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RESEARCH ARTICLE

DETERMINING THE SUITABILITY OF CLAY AT ITU, AKWA IBOM STATE, NIGERIA FOR ROAD CONSTRUCTION

Emanuel B. Umoren, Kufre I. Udo, Akaninyene O. Akankpo, Sunday E. Etuk

Department of Physics, University of Uyo, Uyo, Nigeria
**Corresponding Author Email: emmanuelumoren@uniuyo.edu.ng*

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ABSTRACT

Incessant road failures in Nigeria have become an issue of serious concern in recent times as a large portion of states and federal budgets are dedicated to revamping road infrastructures. In this study, we examined the geotechnical properties of clay samples collected from Ntak Inyang along Calabar-Itu highway, in Itu LGA of Akwa Ibom State, Nigeria with the aim of ascertaining whether the earth material at the study location is suitable for road construction. We carried out proctor's compaction test, sieve analysis, California bearing ratio test and Attenberg's limit test to analyse the clay samples for moisture content, California bearing ratio, plasticity and plastic limit, dry density and particle sizes. Results obtained indicate that the clay sample has an optimum moisture content of 13.53 %, dry density value in the range: 1580 kgm^{-3}-1650 kgm^{-3}, plastic limit of 22.15 %, plasticity index of 23 %, liquid limit of 45.63 %, sieve of 43.36 % with particles less than 0.075 mm and no particle size up to 5.0 mm, California bearing ratios of 9.0 % at 10.0 % moisture content, 6.7 % at 12.0 % moisture content, 2.0 % at 14.0 % moisture content. Based on these results, the clay sample is regarded as a sub-grade material with the classification of A-7-6 according to AASHTO (American Association of State Highway and Transportation Officials) classification. These results make the sample unsuitable for road construction but qualify it as a potential raw material for production of ceramic wares and tiles.

KEYWORDS

Clay, moisture content, California bearing ratio, plasticity, plastic limit, dry density.

1. INTRODUCTION

Clay is one of the most abundant gifts of nature to man. It is a term used to refer to the finest-grain particles in a sediment, soil or rock. According to the Wentworth classification scale (Table 1), clay is finer than silt and is usually characterised by a grain size of less than approximately 4 micrometers. Clay occur most abundantly in soils, sediments, sedimentary rocks and hydrothermal deposits (Brandy, 1974; Braide, 1986). Together with organic matter, water and air, clay forms one of the major components of soil. Clay can be formed: directly in a soil by precipitation from solution (neo-formed clays); or from the partial alteration of clays already present in the soils (transformed clays); or inherited from the underlying bedrock or from sediments transported to the soil by wind' water or ice (inherited clays).

Geologically, clays are produced by the weathering of rocks containing feldspar and other aluminium-bearing materials. Earth scientists distinguish between various types of clays namely: primary clays, also known as residual clays; secondary clays, also called sedimentary clays; plastic clays; white clays; grey clays; coloured clays and Raku clays (Stephen, 1995). Residual clays are clays that remain in the same location as the parent rock from which they are formed. In contrast, secondary clays are formed from particles that have been transported from their source by running water, glaciers, or wind. These sedimentary clays may be deposited in lakes, oceans, or on the flood- plains of streams and rivers. The plastic clays are typically strong clays with ability to withstand vigorous handling during formation while the Raku clays are known to possess great capacity to withstand thermal shock. According to Hamer (1975), some of the distinguishing characteristics of clays include adsorption, ageing, blunging, drying, cracking, plasticity, de-airing, workability, shrinkage and thixotrophy.

Generally, the clay mineral is a loosely defined group of hydrous silicate minerals, essentially consisting of aluminium. Common examples of clay minerals include: Kaolinite, Clorite, Smectite and the Illite group. Clay is a very important commodity to man and has found increasing applications in architectural and civil / structural engineering, agriculture, petroleum industry, etc (Braid, 1983). Due to its diverse properties such as swelling (Bentonite), high melting point, colour, rheological properties (kaolinite – rich clays), etc. Some uses of clay include: catalysts and ion exchangers in drilling mud; as filters and absorbents in food and cosmetics; as binders for taxonite and fertilizers; as paper-coating materials; for the manufacture of bricks and ceramics; as moulding sands; decolorizers; detergents and soaps; medicines; molecular sieves and many other products (Ekpe and Akpabio, 1994). More so, clay in shale play an important role (acts as seals) in the generation of petroleum (Robert, 2001).

Over the years, road construction companies make use of clay as part of their raw materials for road construction. Some construction companies do make use of the clay from Ntak Inyang in Itu for this purpose. Since there has been no published work on the properties of the earth material at this location, it is therefore important to investigate the properties of the material at the said location and determine if it is suitable for road construction purposes or not. In this work, the geotechnical properties of clay samples collected from Ntak Inyang along Calabar-Itu highway has been investigated and analysed to determine its suitability for road construction purposes.

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Table 1: Wentworth Scale for Particle Classification.	
Particle	**Particle**
Boulder	Boulder
Cobble	Cobble
Pebble	Pebble
Granule	Granule
Sand	Sand
Silt	Silt
Clay	Clay

2. STUDY LOCATION

Itu, a Local Government Area in Akwa Ibom State, Nigeria, is located in the south of Nigeria. It occupies a landmass of approximately 606.1 square kilometers. Itu is bounded in the North and North East by Odukpani in Cross River State and Arochukwu in Abia State, in the West by Ibiono Ibom and Ikono Local Government Areas, in the South and southeast by Uyo and Uruan Local Government Areas, respectively.

