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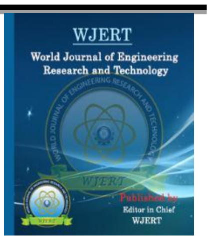

SOME COMPACTION STANDARDS AND QUALITY OF COMPACTED SOIL

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ABSTRACT

Three different compactive efforts, modified AASHTO, British Standard Heavy, and West African Standard were applied to three construction soil aggregates obtained from different aggregates sources in Uyo, in Akwa Ibom state, South eastern Nigeria. The soil aggregates satisfy the requirements for both subgrade and subbase stipulated by United States Unified Facilities Criteria and Nigerian Federal Ministry of Works. All the soil classify as SC (clayey sand), with various percentages of fines passing sieve no 200. The object is to investigate the quality of soil produced by the different compactive efforts. The modified AASHTO effort results in maximum dry density values of 1930 kg/m^3, 1890.4 kg/m^3, 1890 kg/m^3, for samples from Uniuyo, Ukana, and Nsukura aggregates sources respectively. These values represent the highest values obtained for all the standards. Unconfined compressive strength, modulus, and California Bearing Ratio were further determined to evaluate the strength of the compacted samples. Results indicate that soil with maximum dry density values does not necessarily have the largest values of the strength parameters as indicated by poor correlation results between the maximum densities and stiffness or strength parameters.

KEYWORDS: Modified AASHTO, British heavy, West Africa Standard, Clayey sand.

INTRODUCTION

The compaction operation is one of the many important processes that take place during the construction of a pavement. After general alignment clearing, earthworks which involves, grading, spreading, and sometimes haulage, and compaction operation is the next most important operation in pavement construction. Compaction operation which is often controlled based on laboratory testing of potential soil materials represents one critical element of the earthworks operation to an extent such that the performance of a constructed pavement may depend to a large extent on quality of compaction. There are different compaction standards that are used in the laboratory to obtain moisture density curves for soils used in earthworks operation. Such standards include;

- Standard Proctor (ASTM D698-12e2, 2012). commonly used for highways, which uses hammer weighing 2.5 kg , a drop height of 305 mm on three layers of soil in a mold of 943 cm^3. No of blows applied to each layer is 25.
- Modified Proctor/Modified AASHTO, (ASTM D1557 - 12e1, 2015; ASSHTO T-180, 2011), commonly used for airfields and unusually heavily loaded pavement. For modified proctor, a hammer weighing 4.5 kg, dropping over a fall height of 450mm in five layers in a mold of 945 cm^3 is used. No of blows applied to each layer is 25. For modified AASHTO, a mold with a volume of 2124 cm^3, with the same hammer and drop height as modified proctor, five layers but 56 blows.
- British heavy, which uses 4.5 kg hammer falling through 450 mm height, with five layers of soil, each layer receiving 62 blows each (BS 1337, 1990)
- West African compaction standard, which uses 4.5 kg hammer falling through 450 mm, over five layers and a mold with a volume 2210 cm^3 (Federal Republic of Nigeria General specifications: Roads and Bridges, 1997)
- Other standards exist especially in United States of America, put forward by different states for example Texas department of Transportation Standard for Compaction (Tex-114-E, 2011)

Other than general guidelines where for example Standard Proctor is assumed should be used for highway works, a quantitative study on the effect of the different compaction standard on the quality namely the strength of compacted soil if it has been carried out is not widely known. Although there has been numerous studies on prediction of compaction parameters from soil indices especially fine grained soils (Sridharan and Nagaraj, 2005; Sivrikaya, 2008), to cite a few, and a review on both fine grained and coarse grained soils by Verna and Kumar (2019). In these studies different compactive effort has been used on numerous soil samples but the object was to predict optimum compaction parameters from some soil indices. The present study aims to compare compaction results from modified Proctor, British heavy and West African Standard and recommend what to adopt to get optimum results.

2. Study Objectives

1. Obtain soil samples that meets subgrade and subbase requirements primarily of Nigerian Federal Ministry of Works or other relevant standards
2. Carryout compaction tests based on Modified Proctor, British heavy, and West African Standard (WAS).
3. Determine the California Bearing Ratios for each of the soil sample compacted at the different compaction standards
4. Determine the unconfined compressive strength values for the soil samples compacted at the different compaction standards.

3. Geology Of Sediments

According to the Nigerian Geological Survey Agency (2006) base map of Akwa-Ibom State, the geology of the area spans from Cretaceous through Tertiary to Quaternary. Among other Formations, the Coastal Plain Sands dominates the sediments in the area. The Coastal Plain Sands have ages in the range between Tertiary and Early Quaternary. Lithology essentially is sands and clay in the former (Allen 1964, 1965; Short and Stauble 1967). These sands are believed to have been deposited in a continental fluviatile to deltaic environment.

4 MATERIALS AND METHOD

Three different soil samples were obtained from three different aggregate sources. Their names and their location as indicated by their geographical coordinates are presented in Table 1. Two of the aggregate sources are actively being used by the two major road construction companies in Akwa Ibom state; while the third one located within University of Uyo permanent site campus is a potential aggregate source.

Various tests were carried out on the soil samples obtained from the aggregate sources. The tests include, mechanical sieve analysis, Atterberg limits; compaction tests based on Modified proctor, West African Standard, and British heavy. Un-soaked California bearing ratio test and unconfined compression tests were also carried out. Details of parameters used in the compaction tests in the study are listed in Table 2. Compactions of samples were carried out with electromechanical ‘Controls’ compaction machine, model 33-T8502. The device is equipped with facility that allows hammer replacement, adjusting the hammer to required fall height, and setting the required no of blows for the specimen on the machine. Use of this machine eliminates errors due to inaccurate blows either due to under lifting of hammer, and in blow count.

To evaluate strength of the samples, California Bearing ratio, and unconfined compression test was carried out on samples of soil compacted at the different compaction standards. A total of nine unconfined compression tests were carried out. The samples used for the unconfined test are the same in size as that obtained from compaction test using the different compaction standard.

Table 1: Approximate geographical locations of borrow pits location.

S/N	Borrow Pit	Geographical coordinates
1	Ekpri Nsukara borrow pit, Uyo L.G.A	Latitude 5^0 3’ 36.9” N, and Longitude 7^0 57’ 26.9” E.
2	Ukana borrow pit, Essien Udim L.G.A.	Latitude 5^o 7’ 46.9” N, and Longitude 7^o 41’ 6.1” E
2	University of Uyo, Permanent site, Uyo L.G.A. Akwa Ibom S	Latitude 5° 2'40.39"N and Longitude 7°58'27.24"E

Table 2: Compactive efforts details used in the study.

