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Subgrade Quality Evaluation for the Proposed Mbaise Ring Road Project, Intersecting Owerri – Umuahia Federal Road Highway, Southeastern Nigeria

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Abstract Subgrade quality on the proposed Mbaise ring road project intersecting Owerri – Umuahia Federal highway southeastern Nigeria had been evaluated. Backhoe machine was used to collect 60 subgrade samples, at intervals of 500 m and natural moisture content tested in-situ using speedy moisture tester. Laboratory evaluation for the geotechnical properties included CBR test, atterberg limit test, linear shrinkage test, sieve analyses and dry density/moisture content compaction test. The results of natural moisture content ranges between 9.8 and 19.4 % with a mean average of 14.6 %. It is reasonable to say that the water retention of the subgrade material is low to high. Meanwhile, the results of atterberg liquid limit (LL) (24.9 to 45.0 %) and plasticity index (PI) (8.8 to 24.8) of the subgrade proved that the materials have moderate – medium swelling potential in the classification of expansive soil, while the linear shrinkage (5.8 to 21.8 %) showed that 28.3 % of the samples are within the marginal degree of expansion and 71.7 % within the critical degree of expansion. The grains of the subgrade samples is composed of sand, gravel with elastic silt fine and this was achieve through sieve analyses results ranging between 20.0 and 39.3 %. The dry density/moisture content compaction determined the optimal moisture content (OMC) and maximum dry density (MDD) with a range of results 7.5 to 16.4 % and 1.72 to 1.95mg/m^3 respectively. The CBR test conducted on the subgrade was soaked for 96 hours in water with the intention of observing the behaviour of the material when degree of water saturation in it increases, mainly in wet season. The results range is 2 to 17 %. The CBR test being most commonly means of evaluating the strength of subgrade shows that only 6.7 % of the total samples conformed with the requirement while 93.3 % failed the requirement. These may raise issues of modifying the subgrade by cutting off reasonable layers and replacing it with laterite from certified source or treating it with additives such as lime and cements.

Keywords Subgrade, Strength Characteristics

Introduction

Subgrade is that surface of the earth or rock levelled off to receive a foundation. A subgrade that can support a high amount of loading with excessive deformation is considered good. This load bearing capacity is often affected by natural degree of compaction, moisture content, and soil type. Subgrade influences pavement construction operations and long-term pavement performance. CBR test developed by California Division of Highways [1]; measures the strength or bearing capacity of subgrade and other materials.

A review of specification by the Federal Ministry of Works and Housing, Nigeria [2] recommended that the minimum CBR strength for subgrade of any depth shall be 15 %, after 96 hours soaked, if untreated. But that seems to be impossible in the study area, as 93.3 % failed to meet the requirement. Wet season plays a significant role, when the degree of water saturation into subgrade is increased and become threat to the stability of the subgrade.

In the construction industry, subgrade that failed to meet the CBR requirement is cut off as "cut to spoil". The practice of removal of the subgrade and filling it back with lateritic material that meet the requirements is most commonly used option in construction industry in Nigeria. The research had evaluated the subgrade quality on the stated road profile in the study area for flexible pavement design.

2. Study Area Description

2.1 Location of the Study Area

The study area, Mbaise ring road intersecting Owerri – Umuahia road is connected from Aboh Mbaise L.G.A, Imo State, southeastern Nigeria (Fig.1). It lies between latitude $5^0 27'$N and longitude $7^0 14'$E. The area is marked by two main climatic regimes: the wet and dry seasons. The wet season starts from April to October, during which the temperature varies from 23 to 26^{o}C. This season is associated with the prevalent moisture-laden southwest trade wind from the Atlantic Ocean. This wet season is also characterized by double maximum rainfall during which the peaks occur in July and September with a mean annual rainfall of 2152 [3]. A high evapotranspiration rate induced by dry conditions further helps to increase water losses [4]. The dry season starts in November when the dry continental north-eastern wind blows from the Mediterranean Sea across the Sahara Desert and down to the southern part of Nigeria [5] in the study area. Humidity is usually low and clouds are absent during dry season. The effect of the harsh North easterly wind, also called harmattan, is also felt within the period. A mean annual temperature of 32^{o}C is typical of the area [6]. Generally, the study area is dominated by rain forest vegetation whose density is substantially depleted by anthropogenic influences. The study area belongs to freshwater swamp forest, a subdivision of forest vegetation belt of Nigeria. This vegetation belt is typical of which trees are the most dominant species. Offodile [7] reported that vegetation of the area is typically tropical rain forest.

