

An Assessment of the Geotechnical Aspects of Njaba River Sediments in the Eastern Niger Delta Basin, Southeastern Nigeria

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Abstract

Some geotechnical characteristics of sediments in the Njaba River watershed were assessed to highlight their potentials as good construction materials. The studied sections at the river bank is comprised from top to bottom lateritic top soil, fine-medium grained yellowish sand, coarse grained whitish sand and gravel. This succession displays a fining-upward sequence typical of point bar deposits. The obtained values of Plasticity Index (PI), Plastic and Liquid Limits (PL and LL) using standard equipment were 7.10, 16.90 and 24.00 % respectively. The observed low Plasticity Index is indicative of the absence of very active clays such as montmorillonite that cause damages to structures as a result of slaking. Results of Direct Shear Strength, Optimum Moisture Content, Optimum Density, Bulk Density and Dry Density of analyzed laterite samples were 101.20KN/m², 12.00 %, 2.11, 2.24 and 1.97 Mg/m³ respectively, while the California Bearing Ratio (CBR) for soaked and unsoaked laterite samples were 22 and 72 % respectively. The calculated values of Coefficient of Curvature and Coefficient of Uniformity for the laterite, fine-medium grained sand, coarse grained sand and gravelly samples indicate that the sediments are fairly well-graded. The mean values of bulk density, specific gravity, water of absorption, Average Crushing Value (ACV) and Los Angeles Average Value (LAAV) for the gravel samples were 2.31Mg/m³, 1.95, 1.88, 25.53 and 24.90 % respectively. Although the bulk density and LAAV values of gravel samples in the study area did not conform to the BS (1973) Standard, the specific gravity, water of absorption and ACV values were in conformity to the standard. The bulk density and LAAV values indicate that the Njaba River gravels are too soft to be used as wearing surfaces (aggregates) for highway pavements. However, the gravel can be used for the construction of civil structures such as buildings and culverts. The laterites are suitable for use as base and sub-base courses for road construction based on their CBR, direct shear and bulk density values. The sands can be used to make blocks and for the construction of culverts, drainage facilities and buildings.

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1 Introduction

Njaba River is located in the Niger Delta Basin of Nigeria. The section of the river under investigation in the basin is precisely located within Latitudes $5^{\circ} 44'$ and $5^{\circ} 47'$ North and Longitudes $6^{\circ} 49'$ and $7^{\circ} 03'$ East (Figure 1). The Njaba River has a shoreline length of 26.50 km, mean depth of 4.50 m and a mean specific discharge of $1700 \text{ m}^3/\text{h}$ [1]. The area stands on an elevation of about 60 m above the mean sea level. Apart from serving as the major source for aggregates (sediments) and domestic water supply, the river and its watershed constitute a focal point for transport, fishing, sports and tourism [2]. The exploitation of aggregates at the banks of Njaba River has lasted for over 40 years and it is being estimated that about 200 – 400 metric tons of laterite, gravel and sand have been exploited from the banks of the river and used for various construction purposes.

Some studies [3], [4], [5], [6] had variously focused on the geotechnical characteristics of sediments in other localities in southeastern Nigeria. These studies were aimed at understanding their suitability as construction materials. The incessant failures of civil structures especially buildings and the preponderance of erosion spots in the watershed necessitated the investigation of the geotechnical characteristics of the Njaba River sediment based on its continued use as construction materials in the study area and its environs. The exposed fresh rock units in the quarries can be sampled for this purpose.

2 Preliminary Notes

The study area is located within the equatorial belt of Nigeria. The mean monthly temperature of the area varies from 25 to 28.5°C while the mean annual rainfall is about 2.500 mm most of which fall between the months of May and October [7]. The rainy season (May-October) is characterized by moderate temperature and high relative humidity. The months of November to April have scanty rainfall, higher temperatures and low relative humidity [8]. The current climate changes, however, have resulted in heavy rainfall in the month of November in recent times. The wind direction in Owerri area and environs (of which the study area is a part) is mainly south-west, north-west and west with the south-west wind being the strongest [9].