Standard	Hammer weight(kg)	Layers of soil	No of bows	Compactive effort (kN-m/m^3)
Standard Proctor	2.5	3	25	592
Modified AASHTO	4.5	5	56	2,710
West African Standard	4.5	5	25	1123.6
British Heavy	4.5	5	62	2736

Table 3: Soil indices and classification of soil samples from the borrow pits.

Sample source	Natural Moisture Content (%)	Liquid limit (%)	Plastic limit (%)	Plasticity Index (%)	Specific gravity (SG)	Sieve sizes (mm)									Unified Soil Classification System	AASHTO Classification
						4.75	2.36	1.18	0.600	0.425	0.300	0.25	0.150	0.075		
						Percentage passing sieve no										
							7	14	25	36	52		100	200		
Uniuyo	13.6	32.4	19.9	12.5	2.60	100.00	99.76	95.22	78.17	66.68		45.56	28.78	26.59	SC	A-2-6
Ukana	9.29	26.5	16.6	9.9	2.66	99.98	99.5	94.9	76.6	60.5		39.3	23.6	20.6	SC	A-2-4
Nsukara	9.67	26.5	16.5	9.9	2.62	98.76	96.95	89.58	74.59	60.16		35.02	16.19	14.32	SC	A-2-4

Table 4: Gradation and Atterberg limit requirements for subbases and select materials.[1]

	Maximum		Maximum Permissible Value			
			Gradation Requirements			
	Design CBR	Size, mm	2.0 mm (No. 10)	0.075 mm (No. 200)	Liquid Limit(LL)	Plastic Limit(PI)
Subbase	50	75	80	15	25	5
Subbase	40	75	80	15	25	5
Subbase	30	75	100	15	25	5
Select material	20	75	-	25[a]	35[a]	12[a]

[1] Pavement design for airfields,Unified Facilities Criteria, (UFC 3-260-02), 2001.

[a]Limits

Table 5: Values of maximum dry densities and optimum moisture content for the three soils samples for the different standards.

Standard	Modified AASHTO		British Heavy		West Africa Standard	
Sample source	Maximum dry density (kg/m^3)	Optimum water content (%)	Maximum dry density (kg/m^3)	Optimum water content(%)	Maximum dry density (kg/m^3)	Optimum water content (%)
Uniuyo	1930	10.8	1904	10.4	1840	12.0
Ukana	1890.4	8.8	1840	8.8	1880	11.0
Nsukara	1890	10.0	1860	10.8	1880	10.4

Table 6: Un-Soaked CBR (%) values for different samples.

Compaction Standard	Modified AASHTO	British Heavy	West African Standard
Uniuyo sample	36.72	47.4	18.4
Ukana sample	101.7	71.14	63.63
Nsukara sample	78.55	48.7	78.15

Table 7: Unconfined compressive strength for soil samples with different compactive effort.

Compaction standard	Modified AASHTO			British Heavy			West African Standard		
Sample source	Maximum dry density (kg/m^3)	Moisture content (%)	Unconfined compressive strength (Peak) (kPa)	Maximum dry density (kg/m^3)	Moisture content (%)	Unconfined compressive strength (Peak) (kPa)	Maximum dry density (kg/m^3)	Moisture content (%)	Unconfined compressive strength (Peak) (kPa)
Uniuyo	1930	10.6	113.61	1904	10.2	108.13	1840	12.2	66.39
Ukana	1890.4	8.8	214.22	1840	8.6	187.17	1880	10.8	95.44
Nsukara	1890	9.8	136.08	1860	10.6	83.46	1880	10	117.53

Table 8: Linear modulus of samples from unconfined compressive strength test.

Compactive effort	**Modified AASHTO**		**British Heavy**		**West Africa Standard**	
Sample source	**Maximum dry density (kg/m^3)**	**Linear modulus from UCS(MPa)**	**Maximum dry density (kg/m^3)**	**Linear modulus from UCS (MPa)**	**Maximum dry density (kg/m^3)**	**Linear modulus from UCS (MPa)**
Uniuyo	1930	20.66	1904	23.81	1840	9.40
Ukana	1890.4	29.86	1840	21.23	1880	21.65
Nsukara	1890	17.71	1860	10.11	1880	18.47