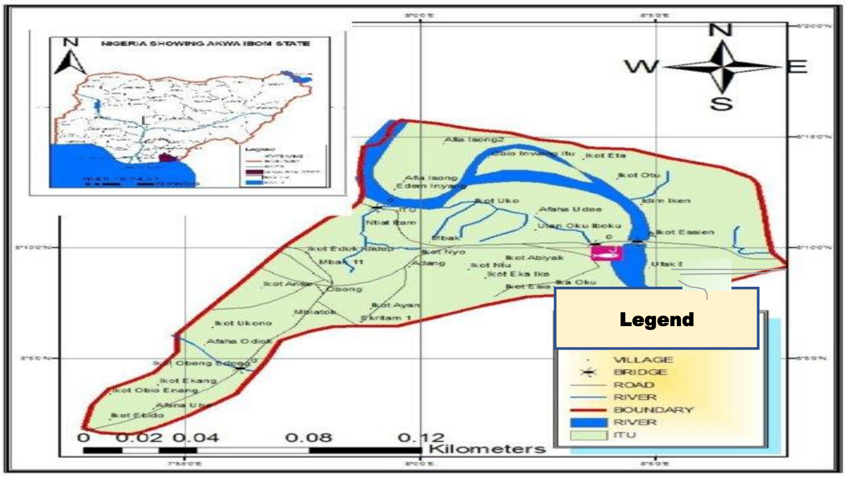

Figure 1: Map of study area.

Source: www.researchgate.net

2. MATERIALS AND METHODS

The clay sample used in the study was obtained at Ntak Inyang along Calabar -Itu Road in Itu LGA, Akwa Ibom State of Nigeria. It was taken to Nigerpet Structures Limited laboratory, Uyo for analysis. The material was originally in dry lumps which were reduced to powdered form by crushing.

3.1 Compaction Test

The proctor's compaction test was carried out to determine the optimum moisture content and maximum dry density of the clay sample, using the expressions in Equations 1 and 2.

$$Percentage\ (\%)\ Moisture = \frac{Weight\ of\ Moisture}{Weight\ of\ Dry\ Sample} \times 100 \quad (1)$$

$$Dry\ Density = \frac{Wet\ Density}{\%\ Moisture\ Content + 100} \quad (2)$$

At least, a total of five determinations were made and we ensured that the moisture content obtained was such that the optimum moisture content at which the dry density occurred lied within the range: 8%, 10%, 12%, 14% respectively

3.2 Sieve Analysis

Sieve analysis was performed to assess the clay sample particle size distribution. 0.50 g of air-dried clay sample was washed through sieve 0.075 mm and the material retained was oven-dried for 24 hours .The dried sample was then passed through standard sieves of 6.70 mm, 4.75 mm, 2.36 mm, 1.18 mm, 0.60 mm, 0.43 mm, 0.30 mm, 0.15 mm, 0.075 mm. A weighed sample was poured into the top sieve which had the largest screen openings. Each lower sieve in the column had smaller openings than the one above. At the base is a round pan, called the receiver. The column was placed in a mechanical shaker which shakes the column, usually for some fixed amount of time. The weight of the sample of each sieve was consequently divided by the total weight to give a percentage retained on each sieve according to Equation 3. The size of the average particle on each sieve was then analysed to get a cut-off point or specific size range, which was subsequently captured on a screen.

$$\%\ Retained = \frac{weight\ of\ soil\ retained}{total\ soil\ weight} \times 100 \quad (3)$$

3.3 California Bearing Ratio Test

California Bearing Ratio (CBR) test was carried out to estimate the load-bearing capacity of the soil. Wet compacted soil was placed on the California bearing ratio machine. When the proofing ring gauge and plunger penetration made contact with the sample and started working simultaneously, readings were taken on the plunger penetration gauge. The first 10 readings made were recorded as first pointer. The test was carried out on the top and bottom of the compacted wet sample. The two highest values recorded were chosen as the actual California bearing ratio. The procedure was repeated for additional 3 compacted wet samples. A graph was plotted for load against penetration base.

3.4 Atterberg Limit Test

The Atterberg limit test was performed to determine the liquid limit and plastic limit of the clay sample. The original Atterberg Liquid Limit (LL) test involved mixing a part of the clay sample in a round bottomed porcelain bowl of 10-12 cm diameter. A groove was cut through a part of the clay sample with a spatula, and the bowl was then struck many times against the palm. If after many blows the groove was only closed to an insignificant height at the base on the pat, then the clay was defined to be at it liquid limit; its water content was just not high enough for it to flow like a liquid given the opportunity to do so. The cup was repeatedly dropped 10 mm onto a hard rubber base at a rate of 120 blows per minute, during which the groove closes up gradually as a result of the impact. The number of blows for the groove to close was recorded. The moisture content at which it took 25 drops of the cup to cause the groove to close over a distance of 13.5 mm (0.53 inch) was defined as the liquid limit. The test was run at several moisture contents, and the moisture content which required 25 blows to close the groove was interpolated from the test results.

