

Prediction of maximum dry unit weight and optimum moisture content for coarse-grained lateritic soils

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Article

Keywords

Compaction
Compactive effort
Lateritic soils
Fines content-sand content ratio
Maximum dry unit weight
Optimum moisture content

Abstract

Laboratory compaction of soils is an important aspect in the selection of materials for earthwork construction. Owing to time constraints and concern for depleting resources, it becomes imperative that empirical relationships would be developed to predict compaction parameters, maximum dry unit weight (MDUW) and optimum moisture content (OMC) from easily measured index properties. The aim of this note is to develop empirical relationships between MDUW /OMC and logarithm of compaction energy (E)/fines content: sand content ratio (FC/S_dC) for some lateritic soils. Index property tests were carried out on twenty (20) lateritic soils to classify them and obtain the FC/S_dC. The soils were compacted at three compaction energies; British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH). Two models were developed from relationships based on slopes and intercepts derived from MDUW/OMC versus log E plots; one model employs 'FC/S_dC' and one compactive effort (BSL) while the other model employs only 'FC/S_dC'. The models were validated for robustness with soils used in the development of the models and six (6) other soils not used to develop the models. For the prediction of BSH, the model employing FC/S_dC and one compactive effort showed typical errors of ±0.63 kN/m³ and ±0.76% for MDUW and OMC respectively. The model employing only FC/S_dC showed typical errors of ±0.4 kN/m³ and ±0.83% for MDUW and OMC respectively. The typical errors are within allowed variations for projects and standards for MDUW and OMC, thus the models are quite robust.

1. Introduction

The continual depletion of valuable earth resources due to structural developments have been of much concern in the quest for sustainability, thus, the importance of soil compaction cannot be overemphasized. The world population is increasing every day and there is constant need of more infrastructures such as roads, runways, dams, buildings, jetties, railways etc. All these structures are built on soils which sometimes do not have adequate bearing capacity to resist the loads coming on them. In Nigeria, the common soils used for construction work which are laterite are sometimes found unsuitable in its natural state for intended use. Thus, there is the need for soil improvement of which compaction is among the commonest and the cheapest.

Laterites are described as highly weathered and altered residual soils formed by insitu weathering and decomposition of parent rocks under tropical and subtropical climatic conditions (Aginam et al., 2014). The increasing use of this soil is linked to its availability, cheapness and amenability to compaction. Compaction of lateritic soils like other soils, increases the bearing capacity of the soils. It also decreases the amount of

undesirable settlement of structures constructed over such soils and increases the stability of slopes of embankments (Ratnam & Prasad, 2019). The strength of foundations largely depend on compaction control which is based on finding the maximum dry unit weight (MDUW) corresponding to an optimum moisture content (OMC) at a given compaction energy.

Laboratory compaction is usually done in Nigeria with British Standard Light (BSL) (equivalent of standard Proctor method), West African Standard (WAS), and British Standard Heavy (BSH) (equivalent of modified Proctor method). These methods are laborious, time-consuming and material-consuming (Jayan & Sankar, 2015). The shortcomings outlined above together with proof by some earlier authors Ring et al. (1962), Ramiah et al. (1970), Benson et al. (1998) and most recently Anjita et al. (2017) that soil type, its grain size distribution, index properties, and specific gravity influence the MDUW and OMC of soils led researchers to develop empirical relationships between MDUW/OMC and index properties of soils. Such index properties as liquid limit (LL), plastic limit (PL), plasticity index (PI), fines content (FC), sand content (S_dC) etc. have previously been used.