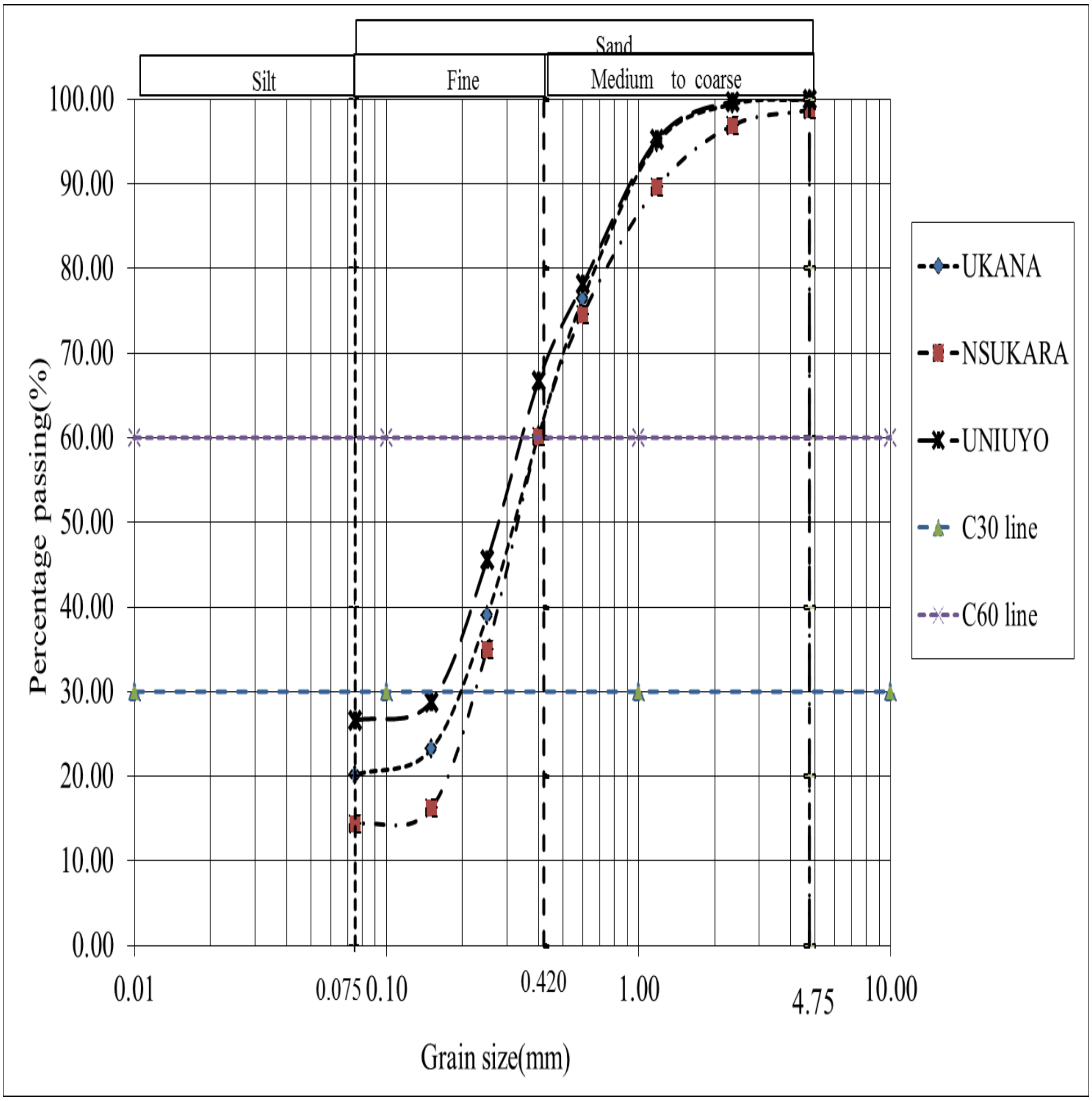

Figure 1: Grain size distribution curve for the soil samples.

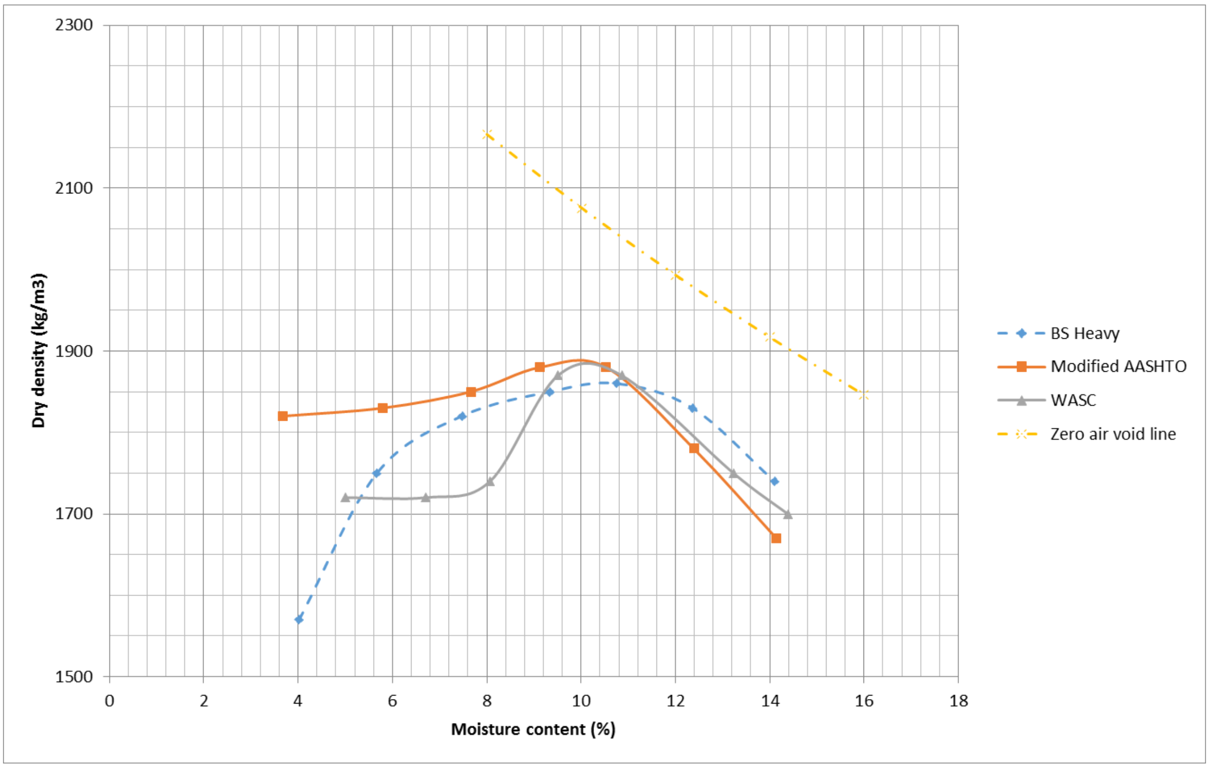

Figure 2: Compaction curves for Nsukara borrow pit sample for different compaction standards.

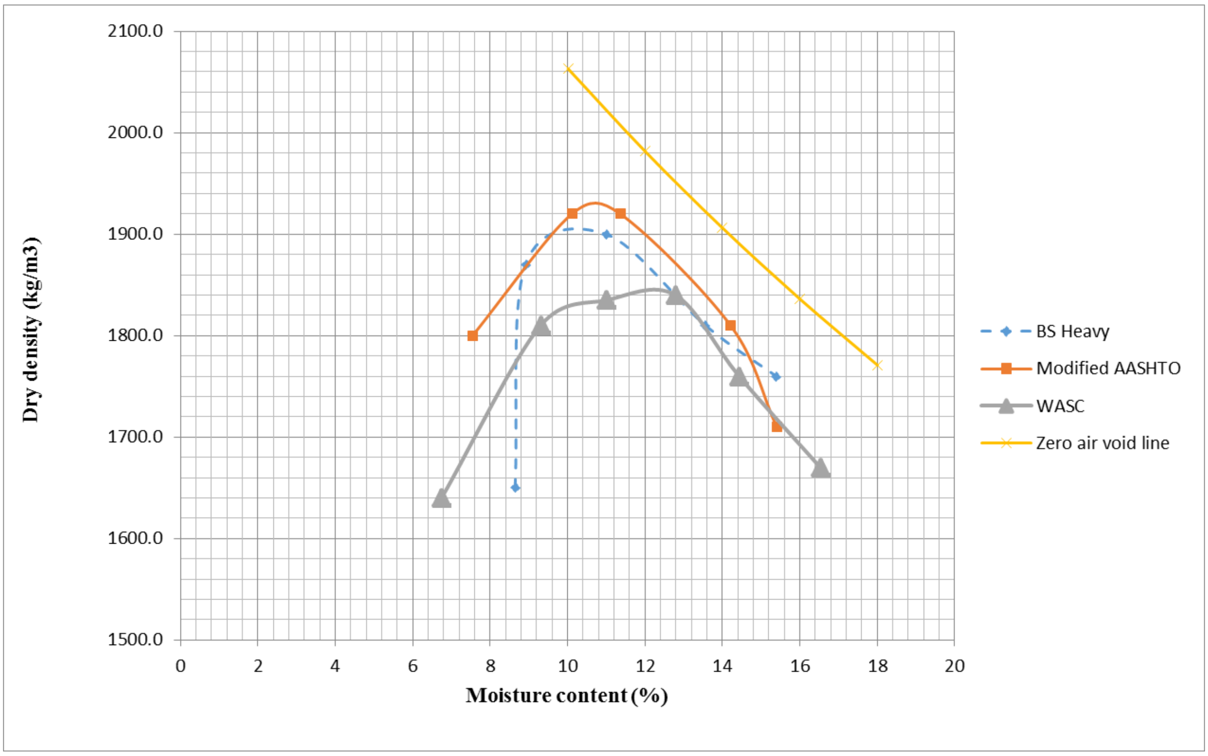

Figure 3: Compaction curves for Uniuyo borrow pit sample for different compaction standards.

