COMPACTION PROPERTIES OF LATERITIC SOILS FROM SELECTED BORROW PITS IN SOKOTO, NIGERIA

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ABSTRACT

The lateritic soil is a construction material that attracted great attention from researchers due to its vital role in so many aspects of geotechnical engineering. It serves as materials for sub-base, sub-grade in highway construction. It's also of great importance in the construction of earth dam and so on. Given that, it is essential to investigate some important properties of this material, such as compaction properties. This paper is aimed at determining the compaction characteristics of laterite used for construction purposes in Sokoto and its environs. Laboratory tests were conducted to determine the moisture content and dry density relationships, consistency limits, CBR values, and grading of the samples obtained from four different borrow pits from Wamakko, Kalambaina, Tangaza-bale and Dange-shuni roads in Sokoto metropolis. These locations were identified here as site 1, 2, 13, and four respectively. It was gathered from the tests that, the Optimum Moisture Content for sites 1, 2, 3, and 4 are 8.6%, 8.4%, 10.1% band 7.1% respectively. Also from the CBR result, samples from sites 1, 2, 3, and 4 have the CBR values for soaked samples as 90%, 96%, 91%, and 85% respectively. The Plasticity Index (PI) for the samples from sites 1, 2, 3, and 4 were found to be 8.3, 5.4, 9.0 and 7.0 respectively. It was concluded that soils from all sites are good lateritic soils, that laterite from site 3 has the best compaction property, and that laterite from all the sites are suitable sub-base and sub-grade construction in the highway.

Keywords: Lateritic Soil, Compaction, Consistency.

INTRODUCTION

The discovery of lateritic soils can be traced to the one done by Francis Buchanan-Hamilton, in Malabar, India by the year 1807 (Aginam et al., 2014). Since Buchanan's time; the word laterite has been used to describe a wide variety of tropical soils without reaching an agreement on the exact origin, composition, and properties of laterites. If there is an attempt to find the definition of laterite through searching of literature, there will be several definitions on the contrary to one another (Erdil, 1976). In most cases, lateritic soils are found in tropical regions that are typically distinguished by wet and dry seasons. Lateritic soils are often used in tropical regions for road constructions. Failures of highway pavements have been standard on the Nigerian highway system since the colonial period (Ogunribido, 2012). Laterites contribute to the general economy of the regions where they are found. They have a vast scope which includes civil engineering, agronomic, and mining engineering (Patrick et al., 2011).

There are instances where laterite may contain a substantial amount of clay minerals that its strength and stability cannot be guaranteed under load, especially when it contains some amount of water. These types of laterite are also common in many tropical regions, such as Nigeria (Sadeeq et al., 2015). The high of failures of roads and highways in Nigeria are generally due to poor geotechnical properties of the underlying soils which constitute the base or sub grade material for the entire road configuration. The necessity to improve soil properties for road building has resulted in the use of various stabilizers (Amu et al., 2011).

Laterite has been defined and described in several different ways. To those in the temperate countries, it could be described as a red friable clay surface. To those in the hilly tropical countries, it could be described as a very hard homogeneous vascular massive clinker – like materials with a framework of red hydrated ferric-oxides of vascular infill of soft aluminum oxides of the yellowish colour and in less hilly country, it could exist as a very hard, or soft coarse angular red. Lateritic soils as a group rather than well-defined materials are most commonly found in a leached soils of humid tropics (Blight and Leong 1997). Laterite is a surface formation in hot and wet tropical areas which is enriched in iron and aluminum and develops by intensive and long lasting weathering of the underlying parent rock (Amu et al., 2011). Failures on Nigeria highways are generally due to poor geotechnical properties of the underlying soils which constitute the base or sub grade material for the entire road configuration (Amu et al. 2010).

