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Comparison of the Geotechnical Properties of Lateritic Soils in Port Harcourt, Nigeria

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Abstract— This present study x-rayed the geotechnical properties of lateritic soils and their suitability as subsoil (subgrade and subbase) materials for road construction and other civil engineering works. Lateritic soil samples were collected from ten different locations in the Port Harcourt metropolis using the hand auger apparatus as the sampling tool at about 1 meter depth. The soil samples were subjected to geotechnical investigation. Results obtained from the test showed that liquid limit (LL) ranges from 32.3% to 38.6%, the plastic limit (PL) ranges from 17.6% to 21.9%, while the plasticity index (PI) is between 13.6% and 20%. The optimum moisture content ranges from 13% to 18.5%, while the results of the maximum dry density of S1 to S10 ranges from 1340kN/m^3 to 1750kN/m^3. Shear stress of the samples fall within 19.64 – 22.86N/mm^2 with an average of 20.76 N/mm^2. The result of all samples showed that the percentage of clay ranges from 16% - 32%. The test results also revealed that the lateritic soil samples are suitable for subgrade for road pavement construction but would require adequatecompaction and stabilization to be used for subbase and base course in road pavement construction and other civil engineering works.

Index Terms— lateritic soils, geotechnical properties, foundation, CBR, road construction

1 Introduction

In geotechnical engineering, soils that have properties that cannot be safely or economically used for construction without adopting some measures of stabilization are known as problem soils. Lateritic soils are the most abundant tropical soil group covering over 50% of the tropics. these soils are mostly yellowish to reddish brown in colour depending on the relative proportions of iron and aluminiumsesquioxides. To the geotechnical and highway engineers, a problem soil is one that poses problems to construction.

These problems may be as a result of the instability of the soil due to expansive, swelling and collapsing nature of the soil and make it unsuitable as construction material in foundations of buildings, highway, water retaining structures, embankments and dam, etc. The geotechnical properties of these soils are of significant importance to the structural and geotechnical engineer. These important properties are required for the design of any structure in the regions in which we have these problem soils.

Lateritic soils which are mostly abundant in the tropical city of Port Harcourt in the oil rich Niger Delta tend to have most of the construction faced with such problematic soils. One of the greatest problems facing the practice of the engineering profession in Nigeria is the non-availability of relevant data for preliminary planning, design and construction of civil engineering structures. The construction of the foundation of most engineering structures requires that adequate information about the geotechnical properties of the soil and sub-soil conditions of the area are known before embarking on the design and construction.

The design and construction in highway planning requires a good knowledge and understanding of the geotechnical and engineering properties of the soil (sub grade) which is important in order to know the strength (CBR value), maximum dry density, optimum moisture content, liquid limit, plastic limit and other vital geotechnical parameters. Also, in the case of foundations for structures, soil bearing capacity is one of the vital geotechnical information needed for safe and most economical design of the structures. These geotechnical properties influence the performance of the structures and parameters of highway during usage over time.

The studies of the geotechnical properties of Nigeria soil can be traced back to about three to four decades. Srinivasaet al. [1] investigated the sub soils along the Nun River channel covering three communities of Kaima, Opokuma and Sabagreeia of Bayelsa in the Niger Delta region. The aim of the study was to provide materials as structural fills for road construction purposes. Results showed an overlying high gray to dark-brown (anhedral), soft to stiff consistency highly plastic silty clay soil in all the studied locations. The particle size distribution results, revealed a range of poorly graded sands with uniform gradation curve displaying very little or no lines (0.1 to 0.4% passing 0.075mm sieves). The soils were classified as SP (poorly graded) under the unified soil classification system (USCS). Nwankwoala and Warmate [2] studied the surface soil characteristics of the underlying soils in a site at D/line, Port-Harcourt for appropriate foundation design considerations for infrastructural development purposes. The study showed that the surface is underlain by soft firm sandy clay of moderate-high compressibility with undrained strength of 46kN/m^2 overlaying a firm-stiff sandy layer. In a nutshell, the allowable bearing capacity profile of sub grade showed low bearing capacities characteristics (1m-2m:<110kN/m^2). The values were relatively lower than the projected foundation loadings.