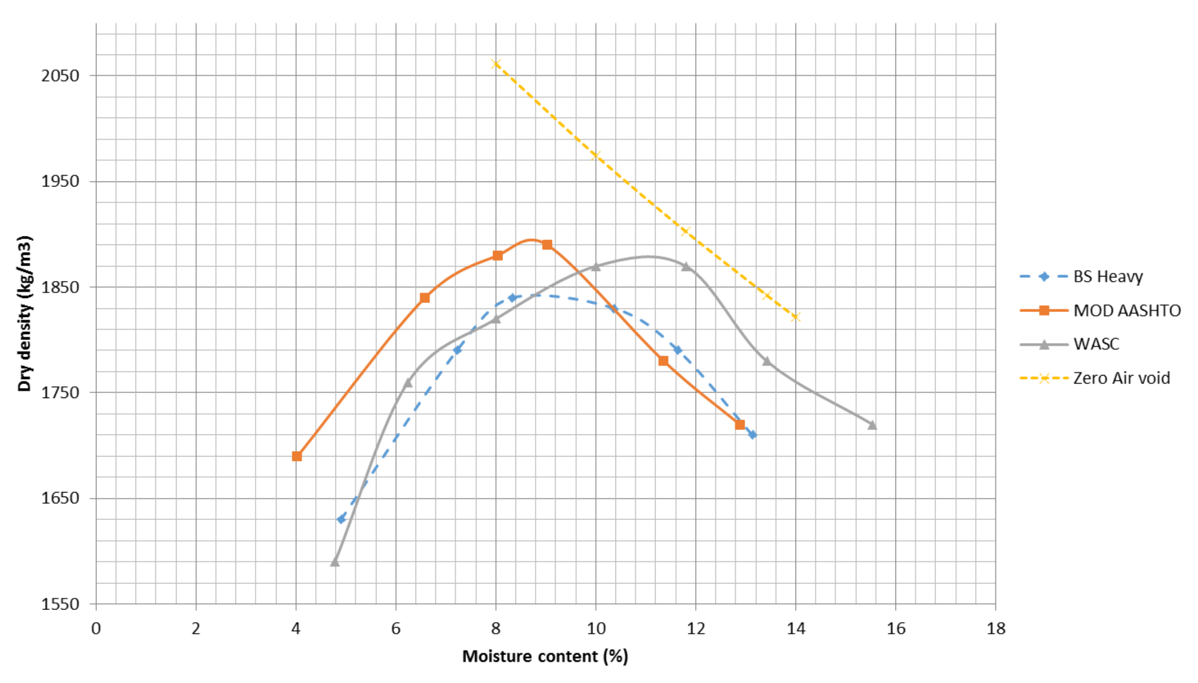

Figure 4 Compaction curves for Ukana borrow pit sample for different compaction standards.

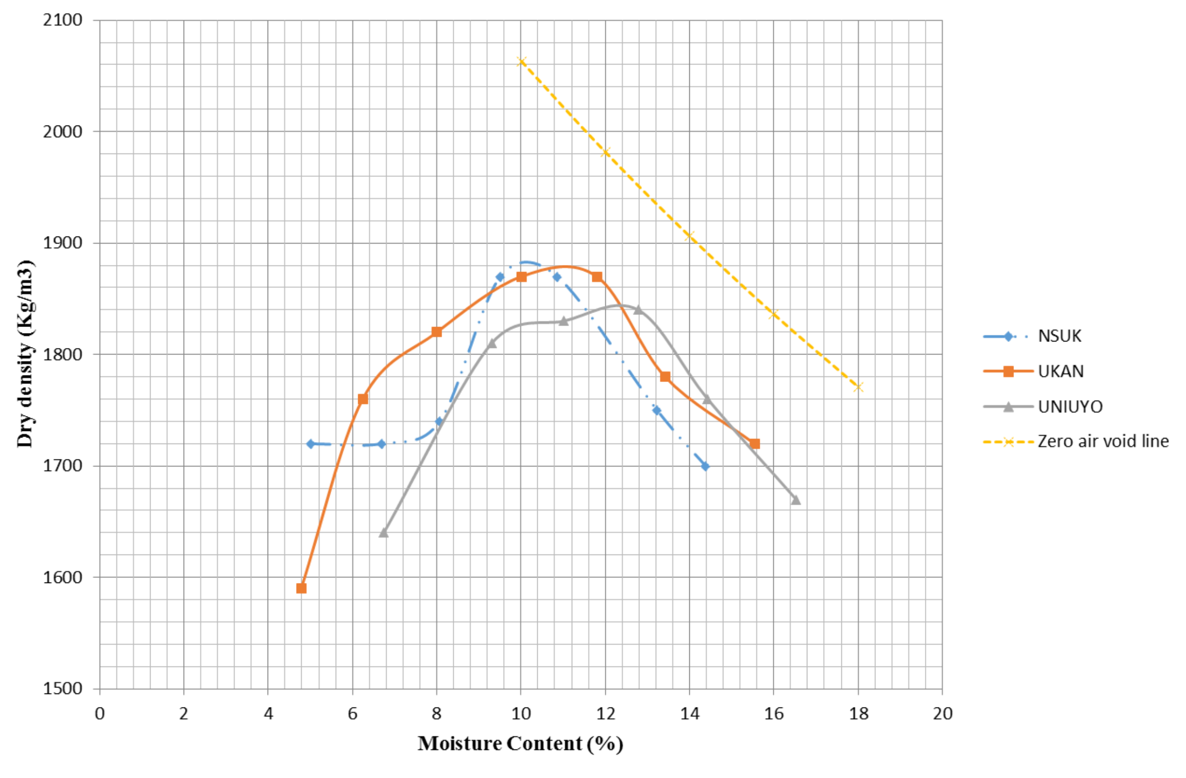

Figure 5: Compaction curves for the soil samples with West African Standard.