The main aim of this research is to determine the compaction properties of lateritic soils obtained from some borrow pits alone Kalambaina, Wamakko, Tangaza-bale and Dinge Shuni roads in Sokoto metropolis. This is achieved through determination of Moisture Content-Dry Density, Gradation test, Consistency test and CBR test on samples taken from these pits. This research is of highly significant, owing to the fact that laterite it is a common material used in the construction and rehabilitation of roads in Nigeria and some other tropical areas where they exist and they are heterogeneous in the sense that one trial of California bearing ratio is not enough to determine the actual strength of the soil. Therefore (a few) CBR values are required to generate probability model which is used to determine the characteristics strength of the soil.

REVIEW OF LITERATURE

Definition and origin of laterite

Tuncer (1976) stated that the recognition of laterite as an earth material, having a unique properties, dates back to 1807, when Buchanan first encountered a material in India which he called 'laterite.' He defined it as "soft enough to be readily cut into blocks with an iron instrument, but which upon exposure to air quickly becomes as hard as a brick, and is reasonably resistant to the action of air and water." Lemougna et al. (2011) also affirmed that, the term Laterite is derived from the Latin word "later," meaning brick and that this was first used by Buchanan in 1807 to describe a red iron-rich material found in the southern parts of India. Lateritic soils are also defined as residual soils with Silicon dioxide (Silica) to Sesquioxide ratio of between 1.33 to 2.0 (Amare, 2008). Amu et al. (2011) stressed that there is no consistent definition as regards lateritic soil. To those in the temperate countries, it could be described as a red friable clay surface. To those in the hilly tropical countries, it could be described as a very hard homogeneous vascular massive clinker – like materials with a framework of red hydrated ferric oxides of vascular infill of soft aluminium oxides of yellowish colour and in less hilly country, it could exist as a very hard, or soft coarse angular red. From the definitions mentioned above, it is clear that the term "laterite" originated from southern part of India. Portelinha et al. (2012) expressed that lateritic soils are widely spread in the Brazilian territory and appear in almost all regions in different climatic conditions, topography and matrix rock.

Engineering Characteristics of Laterite

Many studies have shown that plasticity and grain size distribution data for lateritic soils are extremely varied and erratic. The reasons for this are discussed in detail by several investigators. When soils are manipulated their characteristics vary a lot. Pre-testing drying cause's variations in some properties of lateritic soils, and this behavior is commonly attributed to the dehydration of the colloidal hydrated oxides occurring in these soils. In most of the cases the variation, resulting from drying, is irreversible and results in a soil with more granular characteristics. To disperse such a system for plasticity and grain size determinations is almost impossible. Because of such difficulties, it is tough to derive an acceptable generalization for lateritic soils about plasticity and gradation (Tuncer, 1976).

General Use of Laterite

Concretionary laterites are valuable road pavement materials, widely used in the tropics as sub-base, the base material and for the surface of gravel roads. The term laterite, however, has tended to be indiscriminately applied in tropical highway engineering to any red soil, and as a result, the usefulness of laterites for road construction has been under-estimated. Laterites are also good material for embankment construction (Amare, 2008).

MATERIALS AND METHODS

Materials

The samples for the research were sourced from Sokoto, Nigeria, located at latitude 13^{o}04'N and longitude 5^{o}15'E. It lies along traditional caravan route that leads northward across the Sahara, with an average annual temperature of 28.3° C (82.9° F). The city is also located along the Sokoto (Kebbi) River just east of the latter's junction with the Rima River. These samples were collected from borrow pits along Kalambaina Road at Ch 5 + 800 RHS, Wamakko Road at Ch 2+ 500 Tangaza Bale Road at Ch 7 + 000 LHS and Dange-Shuni Road at Ch 9 + 000. The description of the samples is shown in Table 3.1. One sample was collected from each of the borrow pits. The following test was carried out on the samples: Sieve analysis test, Atterberg Limit (Consistency) test, Compaction test and Califonia Bearing Ratio (CBR) test.