3.5 Determination of Plastic Limit

The plastic limit (PL) was determined by rolling out a thread of the fine portion of the clay sample on a flat, non-porous surface. Where the sample was at a moisture content exhibiting plastic behaviour, the thread retained its shape down to a very narrow diameter. The clay sample was remoulded and the test repeated.

3. RESULTS AND DISCUSSION

The results of the compaction test (proctor), sieve analysis, plastic limit and plasticity index as well as the California bearing ratio for the clay sample collected from Ntak Inyang along Calabar-Itu highway are presented in Tables 2, 3, 4, 5, 6, and 7 respectively. The compaction test results (Table 2) show that the sample has an optimum moisture content of 13.53% and this falls within the standard range of 9-15% recommended for road construction (according to AASHTO classification of soils). The dry density value spans from 1.58gcm^{-3} - 1.65gcm^{-3} (1500kgm^{-3}) which is suitable for road construction.

5. Determination of the Moisture/Density Relation of Sample

Table 2: Result of Proctor Compaction Test from Itu

DESCRIPTION: SUB-GRADE	**WEIGHT OF SAMPLE:**			**6,000.00g**				
VOLUME OF MOULD:	**2,305.00 cm³**							
Water Content	**8%**	**10%**	**12%**	**14%**				
Wt. of Mould + Wet Soil (a)	9,660.0	9,789.0	9,910.0	9,800.0				
Wt. of Mould (b)	5,640.0	5,630.0	5,590.0	5,560.0				
Wt of Wet Soil (a - b)	4,020.0	4,159.0	4,320.0	4,240.0				
Bulk Density gm/cm³	1.74	1.80	1.87	1.84				
Water Content %	**8%**		**10%**		**12%**		**14%**	
Container No.	**11**	**4**	**2**	**16**	**23**	**26**	**13**	**10**
Wt of Wet Soil + Container	57.87	59.01	77.32	78.98	80.20	85.25	97.11	99.38
Wt of Dry Soil + Container	55.69	57.08	73.00	74.25	74.93	79.45	88.55	90.59
Wt of Container Empty	36.35	36.24	36.54	36.28	36.39	36.10	36.33	36.29
Wt of Moisture	2.18	1.93	4.32	4.73	5.27	5.80	8.56	8.79
Wt of Dry Soil	19.34	20.84	36.46	37.97	38.54	43.35	52.22	54.30
Moisture Conten	11.27	9.26	11.85	12.46	13.67	13.38	16.39	16.19
Average Moisture Content	10.27		12.15		13.53		16.29	
Dry Density gm/cm³	1.58		1.61		1.65		1.58	
Water Content %	**8%**		**10%**		**12%**		**14%**	
CBR %			9.0%		6.7%		2.0%	

Max. Dry Density: 1.65gm/cm³
Optimum Moisture Content: 13.53%
C.B.R. @ Opt. M.C.: 6.70%

