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GEOTECHNICAL PROPERTIES OF AJALI SANDSTONE IN ENUGU, NIGERIA FOR ENGINEERING USE

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ABSTRACT
Twelve soil samples collected at different intervals from 0.1 meter deep in Onyeama Mine, Enugu State from the Ajali sandstone were subjected to geotechnical analysis (moisture content, sieve analysis, Atterberg's limits) to determine their suitability for the siting of some engineering structures. The results show that the soils are cohesive at shallow depths (1.8m – 1.0m). It is cohesionless with greater sandy fraction at greater depths. The moisture content values are low and averages 10.65% (from depth 0.00m– 1.8m). For the Atterberg limit; liquid limit ranges from 31% - 36% while the plasticity limit was 25%. On the AASHTO classification and plasticity chart, part of these results show that the top soils at shallow depths (1.8m – 1.0m) are inorganic clays. Consequently, the top inorganic layer needs to be stabilized or excavated and back-filled with more stable materials for engineering structures purposes.

Keywords: *Engineering, Geotechnical Analysis, Geotechnical Properties, Moisture Content, Sandstone, Structures.*

1. INTRODUCTION

The success of any engineering structures such as roads, buildings, railway lines depends to a large extent on the nature of the soil on which the structures are situated. If the bearing capacity of the soil is not good enough to sustain the imposed structure, it is bound to fail. It is therefore necessary to always study the geo-technical index properties of the soil before structures are located on them. This is because the geotechnical properties of soil influences the stability of civil engineering structures structures [1]. In evaluating the earth's materials, several criteria are used. One of such criteria is the particle size distribution analysis; since every soil is greatly influenced by the major size fraction within the particles size distribution (PSD).In order to classify a soil for engineering purpose, one need to know the distribution of the size of grains in a given soil mass. The particle size distribution curve is extremely useful for classification of coarse-grained soils as the behaviour of fine-grained soil depends on the plasticity characteristics and not on particular size. The properties of the soil such as plasticity, compressibility or strength of the soil always affect the design in the construction. Lack of understanding of the properties of the soil can lead to the construction errors. The suitability of soil for a particular use should be determined based on its engineering characteristics and not on visual inspection or apparent similarity to other soils [1]. The loading capability of soil depends upon the type of soil. Generally, fine grained soils have a relative smaller capacity in bearing of load than the coarser grained soils [2]. Plasticity index and liquid limit are the important factors that help an engineer to understand the consistency or plasticity of clay. Though shearing strength constants at liquid limits but varies for plastic limits for all clays [3]. Permeability influences the civil engineering structures. According to [4], the shear strength of soils is of special relevance among geotechnical soil properties because

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it is one of the essential parameters for analyzing and solving stability problems (calculating earth pressure, the bearing capacity of footings and foundations, slope stability or stability of embankments and earth dams). This research evaluated the geo-technical properties of Ajali Sandstone in Anambra Basin in order to assess their suitability for engineering use. This was done using different approaches including the determination of the particle size distribution, the moisture content of the soil and evaluation of the consistency of the soil based on Atterberg's limits.

The study area is located in the Ajali Formation of Anambra Basin, specifically in the Onyeama Mine area, Enugu State, Southeast Nigeria. It lies within latitude $7^0 26'$N of the equator and longitude $6^0 28'$E of the Greenwich Meridian.

2. GEOLOGY OF THE AREA

The sequence of deposition in the Anambra Basin is predominantly of massive continental deposits overlying marginal sandstone, shale and coal. The Upper Cretaceous Ajali sandstone in the southern sedimentary Basin of Nigeria is an extensive stratigraphic unit. It was referred to as the false bedded sandstones in the reports of the Nigerian Geological Survey [5, 7] and was formally named the Ajali sandstone by Reyment [8]. The Formation is conspicuous along the Udi plateau and extends continuously in a thin outcrop to the southeast of Okigwe. It is underlain by the Mamu Formation and overlain conformably by the Nsukka formation

The thickest section is present in the Udi plateau where it has been variously reported to be over 350m thick [6, 7]. The Formation rapidly thins south of the Oji River and is no more than a few tens of meters over the Okigwe axis.

3. METHODOLOGY

3.1 Technical Method

Systematic sampling was used in collecting the soil samples at different intervals for laboratory analyses. The thickness of each successive unit is about 0.61 metres.