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The empirical relationships developed were often based on soft computational methods such as regression analysis (Tenpe & Kaur, 2015) as in the works of Benson et al. (1998), Parkoh (2016) and Oyelakin et al. (2016). Due to the fact that many factors affect compaction parameters as opined by Ardakani & Kordnaej (2017), most empirical relationships developed from statistical methods such as regression analysis may contain some deviation. However, this opinion seems not well substantiated. Ardakani & Kordnaej (2017) among other authors employed the use of artificial neural network and genetic algorithm to develop similar relationships to predict MDUW and OMC. Chenari et al. (2015) employed evolutionary polynomial regression method to develop models to predict MDUW and OMC while Gansonré et al. (2019) recently developed a method of predicting insitu dry unit weight from penetrometer tests in calibration chamber. These are novel achievements in this field, however the interest of this technical note is to examine how fines content-sand content ratio (FC/S_dC) affect the compaction properties of soil and the empirical relationship to be developed would be based on regression analysis. The importance of this research is derived from the fact that no literature consulted have been found to carry out similar research and to have used lateritic soil for such. Besides this, previous particle size analysis carried out in most lateritic soils available in Nigeria showed that they have significant FC and S_dC and in most cases negligible gravel content (GC). Since the level of FC have been found to affect important properties of soil including soil composition, particle friction, compaction, moisture, and type of soil (Hveem, 2000; Ayodele et al., 2009), the authors wish to examine how the numerical properties of MDUW/OMC can be affected based on the ratio of fines content to sand content (FC/S_dC) present in the soil.

2. Materials and methods

2.1 Materials

Twenty (20) lateritic soils drawn from different sources were used in the research. The samples were collected from different parts of Anambra state of Nigeria. Anambra is a state located in the southern part of Nigeria. The state is bordered to the North by Kogi state, to the East by Enugu state, to the west by Delta state and to the South by Imo and Rivers states. The state is notable in Nigeria for its trading activities. It is host to the largest market in West Africa which is Onitsha main market. Figure 1 showed the map of Nigeria showing the location of Anambra state while Figure 2 showed full map of Anambra state with geographical coordinates.

The climatic classification of Anambra state based on Koppen Geiger classification is *Aw* which is a symbol used to denote tropical savannah climate with dry winter characteristics. The annual average temperature is 27.0 °C. The rainfall is around 1828 mm per year with much rainfall in summer than in winter (Climate-Data.org, 2020). The collected samples labeled 1 to 20 (including the sources) are shown in Table 1. The samples were packaged in polythene bags after collection to avoid moisture loss. They were transferred to



Figure 1. Anambra state in Nigeria (online Wikipedia content).

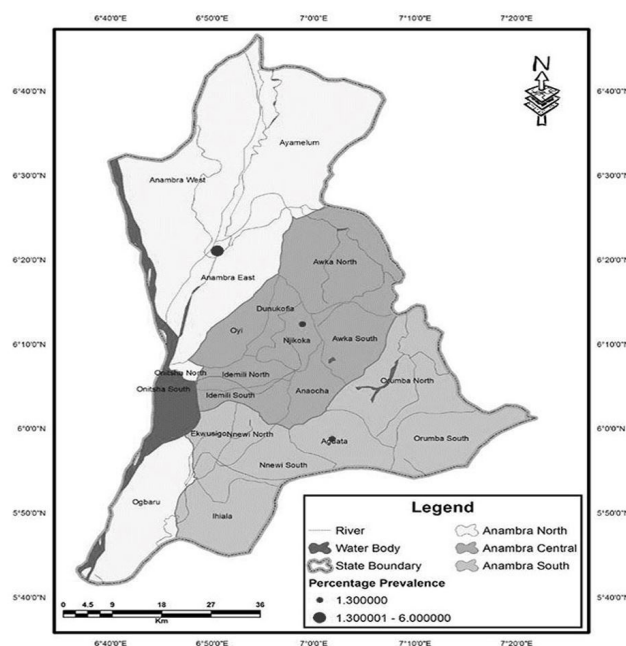


Figure 2. Map of Anambra State showing the geographical coordinates (Ndukwe et al., 2019).

Table 1. Sources of samples used in the work.

Samples	1 to 4	5 to 13	14 to 20
Sources	Mbamalu (2016)	Ozor (2017)	Anjorin (2016)

civil engineering laboratory of Nnamdi Azikiwe University, Awka for laboratory tests.

2.1.1 Sample preparation

Prior to compaction tests on the soils, the samples were first air-dried and clods were broken down. The whole gradation of each soil was used in the compaction tests because the soils do not have sizes greater than 4.75 mm.