The area is part of the rain forest belt and the vegetation cover includes shrubs and economic trees such as oil palm (*arecaceae*), Indian bamboo (*bambusae*), avocado pea (*Persia Americana*), African bread fruit (*Trelulia Africana*), oil bean (*pentaclethra mahophlla*), miracle (*spondias mombin*) and raffia palm (*raphia ruffia*). Most of these vegetations, however, have been removed due to human activities such as farming and construction of civil structures.

The study area is underlain by the Benin Formation (a major stratigraphic unit in the Niger Delta Basin (Figure 1). The formation consists of friable sands with intercalations of shale/clay of Pliocene to Miocene age [10]. It also contains some isolated gravels, conglomerates, very coarse grained sandstone in some places [10]. The mean thickness of the formation in the study area is about 800m while the mean depth to water table is about

18.3m [11]. The formation is overlain by alluvial deposits and underlain by the Ogwashi-Asaba Formation which consists of lignite, sandstones, clays and shale. The Benin Formation provides the aquifer for groundwater storage because of its high porosity and permeability. The incidence of high porosity and permeability as well as shallow water table conditions make the groundwater system in some parts of the area very vulnerable to pollution [12]. The geological setting of the area, therefore, calls for proper land use and waste management practices so as to protect the soil and water resources from degradation.

The section of the quarry that exposed the studied section has an average length, width and depth of 120 m, 80 m and 40 m respectively. Sampling points were selected on the basis of the vertical succession of the sediments in the mine site. The samples were obtained with the aid of a hand auger and collected in air-tight sampling bags and sent to the laboratory within 24 hours of collection. Six samples of each of the identified units (laterite, yellowish sand, whitish sand and gravel) were randomly collected from different spots based on the respective depths of occurrence of the units in the quarry (Figure 2). The collected six laterite samples were later mixed together to obtain a representative sample and used for particle size analysis, Atterberg limit, direct shear, California Bearing Ratio (CBR) and Proctor compaction tests. Also, the collected six samples of the yellowish and whitish sands were respectively mixed and used for particle size analysis. A part of each of the six gravel samples on the other hand, were individually analyzed for bulk density, specific gravity, average crushing strength, water of absorption and Los Angeles averaging value, while the other part of each of the six gravel samples were mixed and used for particle size analysis.

All the tests including Proctor compaction, Atterberg limits, direct shear stress, California Bearing Ratio (CBR) and particle size analyses of laterite, yellowish sand, whitish sand and gravel were performed in accordance with [13].

The bulk density of the laterite was determined by dividing the weight of the compacted sample by the volume of a mould while its dry density was obtained by dividing the weight of the dry sample by the water content.

The activity, Coefficient of Uniformity (C U) and the Coefficient of Curvature (CC) of the lateritic cover were investigated using the equations below:

$$\text{Activity} = \frac{\text{Plasticity index (PI)}}{\text{Percent fines}} \quad (1)$$

$$\text{Coefficient of Uniformity (CU)} = \frac{D_{60}}{D_{10}} \quad (2)$$

Where, D_{60} and D_{10} are grain sizes corresponding to 60 and 10 % passing respectively.

$$\text{Coefficient of Curvature (CC)} = \frac{(D_{30})^2}{D_{60} * D_{10}} \quad (3)$$

Where, D_{60} , D_{30} and D_{10} are grain sizes corresponding to 60, 30 and 10 % passing respectively.

The determination of bulk density of the gravelly unit was done on about 200 g of the sample using the water displacement method [14]. The specific gravity of gravel was determined by soaking the sample in distilled water for about 24 hours and weighing it in air thereafter. The sample was later dried and weighed in air and subsequently reweighed

in air after oven drying for 24 hours. The bulk specific gravity was obtained by dividing the weight of the oven-dried sample (in air) by the difference in weight between the saturated sample in air and water.

Water of absorption was determined by soaking about 200 g of the gravel for about 24 hours, the sample was then surface-dried, weighed in air and then oven-dried and reweighed in air. The water of absorption was determined by expressing the difference between the weights of the saturated and oven-dried samples in air as percentages of the later [14].

The determination of the Gravel Crushing Value (aggregate crushing value) was carried out using about 3 kg of samples passing the 12.70 mm sieve mesh and that retained by the 9.52 mm BS sieve mesh placed in a standard mould. A load of about 450 tonnes was gradually applied to the material for about 10 minutes. The load was then removed and the amount (weight) of materials passing the 2.36 mm BS sieve mesh was determined. This weight which is expressed as a percentage of the total weight of the material used is the aggregate crushing value of the sample.