3.2 Laboratory Analysis

The soil samples were subjected to the following laboratory tests: Moisture content, Atterberg's (consistency) limits and particle size distribution (PSD) analysis.

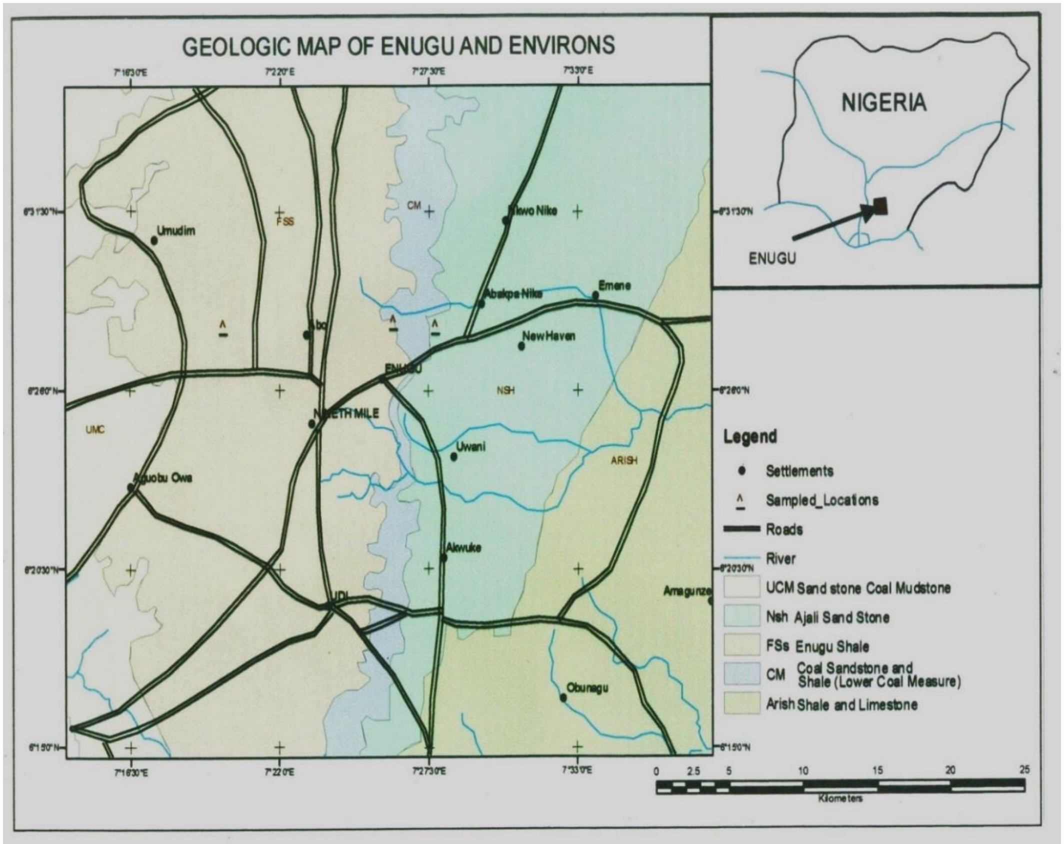

Figure 1: Location map showing sampled points

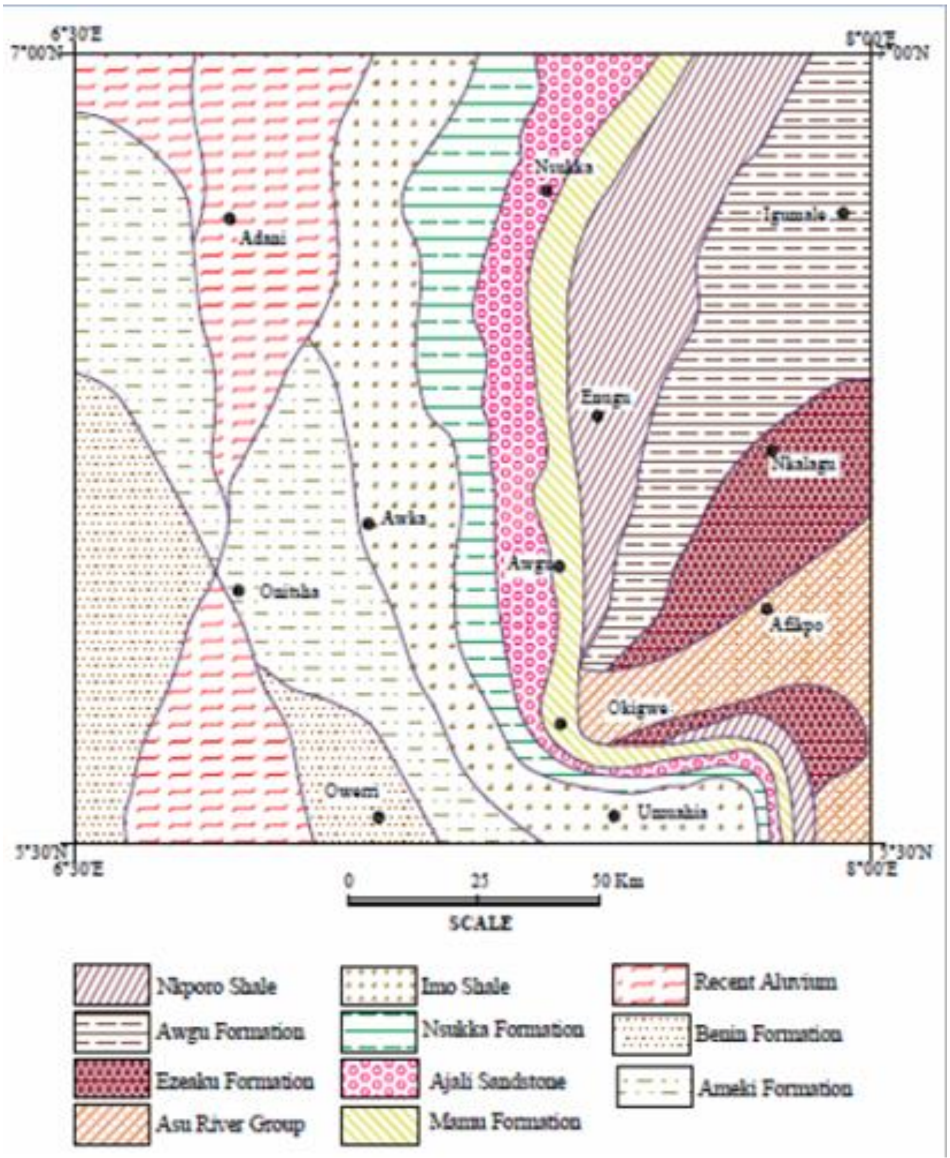

Figure 2: Geological Map of the Anambra Basin (After 9)

3.3 Moisture Content Determination (MC)

Moisture content is defined as the ratio (usually expressed as percentage) of mass of water in the voids to the mass of solids.

$$Moisture\ content = \frac{Mw}{Ms} \times 100\% \quad (1)$$

Where: Mw is the Mass of Water and Ms is the Mass of Solid

3.4 Atterberg's Limit Determination

Atterberg's limit tests are commonly made on cohesive soils for both classification and correlation purpose.Test on the portion of samples that passes an ASTM [10], standard sieve No.40 (0.425mm), determines the percentage of moisture based on dry weight at which each changes in consistency takes place.

3.5 Liquid Limit and Plastic Limit

The plastic and liquid limits were plotted on the Casangrande charts as shown in the output graphs in Figures 4, 5 and 6. Plastic limit was measured in the moisture content, in percent of clay at the boundary between the plastic and brittle (semi-solid) state of that particular soil under defined condition. The values for the liquid and plastic limits were read off from the red lines which are projected to meet the flowline as shown in Figures 4, 5 and 6. The differences between them gave the plasticity index as shown in Table 4.

3.6 Particle Size Distribution (Sieve Analysis)

Sieve test was carried out to determine the diameter of the soil particles making up the soil mass. This was done by sieving 267.29g of the soil sample through a stack of sieves of progressively smaller mesh openings from top to bottom of the stack.

4. RESULTS AND DISCUSSION

A lithologic log was created along a vertical section of the study area and is presented in Figure 3. From the top to about 1.9 metres, sandy-clays were dominant.

3.1 Natural Moisture Content

The results show low moisture content for the Ajali sandstones with average values of 10.06 (Table 1). Another striking feature is that the moisture content increases with depth.