Table 3.1: Description of samples

S/N	SAMPLE	LOCATION	COLOUR
1	Sample 1	Kalambaina Road	Reddish
2	Sample 2	Wamakko Roag	Reddish
3	Sample 3	Tangaza-Balle Road	Reddish
4	Sample 4	Dange-Shuni Road	Reddish

METHODS

Sieve Analysis

As for the Sieve analysis, each of the samples was thoroughly dried with the lumps being pulverized utilizing wooden mallet. 300g of the samples were weighed and soaked in water for 24 hours. The soaked samples were sieve washed using 2.00mm and 0.075mm sieve; the washed samples were then oven dries for 24hours. After this the oven dried samples were reweighed. These were poured on the sets of sieves and placed on an electric sieve shaker. Each sieve was cleaned, and the weight of the sample retained on each sieve was recorded. Percentage passing sieves were plotted against sieve sizes on a logarithmic graph to obtain the particle size distribution curve.

Consistency Limit Tests

For the Atterberge tests, each sample was pulverized, and oven dried. This was sieved through 0.425mm sieve. 200g of the sample was measured and mixed with distilled water to a stiff consistency.

Liquid Limit Test

A portion of it was placed in the penetrometer cup, the soil being struck off with the top of the cup. The penetrometer cone was then clamped with its tip just touching the ground. The clamp was then released, and cone allowed penetrate the soil for 5 seconds when the cone was reapplied. The amount of penetration was read on the dial gauge this was repeated until two consecutive tests give the same penetration and these readings were recorded. At each stage, the moisture content of the soil in the cup was determined. The whole procedure was repeated with successive additions of distilled water to the sample, and the relationship between moisture content and penetration plotted on a graph.

Plastic Limit Test

200g of the dried soil sample passing the 0.425mm sieve was mixed with distilled water and molded into a ball. The ball was rolled by hand on a glass plate with sufficient pressure to form a thread. When the diameter of the resulting thread becomes 3mm, the soil is kneaded together and then rolled out again. The process was continued until the thread crumbles when it is 3mm diameter, and at this stage, the moisture content of the soil was determined. The whole procedure was repeated twice and the average value of moisture content taken as the plastic limit of the soil.

Compaction Test

For the compaction test, 300g of the dried sample with all lumps pulverized and passed through 4.75mm sieve was taken in a tray. The quantity of water to be added for the first trial was computed. The computed amount of water was added to the soil in the tray and mixed thoroughly with hand to ensure uniform distribution water. The mass of mold with the base plate (M_1) is found. The mold is filled with some quantity of the wet soil taken from the tray and compacted with 25 uniformly distributed blows on the surface, using the standard hammer. The surface of the compacted soil was scratched with a knife to ensure bond with the next layer. The collar was fitted on the mold and the soil for the second layer was put inside the mold and compacted as explained before.

Similarly the layer of compacted soil was obtained with care being taken to see that it does not protrude more than 6mm into the collar. The collar was removed, and the excess soil projection above the top of the mold was trimmed off. The mass of mold plus base plate plus compacted soil (M_2) was found. The soil was removed and put back in the tray. While removing the dirt from the mold, representative samples were taken for water content determination. Knowing the mass of compacted soil (M_2-M_1), the bulk density $\gamma$was calculated. After determining the water contentω, dry density $\Gamma\alpha$ was computed. The soil in the tray was again pulverized, and the water content was increased by a suitable amount 4% for the second trail. The steps were repeated to get five sets of water content, and the dry density values with two trials after the drop in the mass of compacted soil occurs during the test. The dry density, $\Gamma\alpha$, was plotted against water $\omega,$ to obtain the compaction curve.

CBR Test

While for the CBR test, Normally 3 specimens each of about 7kg must be compacted so that their compacted densities range from 95% - 100% general with 10, 30 and 65 blow, weigh the empty mould, and then add water to first specimen (compact in five layers by giving 10 blow per layer). After compaction, remove the collar and level the surface, then take the samples for determination of moisture content. Weigh the mold and the compacted specimen and then place the mold in the soaking tank for four days.