About 5 kg of the sample passing the 12.70 mm BS sieve mesh but retained on the 9.52 mm BS sieve mesh was used to determine the Los Angeles Abrasive Value (LAAV). The samples were placed in a steel cylinder with 12 steel balls. The cylinders were rotated at 20 revolutions per minute covering a total of about 500 revolutions. The sample was thereafter passed through the 1.77 BS sieve mesh and the total weight that passed the mesh and expressed as a percentage of the original weight is the LAAV [15].

3 Main Results

3.1 Lithological Description

The lithological description of the studied sections shows that the section is comprised of fine grained yellowish sand of about 10m thick, overlain by reddish laterite of about 10m thick and underlain by coarse grained whitish sand of about 10m thick (Figure 2). The coarse grained whitish sand is underlain by a whitish brown gravel of about 10m thick (Figure 2). The sediments (laterite, sand and gravel) are loosely consolidated and susceptible to erosion. Field observations revealed series of erosion sites and other environmentally degraded spots arising from the indiscriminate mining activities and/or the properties of the sediments in the watershed.

The results of the grain size analysis (sediment granulometry), Atterberg limits, Proctor Compaction, Direct Shear Test and California Bearing Ratio (CBR) values are shown in Tables 1, 2, 3, 4 and 5 respectively.

3.2 Sediment Granulometry

The mean grain sizes of the laterite, yellowish sand, whitish sand and gravel indicate internal fining-up sequences. The overall stacking patterns also show upward decrease in grain size, grading from gravel through coarse grained and fine-medium grained sands to laterite. These sequences indicate point bar deposits of fluvial settings confirming that the sediments are recent deposits of the meandering Njaba River. It also shows that the reservoir properties of the sediments are best at the bottom than on top.

The Coefficient of Curvature of the laterite, yellowish sand, whitish sand and the gravel

are 6.0, 2.0, 1.0 and 1.4 respectively, while the Coefficient of Uniformity are 20.0, 3.0, 3.3 and 1.8 for the laterite, yellowish sand, whitish sand and gravel respectively. This shows that the degree of similarity of the units is in the order: yellowish sand > whitish sand > gravel > laterite showing increase with respect to grading towards fine grained sediments. Similarly the particle size analysis also substantiated the degree of sorting for the units earlier highlighted by the Coefficient of Uniformity. Laterite contains about 23.40 % fines while the yellowish and whitish sands contain about 15 and 10 % fines respectively. The gravel contains about 80 % sands. The sediments are therefore fairly well graded (Figure 3). Both the yellowish and whitish sands are sharp enough to be used for block making and for the construction of roads, culverts and drainages.

3.3 Atterberg Limit

The values of Atterberg Limits on the laterite sample indicates a Liquid Limit (LL) of 24.00 %, Plastic Limit (PL) and Plasticity Index (PI) of 16.90 and 7.10 % respectively (Table 2; Figure 4). Laterite with Liquid Limit of less than 35 % as was the case with the studied samples is therefore classed as samples exhibiting low plasticity. The activity of the laterite is 0.44 indicating absence of active clays such as montmorillonite. Such clays have high swelling capacity and thus inimical to construction of civil structures such as buildings and roads. On the basis of the values of Atterberg Limit, the laterite can both be used as base and sub-base courses in road construction.

3.4 Proctor Compaction Test

The result of the Proctor Compaction Test on the laterite sample shows that the dry density of the laterite is 1.97 Mg/m^3 while the optimum dry density and optimum moisture contents are 2.11 Mg/m^3 and 12.00% (Table 3; Figure 5). The Bulk Dry Density of the laterite is about 2.24 Mg/m^3 . These values indicate that the laterite in the study area possess good engineering properties for the construction of civil structures such as buildings and roads.

3.5 Direct Shear Test

The result of Direct Shear Test on the laterite indicates a shear strength of about 101.20 KN/m^2 with a cohesion value of about 16 KN/m^2 (Table 4; Figure 6) indicating a cohesive sediment. The shear strength of the laterite further supports its suitability for construction purposes.

3.6 California bearing Ratio (CBR)

The values of CBR for the soaked and unsoaked laterite samples are 22 and 72 % (Table 4) respectively. The results also present the laterite in Njaba River as good engineering properties for road construction.