Omange et.al. [3], conduted a study on the classification characteristics, compaction and strength characteristics of soils in Bayelsa, Rivers, Delta, Edo, Cross Rivers, Abia and Imo states of the Niger Delta region. Test results showed that Bayelsa and Rivers States soils had silts and clay fractions varying from 5% to 97% with majority falling within the range of 23% and 73%. The liquid limits varied from 0-71% with a mean value of 40%, while the plasticity index (0-39%) had a mean value of 24%. A plot of liquid limit against the plasticity index confirms the fact that soils in the same formation tend to be parallel to the Casagrande's A-line.

Omange and Aitsebaoma [4] also assessed the geotechnical properties of soils in Delta and Edo states. Their study revealed the soils in these states had liquids limit (0-89.4%), plastic limits (0-36.4%) while the plasticity index ranged between 0-53% with mean value of 17.92%. Sadiku[5] gave the geotechnical properties of the materials used in the construction of Ikom-Obudu road in Cross-River State. The soil was found to be predominantly A-7group with a few A-2-7. The ranges were liquid limits (44-49%), Plastic limit (19-40%).

The aim of this research is to reduce the rate of failure of structures, road pavement and other construction works as a result of poor materials used for construction by providing geotechnical data of suitable materials (laterites) for construction.

2 Materials and Methods

2.1 Materials

Disturbed laterite soil samples were obtained from ten different locations in Port Harcourt: Abuloma, Omumah Igwuruta, Omusele Road Igwuruta, 1st Artillery Junction, Uniport (Abuja Campus), Peter Odili Road, Rumuosi Town, Aba Road (Oil Mill), Igwuruta GPH, and Uniport (Choba Campus). The soil samples were collected at about 1m depth using the hand auger apparatus. The geotechnical properties of the soil samples were assessed at the civil engineering laboratory of Rivers State University, Nigeria. Laboratory experiments were restricted to: particle size distribution (PSD), Atterberg limit (LL, PL, and PI), compaction test (OMC, MDD), California bearing ratio (CBR), and Unconfined compressive test.

Table 1. Sample Locations

S/N	SOIL SAMPLES LOCATION	GPS (UTM 32N)	
		NORTHING (m)	EASTHING (m)
1	Abuloma	529649.31	282604.36
2	Omumah Igwuruta	538086.52	276874.24
3	Omusele Road Igwuruta	548047.36	279729.45
4	1st Artillery Junction	535515.17	282589.39
5	Uniport (Abuja Campus)	541286.71	269115.09
6	Peter Odili Road	530877.73	283908.08
7	Rumuosi Town	539823.56	271598.30
8	Aba Road (Oil Mill)	536742.43	285551.32
9	Igwuruta GPH	548047.36	279729.45
10	Uniport (Choba Campus)	542166.64	269455.32

2.2 Methods

2.2.1 Experimental Programs

The computation of the parameters in Table 2 was made on the basis of their averages

Table 2. Experimental Parameters

Experiments	Parameters	Standard
Sieve Analysis	Particle Size Distribution	BS 1377-2: 1990
Atterberg Limit Tests	Liquid Limit, Plastic Limit and Plasticity Index	BS 1377-2: 1990
Standard proctor Compaction	Optimum Moisture Content, Maximum Dry Density	BS 1377-4: 1990
California Bearing Ratio	CBR(Soaked and Unsaoked)	BS 1377-5:1990
Unconfined Compressive Test	Shear Strength	BS 1377-5: 1990

2.2.1.1 Sieve Analysis

Sieve analysis was performed in order to determine the soil particle size distribution. Representative sample of approximately 300g was used for the test after washing and oven-dried. The samples were washed using the BS 200 sieve and the fraction retained on the sieve was air dried and used for the sieve analysis. The sieving was done by mechanical method using an automatic shaker and a set of sieves.

2.2.1.2 Atterberg Limit Test

For the determination of liquid limit, the soil sample passing through 425 µm sieve, weighing 200 g was mixed with water to form a thick homogeneous paste. The paste was collected inside the Casangrade's apparatus cup with a grove created and the number of blows to close it was Similarly, for plastic limit determination, the soil sample weighing 200 g was taken from the material passing the 425 µm test sieve and then mixed with water till it became homogenous and plastic to be shaped to ball. The ball of soil was rolled on a glass plate until the thread cracks at approximately 3 mm diameter. The 3 mm diameter sample was placed in the oven at 105°C to determine the plastic limit.