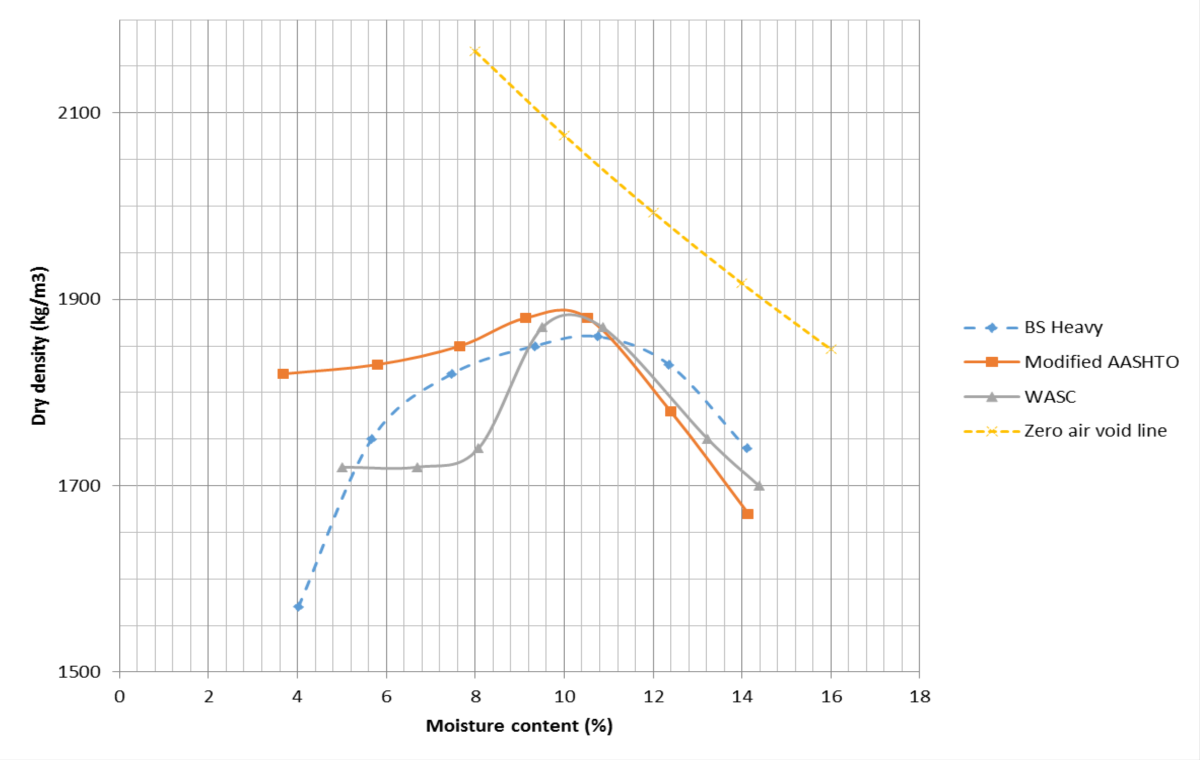

Figure 6: Compaction curves for the three soil samples with British heavy Standard .

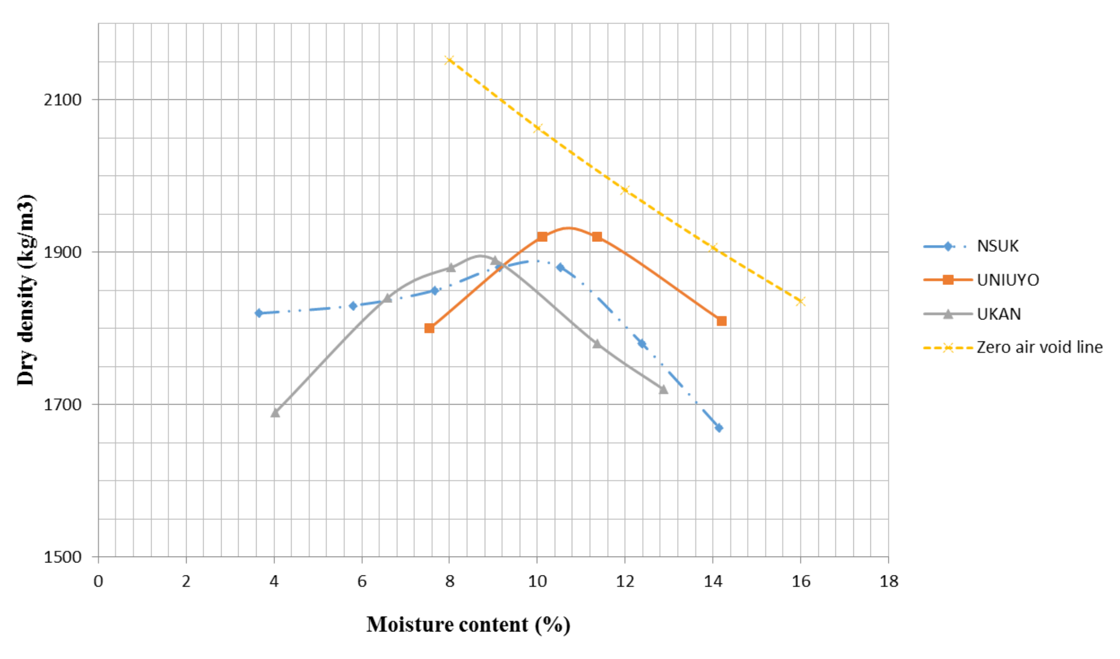

Figure 7: Compaction curves for the three soil samples with Modified AASHTO Standard.