3.7 Bulk Density, Specific Gravity, Water of Absorption, ACV and LAAV of the Gravel Unit

The mean values of the bulk density, specific gravity and water of absorption of the gravel samples are 2.31Mg/m³, 1.95 and 1.88 %, respectively (Table 6). The average crushing value (ACV) and the Los Angeles Average Value (LAAV) are 25.53 and 24.90 % respectively. When compared with the BSS 882 (1973) standards for highway pavements it was noted that the values of the Bulk Dry Density and Los Angeles Average Value (LAAV) of the gravelly units did not conform to the required standards while the water of absorption and Average Crushing Value (ACV) of the unit conformed to the [16] standards for highway pavement construction (Table 6). The values of Bulk Density and LAAV, therefore, indicated that the Njaba River gravels are too soft to be used as wearing surfaces (aggregates) for highway pavements. The gravel, however, can be used for the construction of civil works such as buildings, culverts and embankments. It had also been observed that the gravel deposits in Ihiagwa, southeastern Nigeria is poor when used as wearing surfaces (aggregates) for highway pavement [3]. Both the Ihiagwa and Njaba River gravel deposits occur within the Benin Formation of Miocene-Pleistocene age.

4 Labels of Figures and Tables

Table 1: Particle size analysis

Sieve size (mm)	% Passing			
	Laterite	Yellowish sand (F-M Grained)	Whitish sand (Coarse Grained)	Gravel
2.00	99.70	98.30	89.00	27.70
1.18	97.80	95.00	89.00	23.70
0.850	95.30	88.40	68.50	19.40
0.600	92.00	74.40	49.70	13.30
0.425	80.70	36.70	31.50	6.80
0.300	57.90	21.40	16.90	3.60
0.150	28.20	5.80	10.00	0.90
0.075	23.40	0.60	.50	0.70
Pan			0.30	

Table 2: Results of Atterberg Limit Determination

Trial number	1	2	3	Mean
Number of blows	6	17	29	17.33
Water content (%)	27.70	24.50	21.60	24.60
Liquid limit (LL), % (from graph)	24.0			
Trial number	1	2	3	Mean
Water content (%)	17.00	16.70	16.70	12.80
Plastic limit (PL)	16.90	16.90	16.90	12.90
Plasticity Index (PI): LL- PL	7.10			

Table 3: Showing Results of Proctor Compaction Tests on Laterite

Compaction test no.	1	2	3	Mean
Bulk density (Mg/m^3)	2.17	2.38	2.17	2.24
Dry density (Mg/m^3)	2.03	2.10	1.79	1.97
Water content (%)	7.00	13.40	21.10	13.83

Table 4: Showing Results of Direct Shear Tests

Load (Kg)	Load (KN)	Area (m^2)	Normal Stress (KN/m^2), q_1		
24	0.24	0.0036	66.70		
44	0.44	0.0036	122.20		
64	0.64	0.0036	177.80		
Shear Stress					
Load (KN)	Max. H.R (1)	X 0.002	X 0.88	Area (m^2)	C (KN/m^2)
0.24	105	0.210	0.1848	0.0036	51.30
0.44	145	0.290	0.2552	0.0036	70.90
0.64	219	0.438	0.38544	0.0036	107.10
C =16 KN/m^2					
READINGS					
Time (s)	Load, 24Kg	Load, 44Kg	Load, 64Kg		
30	21	58	65		
60	39	77	126		
90	39	75	142		
120	60	96	175		
150	73	130	200		
180	83	151	219		
210	93	145	218		
240	105	145	218		
270	103	145	218		
300	102	145	218		
330	102	145	218		

Table 5: Summary of geotechnical properties of laterite, yellowish and whitish sands

Parameters	Laterite	Yellowish sand	Whitish sand
Coefficient of curvature	6	2	1
Coefficient uniformity	20.0	3.0	3.3
Mean grain size (mm)	0.28	0.47	0.75
Optimum moisture content (OMC), (%)	12.00		
Optimum dry density (Mg/m ³)	2.11		
Plastic limit (%)	12.90	Non plastic	Non plastic
Liquid limit (%)	22.60		
Plasticity index	9.70		
Direct shear strength (KN/m ²)	101.20		
Bulk dry density (Mg/m ³)	2.24		
Dry density (Mg/m ³)	1.97		
California bearing ratio (CBR), (%) unsoaked (%)	72		
CBR (%), Soaked (%)	22		
% FINES	22	0.60	0.30
Activity	0.44		
Cohesion (C), KN/m ²	16		