2.2.1.3 Compaction

In the laboratory test carried out, the density of the compacted soil is measured in terms of the dry unit weight of the soil. The dry unit weight is simply a measure of the amount of solid materials present in a unit volume of soil. The greater the solid materials, the stronger and more stable is the soil. The proctor compaction test conforms to the requirement of BS 1377 (1990). The aim of the test was to ascertain the maximum dry density (MDD) and optimum moisture content (OMC) of the soil samples.

Plate 1. Weighing of compacted soil sample in the mould

2.2.1.4 California bearing ratio

The CBR test was done in accordance with the BS 1377(1990), Part 4 guidelines. The test procedure entails causing a plunger of standard size from a CBR machine to penetrate a soil specimen prepared to the density and moisture of the soil to be tested on standard mould.

Plate 2. Uncoupling the CBR mould with soil from the collar

For the unsoaked CBR dried soil sample of 6kg is mixed with water to attain optimum moisture content. The base plate is fixed to the bottom of the mould and extention collar to its top, the sample is compacted with 25blows on each of the 5 layers with a standard rammer of 4.5kg of weight. The collar is removed and excess soil is trimmed off, the base plate is removed and the compacted soil and mould is weighed thereafter the sample is placed under the CBR Machine, the surcharge weight is placed on top of the soil as load is applied to the plunger and readings were taken respectively at penetration. While for soaked CBR the well compacted sample is immersed in water and soaked for 24 hours to stimulate the weakest condition that may likely occur in the field, surcharge is placed on the sample which represents the mass of pavement materials above the subgrade as readings were taken respectively for loads at penetration

2.2.1.5 Unconfined compressive strength test

BS 1377 (1990), Part 7 method was adopted for the determination of the unconfined compressive strength of soil samples. The unconfined compressive test is the most commonly used strength test on cohesive soils or soils stabilized with additives which binds the soil particle together. For accurate results, the test should be performed carefully, with raw soils the test is best carried out on cylindrical specimen of about 38mm and height to diameter ratio of 2:1. The ends of the specimen should be flat, smooth and parallel. The ends should be exactly perpendicular to axis of the cylinder, cores obtained during exploration are usually trimmed for this purpose.

Plate 3. Unconfined compressive test

The specimen is subjected to compression between the cross-head and the platen of a compression testing machine according to BS:1377 (1990), Part 7 guidelines. The specimen should preferably have a diameter of 38mm. In no case should the diameter be less than 38mm. The load should be applied continuously with a stress rate of 0.5 to 1.0 kN per second. The compressive strength (q_u) is determined from the relation $q_u=P/A$ where P is the load at peak and A is the initial area of cross section of the specimen.

2.2.1.6 Silica Sesquioxide Ratio of Soil Samples

The soil sample S7 (Rumuosi Town) was collected at random. The representative sample was taken to the chemical laboratory, Rivers State University, Port Harcourt, for chemical analysis, in order to quantify the level of silicon oxide (SiO_2), iron oxide (Fe_2O_3) and aluminium oxide in the soil, otherwise known as the silica sesquioxide ratio(S-S). This ratio enables us to classify soils are true laterites, lateritic or non lateritic soils.

3 Results and Discussion

The results obtained from the various laboratory tests are presented and discussed under the relevant subheadings that follow.

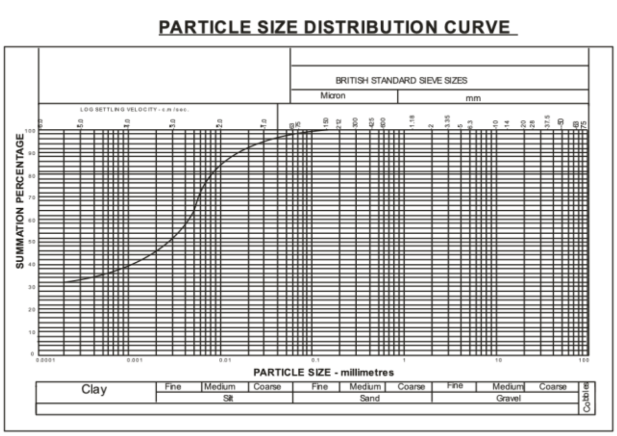
3.1 Sieve Analysis

The sieve analysis results and particle size distribution graph of samples and are shown in Table 3 and Figures 1a-f respectively.