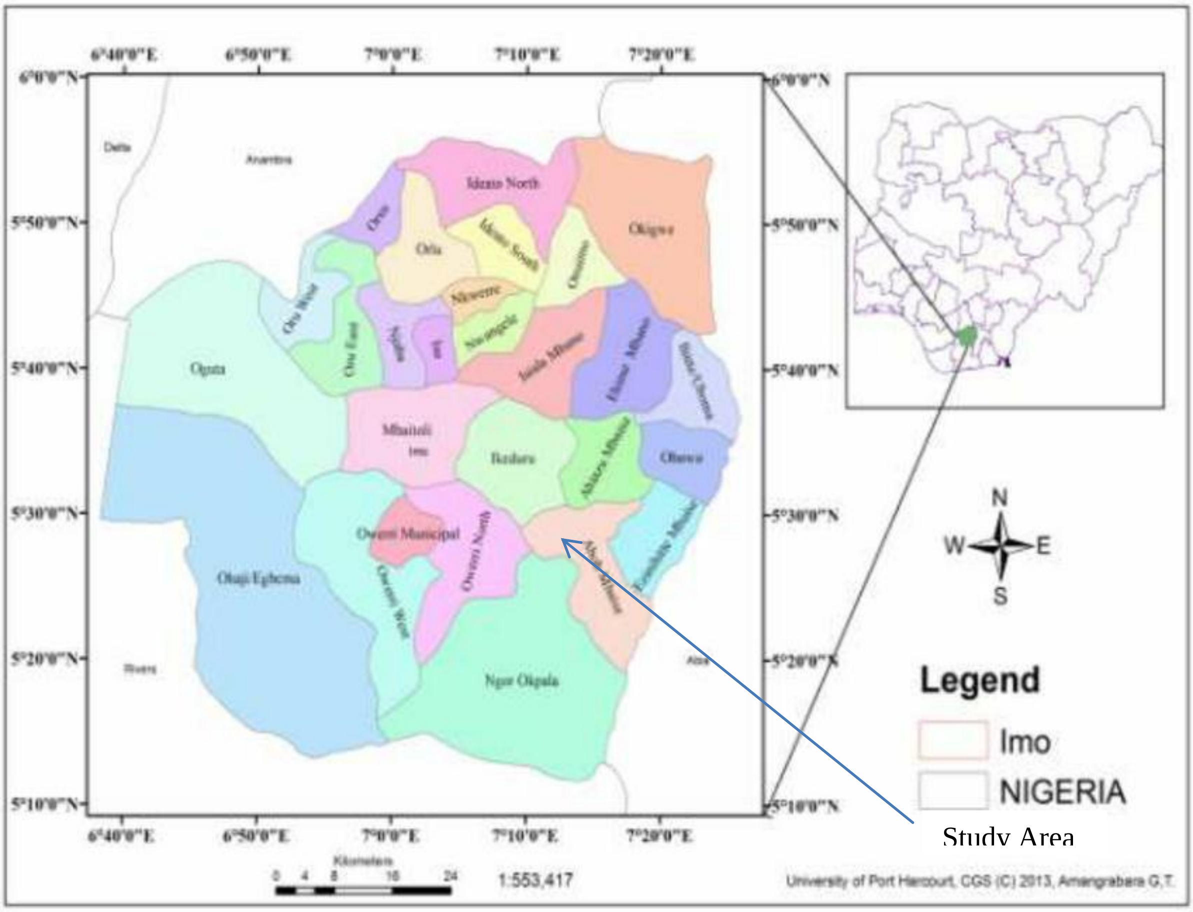

Figure 1: Location Map of the Study Area

2.2 Geology of the Study Area

The study area is underlain by the Benin Formation (Fig. 2). The Benin Formation within the Imo River Basin consists of unconsolidated yellow and white coastal plain sands with gravel beds, occasionally pebbly with grey sandy clay lenses [8]. The Benin Formation comprises of a thick sequence of poorly consolidated to unconsolidated sandstones that are friable with sorting ranging from poorly to fairly sorted [9]. The Benin Formation has lithologies consisting of sands, silt, gravel and clayey intercalations [10]. The sediments represent upper deltaic plain deposits and the environment of deposition is partly lagoonal and fluvio-lacustrine/deltaic [11].

In many places within the area, the formation is overlain by a considerable thickness of earth (laterite) composed of iron-stained regolith formed by the weathering and subsequent ferruginization of the weathered materials. Figure 2 is the geologic map of Imo State showing the study area, while Table 1 show the stratigraphic succession of rocks units in the study area.

