08	459.38	86.3	93.88	406.12	81.224
0.425	329.17	521.32	192.15	286.03	213.97	42.794
0.3	318.04	434.06	116.02	402.05	97.95	19.59
0.212	306.21	318.6	12.39	414.44	85.56	17.112
0.15	298.15	349.08	50.93	465.37	34.63	6.926
0.063	290.58	291.3	0.72	466.09	33.91	6.782
Pan	272.8	306.64	33.84	499.93	0.07	0.014

TABLE VIII. SIEVE ANALYSIS TEST FOR UMUAKPU SOIL SAMPLE 9 AT BH-1

Location	Umuakpu Community School Ohaji, Umuakpu.					
PARTICLE SIZE DISTRIBUTION TABLE						
Borehole No. 1 (Sample 9)						
Weight of sample taken for analysis (g)						500
Weight retained on sieve No. 63µm (g)						21.14
Weight passing sieve No. 63µm (g)						478.5
Sieve size (mm)	Mass of sieve (g)	Sieve size (mm)	Mass of sieve (g)	Sieve size (mm)	Mass of sieve (g)	Sieve size (mm)
2.36	352.82	352.95	0.13	0.13	499.87	99.974
1.18	363.72	364.2	0.48	0.61	499.39	99.878
0.6	373.08	409.92	36.84	37.45	462.55	92.51
0.425	329.17	569.05	239.88	277.33	222.67	44.534
0.3	318.04	440.07	122.03	399.36	100.64	20.128
0.212	306.21	335.09	28.88	428.24	71.76	14.352
0.15	298.15	340.59	42.44	470.68	29.32	5.864
0.063	290.58	298.4	7.82	478.5	21.5	4.3
Pan	272.8	293.94	21.14	499.64	0.36	0.072

TABLE IX. LIQUID LIMIT TEST RESULT ON THE FUTO SOIL OF BH-2, SAMPLE 9

Location	FUTO Workshop Area		
LIQUID LIMIT TEST Using the Casagrande's Apparatus			
Borehole No.	2		
Sample No.	9		
Depth of Collection	1.8m		
Observation	Test No.		
	1	2	3
No. of blows, N	50	30	23
Mass of Can (g)	16.57	16.64	16.39
Mass of can + wet Soil (g)	27.62	26.32	28.16
Mass of can + Dry Soil (g)	25.32	24.14	25.3
Mass of water (g)	2.3	2.18	2.86
Mass of Dry Soil (g)	8.75	7.5	8.91
Moisture Content (%)	26.29	29.07	32.1
Log N	1.7	1.48	1.36

TABLE X. LIQUID LIMIT TEST RESULT ON THE FUTO SOIL OF BH-1, SAMPLE 9

Location	FUTO Workshop Area		
LIQUID LIMIT TEST Using the Casagrande's Apparatus			
Borehole No.	1		
Sample No.	9		
Depth of Collection	1.8m		
Observation	Test No.		
	1	2	3
No. of blows, N	60	45	21
Mass of Can (g)	16.14	16.92	16.52
Mass of can + wet Soil (g)	22.32	25.08	28.48
Mass of can + Dry Soil (g)	20.92	23.11	25.2
Mass of water (g)	1.4	1.97	3.28
Mass of Dry Soil (g)	4.78	6.19	8.68
Moisture Content (%)	29.29	31.83	37.79
Log N	1.78	1.65	1.32

TABLE XI. LIQUID LIMIT TEST RESULT ON THE FUTO SOIL OF BH-3, SAMPLE 9

Location	FUTO Workshop Area		
LIQUID LIMIT TEST Using the Casagrande's Apparatus			
Borehole No.	3		
Sample No.	9		
Depth of Collection	1.8m		
Observation	Test No.		
	1	2	3
No. of blows, N	55	48	24
Mass of Can (g)	16.15	16.93	16.53
Mass of can + wet Soil (g)	24.61	28.02	29.51
Mass of can + Dry Soil (g)	22.51	25.04	25.63
Mass of water (g)	2.1	2.98	3.88
Mass of Dry Soil (g)	6.36	8.11	9.1
Moisture Content (%)	33.02	36.74	42.64
Log N	1.74	1.68	1.38