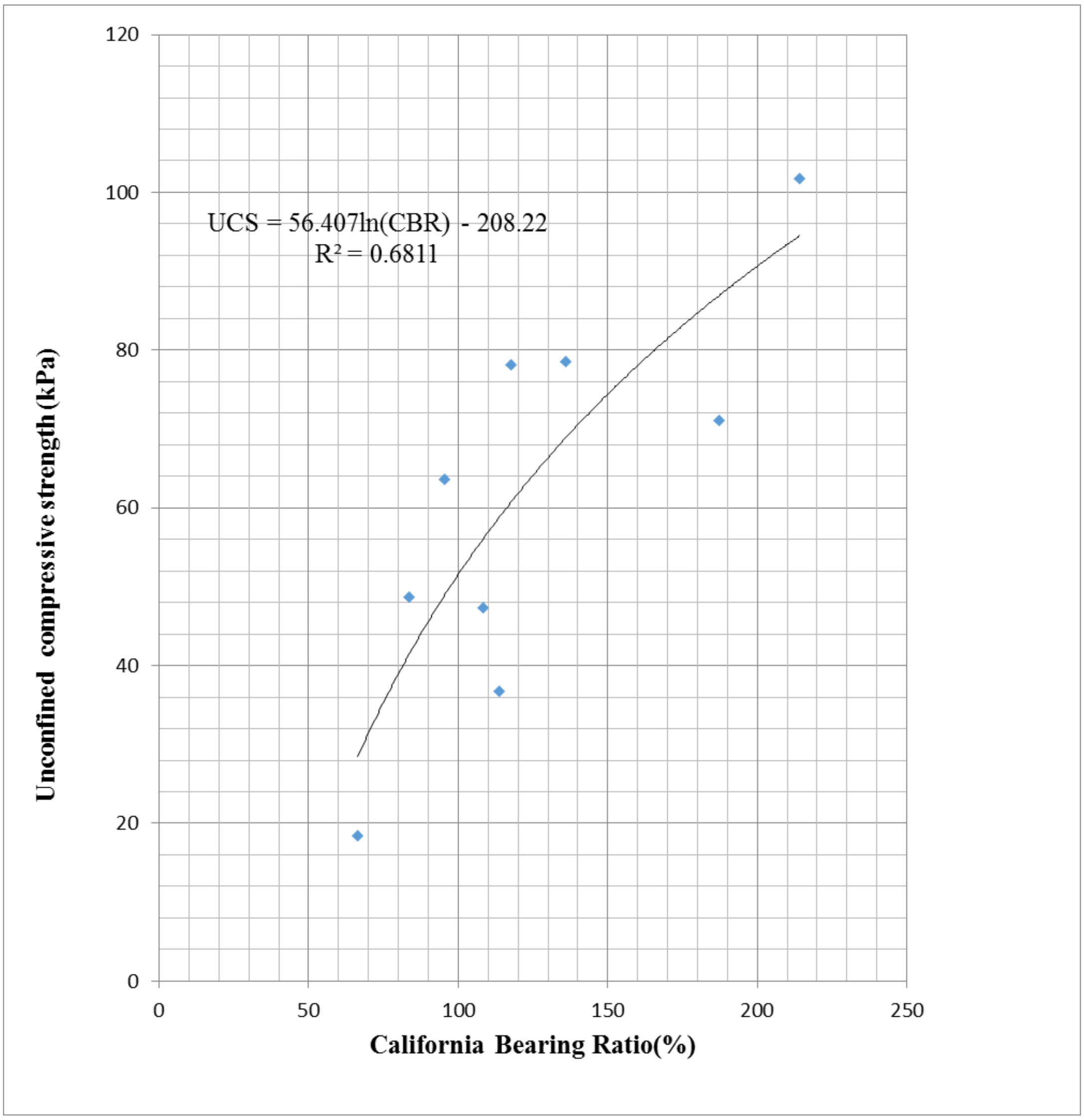

Figure 8: Correlation between unconfined compressive strength and California Bearing Ratio for soil samples.

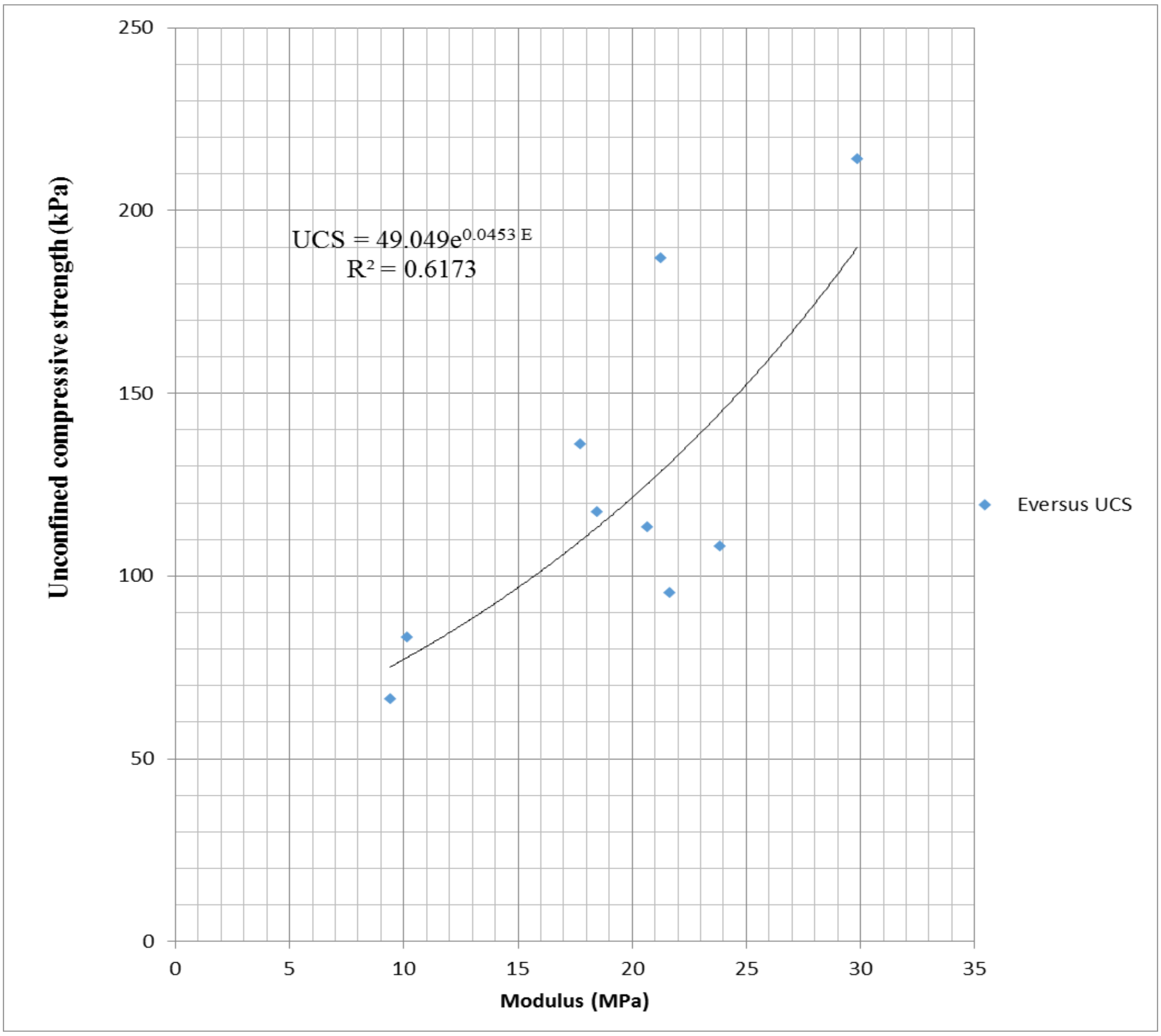

Figure 9: Correlation plot between unconfined compressive strength and soil modulus.