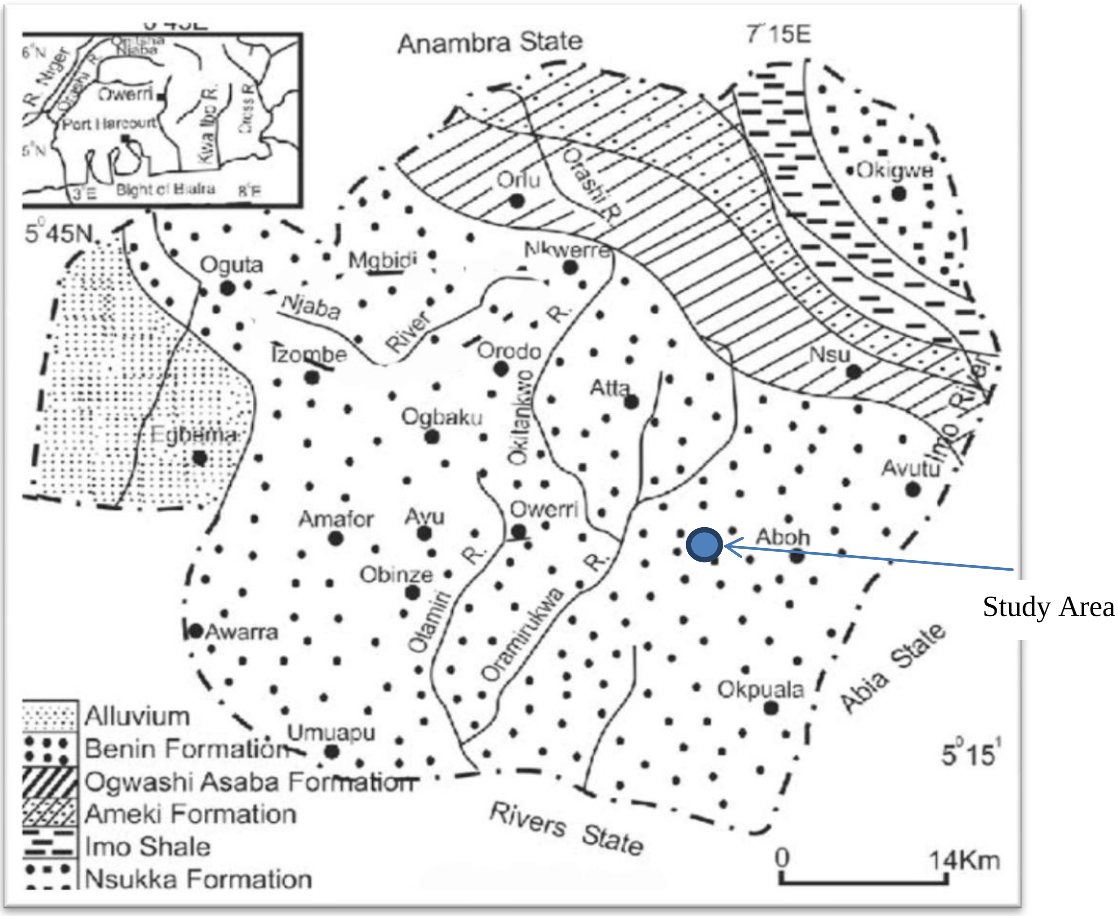

Figure 2: Geological Map of Imo State Showing the Study Area

Table 1: Stratigraphic Succession of Rock Units in the Study Area [28]

Age	Formation	Lithology
Miocene-Recent	Benin Formation	Medium to coarse grained poorly consolidated with clay lenses and stringers.
Tertiary-Oligocene-Miocene	Ogwashi-Asaba Formation	Unconsolidated sand with lignite at various layers.
Eocene	Ameki Formation	Grey clayey-sand stone and sandy clay stone.
Paleocene	Imo Shale	Laminated clayey-shale.
Maastrichian-Upper Cretaceous	Nsukka Formation	Sand stone intercalated with shale and coal beds.

3. Materials and Method

3.1. Field Study/Measurement

The analysis is intended to highlight the strength variability of subgrade materials' characteristics and potential settlements on the road profile.

Soil samples were collected disturbed at 60 different locations, interval of 500 m at distance of 30 km. The samples were clearly collected in a neat polythene bag with backhoe machine between the depth of 100 to 150 cm, labelled and transported to the laboratory for analyses. Soil samples collection was done in accordance with Backhoe sampling method of U.S Environmental Protection Agency, Science and Ecosystem Support Division [12]. The practice of preserving and transporting soil samples to the laboratory was done as outlined by ASTM D4220 [13].

The natural moisture content of each samples were tested in-situ, using speedy moisture tester as laid down by ASTM D4944 – 11 [14].

3.2 Laboratory analyses

The analysis was carried out at the geotechnical laboratory of Arab Contractors O.A.O Nig. Ltd, Imo State, Nigeria.

These methods cover the laboratory analyses carried out on the soil samples: Testing method of sieve analyses for fine and coarse soil [15-16]. Testing method for liquid limit, plastic limit, and plasticity index of soil samples was ASTM D4318 [17]. Method of experimentally determining the optimal moisture content (OMC) at which a given soil type will become most dense and achieve its maximum dry density (MDD) using standard proctor compaction mould was achieved as designated by ASTM D 696 [18]. The CBR test which measures the resistance of a material to penetration of standard plunger under controlled density and moisture conditions was done as stated in ASTM D1883 – 16 [7] and IS – 2720 part – 16 [19]. Linear shrinkage was in line with ASTM D 4943 [20]. Soil samples of CBR test were soaked in water for 96 hours, as described in Nigerian Federal Ministry of Works and Housing, on the review of subgrade specification [2].