3.2 Particle Size Distribution (PSD)

Table 2 shows the result of the grain size analysis. The particle size distribution was consistent for all the samples as they mostly settle within the 2.0mm and 0.075mm sieve sizes; which correspond to the fine, medium and coarse sand fractions. The sand are therefore well graded (Table 3). About 60% of the sand grains are fine while 40% are medium to coarse grained. The percentage of fine sand is well above 60% at depths 1.8m, 1.3m, 1.0m, 0.8m, 0.7m, 0.6m, 0.5m and 0.4m. The highest percentage of fine sand was 80.9% recorded at 0.8m while the lowest was 41.1% recorded at 1.1m. This is an indication that the fine sand are prominent at shallower depth

Table 1: Results of the natural moisture content

Sample	Depth (M)	Moisture Content (%)	Average
A	0.00	0.60	
B	0.30	8.16	
C	0.40	7.88	
D	0.50	13.10	
E	0.60	14.60	
F	0.70	8.17	
G	0.80	13.26	10.06
H	0.10	11.41	
I	1.10	8.03	
J	1.20	11.71	
K	1.30	11.03	
L	1.80	12.71	

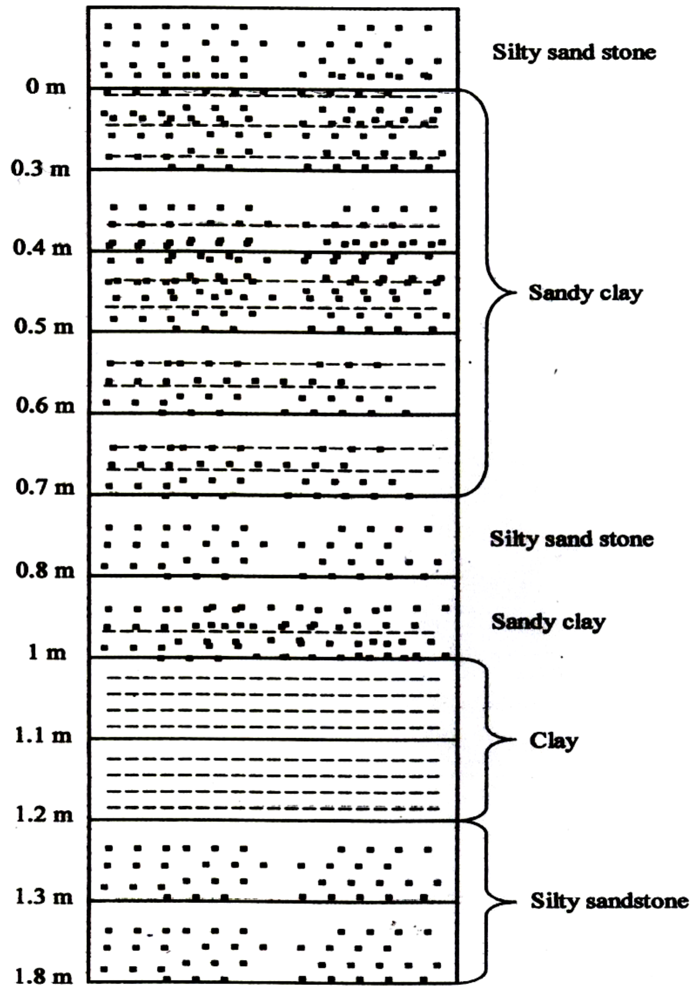

Figure 3: Lithologic section of the study area

Table 2: Result of grain size analysis with the sieve sizes and weight retained for sample 1. The weight of sample before washing was 267.29g

Sieve size		Weight Retained	Percent Retained	Percent passing
#	*(mm)*	*(g)*	*(%)*	*(%)*
3in.	75.00	0.00	0.00	100.0
1.5in.	37.50	0.00	0.00	100.0
3/4in.	19.00	0.00	0.00	100.0
3/8in.	9.50	0.00	0.00	100.0
No.4	4.875	0.00	0.00	100.0
No.10	2.00	0.96	0.4	99.6
No.16	1.18	0.92	0.3	99.3
No.30	0.600	2.34	0.9	98.4
No.40	0.425	1.74	0.7	97.8
No.50	0.300	2.27	0.8	96.9
No.100	0.150	9.88	3.7	93.2
No.200	0.075	151.53	56.7	36.5
Pan		97.65	36.5	
Total		267.29		