Table 6: Summary of some geotechnical properties of Njaba Gravel

Sampling points	Bulk density (Mg/m ³)	Specific gravity	Water of absorption (%)	Average crushing value (ACV), (%)	Los Angeles abrasive value (LAAV), (%)
1	2.40	2.00	1.90	23.50	25.00
2	2.20	1.98	1.84	25.40	25.80
3	2.30	2.02	1.87	26.80	22.10
4	2.45	1.90	1.80	24.20	28.00
5	2.25	1.86	2.00	26.30	26.60
6	2.28	1.96	1.84	27.00	21.90
Mean	2.31	1.95	1.88	25.53	24.90
BSS 882 (1973) Standard	>2.60		<3.00	Maximum 30	Maximum 15
Coefficient of uniformity	1.80				
Coefficient of curvature	1.40				
Mean grain size (mm)	1.00				
% Gravel	80				

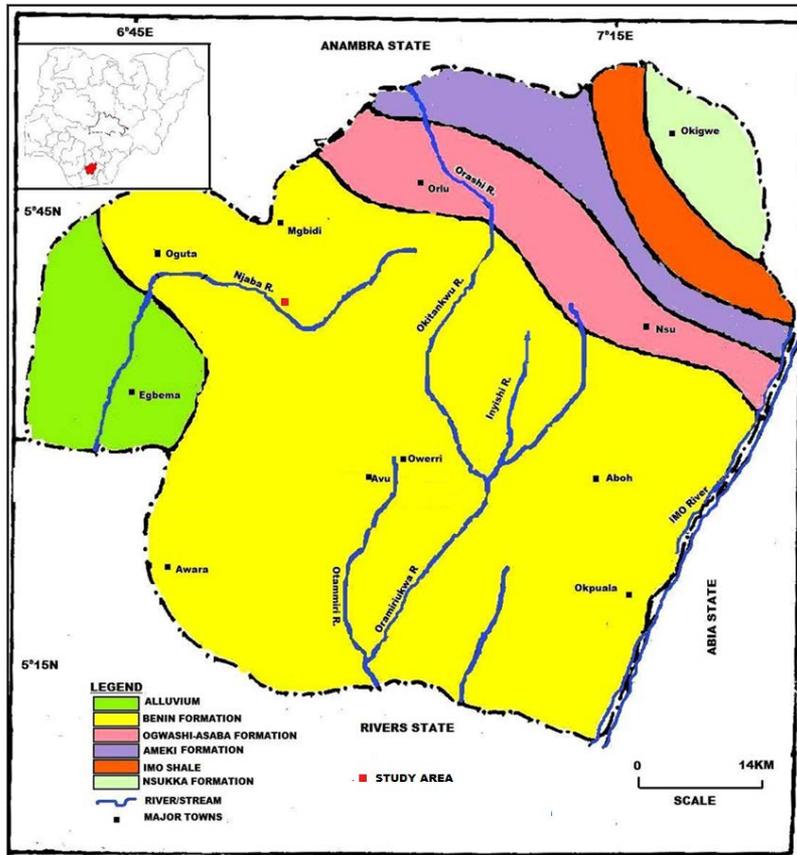


Figure 1: Geological map of Imo State showing the study area

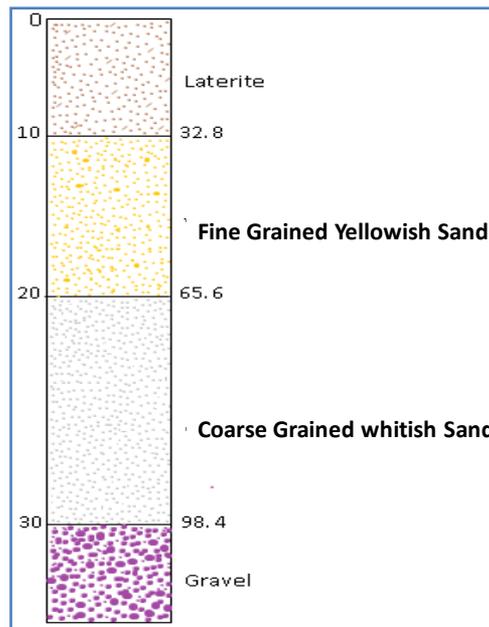


Figure 2: Stratigraphic sequence in the study area

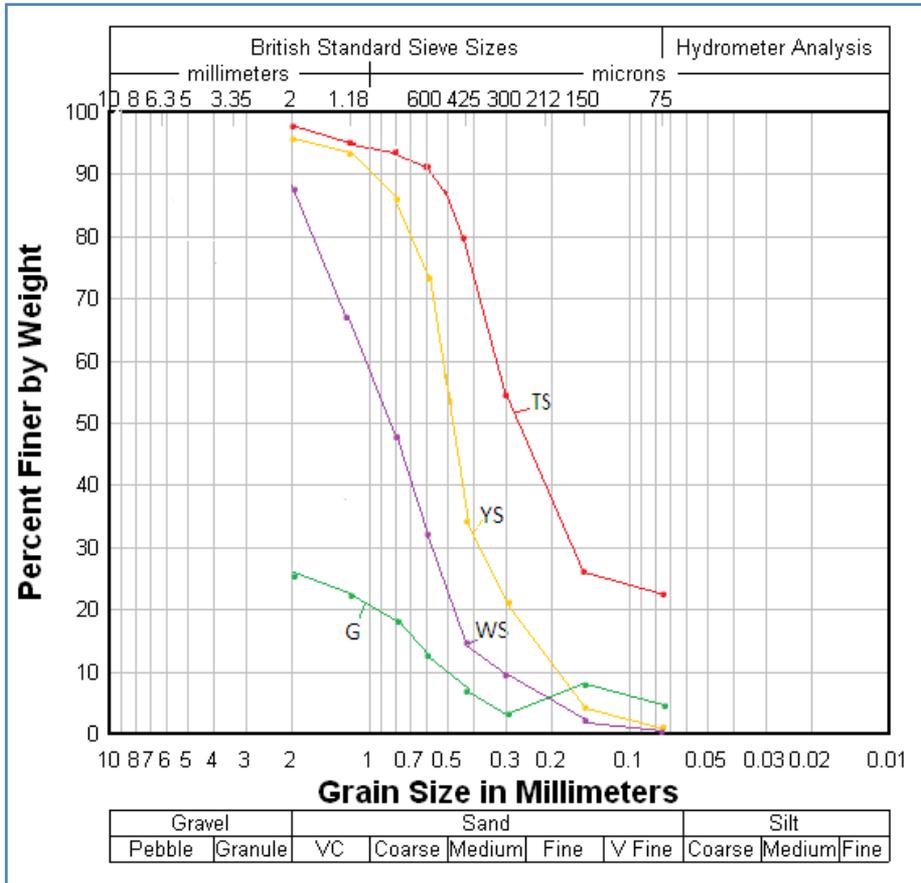


Figure 3: Grain size distribution of the Njaba sediments