4. Results and Discussions

The summary of geotechnical properties of the subgrade on the road profile is presented in Tables 2, 3, 4, 5, 6 and Figures 3, 4, 5, 6.

Table 2: Geotechnical Properties of Subgrade on the Road profile in the Study Area

S/No	Natural Moisture Contents (%)	Atterberg Limits			Linear Shrinkage (%)	Sieve Analyses (%) Passing Sieve No. 200	CBR (%) (Soaked for 96 hrs)	Compaction Test	
		L.L (%)	P.L (%)	P.I				MDD (Mg/m^3)	OMC (%)
1	14.6	26.9	15.1	11.8	6.2	27.7	12	1.87	12.1
2	15.2	24.9	14.1	10.8	6.0	20.7	14	1.87	12.7
3	18.6	26.7	15.3	11.4	6.4	20.0	11	1.85	14.6
4	15.5	26.0	14.1	11.9	6.5	25.0	12	1.89	12.4
5	16.3	26.0	12.7	13.3	9.8	33.4	7	1.83	13.9
6	17.4	36.0	19.9	16.1	14.4	37.5	3	1.83	14.6
7	17.1	33.0	20.3	12.7	7.2	23.6	5	1.85	13.0
8	18.9	33.0	17.7	15.3	12.2	37.1	2	1.81	15.6
9	14.2	32.5	16.8	15.8	12.2	36.6	6	1.88	12.5
10	11.4	27.0	15.1	11.9	6.5	24.9	15	1.91	8.0
11	13.4	28.0	18.1	9.9	7.0	22.6	14	1.90	10.5
12	14.4	29.0	18.7	10.3	6.2	31.0	12	1.82	12.7
13	15.3	29.0	16.7	12.3	7.4	28.5	13	1.80	12.6
14	16.1	35.0	20.0	15.0	12.0	25.1	9	1.87	12.9
15	16.0	34.0	19.3	14.7	10.2	23.7	4	1.88	13.9
16	16.5	34.0	14.6	19.4	17.3	28.0	3	1.83	13.0
17	19.4	34.0	12.4	21.7	19.6	35.3	2	1.81	16.1
18	17.8	35.0	11.6	23.3	20.8	37.1	3	1.79	15.1
19	15.1	32.5	12.2	20.3	17.9	36.1	3	1.82	12.3
20	9.8	30.0	15.7	14.3	9.9	22.1	6	1.95	7.5

21	15.2	33.0	19.9	13.1	9.8	20.3	10	1.83	11.2
22	17.3	31.0	16.8	14.2	10.0	21.8	8	1.88	13.0
23	14.8	34.0	13.7	20.3	18.1	37.2	3	1.83	12.6
24	15.2	32.0	10.9	21.1	18.5	35.1	3	1.82	12.9
25	18.0	33.0	10.4	22.6	18.8	36.3	3	1.77	14.6
26	14.9	35.0	12.3	22.7	19.0	38.1	2	1.83	12.6
27	16.5	34.0	11.4	22.7	18.7	35.8	4	1.88	14.8
28	12.4	34.0	16.6	17.3	15.6	24.4	11	1.90	10.6
29	13.0	32.5	19.4	12.7	7.3	23.3	11	1.89	10.8
30	10.8	30.5	18.4	12.2	7.0	21.9	15	1.95	7.9
31	13.3	28.0	18.2	9.8	6.1	23.4	13	1.88	10.8
32	13.8	29.0	19.2	8.8	5.8	22.9	11	1.88	11.5
33	13.8	34.8	21.4	14.9	10.7	23.5	7	1.91	11.1
34	12.6	31.8	15.2	15.8	12.5	37.1	3	1.90	10.9
35	12.6	34.0	11.5	22.5	19.3	35.6	3	1.92	9.9
36	11.4	31.0	11.0	20.0	17.4	36.7	3	2.01	8.4
37	12.9	33.0	14.2	18.8	15.8	22.2	3	1.91	9.1
38	14.6	33.0	18.8	14.3	10.0	22.3	7	1.89	12.0
39	12.7	33.0	20.5	12.5	7.0	24.2	12	1.90	10.5
40	12.9	32.5	20.2	12.3	7.2	27.3	17	1.95	10.0
41	12.5	29.5	18.8	10.7	6.1	28.3	15	1.86	11.5
42	18.6	28.5	16.3	12.0	7.0	23.9	12	1.74	16.4
43	14.2	32.0	18.7	13.3	9.6	26.9	10	1.90	11.6
44	15.6	31.0	16.3	14.7	10.0	26.9	7	1.92	13.0
45	13.0	32.5	17.3	15.2	12.1	28.2	8	1.89	11.0
46	13.8	32.5	12.2	20.3	18.2	32.3	2	1.90	10.4
47	17.2	33.5	11.2	22.4	18.5	35.1	3	1.86	14.6
48	16.0	40.5	19.9	20.6	17.8	37.8	2	1.83	13.3
49	15.6	44.0	23.2	20.9	17.5	39.3	3	1.78	13.3
50	12.4	34.0	18.7	15.4	11.6	25.7	9	1.87	9.5
51	15.8	34.0	16.0	18.0	15.7	30.1	8	1.83	13.8
52	16.3	34.5	18.2	16.3	13.7	35.9	8	1.78	14.1
53	18.4	41.5	19.9	21.5	19.0	37.4	6	1.75	15.1
54	17.8	34.5	16.5	18.0	18.1	38.2	2	1.80	14.5
55	18.0	41.0	15.2	25.8	21.8	36.2	3	1.81	15.1
56	19.2	42.5	17.7	24.8	21.2	35.0	5	1.72	16.2
57	18.6	45.0	20.3	24.8	21.3	33.4	3	1.74	15.4
58	16.6	42.5	20.6	21.9	17.5	36.9	3	1.81	14.3
59	17.0	44.0	21.0	23.0	19.7	39.1	3	1.77	15.1
60	16.2	36.0	16.6	19.3	17.4	37.7	4	1.78	13.5