Take other samples and apply different blow, repeat the same procedures. After the four days, measure the swell reading and find the percentage swell. Remove the mold from the tank and allow water to drain. Then place the specimen under the penetration piston and place surcharge load of 10lb apply the load and note the penetration load values.

Draw the graphs between penetration 9in) and penetration pressure (in) and find the value of the CBR and also draw the graph between the percentage CBR and dry Density, and find the CBR at required degree of compaction.

RESULTS AND DISCUSSION

Some results obtained from laboratory test conducted on samples from all the borrow pits investigated, and their graphical representations are presented in this section. Table 3.1, 3.2, 3.3, and 3.4 presents the compaction test result, Sieve analysis result, plastic and liquid limit test result and CBR test result respectively for Wamakko road borrow pit, while the summary of results obtained for the other borrow pits, Kalambaina Road, Dange-shuni road, and Tangaza-Balle road can be seen summarized in table 3.5.

Table 3.1: Assho Compaction Test for Wamakko B/pit

Water added	4%	6%	8%	10%	12%	
W_t of cylinder + wet soil (gms) W_1 gm	9520	9862	10089	10029	9	
Wt of cylinder (gms)	4	7	6	4		
Wt of wet soil (A) (gms)	4756	5099	5325	5258	5094	
Volume of cylinder	2		2	7	5	
Wt Density G/CM3 (DW)	209	2.24	2.34	2.31	2.24	

MOISTURE CONTENT DETERMINATIONS

Container No	17b	14b	99	67	132	6b	1	70B	82	31C
Wt of soil tia (gms)	75.5	90.9	74.6	82.9	761	74.1	77.3	82.7	96.0	76.0
Wt of dried soil + tin (gms)	72.9	87.7	71.0	78.1	71.3	74.1	71.4	76.5	87.0	64.9
Wt of tin (gms)	100	16.1	15.7	16.1	15.3	15.7	15.7	16.2	160	16.0
Wt dry soil (gms)	56.9	71.6	55.3	73.3	56.0	58.4	55.7	60.3	71.0	48.9
Wt of Moinsture (gms)	2.6	3.2	3.6	4.8	4.8	5.0	5.9	6.2	9.0	6.1
Moinsture content – (m) (%)	4.6	4.5	6.5	6.5	8.6	8.6	10.6	10.3	12.7	12.5
Average	4	6	6	5	6	6	10	5	12	6
DRY DENSITY G/cm3 Ds) $D = \frac{100\ DW}{100 + M}$	**2.00**		**2.10**		**2.15**		**2.09**		**1.99**	