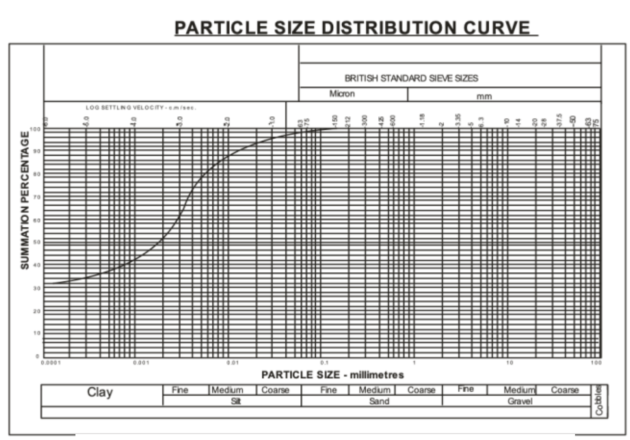
Table 3. Sieve Analysis

Total mass of dry soil = 300g
Mass of soil retained on 4.75 0
Mass of soil retained after washing 230g

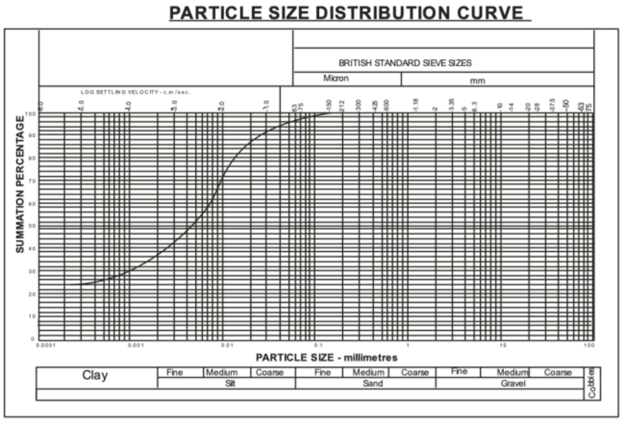
S/NO	Sieve	Size of opening	Mass of soil Retained	Percentage Retained	Cumulative % Retained	% finer
1	100mm	100mm		-	-	
2	80mm	80mm		-	-	
3	40mm	40mm		-	-	
4	20mm	20mm		-	-	
5	10mm	10mm		-	-	
6	4.75mm	4.75mm		-	-	
7	2mm	2mm		-	-	
8	1mm	1mm		-	-	
9	600u	0.600mm		-	-	
10	425u	0.425mm		-	-	
11	300u	0.300mm	0	-	-	100
12	212u	0.212mm	5	1.7	1.7	98.3
13	150u	0.150mm	18	6	7.7	92.3
14	75u	0.075mm	7	2.3	10.0	90.0
15	pan	-	200	66.7	76.7	23