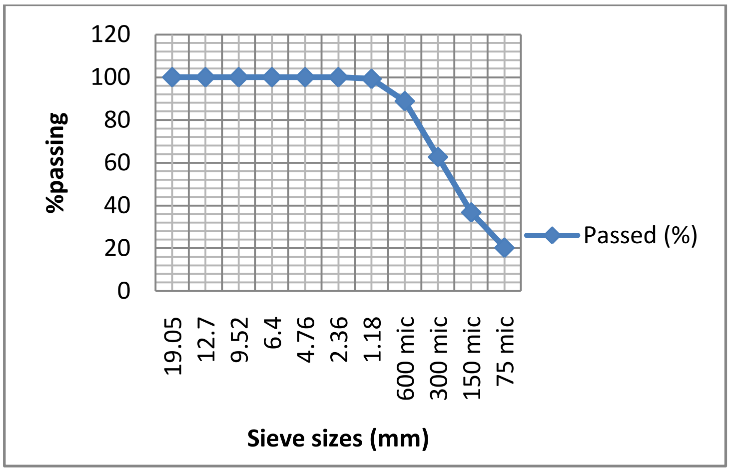

Figure 3: Typical Graphs of Sieve sizes Vs % passing at CH 10 + 500

Table 3: Sieve Analysis Reading at CH10 + 500

Weight	504 g
B.S Sieve (mm)	**Passed (%)**
19.05	100
12.7	100
9.52	100
6.4	100
4.76	100
2.36	100
1.18	99.2
600 mic	88.8
300 mic	62.7
150 mic	36.8
75 mic	20.3

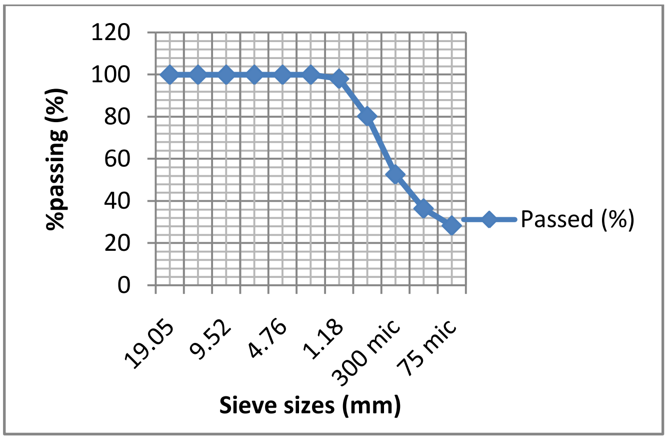

Figure 4: Typical Graphs of Sieve sizes Vs % passing at CH 20 + 500

Table 4: Sieve Analysis Reading at CH20 + 500

Weight	519.2g
B.S Sieve (mm)	**Passed (%)**
19.05	100
12.7	100
9.52	100
6.4	100
4.76	100
2.36	100
1.18	98.1
600 mic	80.3
300 mic	52.6
150 mic	36.4
75 mic	28.3