TABLE XII. LIQUID LIMIT TEST RESULT ON THE UMUAKPU SOIL OF BOREHOLE 3, SAMPLE 9

Location	Umuakpu Community School Ohaji, Umuakpu.		
LIQUID LIMIT TEST Using the Casagrande's Apparatus			
Borehole No.	3		
Sample No.	9		
Depth of Collection	1.8m		
Observation	Test No.		
	1	2	3
No. of blows, N	37	27	17
Mass of Can (g)	43.84	45.06	44.64
Mass of can + wet Soil (g)	65.05	69.22	65.52
Mass of can + Dry Soil (g)	59.66	62.75	59.61
Mass of water (g)	5.38	6.47	5.91
Mass of Dry Soil (g)	15.82	17.69	14.97
Moisture Content (%)	34	36.6	39.5
Log N	1.57	1.43	1.23

TABLE XIII. LIQUID LIMIT TEST RESULT ON THE FUTO SOIL OF BH-2, SAMPLE 9

Location	Umuakpu Community School Ohaji, Umuakpu.		
LIQUID LIMIT TEST Using the Casagrande's Apparatus			
Borehole No.	2		
Sample No.	9		
Depth of Collection	1.8m		
Observation	Test No.		
	1	2	3
No. of blows, N	30	29	21
Mass of Can (g)	47.05	45.39	45.21
Mass of can + wet Soil (g)	65.98	65.02	59.63
Mass of can + Dry Soil (g)	61.39	60.28	56.03
Mass of water (g)	4.49	4.74	3.6
Mass of Dry Soil (g)	14.34	14.89	10.82
Moisture Content (%)	32	32	33.33
Log N	1.48	1.46	1.32

TABLE XIV. LIQUID LIMIT TEST RESULT ON THE UMUAKPU SOIL OF BH-2, SAMPLE 9

Location	Umuakpu Community School Ohaji, Umuakpu.		
LIQUID LIMIT TEST Using the Casagrande's Apparatus			
Borehole No.	1		
Sample No.	9		
Depth of Collection	1.8m		
Observation	Test No.		
	1	2	3
No. of blows, N	55	48	24
Mass of Can (g)	16.15	16.93	16.53
Mass of can + wet Soil (g)	24.61	28.02	29.51
Mass of can + Dry Soil (g)	22.51	25.04	25.63
Mass of water (g)	2.1	2.98	3.88
Mass of Dry Soil (g)	6.36	8.11	9.1
Moisture Content (%)	33.02	36.74	42.64
Log N	1.74	1.68	1.38

TABLE XV. PLASTIC LIMIT TEST RESULT FOR FUTO SOIL OF BOREHOLE2, SAMPLE9.

Location	FUTO Workshop Area		
PLASTIC LIMIT TEST			
Borehole No.	2		
Sample No.	9		
Depth of Collection	1.8m		
Observation		Test No.	
		1	2
Mass of Can (g)		16.44	16.46
Mass of Can + Wet Soil (g)		18.86	18.93
Mass of Can + Dry Soil (g)		18.42	18.58
Mass of Water in Soil (g)		0.44	0.4
Mass of Dry Soil (g)		1.98	2.07
Moisture Content (%)		22.22	19.32
Plastic Limit (PL) = $\frac{PL_1+PL_2}{2}$ = 20.77%			

TABLE XVI. PLASTIC LIMIT TEST RESULT FOR FUTO SOIL OF BH-1, SAMPLE9

Location	FUTO Workshop Area		
PLASTIC LIMIT TEST			
Borehole No.	1		
Sample No.	9		
Depth of Collection	1.8m		
Observation		Test No.	
		1	2
Mass of Can (g)		17.88	19.68
Mass of Can + Wet Soil (g)		20.24	22.14
Mass of Can + Dry Soil (g)		19.82	21.69
Mass of Water in Soil (g)		0.42	0.45
Mass of Dry Soil (g)		1.94	2.01
Moisture Content (%)		21.65	22.39
Plastic Limit (PL) = $\frac{PL_1+PL_2}{2}$ = 22.02%			