2.2 Methods

The index properties of the soils were determined in accordance with BS (1990a). Three compactive efforts British Standard Light (BSL) BS (1990b), West African Standard (WAS), and British Standard Heavy (BSH) BS (1990b) corresponding to 605.90 kNm/m³, 1009.82 kNm/m³ and 2726.19 kNm/m³ compaction energies respectively were used to obtain the compaction characteristics of the soils. Each compaction utilized the BS mould which has a volume of 1000 cm³. The BSL compaction involves a 2.5 kg rammer falling through a height of 304.8 mm onto three (3) layers of soil in the BS mould, each layer receiving 27 blows of the rammer. The WAS compaction involves the use of 4.5 kg rammer falling through a height of 457 mm onto five (5) layers of soil, with each layer receiving 10 blows of the rammer (Osinubi & Nwaiwu, 2006). In the case of BSH compaction, the 4.5 kg rammer was made to fall through a height of 457 mm onto five (5) layers of soil, each layer receiving 27 blows of the rammer.

3. Results and discussion

3.1 Index and compaction characteristics of the soils

Table 2 showed the index and compaction characteristics of the twenty (20) lateritic soils used to develop the models. The soils fall into different classes according USCS. Samples 1 to 4 fall under (SC) which represented clayey sands. Samples 5 to 13 were classified as inorganic clay of low to medium plasticity (CI or CL) except sample 11 which was

an inorganic silt of medium compressibility (MI). Sample 14 was silty sand while the other remaining samples (15 to 20) were all clayey sands (SC). These classes were typical of the constituents of laterite. The percentage fines for all the soil samples were less than 50% which is typical of most lateritic soils found in South-Eastern part of Nigeria. Figures 3 and 4 show the graphical distribution (bar chart) of MDUW and OMC respectively for the samples.

3.2 Linear relationships between MDUW/OMC and Log E

Figures 5 and 6 show the linear relationships between MDUW/OMC and log E. The slope and intercept obtained from the linear relationships were described using Figures 7 and 8, respectively. It was observed from the Figures 7 and 8 that when the slope became maximum, the intercept became minimum and vice versa. The R-squared values obtained from the relationship in Figures 5 and 6 were all significant with values ranging from 0.7424 to 0.9987 for MDUW (Average of 0.9325) and 0.7632 to 1 for OMC (Average of 0.9405). The equations used to describe the relationship were of the form shown in (1) and (2).

$$\gamma_{dmax} = m \log E + c \quad (1)$$

where γ_{dmax} is maximum dry unit weight; m is slope; E is compactive effort; c is intercept

$$W_{opt.} = n \log E + d \quad (2)$$

where w_{opt} is optimum moisture content; n is slope; E is compactive effort; d is intercept.

Table 2. Index and compaction characteristics of soils used to develop models.