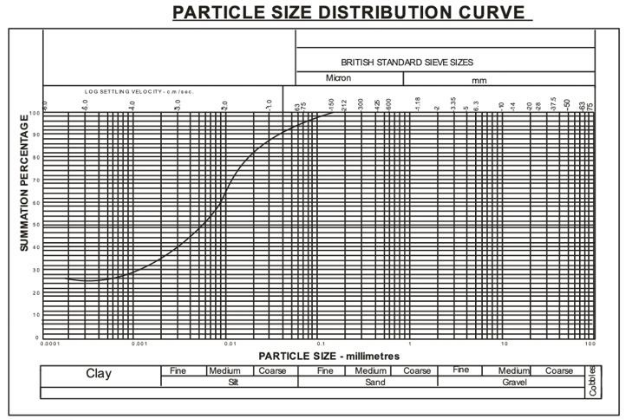
(a) Abuloma



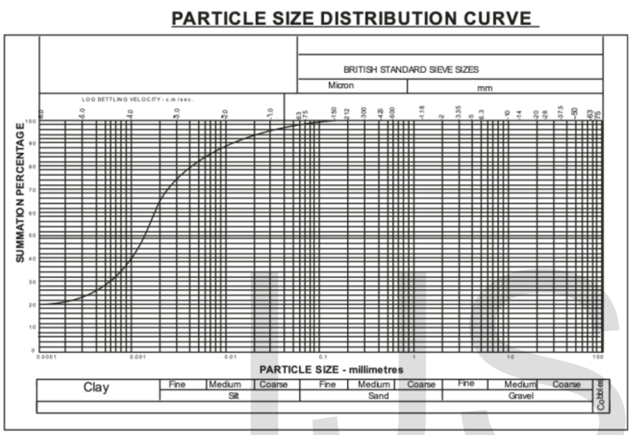
(b) Omusele Road Iguruta



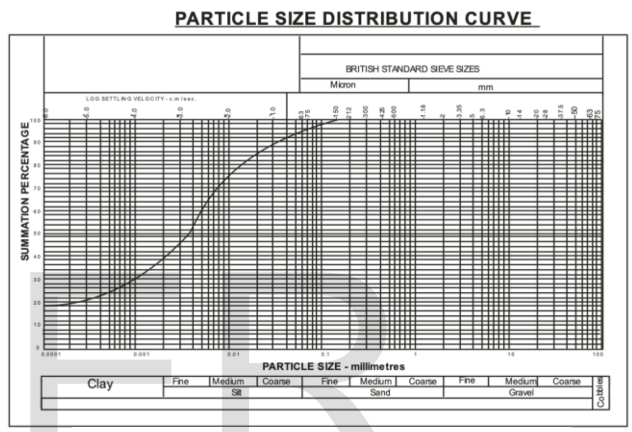
(c) 1st Artillery Junction



(d) Uniport (Abuja Campus)



(e) Rumuosi Town



(f) Uniport (Choba Campus)

Figures 1(a)-(f). Particle size distribution graphs of some samples

The result of all samples shows that the percentage of clay ranges from 16% - 32%. Therefore, according to the unified soil classification system (USCS) the soil samples explored are classified as low clay (CL), which are clays of low plasticity.

3.2 Atterberg Limits

The comprehensive summary result of Atterberg limit testis shown in Table 4.

Table 4. Results of Atterberg Limit Analyses of the Ten Studied Soils

Sample No.	Location	Liquid Limit LL(%)	Plastic Limit PL (%)	Plasticity Index PI (%)
S1	Abuloma	36.2	21.9	14.3
S2	Omumah Igwuruta	33.5	18.7	14.8
S3	Omusele Road Igwuruta	34.2	18.7	15.5
S4	1st Artillery Junction	37.8	17.8	20.0
S5	Uniport (Abuja Campus)	38.2	20.8	17.4
S6	Peter Odili Road	35.4	20.8	14.6
S7	Rumuosi Town	36.1	18.7	17.4
S8	Aba Road (Oil Mill)	38.6	21.9	16.7
S9	Igwuruta GPH	36.5	17.6	18.9
S10	Uniport (Choba Campus)	32.3	18.7	13.6

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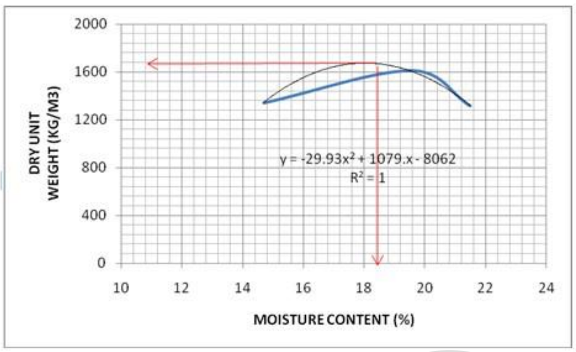
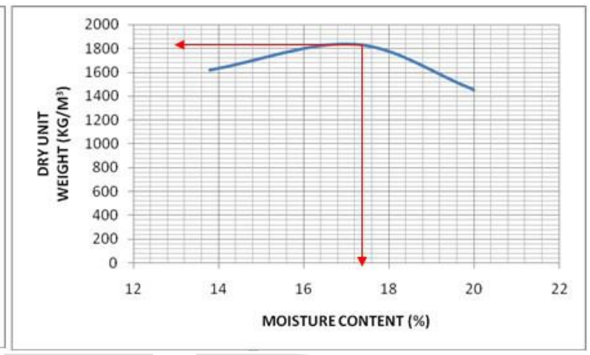
Results obtained from the test show that liquid limit (LL) ranges from 32.3% to 38.6%, the plastic limit (PL) ranges from 17.6% to 21.9%, while the plasticity index (PI) is between 13.6% and 20.0%. However, the Federal Ministry of Works and Housing for road construction works and housing recommends liquid limit of 50% (maximum) for subbase and base materials and according to the AASHTO soil classification system used as a guide in the classification of soil and soil- aggregate mixture for highway construction, the soil samples fall within the A7 group, subgroup A-7-6 group of soil classification. Therefore, all the soil samples explored in the Port Harcourt metropolis are not suitable for subbase and base materials for road construction without adequate soil improvements (stabilization).