TABLE XVII. PLASTIC LIMIT TEST RESULT FOR FUTO SOIL OF BH-3, SAMPLE9

Location	FUTO Workshop Area		
PLASTIC LIMIT TEST			
Borehole No.	2		
Sample No.	9		
Depth of Collection	1.8m		
Observation		Test No.	
		1	2
Mass of Can (g)		16.88	17.68
Mass of Can + Wet Soil (g)		19.28	20.63
Mass of Can + Dry Soil (g)		18.84	20.13
Mass of Water in Soil (g)		0.44	0.5
Mass of Dry Soil (g)		1.96	2.45
Moisture Content (%)		22.45	20.41
Plastic Limit (PL) = $\frac{PL_1+PL_2}{2}$ = 21.43%			

TABLE XVIII. PLASTIC LIMIT TEST RESULT FOR UMUAPKU SOIL OF BH-3, SAMPLE9

Location	Umuakpu Community School Ohaji, Umuakpu.		
PLASTIC LIMIT TEST			
Borehole No.	3		
Sample No.	9		
Depth of Collection	1.8m		
Observation		Test No.	
		1	2
Mass of Can (g)		19.84	19.3
Mass of Can + Wet Soil (g)		23.86	23.53
Mass of Can + Dry Soil (g)		23.22	22.82
Mass of Water in Soil (g)		0.64	0.71
Mass of Dry Soil (g)		3.38	3.52
Moisture Content (%)		18.93	20.2
Plastic Limit (PL) = $\frac{PL_1+PL_2}{2}$ = 19.57%			

TABLE XIX. PLASTIC LIMIT TEST RESULT FOR UMUAKPU SOIL OF BH-3, SAMPLE9

Location	Umuakpu Community School Ohaji, Umuakpu.		
PLASTIC LIMIT TEST			
Borehole No.	2		
Sample No.	9		
Depth of Collection	1.8m		
Observation		Test No.	
		1	2
Mass of Can (g)		19.88	18.81
Mass of Can + Wet Soil (g)		22.96	22.6
Mass of Can + Dry Soil (g)		22.26	21.95
Mass of Water in Soil (g)		0.7	0.65
Mass of Dry Soil (g)		2.38	3.14
Moisture Content (%)		29.4	20.7
Plastic Limit (PL) = $\frac{PL_1+PL_2}{2}$ = 20.05%			

TABLE XX. PLASTIC LIMIT TEST RESULT FOR UMUAKPU SOIL OF BH-3, SAMPLE9

Location	Umuakpu Community School Ohaji, Umuakpu.		
PLASTIC LIMIT TEST			
Borehole No.	1		
Sample No.	9		
Depth of Collection	1.8m		
Observation		Test No.	
		1	2
Mass of Can (g)		19.4	19.35
Mass of Can + Wet Soil (g)		22.11	23.75
Mass of Can + Dry Soil (g)		21.58	22.99
Mass of Water in Soil (g)		0.53	0.76
Mass of Dry Soil (g)		2.18	3.64
Moisture Content (%)		24.3	20.9
Plastic Limit (PL) = $\frac{PL_1+PL_2}{2}$ = 22.60%			

TABLE XXI. TABLE FOR TRIAXIAL TEST RESULT FOR FUTO WORKSHOP SOIL BH-1, SAMPLE 5

Location:	FUTO Workshop Area			
Borehole No.:	1 (Sample 5)			
Depth:	2.0 m			
Minor Principal Stress σ_3 (KN/m^2)	Deviator Stress $\sigma_1 - \sigma_3$ (KN/m^2)	Major Principal Stress σ_1 (KN/m^2)		
100	143	243		
200	170	370		
300	191	491		
RESULTS FROM TEST AND MORH CIRCLE				
Undrained Cohesion Cu (KN/m^2)	Angle-of Internal Friction Ø	Moisture Content %	Bulk-Unit Weight (KN/m^3)	Dry Unit Weight (KN/m^3)
32	5	13.52	17.53	15.44