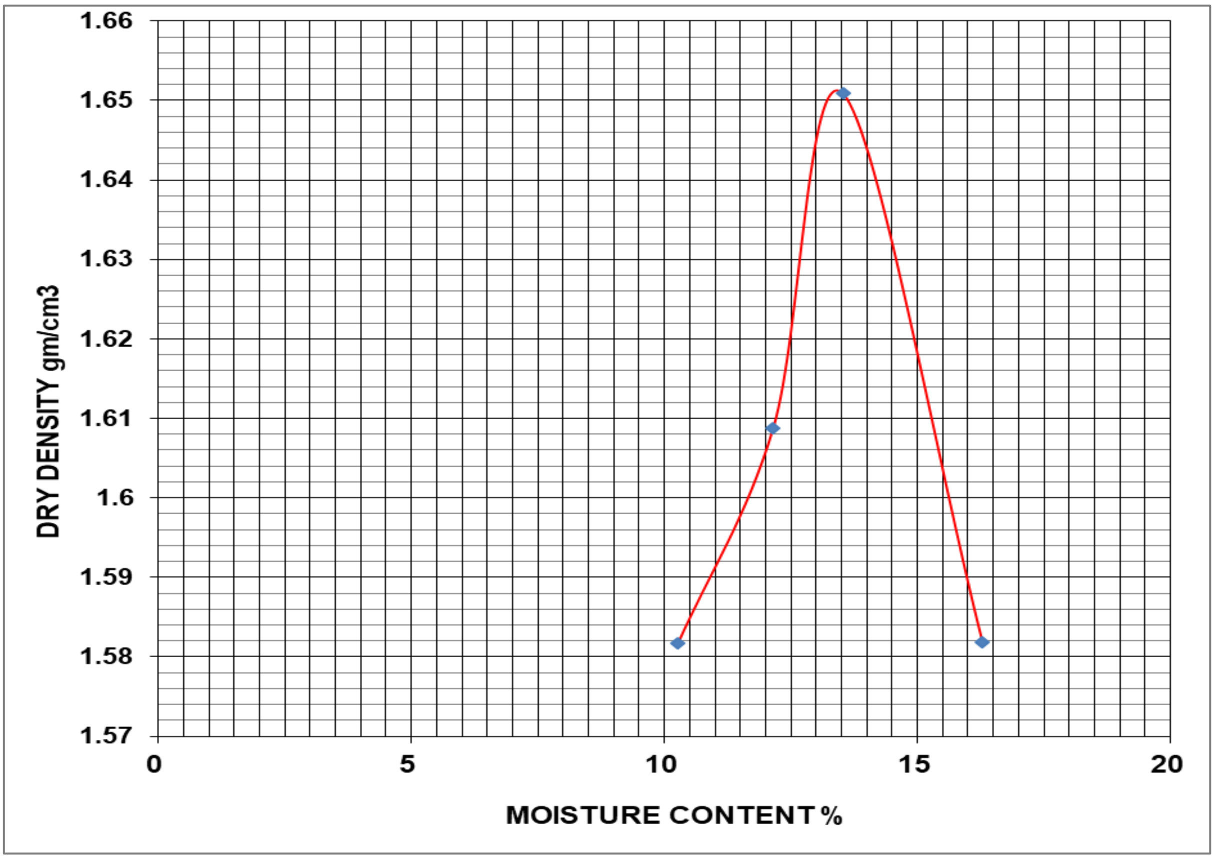

Figure 2: Graph showing Average Moisture Content against Dry Density for clay samples from Ntak Inyang, Itu

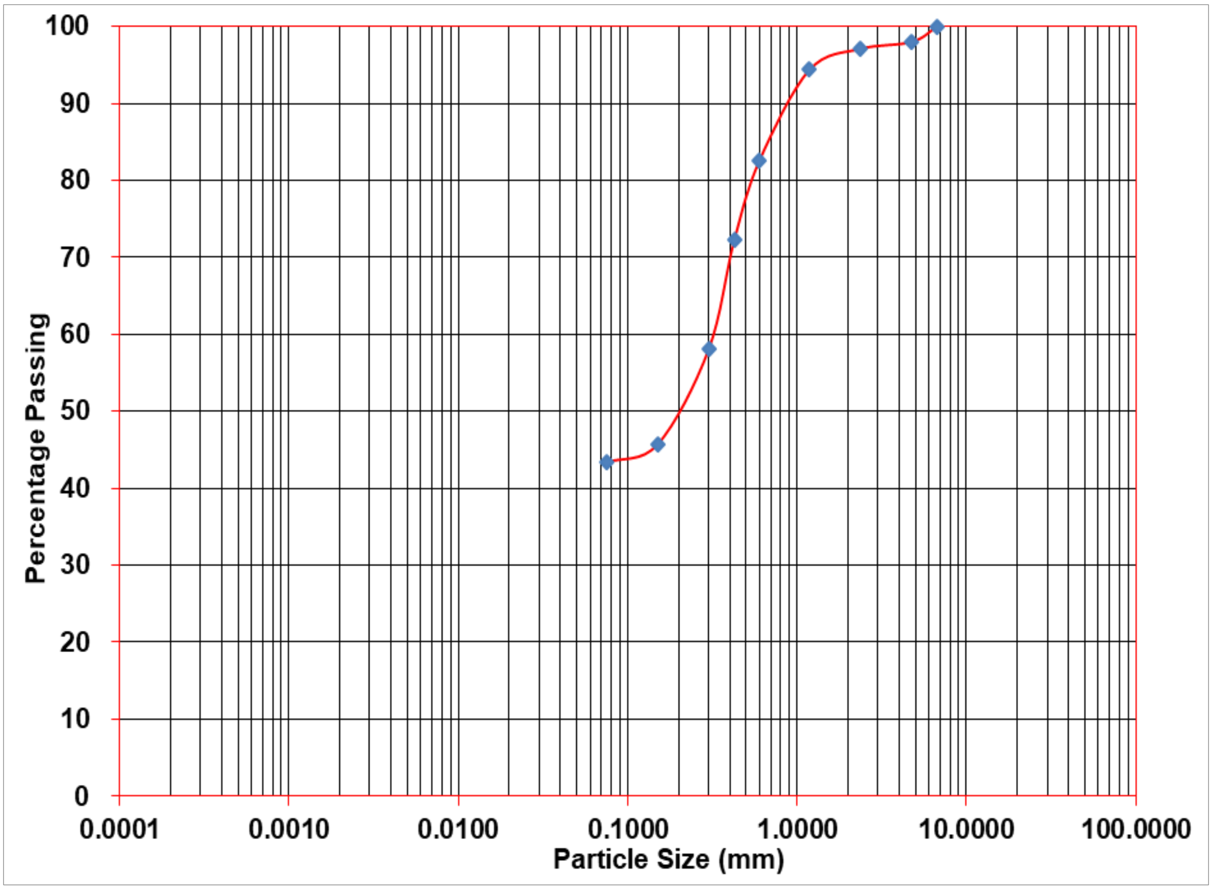

Figure 3: A graph of particle size distribution for clay sample from Ntak Inyang showing percentage passing against particle size.