SAMPLE	SG	PARTICLE SIZE DISTRIBUTION, %				ATTERBERG LIMITS, %			COMPACTION CHARACTERISTICS					
		Fines Content (FC)	Sand Content (S _d C)	FC/SC	Gravel Content (GC)	Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)	British Standard Light (BSL)		West African Standard (WAS)		British Standard Heavy (BSH)	
									MDUW, kN/m ³	OMC, %	MDUW, kN/m ³	OMC, %	MDUW, kN/m ³	OMC, %
1	2.45	38.11	61.17	0.623	0.72	39.5	21.32	18.18	17.46	13.5	17.85	13.5	19.03	13.2
2	2.51	37.45	62.33	0.6	0.22	35.2	24.6	10.6	18.73	13	18.79	12.5	19.23	12
3	2.61	40.7	59.15	0.688	0.15	36.3	27.3	15.97	17.76	15	18.1	14.5	18.54	14
4	2.6	38.18	60.77	0.628	1.045	36.6	23.7	14.15	18.83	12.2	19.23	12	19.52	9
5	2.69	39.82	60.18	0.661	0.11	31	17.8	13.2	17.6	14.4	18.6	13.5	20	12.8
6	2.58	36.03	63.97	0.563	0.14	35.5	23.2	12.3	17.82	13.8	18.72	12.5	21.05	11.5
7	2.62	32.12	67.88	0.473	0.05	34.5	22.2	12.3	18.55	11.6	19.53	11.5	20	10.8
8	2.64	22.04	77.96	0.282	0.12	27.7	15.7	12	18.32	11.8	19.8	11	20.52	9.3
9	2.62	40.46	59.34	0.681	0	36	23.1	12.9	17.78	15.8	18.87	13	19.89	11.5
10	2.66	42.43	57.57	0.737	3.2	37.8	20.1	17.7	16.95	16.5	17.7	15.8	20.2	14.4
11	2.62	40.03	59.97	0.667	3.01	47	30.5	16.5	16.8	17.5	17.95	17	18.6	14
12	2.68	25.04	74.96	0.334	8.88	35.5	18	17.5	18.6	11.2	20.1	10.7	21.05	8.5
13	2.68	31.25	68.75	0.454	0.65	35.5	17.5	18	17.17	13.3	19.38	12.5	20.2	11.5
14	2.48	35.93	63.93	0.562	0.14	51.3	32.55	18.75	18.07	13.8	18.8	12.3	20.46	11.2
15	2.55	19.79	80.21	0.246	0	28	15.98	12.02	19	12.8	18.97	10.4	20.1	8.4
16	2.51	30.09	69.87	0.43	0.04	40.5	19.49	21.01	19.28	12.4	20.03	11.5	20.2	9.5
17	2.59	35.87	64.05	0.563	0.08	24.4	13.37	11.03	18.85	12.4	19.3	11.2	19.65	9.4
18	2.49	25.28	74.72	0.338	0	20.9	8.58	12.32	19.45	11.8	19.71	9.8	20.31	9
19	2.46	27.76	65.56	0.423	6.68	23.6	13.21	10.39	18.84	12.4	19.18	11.5	19.95	8.8
20	2.42	27.75	72.25	0.384	0	22.25	15.78	6.47	19.39	12	19.76	10.1	20.21	9.6

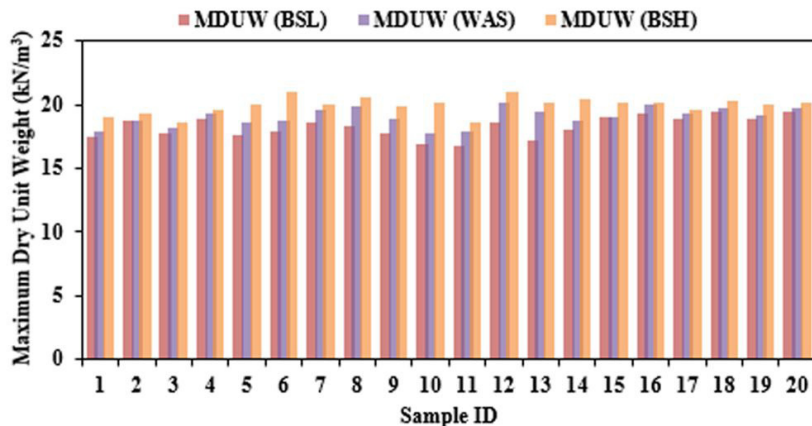


Figure 3. Distribution of maximum dry unit weight of the soils.

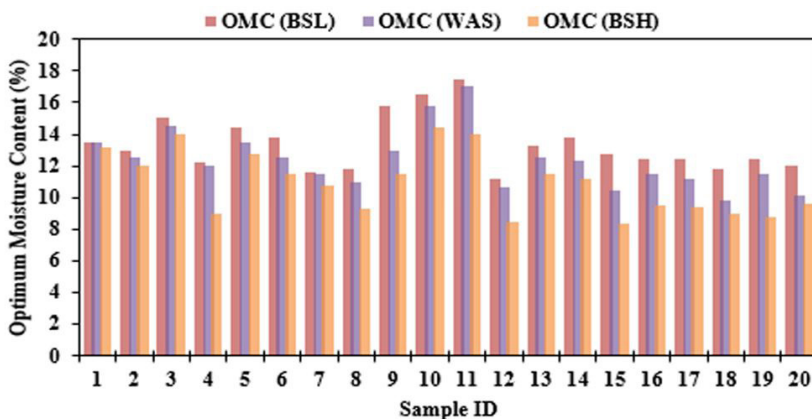


Figure 4. Distribution of optimum moisture content of the soils.