TABLE XXII. TABLE FOR TRIAXIAL TEST RESULT FOR FUTO WORKSHOP SOIL BH-2, SAMPLE 4

Location:	FUTO Workshop Area			
Borehole No.:	2 (Sample 4)			
Depth:	1.6 m			
Minor Principal Stress σ_3 (KN/m^2)	Deviator Stress $\sigma_1 - \sigma_3$ (KN/m^2)	Major Principal Stress σ_1 (KN/m^2)		
100	227	327		
200	300	500		
300	409	680		
RESULTS FROM TEST AND MORH CIRCLE				
Undrained Cohesion Cu (KN/m^2)	Angle-of Internal Friction Ø	Moisture Content %	Bulk-Unit Weight (KN/m^3)	Dry Unit Weight (KN/m^3)
28	19	11.44	17.12	15.36

TABLE XXIII. TABLE FOR TRIAXIAL TEST RESULT FOR FUTO WORKSHOP SOIL BH-3, SAMPLE 3

Location:	FUTO Workshop Area			
Borehole No.:	3 (Sample 3)			
Depth:	1.2 m			
Minor Principal Stress σ_3 (KN/m^2)	Deviator Stress $\sigma_1 - \sigma_3$ (KN/m^2)	Major Principal Stress σ_1 (KN/m^2)		
100	190	290		
200	279	479		
300	340	640		
RESULTS FROM TEST AND MORH CIRCLE				
Undrained Cohesion Cu (KN/m^2)	Angle-of Internal Friction Ø	Moisture Content %	Bulk-Unit Weight (KN/m^3)	Dry Unit Weight (KN/m^3)
26	17.24	12.63	19.40	17.22

TABLE XXIV. TABLE FOR TRIAXIAL TEST RESULT FOR UMUAKPU SOIL BH-1, SAMPLE 9

Location:	Umuakpu Community School Ohaji, Umuakpu.			
Borehole No.:	1 (Sample 9)			
Depth:	1.8 m			
Minor Principal Stress σ_3 (KN/m^2)	Deviator Stress $\sigma_1 - \sigma_3$ (KN/m^2)	Major Principal Stress σ_1 (KN/m^2)		
100	253	353		
200	300	500		
300	372	672		
RESULTS FROM TEST AND MORH CIRCLE				
Undrained Cohesion Cu (KN/m^2)	Angle-of Internal Friction Ø	Moisture Content %	Bulk-Unit Weight (KN/m^3)	Dry Unit Weight (KN/m^3)
40	14	16.50	16.99	14.58

TABLE XXV. TABLE FOR TRIAXIAL TEST RESULT FOR UMUAKPU SOIL BH-2, SAMPLE 8

Location:	Umuakpu Community School Ohaji, Umuakpu.			
Borehole No.:	2 (Sample 8)			
Depth:	1.6 m			
Minor Principal Stress σ_3 (KN/m^2)	Deviator Stress $\sigma_1 - \sigma_3$ (KN/m^2)	Major Principal Stress σ_1 (KN/m^2)		
100	168	268		
200	204	404		
300	260	560		
RESULTS FROM TEST AND MORH CIRCLE				
Undrained Cohesion Cu (KN/m^2)	Angle-of Internal Friction Ø	Moisture Content %	Bulk-Unit Weight (KN/m^3)	Dry Unit Weight (KN/m^3)
30	11	17.35	17.53	14.94

TABLE XXVI. TABLE FOR TRIAXIAL TEST RESULT FOR UMUAKPU SOIL BH-3, SAMPLE 7

Location:	Umuakpu Community School Ohaji, Umuakpu.			
Borehole No.:	3 (Sample 7)			
Depth:	1.6 m			
Minor Principal Stress σ_3 (KN/m^2)	Deviator Stress $\sigma_1 - \sigma_3$ (KN/m^2)	Major Principal Stress σ_1 (KN/m^2)		
100	161	261		
200	204	404		
300	256	556		
RESULTS FROM TEST AND MORH CIRCLE				
Undrained Cohesion Cu (KN/m^2)	Angle-of Internal Friction Ø	Moisture Content %	Bulk-Unit Weight (KN/m^3)	Dry Unit Weight (KN/m^3)
31	9	18.49	18.58	13.99