Table 5: Atterberg Reading at CH10 + 500

Type of Test	**LL**	**LL**	**LL**	**LL**
No. of Blows/shrinkage %	13.00	20.00	29.00	39.00
Container No.	1.00	2.00	3.00	4.00
Wt of wet soil & container (g)	67.20	67.30	67.60	69.00
Wt of dried soil & container (g)	60.40	60.90	64.50	63.20
Wt of container (g)	42.90	42.70	43.00	43.10
Wt of dry soil (Wd) (g)	17.50	18.20	18.50	20.10
Wt of moisture (Wm) (g)	6.80	6.40	6.10	5.80
Moisture content 100 (Wm/Wd)	38.86	35.16	32.97	28.86
Type of Test	PL	PL	PL	PL
No. of Blows/shrinkage %				

Container No.	5.00	6.00
Wt of wet soil & container (g)	56.00	57.20
Wt of dried soil & container (g)	53.80	54.90
Wt of container (g)	43.10	43.00
Wt of dry soil (Wd) (g)	10.70	11.90
Wt of moisture (Wm) (g)	2.20	2.30
Moisture contents 100 (Wm/Wd)	20.56	19.33

Table 6: Atterberg Reading at CH20 + 500

Type of Test	**LL**	**LL**	**LL**	**LL**
No. of Blows/shrinkage %	12.00	18.00	28.00	37.00
Container No.	1.00	2.00	3.00	4.00
Wt of wet soil & container (g)	65.90	64.50	66.00	63.60
Wt of dried soil & container (g)	60.10	59.50	61.00	59.20
Wt of container (g)	43.00	43.10	43.10	43.00
Wt of dry soil (Wd) (g)	17.10	16.40	17.90	16.20
Wt of moisture (Wm) (g)	5.80	5.00	5.00	4.40
Moisture content 100 (Wm/Wd)	33.92	30.49	27.93	27.16
Type of Test	PL	PL	PL	
No. of Blows/shrinkage %				
Container No.	5.00	6.00		
Wt of wet soil & container (g)	52.20	50.40		
Wt of dried soil & container (g)	50.80	49.20		
Wt of container (g)	43.00	43.10		
Wt of dry soil (Wd) (g)	7.80	6.10		
Wt of moisture (Wm) (g)	1.40	1.20		
Moisture contents 100 (Wm/Wd)	17.95	19.67		