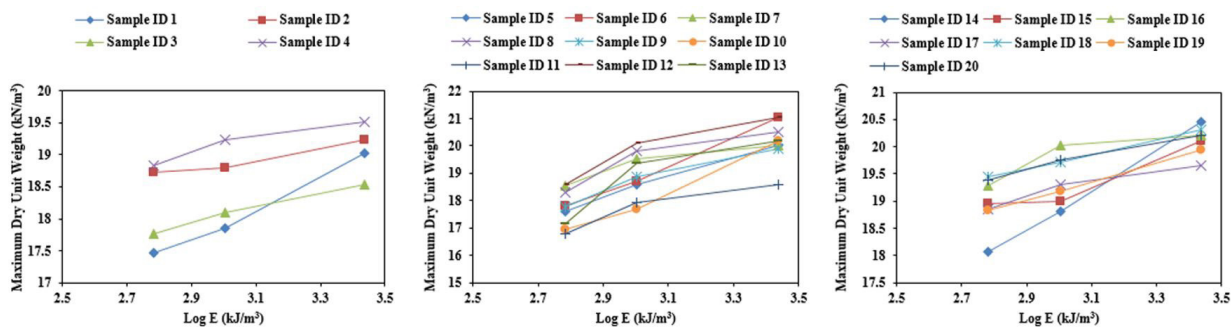


Figure 5. Linear relationship between maximum dry unit weight (MDUW) and log E.

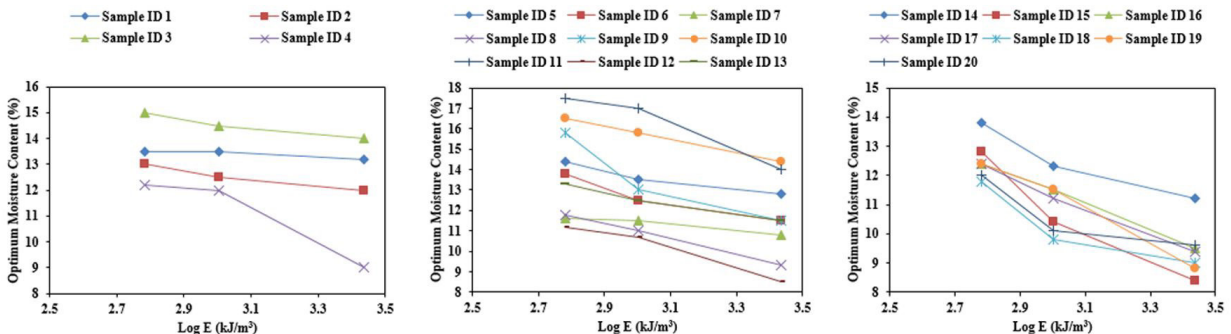


Figure 6. Linear relationship between optimum moisture content (OMC) and log E.

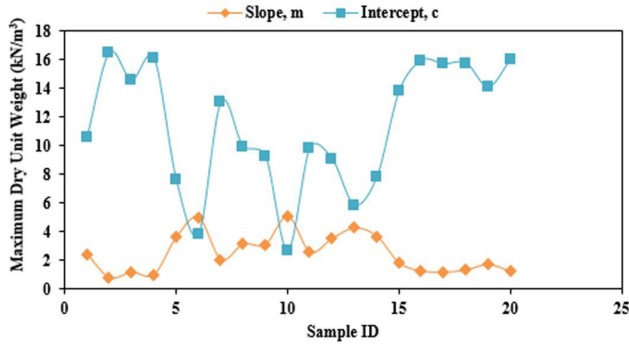


Figure 7. Graph of slope/intercept versus sample ID for MDUW.