Table 3: Particle size distribution for clay sample from Ntak Inyang, Itu

PARTICLE SIZE DISTRIBUTION						
SAMPLE REF: SUB GRADE			**Weight of Wet Sample:**	**500.00 grams**	**Weight of Dry Sample:**	**283.93 grms**
SIEVES		**Weight Retained**	**Percentage Retained**	**Percentage Cummulative**	**Percentage Passing**	**Specification**
3 Inches	75 mm	-	-	-	100.00	
2 1/2 Inches	63 mm	-	-	-	100.00	
1 1/2 Inches	37.50 mm	-	-	-	100.00	
1 Inches	26.50 mm	-	-	-	100.00	
3/4 Inches	19 mm	-	-	-	100.00	
1/2 Inches	13.20 mm		-	-	100.00	
3/8 Inches	9.50 mm		-	-	100.00	
1/4 Inches	6.70 mm		-	-	100.00	
3/16 Inches	4.75 mm	10.06	2.01	2.01	97.99	
7 No	2.36 mm	4.49	0.90	2.91	97.09	
14 No	1.18 mm	13.70	2.74	5.65	94.35	
25 No	0.60 mm	58.68	11.74	17.39	82.61	
36 No	0.43 mm	52.00	10.40	27.79	72.21	
52 No	0.30 mm	71.01	14.20	41.99	58.01	
100 No	0.15 mm	61.56	12.31	54.30	45.70	
200 No	0.075 mm	11.69	2.34	56.64	43.36	
Base	Base					
SUBGRADE	**SUITABLE**					

Table 4: Results of Plastic Limit Test for clay sample from Ntak Inyang, Itu

LIQUID AND PLASTIC LIMITS							
PROJECT/LOCATION: Ntak Inyang							
PROJECT/LOCATION: SUB GRADE				**CLASIFICATION:**	**A- 7 – 6**		
Type of Test		**LIQUID LIMIT**				**PLASTIC LIMIT**	
No. of Blows(Liquid Limit Test)		12	22	29	38	PL	PL
Container No.		2	24	26	29	19	37
Mass of wet soil + container	**W2**	55.96	58.85	60.84	63.75	41.53	42.74
Mass of dry soil + container	**W3**	49.56	51.65	53.20	55.55	40.58	41.61
Mass of container	**W1**	36.39	36.21	36.09	36.33	36.28	36.52
Mass of moisture	**W2 - W3 (a)**	6.40	7.20	7.64	8.20	0.95	1.13
Mass of dry soil	**W3 - W1 (b)**	**13.17**	15.44	17.11	19.22	4.30	5.09
Moisture Content (%)	**a x 100/b**	**48.60**	46.63	44.65	42.66	22.09	22.20
LIQUID LIMIT %	**SUBGRADE**		**SUB BASE**		**BASE COURSE**		
45							
PLASTIC LIMIT %							
22							
PLASTICITY INDEX %							
23							
SHRINKAGE LIMIT %							

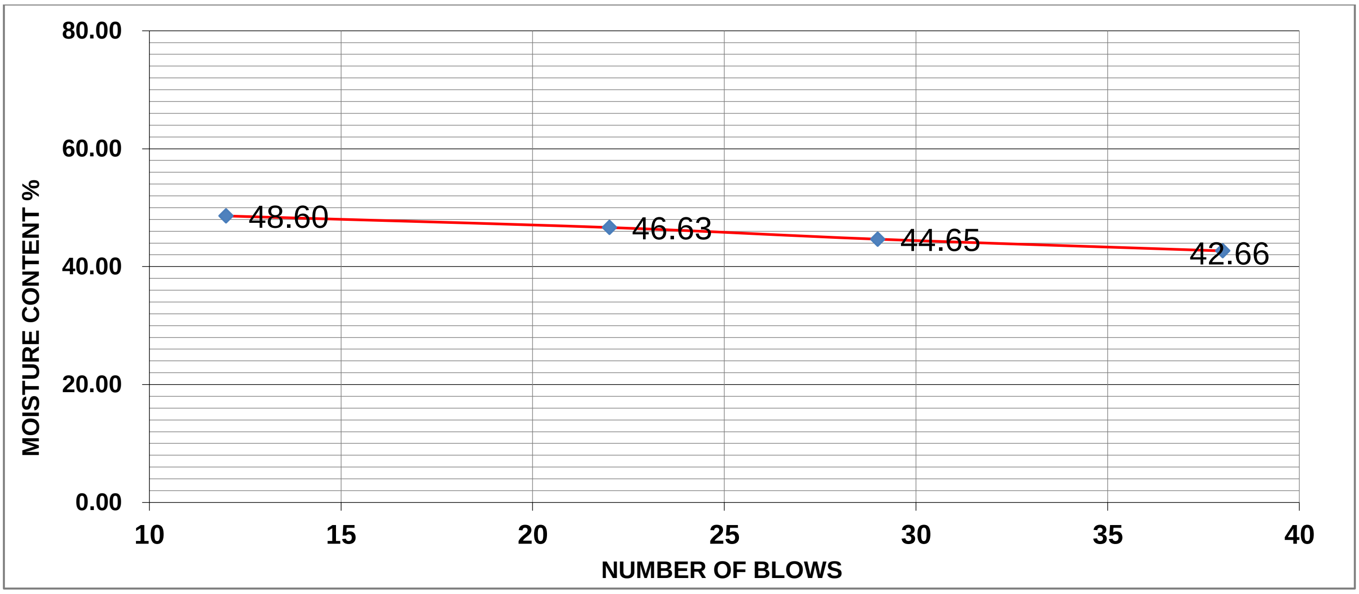

Figure 4: A graph of Percentage Moisture Content against Number of Blows for clay sample from Ntak Inyang, Itu.