Table 3: Percentage of Sand Fraction

Depth	% Coarse Medium	% fine	Classification
0	46.2	53.8	Well Graded
0.3	47	53	Well Graded
0.4	35.4	64.6	Well Graded
0.5	38.6	61.4	Well Graded
0.6	37.1	62.9	Well Graded
0.7	37.6	62.4	Well Graded
0.8	19.1	80.9	Well Graded
1	38.3	61.7	Well Graded
1.1	58.9	41.1	Well Graded
1.2	55.3	44.7	Well Graded
1.3	34.2	65.8	Well Graded
1.8	38.2	61.3	Well Graded

3.3 Atterberg's Limits

Results for the Atterberg's limits of the samples are summarized in Table 4. The average value for the liquid limits is 34.70% (which means it is medium, based on the ASTM chart), plastic limit averages at 25% and plasticity index has an average value of 9.7% which shows the soil to be moderately plastic.

Plastic soils are not very suitable for construction because of their clayey nature. Consequently, they are usually excavated and filled with more suitable materials.

Table 4: Average Atterberg's Limit Value for Soils in the Area

Depth (m)	LL (%)	PL (%)	PI (%)
0.0-0.5	31	25	6
0.6-1.0	36.5	25	11.5
1.1-1.8	36.5	25	11.5
Average	34.7	25	9.7

A plot of the Atterberg's limit parameters on the *Casangrande* [11] plasticity charts (Figures 4 and 6) indicate that the top soil (0-0.5 and 0.6-1.1) are silty materials and clayey as they fall above the A-line and those of greater depths are sandy clay.

Table 5 (a): Showing the test details for 0.0-1.1m

Description	Test					
Test Type	Liquid Limit			Plastic Limit		
Test No	1	2	3	1	2	Average
No of Blows (Liquid Limit Test	16	23	34			
Liquid Limit @ 2.9m	38.29	36.55	36.19	18.76	18.60	
Liquid Limit @ 3.2m (g)	28.16	26.88	25.09	18.93	18.90	18.64
Liquid Limit @ 3.3m (g)	31.15	29.09	26.97	18.55	18.12	
Average (2.9m – 3.3m) %	32.53	30.84	29.42	18.75	18.54	

Table 5 (b): Showing the test details for 0.0-1.1m

Liquid Limit	(LL)	31.0
Plastic Limit	(PL)	25
Plasticity Index	(PI)	6

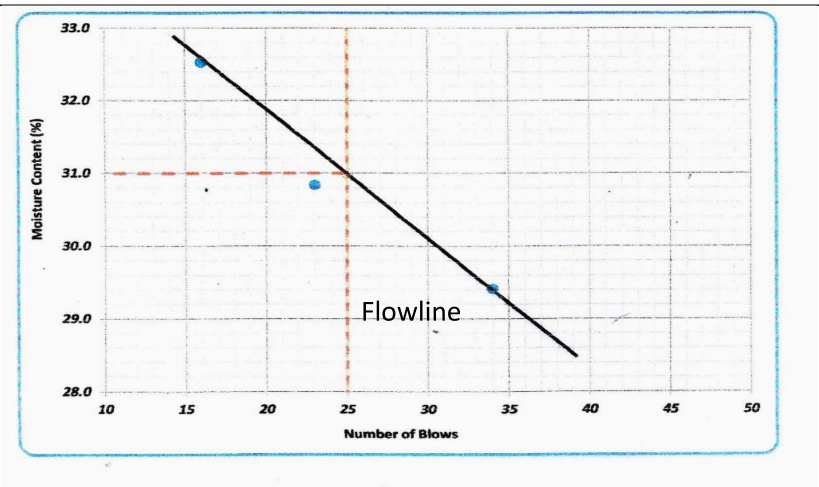

Figure 4: Test Output Graph for 0.0-1.1m

Table 6 (a): Showing the test details for 0.5-1.8m

Description	Test					
Test Type	Liquid Limit			Plastic Limit		
Test No	1	2	3	1	2	Average
No of Blows (Liquid Limit Test)	16	23	34			23.43
Liquid Limit @ 2.1m	21.42	18.20	16.84	0.00	0.00	
Liquid Limit @ 2.6m (g)	20.23	18.45	16.67	0.00	0.00	
Liquid Limit @ 2.7m	32.37	31.83	31.35	23.14	22.91	
Liquid Limit @ 2.8m (g)	39.39	38.27	36.92	23.22	24.43	
Average (2.1m – 2.8m) %	28.35	26.69	25.45	23.18	23.67	