3.3 Compaction

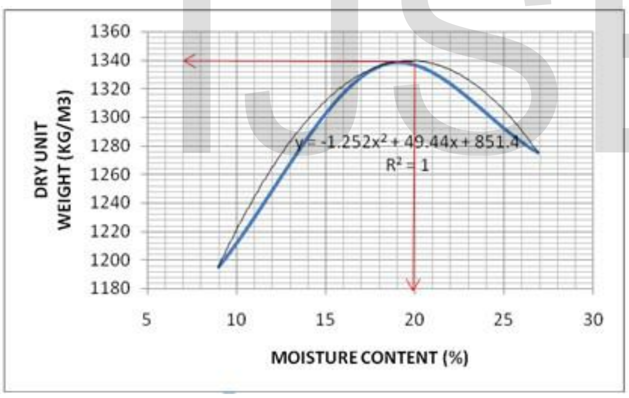
From the proctor compaction tests of all soil samples, the optimum moisture content ranges from 13% to 18.5%, while the results of the maximum dry density of S1 to S10 ranges from 1340kN/m^3 to 1750kN/m^3. Furthermore, from the dry density/ moisture content graphs (Figures 2(a) – (f)), we can deduce the value of the MDD by substituting the value of the OMC in the graphical equation on the graphs.



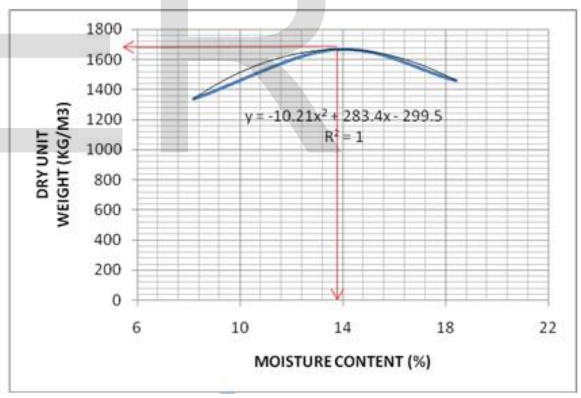
(a) Abuloma



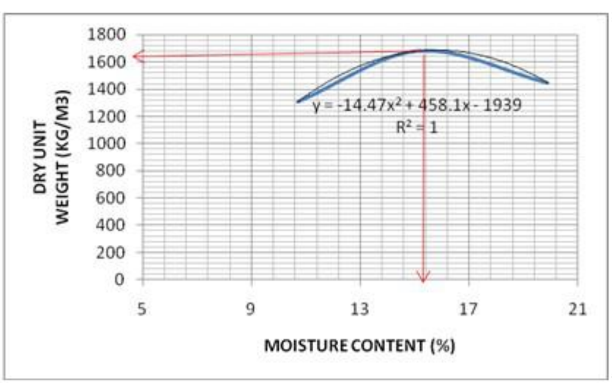
(b) Omumah Igwuruta



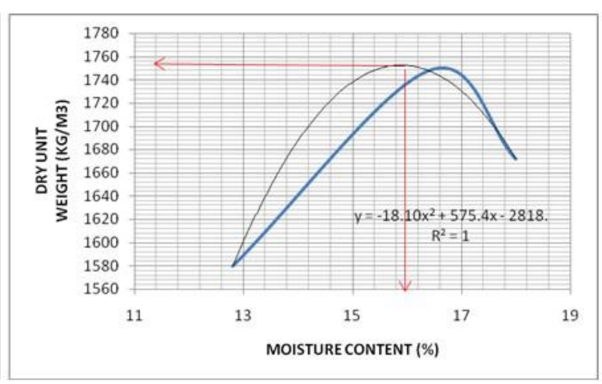
(c) 1st Artillery Junction



(d) Uniport (Abuja Campus)



(e) Peter Odili Road



(f) Aba Road (Oil Mill)

Figures 2(a)-(f). Dry density/ moisture content graphs of some of the soil samples

The range of values that may be anticipated when using the standard proctor test methods are: for clay, maximum dry density (MDD) may fall before 1440kN/m³ and 1685kN/m³ and optimum moisture content (OMC) may fall between 20-30%. The mechanical improvement of the soil properties by cement stabilization can increase the MDD and decrease the OMC that will meet the anticipated requirement as recommended by O' Flaherty.

3.4 California Bearing Ratio

Table 5 shows the results of the CBR test.