Table 5 : California Bearing Ratio of 10 %

	Base		Top		**CBR CALCULATIONS**		
Pen (mm)	Dial	Load	Dial	Load	CBR @ 2.5mm = Load/13.6		
0.625	0.24	24	0.121	12.1	CBR @ 5.0mm = Load/20.4		
1.25	0.439	43.9	0.186	18.6			
1.875	0.587	58.7	0.26	26	**CORRECTED LOAD**		
2.5	0.929	92.9	0.859	85.9	PEN	BASE	
3.75	1.402	140.2	1.369	136.9	MM		TOP
5	1.473	147.3	1.47	147	2.500	92.90	136.90
6.25	1.674	167.4	1.491	149.1	5.000	147.30	147.00
					CORRECTED CBR %		
					2.500	6.83	10.07
SUBGRADE:		**UNSUITABLE**			5.000	7.22	7.21
SUB BASE:		**UNSUITABLE**				7.22	10.07
BASE COURSE:		**UNSUITABLE**				**CBR:**	**9%**

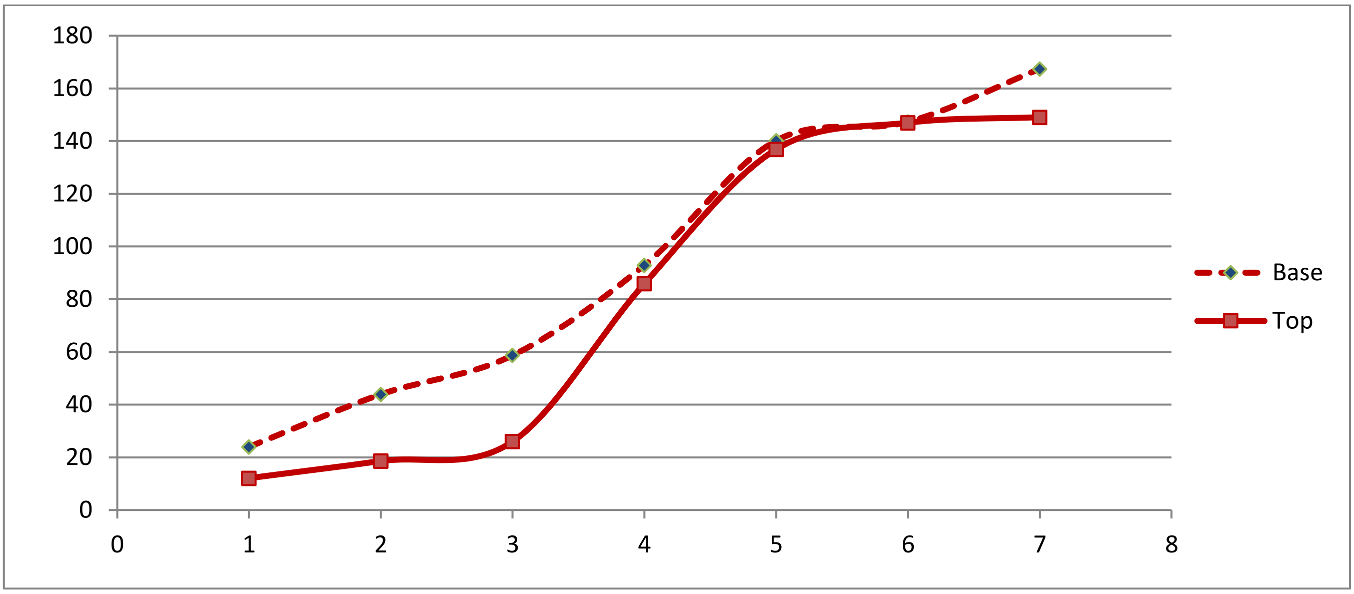

Figure 5: A graph showing 10 % of Load Base and Top Base against Penetration

Table 6: California Bearing Ratio of 12 %

	Base		Top		CBR CALCULATIONS		
Pen (mm)	Dial	Load	Dial	Load	CBR @ 2.5mm = Load/13.6		
0.625	0.661	66.1	0.537	53.7	CBR @ 5.0mm = Load/20.4		
1.25	0.857	85.7	0.64	64			
1.875	1.03	103	0.713	71.3	**CORRECTED LOAD**		
2.5	1.15	115	0.771	77.1	PEN	BASE	
3.75	1.339	133.9	0.89	89	MM		TOP
5	1.502	150.2	1.016	101.6	2.500	115. 00	77.10
6.25	1.642	164.2	1.131	113.1	5.000	150.20	101.60
					CORRECTED CBR %		
					2.500	8.46	5.67
	SUBGRADE:	**UNSUITABLE**			5.000	7.36	4.98
	SUB BASE:	**UNSUITABLE**				8.46	5.67
	BASE COURSE:	**UNSUITABLE**				**CBR:**	**6.7%**