Table 6 (b): showing the test results for 0.5-1.8m

Liquid Limit	(LL)	36.5
Plastic Limit	(PL)	25
Plasticity Index	(PI)	11.5

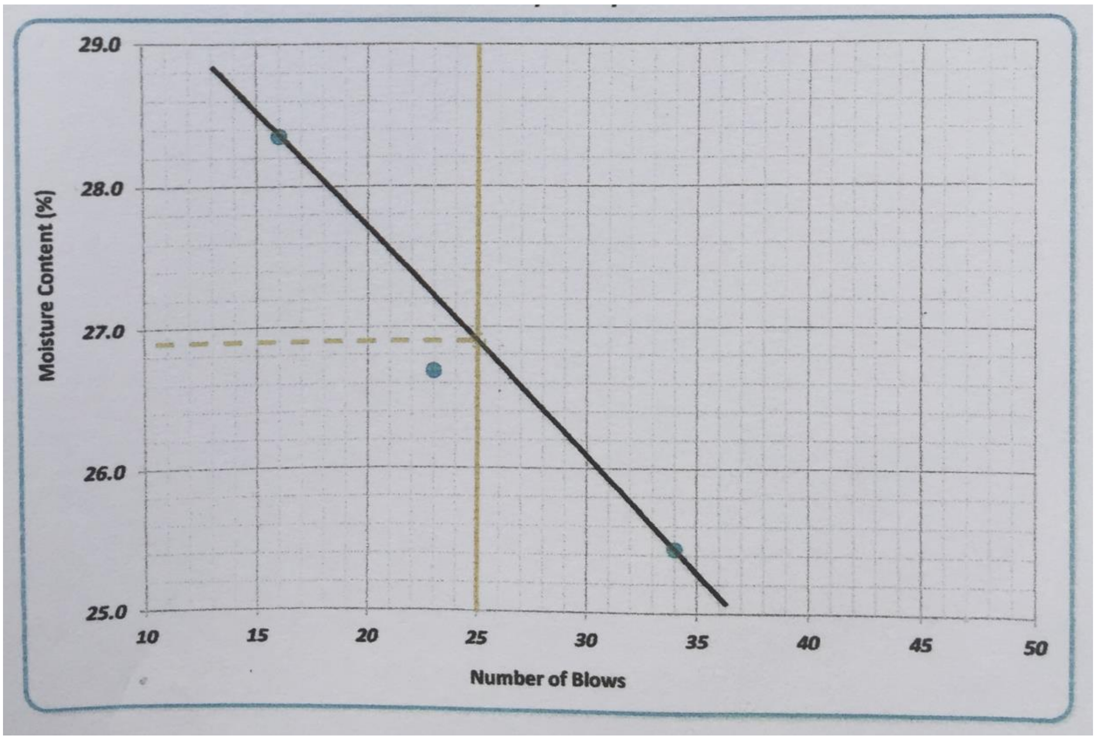

Figure 5: Test Output Graph for 0.5-1.8m

Table 7 (a): Test details for 1.0-0.6m

Description	Test					
Test Type	Liquid Limit			Plastic Limit		
Test No	1	2	3	1	2	Average
No of Blows (Liquid Limit Test	16	23	34			23.01
Liquid Limit @ 3.4m	32.03	30.77	29.98	16.24	16.25	
Liquid Limit @ 3.5m (g)	34.75	33.38	31.69	22.90	23.08	
Liquid Limit @ 3.6m (g)	43.61	40.15	39.70	25.33	25.78	
Liquid Limit @ 3.9m (g)	41.15	40.11	39.20	27.16	27.37	
Average (3.4m – 3.9m) %	37.89	36.10	35.14	22.91	23.12	