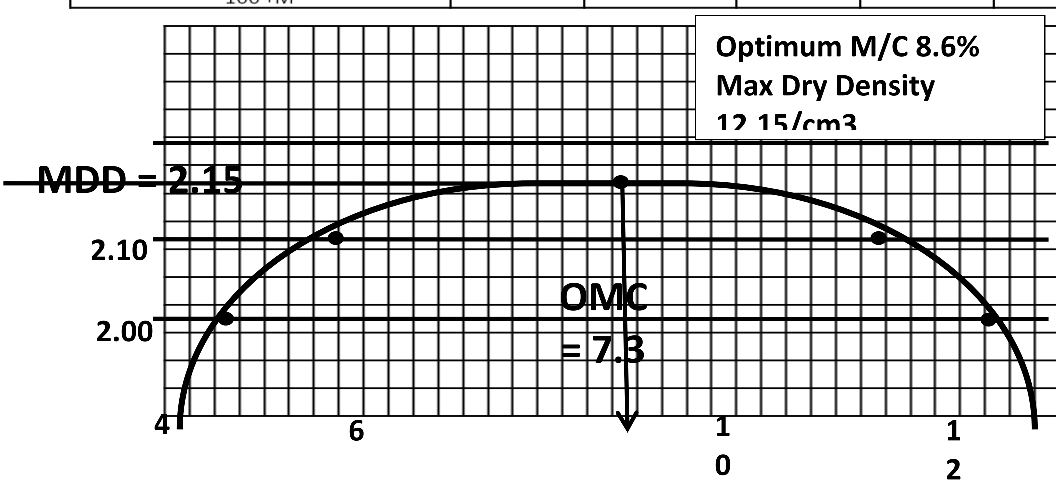

Table 3.2: Sieve analysis result (wet/dry sieving) for Wamakko b/pit

B.S. SIEVE SIZE		WEIGHT RET	PERCENT RETAINED	TOTAL PASSING	REMARTS	MAR SIEVE LOAD
		Gr	%	%		Gr
3IN	75mm					
2 ½ IN	63.5mm					
2 IN	50mm					4500
1 ½ IN	37.5mm					5300
1 IN	25mm					2500
¾ IN	20mm	-	-	1000		2000
½ IN	12.5mm	25.4	2.54	97.46		1500
3/8IN	10mm	56.6	5.66	9.18		1000
¼ IN	6.3mm	124.7	12.47	79.33		750
3/16IN	5mm	66.5	6.65	72.68		500
PASSING 3/16 IN						
RIFLLED SAMPLE PASSING 3/16"						
18 IN	3.35mm					300
NO 7	2.36mm	181.0	18.10	14.58		200
NO 14	1.18mm	97.0	9.70	44.88		100
NO 25	600um	117.7	11.77	33.11		75
NO 36	425um	30.0	3.00	30.11	17	75
NO 52	300um	39.3	3.93	26.18		50
NO 72	212um	-	-	-		50
NO 100	150um	59.8	5.98	20.2	%	40
NO 200	75um	33.1	3.31	16.89		25
PASSING 200	1.4167.2	1689	16.89			
TOTAL						

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Table 3.3: Liquid and Plastic limits result for Wamakko B/pit

Test No.		1	2	3	4		1	2
Borehole No.								
Depth of sample								
Type of test		L	L	L	L		P	L
Container No.		329	83	A	49		15	5A
W_t of wet soil + container W_1 gm		19.3	19.9	17.9	15.7		15.1	14.3
Wt of dried soil + container W_2 gm		16.9	17.7	15.9	14.3		14.2	13.5
Wt of moisture W_1 W_2 gm		2.4	2.2	2.0	1.4		0.9	0.8
Wt of tin W_3		8.0	9.3	8.1	8.8		4.2	9.0
Wt of dried soil $W_2 - W_3$gm		8.9	8.4	7.8	5.5		5.0	4.5
Moisture content m%		27.0	26.2	25.6	29.5		18.0	17.8
Number of blows		11	22	34	45		AV	179