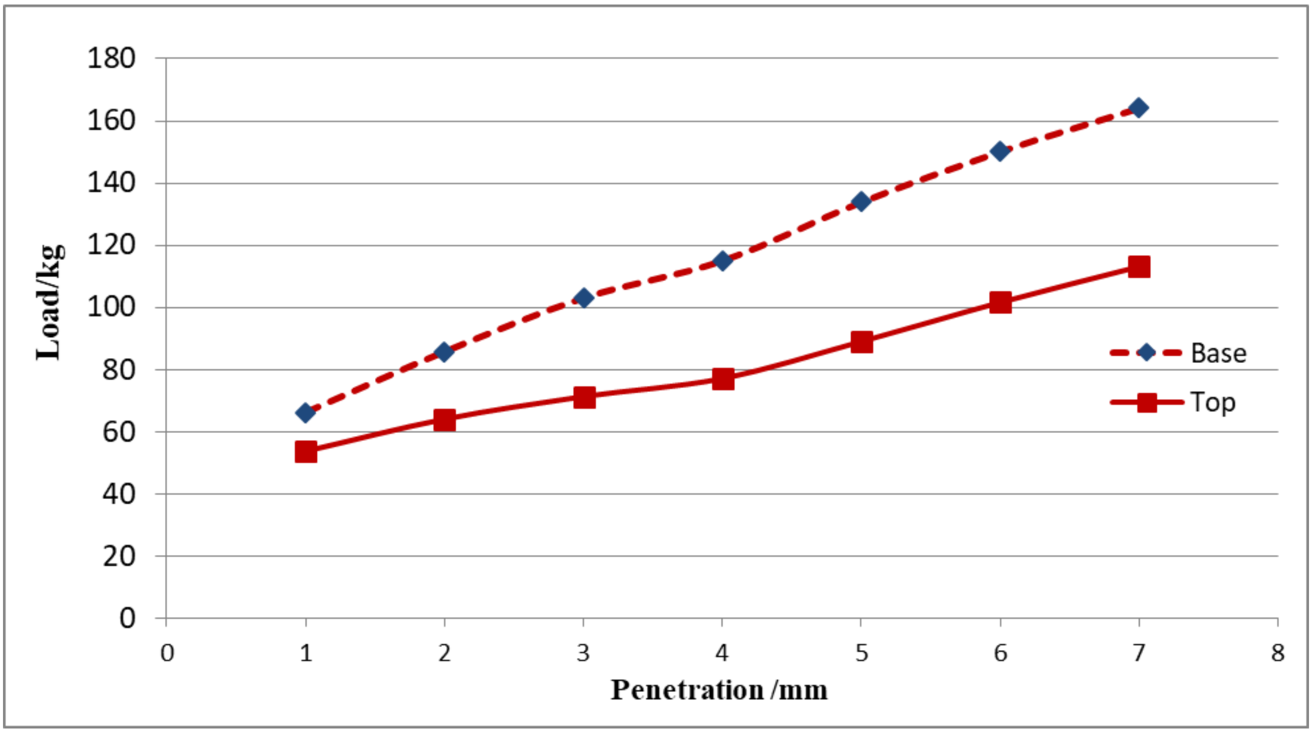

Figure 6: A graph showing 12 % of Load (Base and Top) against Penetration

Table 7: California Bearing Ratio of 14 %

	Base		Top		CBR CALCULATIONS		
Pen (mm)	Dial	Load	Dial	Load	CBR @ 2.5mm = Load/13.6		
0.625	0.151	15.1	0.217	21.7	CBR @ 5.0mm = Load/20.4		
1.25	0.191	19.1	0.245	24.5			
1.875	0.227	22.7	0.286	28.6	**CORRECTED LOAD**		
2.5	0.253	25.3	0.295	29.5	PEN	BASE	
3.75	0.306	30.6	0.339	33.9	MM		TOP
5	0.335	33.5	0.375	37.5	2.500	25.30	29.50
6.25	0.396	39.6	0.411	41.1	5.000	35.50	37.30
					CORRECTED CBR %		
					2.500	1.86	2.17
SUBGRADE:		**UNSUITABLE**			5.000	1.74	1.83
SUB BASE:		**UNSUITABLE**				1.86	2.17
BASE COURSE:		**UNSUITABLE**				**CBR:**	**2%**