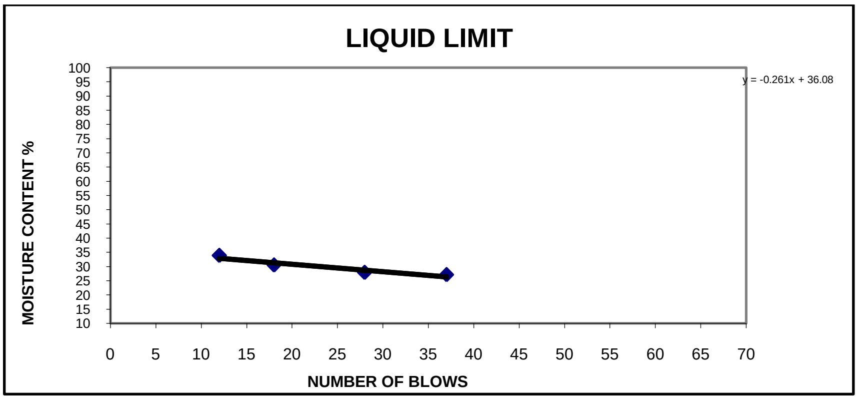

Figure 5: Typical Graph of Atterberg Limit at CH 10 + 500

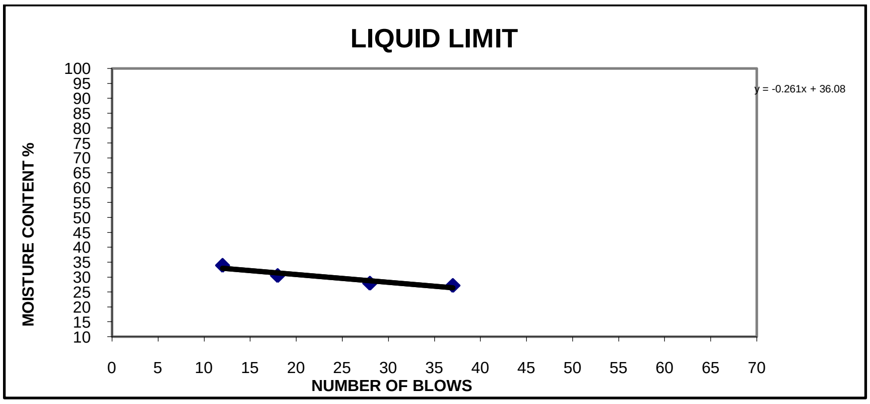

Figure 6: Typical Graph of Atterberg Limitat CH 20 + 500

The natural moisture contents give an idea of the state of soil in the field. The result of the natural moisture contents ranges from 9.8 to 19.4 %. Strength of soil decreases as moisture content increases, which also has influence on the density. The natural moisture content of a material is a measure of the water-holding ability of the material, usually reflecting clay content and type of material [21]. The results of atterberg liquid limit (LL) and plasticity index (PI) ranges from 24.9 to 45.0 % and 8.8 to 24.8 respectively. Results of sieve analyses as per percentages passing IS sieve no 200 (75µm) ranges from 20.0 to 39.3 % and, the CBR test results ranges from 1.9 to 16.9 %. The sieve analyses results are between 20.0 and 39.3 % while the linear shrinkage results are in the range of 5.8 to 21.8 %. The dry density/moisture content compaction test revealed a range of maximum dry density (MDD) of 1.72 to 1.95 Mg/m^3 and optimum moisture contents (OMC) of 7.5 to 16 %. The dry density of the soil increased with decrease in moisture content.

Recent investigation conducted by the department of materials geotechnics and quality control of the Nigerian Federal Ministry of Works and Housing (FMWH) [2] revealed that most premature failures experienced on the roads are attributed to weak subgrade. Nigerian FMWH on the review of subgrade specification [2], stated that the desired limit of subgrade for highway construction are as follows: plasticity index (PI) <30 %, liquid limit < 50 %, percentage passing IS sieve no 200 (75µm)<35 % and that CBR soaking period shall be 96 hours with a minimum CBR value of 15 % (Table 7).The idea is to subject the subgrade materials to some level of saturated condition in order to measure its strength during a long period of wet season.

The sieve analyses results showed that only 70 % of the samples fall within the desired limit while 30 % are above the limits of 35 %" (Table 7). According to ASTM's (1992) Unified Classification System (UCS) [22], the sieve analyses results as per percentage passing IS sieve no 200(75µm), 70 % of samples that are less than 35 % are classified as sand, gravel with elastic silt fines.

CBR test results showed that only 6.7 % of the total samples fall within the desired limit of >15 % after 96 hours soaked", while 93.3 % of the samples failed to meet with the requirement.

The results of atterberg limit revealed that 100 % of the samples fall within the desired limit (LL <50 %, and plasticity index (PI) <30 %). The samples' results for atterberg limits generally agreed with Ola's [23] and Holtz and Gibbs' [24] classification of expansive soil with moderate/medium swelling potential, on the basis of plasticity index (PI) and liquid limit (LL) (Table 8). These samples may have also have agreed with Okeke and Okegbue's [25] that the samples with low PI might have had their expansive clays converted to less expansive types.

The linear shrinkage results show that 28.3 % of the samples fall within the desired limit of 0 to 8 %, as designated by FMWH [26], while 71.7 % are above the limits. In line with Attimeyer's (1956) relationship between degree of expansion and linear shrinkage revealed that 28.3 % of these samples fall within marginal degree of expansion while 71.7 % are within critical degree of expansion (Table 9).

Table 7: Federal Ministry of Works, Material & Geotechnics and Quality Control Department, Reviewed Subgrade Specification (Adapted from FMWH, 2011 [26])

Parameters	Specification for subgrade as reviewed, FMWH (2011)
Sieve analyses	<35 % (% passing BS sieve 75µm)
Atterberg limits	
-LL	<50 %
-PI	<30
CBR	
(96 hrs Soaked)	> 15 %

Table 8: Classification of expansive soils on the basis of plasticity index (PI) and Liquid limit (LL)

Swelling Potential	Ola, 1981; PI	Holtz and Gibbs, 1956; LL (%)
Low	< 15	< 35
Moderate/median	15 – 25	35 – 50
High	25 – 35	50 – 70
Very high	>35	> 70

Table 9: Relationship between degree of expansion and linear shrinkage (Attimeyer, 1956)

Degree of Expansion	Linear Shrinkage (%)
Non-Critical	< 5
Marginal	5 – 8
Critical	> 8

5. Conclusions

The study had been able to highlight the subgrade quality materials' in terms of characteristics and potential settlements on the road profile in the study area.

The samples collected in the study area composed of top soil and highly weathered part of Benin Formation. The results proved that weathering may have affected the geotechnical properties of the subgrade because of the discrepancies in their properties within a short distance of sampling.

Generally, the CBR test being one the commonly means and important parameter to evaluate the bearing capacity of subgrade, did not in any way meet with the requirement of subgrade for design or construction of flexible pavements. In this case, the 93.3 % of the CBR samples taken that are below 15 % may be referred to unsuitable. The sampling points that failed to reach the requirements proved that soil settlement may occur on the pavement with time, causing deformation such as cracks and potholes.

The other parameters such as the sieve analyses, LL and PI may be considered in pavement design. The sieve analyses results classified grains of the subgrade as sandy gravel with elastic silt fines and, 70 % of the samples meet the requirement, while 30 % failed. The sand and gravel component may have attributed to the decrease in natural moisture content, as it cannot hold water, thereby increasing the dry density which has effect on the materials' strength.