Table 5. Results of CBR Test

Sample No.	Location	CBR Unsoaked (%)	CBR Soaked (%)	% Loss in CBR after soaking
S1	Abuloma	10.167	9.385	7.692
S2	Omumah Igwuruta	9.441	8.816	6.620
S3	Omusele Road Igwuruta	10.167	9.385	7.692
S4	1st Artillery Junction	8.816	8.771	0.510
S5	Uniport (Abuja Campus)	10.167	9.385	7.692
S6	Peter Odili Road	8.816	8.771	0.510
S7	Rumuosi Town	10.167	9.385	7.692
S8	Aba Road (Oil Mill)	9.314	7.715	17.168
S9	Igwuruta GPH	8.816	8.771	0.510
S10	Uniport (Choba Campus)	9.441	8.816	6.620

Test results from the CBR (unsoaked) show that 40% of soil samples from the studied locations met the Federal Ministry of Works recommendation that soils to be used as subgradeshould have CBR (unsoaked) value equal to or greater than 10%. However, samples S2, S4, S6, S8, S9, and S10, all have CBR values less than 10%. CBR values of unsoaked samples usually have higher percentage than soaked samples.

3.5 Unconfined Compressive Test

Results of the unconfined compressive test and their respective shear stresses are shown in Table 6. The result reveals that the shear stress ranges from 19.64 – 22.86 N/mm² with an average of 20.76 N/mm². As can be deduced from Table 6, the shear stress values of soil samples from areas studies fall within the Cu value range of 12-25 N/mm² which indicates that the soil samples are soft to medium clays.

Table 6. Unconfined Compressive Test Results

Sample No.	Material	Location	Size of Cylinder (mm)	Weight of Specimen GM/CC	Age in Days	Gauge Reading	Corrected Gauge Reading	Stress N/mm²	q_uN/mm²
S1	Lateritic clay	Abuloma	105/114	179	1	170	0.34	339.26	19.64
S2	Lateritic clay	Omumah Igwuruta	105/114	198	1	180	0.36	41.57	20.78
S3	Lateritic clay	Omusele Road Iwguruta	105/114	200	1	163	0.326	37.644	18.82
S4	Lateritic clay	1st Artillery Junction	105/114	170	1	179	0.358	41.339	20.67
S5	Lateritic clay	Uniport (Abuja Campus)	105/114	183	1	180	0.36	41.57	20.78
S6	Lateritic clay	Peter Odili Road	105/114	176	1	196	0.392	45.265	22.63
S7	Lateritic clay	Rumuosi Town	105/114	183	1	176	0.352	40.646	20.32
S8	Lateritic clay	Aba Road (Oil Mill)	105/114	190	1	179	0.358	41.339	20.67
S9	Lateritic clay	Igwuruta GPH	105/114	191	1	177	0.354	40.877	20.44
S10	Lateritic clay	Uniport (Choba Campus)	105/114	178	1	198	0.396	45.727	22.86

3.6 Silica Sesquioxide Ratio of Soil Sample

Results of soil sample selected from Rumuosi Town for the assessment of the silica sequioxide ratio(S-S) is shown in Table 7.

Table 7. Results of Soil S-S Ratio for Rumuosi Town

Sample No.	Location	S_10_2(ppm)	Fe_z0_3(ppm)	Al_20_3 (ppm)	S-S Ratio
S7	Rumuosi Town	49.80	20.02	20.70	1.22

The degree of laterization is estimated by the silica sesquioxide (S-S) ratio: $S_i0_2/(Fe_2\,0_3 + AL_2\,O_3)$. Silica sesquioxide (S-S) ratio less than 1.33 shows that the soil is laterite, those between 1.33 and 2.00 are lateritic soils while those greater than 2.00 are non lateritic soil. The silica sesquioxide ratio in the laterite sample fell below the 1.33 benchmark of the S-S ratio. Therefore, sample 7 can be classified as a true laterite soil.

4 Conclusions

The geotechnical properties of lateritic soils (subsoil) in the Port Harcourt metropolis have been assessed in compliance with the BS1377 (1990) laboratory procedure for the determination of basic soil properties. The comparative analysis of all ten soil samples explored showed that the soils are lateritic clay of low plasticity with relatively high optimum moisture content and low maximum dry densities. The test results also revealed that the laterite soil samples are suitable as subgrade for road pavement construction but would require adequate compaction and stabilization to be used as subbase and base course in road pavement construction and other civil engineering purposes.

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