TABLE XXVII. TABLE FOR OEDOMETER (CONSOLIDATION) RESULT FOR BOREHOLE 3, SAMPLE 4

PROJECT	Determination of Settlement Characteristics of Soil for the Construction of Buildings					
LOCATION	FUTO Workshop Area					
CONSOLIDATION TEST						
BOREHOLE NO.: 3			Sample no: 4 Depth: 1.60m			
Diameter of Ring, (mm)	73		Height of Solids, H_s (mm)			15.53
Height of Ring (mm)	20		Height of Void, H_v (mm)			4.47
Area of Ring (mm^2)	4185.39		Initial Void ratio, e_o			0.976
Specific Gravity,	2.6		Final Void ratio, e_f			0.08
Total change in Height	3.16		Change in Void Ratio, e_d			0.896
$C_c = 0.18,\ C_s = 0.038$						
Pressure (KN/m^2)	0	25	50	100	200	50	0
(mm)	0	1.4	2.9	3.1	3.16	3.06	3.01
H (mm)	20	18.60	17.10	16.90	16.84	16.88	17.01
e	0.961	0.944	0.916	0.885	0.837	0.84	0.893
e_d	0.017	0.028	0.079	0.048	0.003	0.003	0.053

TABLE XXVIII. TABLE FOR OEDOMETER (CONSOLIDATION) TEST RESULT FOR BOREHOLE 2, SAMPLE 8

PROJECT	Determination of Settlement Characteristics of Soil for the Construction of Buildings									
LOCATION	Umuakpu Community School Ohaji, Umuakpu.									
CONSOLIDATION TEST										
BOREHOLE NO.: 2					Sample no: 8 Depth: 1.60m					
Diameter of Ring, (mm)	73				Height of Solids, H_s (mm)					11.58
Height of Ring (mm)	20				Height of Void, H_v (mm)					8.46
Area of Ring (mm^2)	4185.39				Initial Void ratio, e_o					0.29
Specific Gravity,	2.58				Final Void ratio, e_f					0.01
Total change in Height	2.92				Change in Void Ratio, e_d					0.28
$C_c = 0.718,\ C_s = 0.377$										
Pressure (KN/m^2)	0	25	50	100	200	50	0	0	25	50
(mm)	0	0.15	0.17	0.28	0.32	1.06	0.30	0.00	0.15	0.17
H (mm)	20	19.85	19.68	19.4	17.08	18.14	18.44	20	19.85	19.68
e	0.29	0.20	0.10	0.09	0.08	0.09	0.10	0.29	0.20	0.10
e_d	0.09	0.1	0.013	0.004	0.01	0.01	0.01	0.09	0.10	0.013

B. Data Analysis

1) Bulk Density and Dry Density Test.

Volume of Core Cutter, $V = \frac{\pi D^2}{4} = \frac{\pi(45)^2}{4} \times 10^{-6} = 1.473$ x $10^{-7}\ m^3$

Bulk density, $\rho = \frac{M_2 - M_1}{V} = \frac{M_4}{V}$

Dry density, $\rho_d = \frac{M_3 - M_1}{V} = \frac{M_5}{V}$

2) Atterberg Limit Test.

a) For Lateritic Soils

The Moisture content corresponding to 25 blows on the liquid limit curve

Liquid Limit, LL = 31.00%

The average of the moisture content of the tests trial

Plastic Limit (PL) = $\frac{PL_1 + PL_2}{2} = 20.77\%$

Plasticity index, PI = LL – PL = 10.23%

This Soil is Slightly Plastic thus implying small clay content, Lateritic soil confirmed.

b) For Clayey Soils

Liquid Limit, LL = 37.02%

Plastic Limit, PL = 19.57%

Plasticity Index, PI = LL – PL =17.63%

The soil has medium Plasticity implying much clay content, clayey soil confirmed.