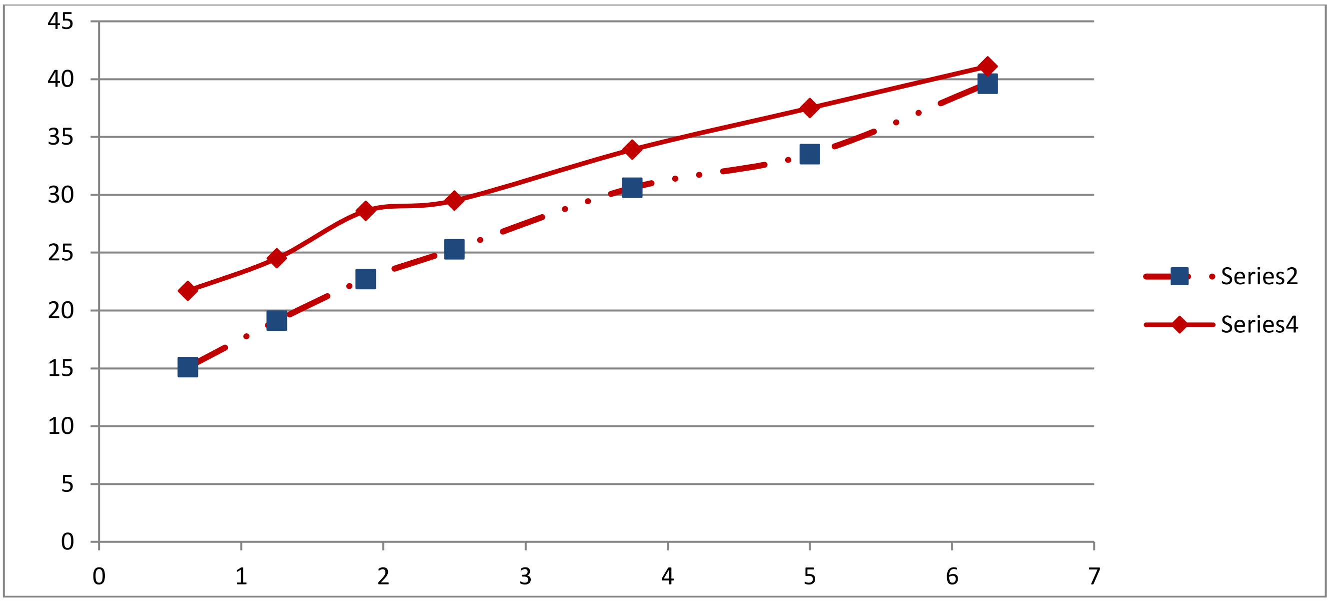

Figure 7: A graph showing 14 % of Load (Base and Top) against Penetration.

Based on Table 3, results of sieve analyses for particle size distribution indicate that out of 283.93 g of dry clay sample used for particle analyses, no particle was retained by sieves of 75mm, 63mm, 37.50mm, 26.50mm, 19mm, 13.20mm, 9.50mm and 6.70mm sizes. However, 97.99% of the sample used passed through a 4.75mm sieve retaining about 2.01%, 97.99% passed through 2.36mm sieve retaining 0.90%, 94.35% passed through a sieve of 1.18mm retaining 2.74%, 82.61% of the sample pass through 0.60mm sieve retaining 11.74%, 72.21% of the sample pass through 0.43mm sieve retaining 10.40%, 58.01% of the sample used passed through a sieve having a size of 0.30mm, 45.70% passed through a 0.15mm sieve size retaining 12.31%, whereas 43.36% of the sample has particle size less than 0.075mm, 2.34% less than 0.15mm, 12.31% less than 0.30mm, 14.20% less than 0.43mm, 10.40% less than 0.60mm, 11.74% less than 1.18mm, 2.74% less than 2.36mm, 0.90% less than 4.75mm and 2.01% less than 5.00mm. It is observed from these results that a greater percentage of the clay sample investigated has tiny particle sizes. More so, it can be seen that the relationship between percentage passing and the particle size is not a linear relationship for the sample (Figure 3).

Furthermore, results of the Atterberg's Limit test reveal that the clay sample investigated has 22% plastic limit with a plasticity index of 23%. This plasticity index is far above the standard 12 %, recommended for road construction. Also, the liquid limit for the clay sample investigated is shown to be 45%, 10% higher than the 35% recommended for road construction. However, there exist a linear relationship between the percentage moisture content and number of blows for the sample (Figure 4).

The California bearing ratio at 10% moisture content is presented in Table 5 while the plot of Load against penetration is presented in Figure 5. This plot shows a precision of Base with Top from 60 kg to 147 kg load. At penetration of 5, the Base and the Top seems to meet. The California bearing ratio of the sample at 10% moisture content is 9%. Similarly, Table 6 presents the California bearing ratio at 12% moisture content. The plots for both base and top (Figure 6) indicates a departure from that obtained at 10% moisture content. The two curves seem to meet at lower load value of about 60kg, with a California bearing ratio of 6.7%. Table 7 presents the Califonia bearing ratio at 14% moisture content. Based on Figure 5, it can be observed that there is divergence at the lower load value between the base and the top plots, whereas the base and top plots seem to converge at the upper load value for a California bearing ratio of 2.0%. It is clear from the three results that California bearing ratio increases with decrease in moisture content, but decreases with increase in moisture content.

The results of the sample analyses using California bearing ratio machine, sieve and Atterberg's limit machines lead to the classification of the sample as sub-grade and unsuitable for road construction. This is because the sample investigated swells when water penetrates, thus does not have the ability to carry load. However, this can be a potential raw material for ceramic wares and tiles.

4. Purpose and Plan of the Experiment

The purpose of the experiment was to find out if the earth material which contains clay in Itu LGA in Akwa Ibom State, Nigeria has the required characteristics for it to be used in constructing roads. The experiment was undertaken between March and June 2021 at Nigerpet Nigeria Ltd Laboratory in Uyo, Akwa Ibom State.

5. Conclusion

The geotechnical properties of the earth sample taken from Itu has been investigated. Based on our experimental results, it is observed that clay sample from Ntak Inyang, Itu along Calabar Itu highway possesses small particle sizes, dry density range of 1580 kgm^{-3} – 1650kgm^{-3} , optimum moisture content of 13.53%, plastic limit of 22%, liquid limit of 45% and plasticity index of 23%. Its C.B.R increases with decrease in moisture content and vice versa. The sample according to the result as analyzed using California bearing machine, sieve and Atterberg limit machines leads to the classification of the sample under sub-grade and unsuitable for road construction. This is so because it swells when water penetrates, thus would not have the ability to carry load. However, this can be a potential raw material for ceramic wares and tiles. These results qualify the sample as sub-grade and a poor material for road construction due to the swelling nature of the sample upon moisture intake.

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