All the samples tested for its liquid limit (LL) and plasticity index (PI) meet 100 % of the requirement, as it is classified low to medium swell-shrink potential based on PI.

On the basis of strength characterization, the subgrade materials do not meet the requirement of relevant specification. Their quality may be improved however by stabilizing them in-situ with appropriate percentages of cements, lime or river sand.

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References

[1]. California Division of Highway (1930). Standard Specification. January, 1930. Sacramento, also by California (Highway Commission HathiTrust).

[2]. Federal Ministry of Works and Housing (FMWH, 2011). General Specification for Roads and Bridges. Federal Government of Nigeria (Amended).

[3]. Short, K.C and Stauble A.J. (1967). Outline Geology of the Niger Delta, Nigeria. American Association of Petroleum Geologist, Volume 5: pp.761-779.

[4]. Etu-Efeotor, J. O and Odigi, M.I (1983). Water Supply Problems in Eastern Niger Delta, Nigeria. Journal of Mineral Geology, Volume 20 (1 and 2): pp. 183-193.

[5]. Nigerian Meteorological Agency, Owerri (NIMET) (2015). Records of Meteorological Data 2000 to 2015.

[6]. Ezeigbo, H.I. (1987). Quality of Water Resources in Anambra State. Nigeria. Journal of Mineral Geology, Volume 23: pp. 97- 103.

[7]. Offodile, M.E. (2002). Groundwater Study and Development in Nigeria. Mecon Geology and Engineering services Ltd. Jos, Nigeria, 2nd Ed. pp. 247-338.

[8]. Nwachukwu M. A, Feng, H and Ophori, D. (2010). Groundwater Flow Model and Particle Track Analysis for Selecting Water Quality Monitoring Well, Sites and Soil Sampling Points. Journal of Spatial Hydrology Volume 10 (1): Spring 2010.

[9]. Onyeagocha, A.C (1980). Petrography and Depositional Environment of the Benin Formation. Nigeria Journal of Mineral Geology, Volume 17, pp.147-151.

[10]. Asseez I O (1989). Review of the Stratigraphy, Sedimentation and Structure of the Niger delta in: Kogbe (ed) Geology of Nigeria. *Rockview Publication, Jos, pp. 311-334.*

[11]. Reyment, R. A. (1965) Aspects of Geology of Nigeria. Ibadan University Press, Ibadan. 628 p.

[12]. U.S Environmental Protection Agency (2015). Amending the Natural and Environment Policy Act. Ecosystem Support Division. Washington DC. Journal of Land Use and Environmental Law: pp 275 – 301.

[13]. ASTM D 4220. American Standard Test Method of Practice and Transporting Soil Samples.

[14]. ASTM D 4944 – 11. American Standard Test Method: *Field Determination of Water (Moisture) Content of Soil by Calcium Carbide Gas Pressure Tester*.

[15]. IS 2386 Part 1 (1963). International Standard Method of Test for Soils: Size and Shape by Bureau of Indian Standards (BIS).

[16]. ASTM C136/C136 M. American Standard Test Method for Sieve analyses for Fine and Coarse Aggregate Samples.

[17]. ASTM D 4318. American Standard Test Method for Liquid Limits, Plastic Limit, and Plasticity index of Soil Samples.

[18]. ASTM D 696. American Standard Test Method for Standard Proctor Compaction Test.

[19]. IS 2720 (Part 16) - 1979. International Standard Method of Test for Soils: Laboratory Determination of California Bearing Ratio (CBR).

[20]. ASTM D 4943. American Standard Test Method for Shrinkage limit of fine soil Samples.

[21]. Sowers, G.B. and Sowers, G.F.(1970). Introductory Soil Mechanics and Foundations, Macmillan, NY. 556p.

[22]. Unified Soil System Classification (1992). American Standard Testing Method for Classification of Soils for Engineering Purposes: ASTM Standard D2487. American Society for Testing Materials, West Conshohocken, Pa.

[23]. Ola, S. A., (1981). Mineralogical Properties of some Nigeria Residual Soils in Relation with Building Problems. Engineering Geology Volume 15, pp.1-13.

[24]. Attimeyer, W. T., (1956). Discussion of engineering properties of expansive soils by Holtz, W.G and Gibbs, H. J. (1956). Trans., ASCE, Vol. 21, pp. 666-669.

[25]. Okeke O. C., and Okegbue, C. O. (2011). Shales; A Review of their Classifications, Properties and Importance to the Petroleum Industries. Global Journal of Geological Science, Volume 9, No. 1, pp. 55-73.

[26]. Federal Ministry of Works and Housing (FMWH, 1997). General Specification for Roads and Bridges. Federal Government of Nigeria.