3) The triaxial test

a) For the Lateritic Soil

From the Mohr circle plot,

Undrained Strength at z = 1.8m, $C_u = 28\ 30$ KN/m^2

Angle of internal friction at 1.8m, Ø = 19°

Bulk-Unit Weight, γ =17.12 KN/m^3

Thus, Bearing Capacity coefficients are, $N_c = 18$, $N_q = 5$, $N_r = 3$

Bearing Capacity of the soil;

$$q = cN_c + \gamma z N_q + \tfrac{1}{2}B\gamma N_r \quad (9)$$

q= 615.28 KN/m^2

For a factor of safety, F=4

Allowable bearing capacity

$q_a = 153.82\text{KN}/m^2$

b) For the Clayey Soil

From the Mohr circle plot,

Undrained Strength at z = 1.8m, $C_u = 3040$ KN/m^2

Angle of internal friction z = 1.8m, Ø = 11°

Bulk-Unit Weight, γ =17.53 KN/m^3

Thus, Bearing Capacity coefficients are, $N_c = 9$, $N_q = 5$, $N_r = 3$

Bearing Capacity of the soil;

From eqn (4.1),

$q = cN_c + \gamma z N_q + \tfrac{1}{2}B\gamma N_r$

q= 383.95 KN/m^2

For a factor of safety, F=4

Allowable bearing capacity

$q_a = 96.00\text{KN}/m^2$

4) Computation of immediate settlement from the oedometer test

The ultimate Primary consolidation settlement is given by;

$$S = \frac{C_s H}{1+e_o}\log\left(\frac{p_o + \Delta p}{p_o}\right) \quad (10)$$

a) For the Lateritic Soil

Swell Index, $C_s = 0.038$

Initial Void ratio, $e_o = 0.976$

Initial Pressure, $P_{o=}25\text{KN/m}^2$

Increament in Pressure, $\Delta P = 175\text{KN/m}^2$

Height of clay before compression, $H = 20$ mm = 0.02m

Thus;

Settlement, s = 0.000347m = 0.35mm

b) For the clayey Soil

Swell Index, $C_s = 0.177$

Initial Void ratio, $e_o = 0.29$

Initial Pressure, $P_{o=}25\text{KN/m}^2$

Increament in Pressure, $\Delta P = 175\text{KN/m}^2$

Height of clay before compression, $H = 20$ mm = 0.02m

Thus;

Settlement, s = 0.00529m = 5.29mm

C. Discussion of Results.

1) For the Lateritic Soil

The results of the sieve analysis tests shows that the soil samples collected from FUTO Workshop arena has an even distribution of silt as well as sand, the distribution is such that the amount of sand is much, this gives the idea that the soil comprises of little clay and much silt and sand and thus can be described as being lateritic in nature.

Now from the Atterberg limit test, the Plasticity Index (PI) of this soil was calculated as 10.23%, now from Table A6 in appendix A, the soil can be grouped as being “Slightly Plastic”, this is the common nature of lateritic soils.

The safe bearing capacity of this soil was calculated to be $153.82\text{KN}/m^2$ (per meter depth, per meter width of foundation), the soil safe bearing capacity is adequate for the construction of bungalows and medium rise building employing Pad and stripe foundation.

The primary consolidation settlement (S) of the soil was estimated as 0.35mm, for a Maximum pressure of $200\text{KN}/m^2$, this amount of settlement is tolerable, and a pad foundation can be employed for the construction of bungalows and medium rise buildings without expecting much settlement.

2) For the clayey Soil

The results of the sieve analysis tests (see appendix A for graphs and charts) for soils collected from Umuakpu community showed a well even distribution between clay, silt and sand particles. This is usually the nature of clay and lateritic soils.

From the Atterberg limit tests, the Plasticity Index of this sample was calculated as, PI=17.63% and from Table A6 of appendix A, the soil can be classified as having a “medium plasticity” thus the soil cab be clayey or silted-clay in nature.

The safe bearing capacity of the soil was calculated as $96.00\text{KN}/m^2$ and the primary consolidation settlement (S) under a maximum load of $200\text{KN}/m^2$ was calculated as 5.29mm, the soil is thus not good for supporting large structures with a pad footing. Raft foundation or piling is recommended for constructing very large structures on this soil.