5 RESULTS AND DISCUSSION

5.1 Soil Indices and Classification

Figure 1 shows the grain size analysis curve for the three samples, all soil exhibit similar grain size pattern, they are poorly graded, coarse - medium – fine grained sands. The fine grain sand size constitutes more than fifty percent of the soil material. Atterberg limits and other tests results are presented in Table 3. All the soils are classed as SC under Unified Soil Classification System. Under AASHTO classification, soils from Nsukara and Ukana are classified as A-2-4, while Uniuyo sample is classified as A-2-6. The three materials satisfied the gradation and Atterberg limit requirements for subbases and select materials specified for pavement by United States Armed Forces Unified Facilities Criteria(UFC 3-260-02, 2001), and Nigerian Federal Ministry of Works criteria for subbase requirements (1997). Table 4 presents the former criteria.

5.2 Compaction tests

Three compaction tests standards as mentioned above were used. Their results are presented as follows;-

1. Compaction characteristics of a soil sample with the three standards resulting in a total of nine curves presented as a group of three
2. Compaction characteristics of the three soil samples with one standard.

Compaction curves for each of the sample from the borrow pits with the different compaction standards are presented in Figures 2, 3, 4., while Figures 5,6, and 7 presents compaction curves for the three soil samples with each of the compactive effort. For the former, all the curves shows modified AASHTO standard produces optimum values of density and moisture, although different values for the different samples in all the cases. This is followed by the British heavy standard in one soil sample and West Africa standard ranks the lowest also in the same soil sample as the BHS. For the modified AASHTO, the following are the values for each of the borrow pit samples. Dry density value of 1930 kg/m^3 and 10.8 % moisture content as maximum for the Uniuyo sample, 1890.4 kg/m^3 and 8.8% moisture content for the Ukana borrow pit sample and 1890 kg/m^3 and 10% for the Nsukara sample. For the British heavy (BHS), dry density for the Uniuyo sample is 1904 kg/m^3 at a water content of 10.4 %, for the Ukana sample, dry density is 1840 kg/m^3 at 8.8 %, while the Nsukara sample have 1860 kg/m^3 and 10.8 % moisture content. For West African Standard (WAS), the Uniuyo sample has a dry density value of 1840 kg/m^3, at a water content of about 12%, which is the lowest for this sample among the three standards. Ukana sample density is 1880 kg/m^3, at a water content of 11.0 %, Nsukara sample density is 1880 kg/m^3 at 10.4 %. The values are presented in Table 5. This table also presents different values of density and optimum moisture for different soil samples for the same standard; the graphs of which are presented in Figures 5, 6, 7.

From Table 4, modified ASHTO produces the highest density and least moisture content among the three standards for Uniuyo soil sample, while WAS gave the lowest value at the highest moisture content. For the Ukana sample modified AASHTO also gave the highest at 1890.4 kg/m^3, followed by WAS at 1880 kg/m^3, the BHS gave the lowest value. The Nsukara soil sample follows a similar trend. The WAS density values for the Ukana and Nsukara are higher than the values for the BHS except for the Uniuyo sample. The reason is that for the former two soil samples, the compactive effort of the BHS leads to crushing of the sand grains in the soil while due to the higher percentage of fines passing sieve No 200 (26.57%) in the Uniuyo sample crushing of the soil grains is tempered by the presence of fines and also results in filling of the void spaces between the coarse grains thereby reducing void and leading to bonding of the soil sand grains, thereby leading to increase in density. In line with the above reasoning, Ukana sample should have the next higher density since from Table 3 it has the next bigger value of fines at 20.8%. However the Nsukara sample for the BHS compactive effort has the next higher value of 1860 kg/m^3. The reason for this is that Nsukara sample contains some quantity of fine gravels (slightly less than 2%·, from Table 3), which imparts a higher density on the compacted sample. However, the soil indices (liquid limit, plastic limits, plasticity index) values for both Nkana and Nsukara soils are very close, the MDD of the two soils for the different compactive effort are very close also with 1890.4 kg/m^3, and 1890 kg/m^3 for the Ukana soil and Nsukara soil with modified AASHTO compactive, and 1880 kg/m^3 for both soil when using the WAS compactive effort. The above shows that soil with similar index properties will respond in a similar way to the same compactive effort.

5.3 California Bearing Ratio values (CBRs)

As a means of evaluating the strength of compacted samples, their CBR values were determined. Table 6 presents these values for the three soil samples and the three compactive efforts. The table presents unsoaked CBR values for the entire soil specimen for all the compactive efforts. The CBR value does not have a linear correlation with MDD values. The highest MDD value of 1930 kg/m^3 has a CBR value of 36.72 %, while the lowest MDD value of 1840 kg/m^3 have CBR values of 71.14 % and 18.4 %. Therefore higher density does not necessarily mean higher CBR.

5.4 Unconfined compression strength and dry density

Table 7 presents unconfined compressive strength (UCS) values for the three samples for different compactive efforts. Among all the values, modified AASHTO on Ukana soil sample gave the largest value of 214.22 kPa. Also all the three standard efforts gave the highest values on the same Ukana soil than on any of the remaining two. Apart from 214.22 kPa, the other values are 187.17 kPa for BHS, and 95.44 kPa for the WAS. Generally for all the soil there is general trend of high values of density giving high values of UCS. Although this trend is applicable to specific soil sample, it is does not apply across samples that is sample from different source. For example dry density attained by Uniuyo sample due to modified

AASHTO is 1930 kg/m^3, while the UCS value is 113.61 kPa. The same modified effort gives a dry density value of 1890.4 kg/m^3 to sample from Ukana and a UCS value of 214.22 kPa, which is bigger value than 113.61 kPa for the Uniuyo sample. Burroughs (2001), in a study of quantitative criteria for the selection and stabilization of soils for rammed earth wall construction had indicated that selecting a soil to pass the strength criterion (Unconfined compressive strength) will not necessarily optimize the likelihood of passing the density criterion, that is high Unconfined compressive strength does not imply a high density. This statement is in consonance with the results obtained above in which higher dry density does not uniquely imply high compressive strength.

5.5 CBR, Unconfined compression, and modulus values

Linear modulus of compacted samples was estimated from unconfined compressive strength test graphs. The highest value is 29.86 MPa for the modified AASHTO compactive effort for the Ukana borrow pit sample with MDD value of 1890.4 kg/m^3; while the lowest value from the UCS graphs is 9.40 MPa for WAS compactive effort for the Uniuyo sample which has 1840 kg/m^3 as the maximum density value presented in Table 7 for modified AASHTO. Modulus values from unconfined compressive test are reported to be very conservative (Bowles, 1997), hence the low values.