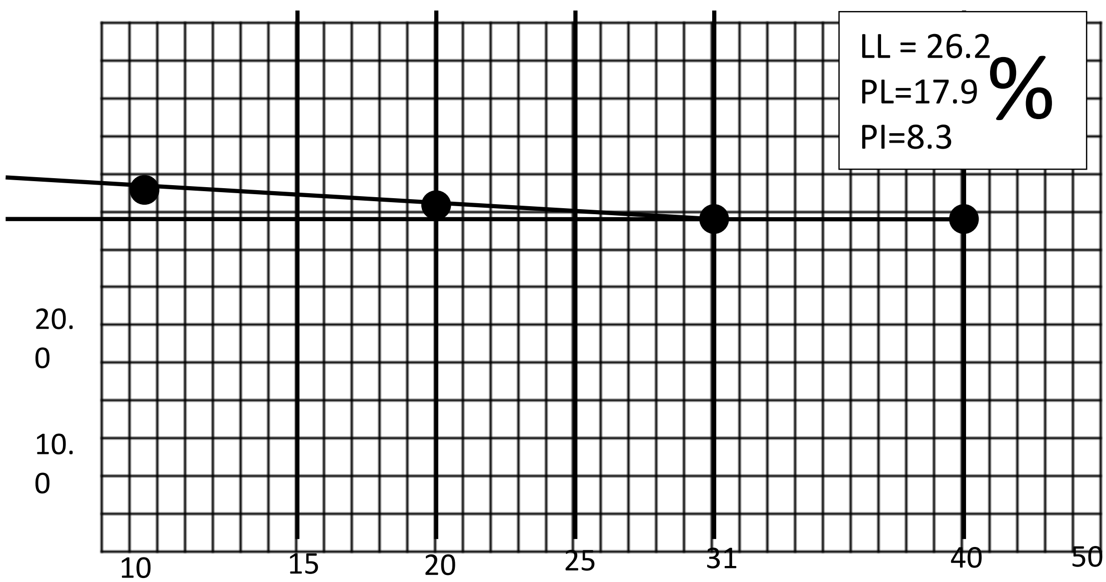

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Table 3.4: California Bearing Ratio test for Wamakko B/pit

CBR% CALCULATION

CBR at 2.5 KN Load r kg Load
13.24 1324
CBR at 5.0 KN Load or kg Load
19.96 19996

PENE MM	BASE			TOP
0.5	87	229	63	166
1.0	165	434	140	368
1.5	260	684	205	539
2.0	345	907	282	742
2.5	420	1105	345	907
3.0	500	1351	408	1073
3.5	595	1565	475	1249
4.0	675	1775	550	1447
4.5	768	2020	630	1657
5.0	870	2288	710	1867
5.5	962	2530	785	2065
6.0				
6.5				
7.0				

CORRECTION LOAD		
MM	BASE	TOP
2.5	1105	907
5	2288	1867
CORRECTION CBR%		
MM	BASE	TOP
2.5	835	68.5
5	114	93.5
AVR. CBR	90%	