IV. CONCLUSIONS AND RECOMMENDATION

A. Conclusion

From the discussion thus so far, it can be seen that the soil sourced from FUTO workshop arena is a medium coarse lateritic soil with a natural moisture content of about 14% and a plasticity index (PI) of 10.23% as can be inferred from the physical and classification tests (bulk and dry density, sieve analysis and Atterberg limit tests), thus the soil sample can be described as being lateritic in nature with low clay content, while those sourced from Umuakpu central area is a medium dense clayey soil, has a plasticity index (PI) of 17.63% and a natural moisture content of about 9% as can also be inferred by the physical and classification tests, thus can be described as being clayey in nature.

Also, from the results of the triaxial strength test and the bearing pressure calculations, the undrained strength and angle of internal friction for the soil sourced from FUTO was obtained as 28 KN/m^2 and 19^o respectively and a calculated bearing pressure of $153.82 \text{KN}/m^2$, while the strength parameters of the soil sourced from Umuakpu central area were obtained to be 30 KN/ m^2 and 11^o respectively with a calculated bearing pressure of $96.00 \text{KN}/m^2$. We then see that the soil sample sourced from FUTO workshop arena has a much higher bearing pressure when compared to those from Umuakpu central area and can thus be used as foundation for low rise building and high rise building extending to a reasonable height (about 23 meters or seven storeys) under pad footing, but for greater heights, pilling is advised. They clayey sample from Umuakpu central area has low bearing capacity which is adequate for supporting low rise buildings but not for tall and high-rise building. For high rise buildings under clayey soils, pile or raft foundation is advised.

From the results of the Oedometer test and also from the settlement analysis calculations, the expected primary consolidation settlement for the soil sourced from FUTO workshop arena is 0.35m under a maximum working load of $200 \text{KN}/m^2$, now BS 1377 allows a maximum settlement of 5mm for a maximum working load of $200 \text{KN}/m^2$, thus the expected settlement from the lateritic soil is well below the limit and is thus adequate for construction of buildings. For the soil sourced from Umuakpu central area, the expected primary consolidation settlement was calculated as 5.29mm under a maximum working load of $200 \text{KN}/m^2$, this is greater than that specified by code, thus for construction, the footing is advised to be well spread to reduce the effect of the point load.

B. Recommendation

From the test results and calculations so far, soils derived from FUTO Workshop arena have good engineering and construction properties and conventional pad and stripe foundations can be adopted for the construction of buildings, but for those in Umuakpu community, it will be advised that raft (spread) foundation be used for the construction of heavy structures and medium rise buildings, but for high rise buildings, pile foundations are recommended. Table 29 accurately describes the recommended foundation for building construction for different storeys and load.

TABLE XXIX. BUILDING TYPES AND RECOMMENDED FOUNDATION TYPE

Soil bearing capacity	Recommended foundation type				
	1-storey	2-storey	3-5-storey	Medium rise	High rise
Good soil >100 kN/m^2	Strip	Strip	Pad	Pad	Pile
Average soil 75-100 kN/m^2	Strip	Wide strip	Pad	Pile	Pile
Poor soil 40-75 kN/m^2	Wide strip	Wide strip	Raft	Pile	Pile
Bad soil <40 kN/m^2	Slab raft	Slab raft	Slab raft	Pile	Pile

Ascalew and Iran (2005)

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Dike, Osunna Paul was born in Nigeria. He studied Civil and Structural Engineering at the Federal University of Technology Owerri, Nigeria, Graduating in 2016 with B.Eng. 1st class honors. He later moved to London to study Advanced Structural Engineering, MSc in 2018 and graduated in 2019.

He has worked as a structural and civil engineer with some prestigious firms and currently works in the UK as an Oil and Gas Structural Engineer. He has publications in the areas of Environmental Engineering and Structural Engineering.

Mr. Dike is currently a graduate member of the Institution of Civil Engineers (ICE) and Institution of Structural Engineers (IStrctE).

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