Table 7 (b): Test results for 1.0-0.6m

Liquid Limit	(LL)	36.5
Plastic Limit	(PL)	25
Plasticity Index	(PI)	11.5

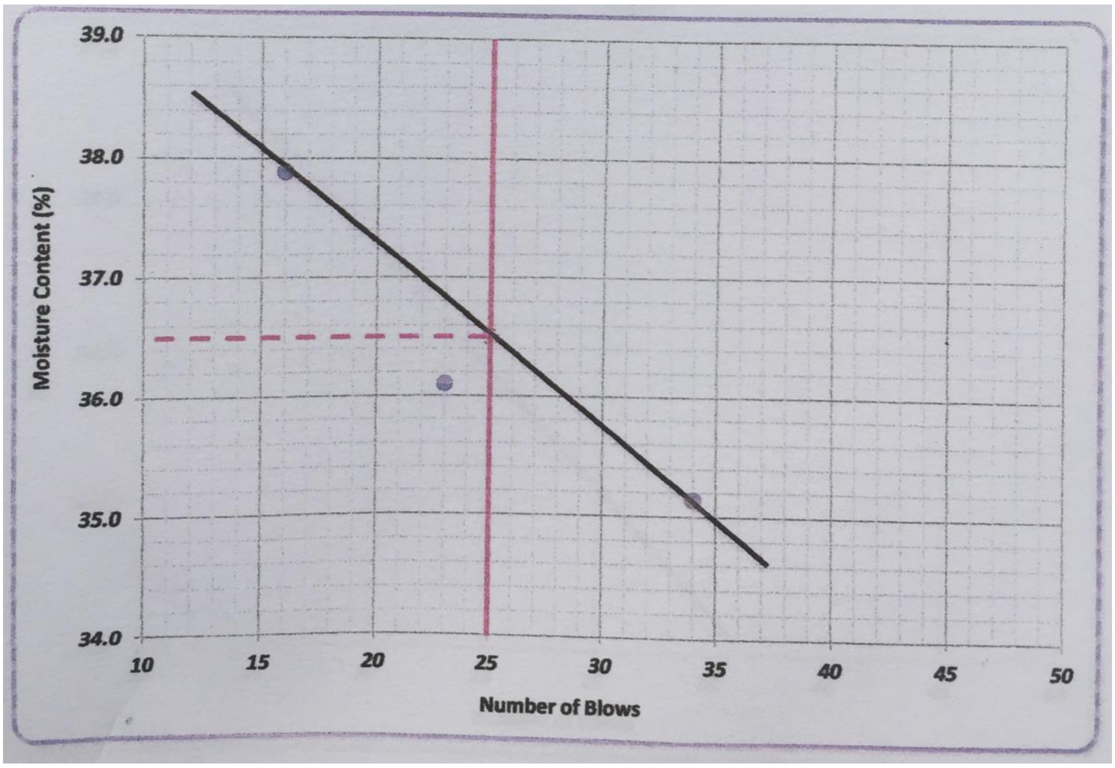

Figure 6: Test Output Graph for 1.0-0.6m

3.4 General Classification and Evaluation of the Soil of the Study Area

When compared to AASHTO (American Association of State Highway and Transportation Officials) Standard chart, the clays in the area are mostly of type SC (Sandy Clay) as shown in Table 8.

Table 8: General Classification and Evaluation of Ajali Sandstone in Anambra Basin

Depth (m)	Soil Class	Soil Description
1.8 – 1.1	SMD	Silty Clay of Intermediate Plasticity
1.0 – 0.6	SC	Sandy Clay of Low Plasticity
0.5 – 0.0	SC	Sandy Clay of Low Plasticity

4. SUMMARY, CONCLUSION AND RECOMMENDATION

4.1 Summary

The soil is well graded and the amount of sand fraction present in the samples ranges from fine to medium and coarse. The sands are finer at shallower depths. About 60% of the sands are fine while 40% are medium to coarse grained. The average value for the liquid limit is 34.7%, plastic limit is 25% while the plasticity index has an average value of 9.7% which indicate that the soil is moderately plastic.

The results also show that the clays in the study area are cohesive and the moisture content is relatively low; averages 10.80%. The low moisture content of the clays and their plastic nature make them suitable only as sub-grade materials.

4.2 Conclusion

The sands generally encountered from 1.0m are good only as sub-grades while the clayey sand sand is poor. Preparation of sub-grade for construction usually involves digging, in order to remove surface vegetation, top soil and other unwanted materials, and to create space for the upper layer of the pavement. Since the sand is a very good sub-grade, it would therefore undergo lesser compaction processes before being used for road construction, compared to the clay which would undergo much compaction because it is not a good sub-grade.

4.3 Recommendation

Considering the poor nature of the sub-grade soil (1.0-1.8m) of the study area, this research therefore recommends removal and replacement. The clays can be removed and replaced with high quality engineering fill like sand.

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