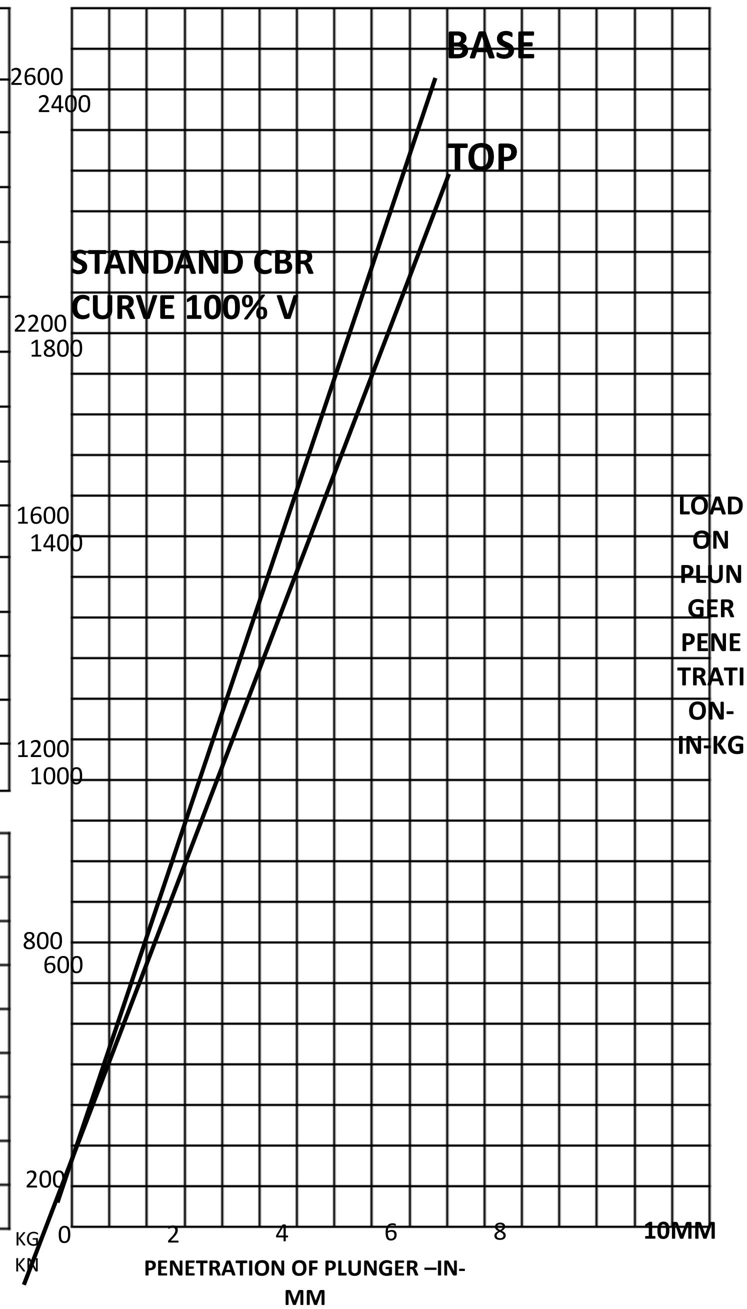

Table 3.5: Summary of results

S/N	Location	% passing B.S Seive				LL	PI	MDD	OMC	CBR %	
		54	7	36	200					Unsoaked	Soaked
1	Wamakko CH 2+500	100	74.7	30.1	17	26.2	8.3	2.15	6.6	90	-
2	Kalambaina CH 5+800	100	49.8	33.4	20	26.0	5.4	2.21	8.4	96	-
3	D-Shuni CH 9+600	100	47.1	26.0	15	27.0	9.0	2.21	10	91	-
4	T-Balle CH 7+700	100	39.7	22.6	7	27.0	7.0	2.26	7.1	85	-

As it can be seen from the liquid and plastic limits result for Wamakko Road pit, table 3.3, the moisture contents are 27.0%, 26.6%, 25.6% and 29.5%, and the differences between them are less than 4%. As stated in Blight, 1997, moisture variations 4 - 6 % or more indicates that loosely bound molecular water is present. From the test results, it means that the soil under investigation does not contain loosely bound water of hydration. Such is the case for all other samples from the rest of the borrow pits.

Looking at the figures, there is an indication that soils with moisture content above the optimum moisture content are impossible to attain the maximum dry density and the optimum moisture content since the initial in-situ moisture is greater than the optimum moisture content of the soil. Also, it can be observed that loss of moisture content affects both maximum dry density and the optimum moisture content of the lateritic soils. Because drying of the soil from it's in situ water content could change its compaction properties, the soil samples have to be treated and tested with the greatest care if the results of compaction tests are to be at all meaningful. Not only was the maximum dry density of the soil significantly altered by oven drying before compaction, but the optimum water content was also considerably changed.

Also from the CBR result, samples from sites 1, 2, 3, and 4 have the CBR values for unsoaked samples as 90%, 96%, 91%, and 85% respectively. The Plasticity Index (PI) for the samples from sites 1, 2, 3, and 4 were found to be 8.3, 5.4, 9.0 and 7.0 respectively.

CONCLUSION

The Geotechnical test results obtained revealed that soils from different pits under investigation, for a given profile, shows a significant change in both the dry density and the optimum moisture content mainly due to the mineralogical effect in the soils as it is impossible to get very distinct single maximum dry density and the optimum moisture contents because the natural moisture content is greater than the optimum moisture content of the soil. The OMC values also indicate that laterites from site 3 have the best compatibility followed by site 1 and 2. Also that CBR result shows that laterites from all the sites are suitable for both highway sub-base and sub-grade as the

Asphalt Institute recommended between 0% and 7% for sub-grade and between 7% and 20% for sub-base.

RECOMMENDATIONS

The following recommendations are given

i. To solve the problem of road failure, laterite for road constructions should always be investigated for adequate compatibility.
ii. Choice of field compaction equipment should be done in line with the design procedure for effective compaction on sites.
iii. A large number of CBR test should be done to obtain the strength of soil.
iv. Better performance of the soil could be achieved by stabilization.

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