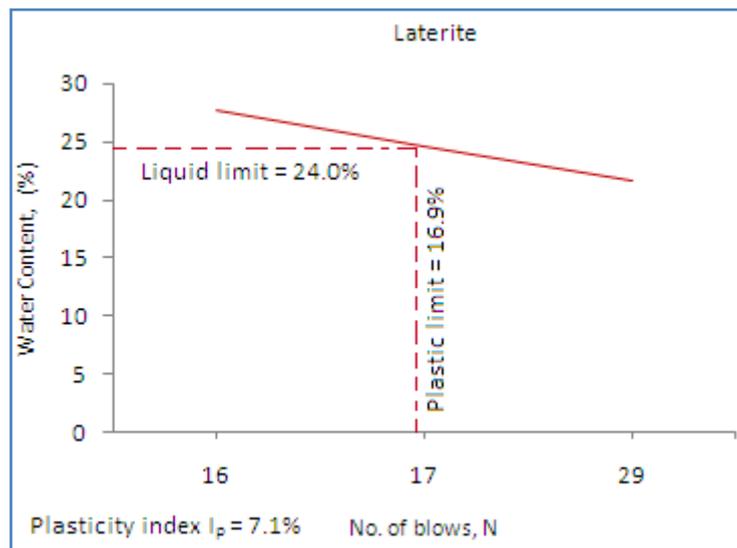


Figure 4: Liquid limit curve of the laterite sediment

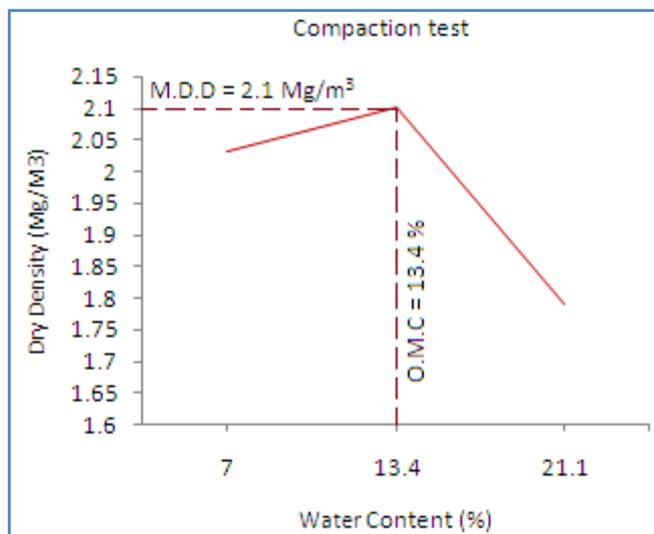


Figure 5: Dry density- water content curve showing Optimum Moisture Content (OMC)

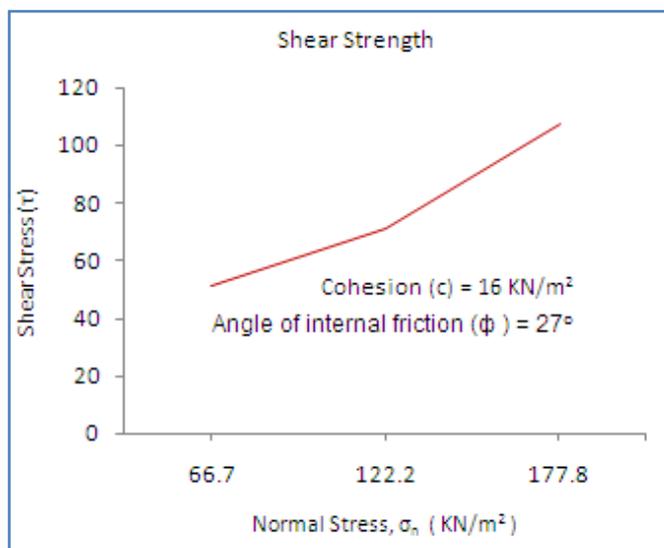


Figure 6: Shear Stress- Normal Stress Relationship Diagram

5 Conclusion

The mean grain size of the laterite, yellowish sand, whitish sand and gravel are 0.28, 0.47, 0.75 and 1.00mm respectively indicating a generally fining-up sequence, characteristic of deposits of fluvial settings, thus confirming that the sediments are recent deposits of Njaba River.

The optimum dry density and corresponding optimum moisture content of the laterite are 2.11 Mg/m³ and 12.0 % respectively why the Bulk Density and Dry Density are 2.24 and 1.97 Mg/m³ respectively. The plasticity index (PI) and activity of the laterite are 7.10 and 0.44 respectively. California Bearing Ratio (CBR) for the unsoaked and soaked laterite

samples are 72 and 22 % respectively while the Direct Shear Strength is 101.20KN/m². These properties show that the laterite in the study area is an excellent material for sub base and base courses in road constructions.

The mean Bulk Density and Specific Gravity of the gravelly sediments are 2.31Mg/m³ and 1.95 respectively, while the Mean Water of Absorption, Average Crushing Value (ACV) and Los Angeles Abrasive Value (LAAV) are 1.88, 25.53 and 24.90 % respectively. These properties show that the gravels can only be used in concretes and not as wearing surfaces in pavements.

The Njaba River sediments therefore exhibit certain geotechnical properties that make them suitable for particular engineering structures. The various sediments should therefore be used for the required purposes.

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