With Uniuyo sample at a value of 113.61 kPa, 214.22 kPa for the Ukana sample, and 136.08 kPa for the Nsukara sample; all UCS values for the modified AASHTO with lager compactive energy are higher than the values from WAS standard with smaller compactive effort. Although, BHS has lager compactive effort than Modified AASHTO the UCS values are higher in the latter. This shows that modified AASHTO gives an optimum values for the types of soil tested than any of the other standards employed in this study.

5.6 Correlation of parameters

Correlations of UCS values, CBR, and soil modulus as determined from UCS test with the MMD of the soils obtained with different compactive efforts gives a poor correlation coefficient whether using the linear, logarithmic, polynomial, and exponential models. The highest correlation coefficient ‘R’ obtained between the parameters is 0.5. Whereas correlations between UCS, CBR, and soil modulus (the strength parameters), gave a highest value of correlation coefficient ‘R’ of 0.83. This value is between UCS and CBR values using the logarithmic model, and that of modulus and UCS is 0.79 using the exponential model. These are presented in Figures 8 and 9. All these indicate that the MDD as a soil parameter does not indicate the largest strength possible in a compacted sample. Other factors such as soil indices like plasticity index, soil structure (coarse or fine grained) and void ratio influence the density and strength. The correlation equations between UCS and CBR is;

$$UCS = 56.407\ \ln(CBR) - 208.22 \ldots\ldots\ldots\ldots \quad (1)$$

Where UCS = unconfined compressive strength in kPa,

CBR = Unsoaked California Bearing Ratio value in (%) ,

Coefficient of correlation R= 0.83,

And between UCS and Modulus

$$UCS = 49.049e^{0.0453E} \quad \ldots\ldots\ldots\ldots \quad (2)$$

Where UCS = unconfined compressive strength in kPa,

E = modulus in MPa, Coefficient of correlation R= 0.79

6.0 COMPARISON OF RESULTS WITH PREVIOUS WORKS

Arcement and Wright (2001), in a study involving evaluation of laboratory compaction procedures for specification of densities for compacting fine sands; they investigated four laboratory compacting standards namely, the Modified Proctor (ASTM D-1557), Maximum Index density(ASTM D-4253), Texas Department of transportation (Tx-114-E), and British vibratory hammer (BS-1337). Based on the outcome of their study, they recommend the Texas DOT,Tx-113-E and Modified Proctor test procedure. Their recommendation is applicable to the following cohesionless soils SW, SP, SW-SM, SP- SM, or SP-SC based on USCS and has less than 12% by weight passing through sieve No 200. The materials in this study classifying as SC partially falls into the group of materials in their study, thus with respect to modified AASHTO, their recommendation is in consonance with the findings in the present study

Lee et al (2007), carried out compaction test with standard and modified compactive effort on both SM and SW soils. For the SM soil, they obtained a value of 17.4 kN/m^3 for MDD using the standard effort, and 18.8 kN/m^3 for the modified effort.

In their study which involves the comparison of the following compaction Standards, standard AASHTO (T-99), modified AASHTO (T-180), gyratory compaction, and field compaction on soils, carried out among other tests, unconfined compression test (UCS) on some subgrade soil among which is a SM soil. They also carried out these tests on samples obtained from block sample recovered from compacted subgrade in the field having the same soil type. They obtain a peak strength of 667 kPa in the UCS test for the soil compacted at AASHTO (T-180), the modified Proctor standard, while a value of 160 kPa was obtained for the AASHTO (T-90), the standard Proctor. They also listed secant modulus at fifty percent of the peak stress for the SM soil at 1.84 MPa for the modified proctor, and 1.93 MPa for standard. The peak value of stress obtained in the present study from UCS tests is 214.22 kPa for the modified AASHTO for Ukana soil sample, while the least is 66.39 kPa for Uniuyo sample using the WAS effort . The linear modulus values are 29.85 MPa for the former soil sample, and 9.40 MPa for the latter. Although they posit that using modified Proctor to determine strength properties can lead to over estimating the strength properties when used for design. They recommended the gyratory compaction test. They did not take cognizance that the modulus value for the SM soil type is the lowest among all the values presented and also the fact that the Gyratory compaction test is not widely in use like other common compaction efforts. Equation (2) is tested by using the secant modulus presented to estimate fifty percent UCS values listed in their study. The following computed values are obtained, with the fifty percent value in brackets 63.04 MPa (57 MPa), 54.63 MPa (67.5 MPa), 63.56 MPa (58.5 MPa), 53.53 MPa (80 MPa), 53.32 MPa (338.5 MPa). The last two values which are for modified effort are outliers to other computed values.

Khalid and Rehman (2018), in a study involving comparison of standard Proctor to modified Proctor on some fine grained soils in Pakistan; the soils include CL, ML, CH, and CL-ML. All the values listed for MDD by modified Proctor are higher than all values by standard Proctor. Some of their results are as follows; for the CL soil, MDD for standard Proctor is in the range 14.3–18.8 kN/m^3, while modified Proctor values are in the range 16.6–20.4 kN/m^3, for the ML soil values are in the range of 15.9 –19.3 kN/m^3 for the standard and 17.8 –20 kN/m^3 for the modified effort. With respect to influence of plasticity on MDD, their study indicated that MDD values drops with plasticity index values.

With respect to MDD and the compactive effort, their study results are in consonance with the ones in this study, however with regard to the effect of plasticity index values on MDD , their study is at variance with one in this study. The present study indicated that MDD increases with increases in plasticity index and the fines content of soil. The opposing reasons could be due to type of soil being investigated. Khalid and Rehman investigated fine grained soils while coarse grained soils are the ones being investigated in the present study

7.0 CONCLUSION

It is generally desired to obtain highest density possible in given compaction operation. A soil attains different dry density with different compactive effort, It does not necessarily follows that a higher compactive effort will give a higher density. There is a compactive effort that gives the optimum density for a given soil. This optimum effort is function of percentage of fines in the soil as well plasticity index. The latter parameters being within the limits in standard specification requirement for pavement construction.

Soils having similar soil indices and grain sizes will respond in the same way to the same compactive effort.

AASHTO modified effort gives higher density for all the soil investigated. This is similar to conclusion drawn from previous studies where though investigation was on fine grained soil. This effort is therefore recommended to be the first compactive that should be considered for laboratory work in a given compaction operation, followed by the West African standard especially if soils are from the study area. The standard Proctor can be used for low volume roads.

High maximum density does not necessarily mean higher strength or stiffness.

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