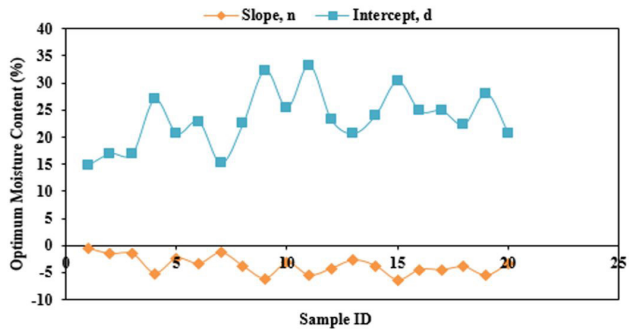


Figure 8. Graph of slope/intercept versus sample ID for OMC.

3.3 Relationship between MDUW/OMC versus Log E linear parameters and 'FC/S_dC'

Researches have shown that significant relationship exist between MDUW/OMC and index parameters such as LL, plastic limit (PL), plasticity index (PI), FC, and S_dC (Hassan et al., 2020) but to the authors' knowledge as noted elsewhere, no work found have sought to know the kind of relationship that exist between MDUW/OMC and 'FC/S_dC'. Benson et al. (1998) showed that stronger linear relationships exist between MDUW/OMC and log E which is also evident in the soils used (Figures 5 and 6).

In order to develop equations in which 'FC/S_dC' would be a function of slopes (m and n) and intercepts (c and d), the authors' sought to establish the relationship between 'm', 'c', 'n', 'd' and 'FC/S_dC', a ratio which can be obtained from easily measured quantities of FC and S_dC. The aim was to obtain a linear equation for 'm', 'c', 'n', and 'd'. The Equations 3 to 6 below were obtained from linear regression between 'm', 'c', 'n', 'd' parameters respectively with 'FC/S_dC' values for all soils where 'm', 'c', 'n', and 'd' represent independent parameters while 'FC/S_dC' represent dependent parameter. The combinations used would be too big to be outlined in the paper. The following equations were obtained from the regression analysis to describe the relationship between 'm', 'n', 'c', 'd' and 'FC/S_dC'

$$m = 1.73(FC / S_dC) + 1.60 \quad (3)$$

$$c = 15.83 - 8.58(FC / S_dC) \quad (4)$$

$$n = 3.07(FC / S_dC) - 5.26 \quad (5)$$

$$d = 23.59 - 0.39(FC / S_dC) \quad (6)$$

3.4 Application of equations

The Equations 3, 4, 5 and 6 developed above can be applied in two ways. First, it can be applied to determine compaction characteristics when only the 'FC/S_dC' is known. The MDUW/OMC for a given soil at a given compactive effort can be determined as follows:

$$\gamma_{d\max} = [1.73(FC / S_dC) + 1.6] \log E + 15.83 - 8.58(FC / S_dC) \quad (7)$$

$$w_{opt} = [3.07(FC / S_dC) - 5.26] \log E + 23.59 - 0.39(FC / S_dC) \quad (8)$$

Alternatively, they can also be applied to determine MDUW/OMC for another compactive effort (E_u) when one compactive effort (E_k) and its corresponding MDUW/OMC (γ_{dmax,k}/w_{opt,k}) are known respectively. The following equations can be applied in this case.

$$\gamma_{d\max,u} = \gamma_{d\max,k} + [1.73(FC / S_dC) + 1.6] \log(E_u / E_k) \quad (9)$$

$$w_{opt,u} = w_{opt,k} + [3.07(FC / S_dC) - 5.26] \log(E_u / E_k) \quad (10)$$

Equations 9 and 10 would definitely have a wide application than (7) and (8) because it can be applied over other compactive efforts. It would be more precisely applied with respect to compactive efforts used to develop the models.

3.5 Validation of equations

The equations were validated for robustness using two Checks known as Checks A and B. Check A was done with data used in the development of the models while Check B was done with data that was not used in the development of the models. In Check A, one compactive effort (BSL) and 'FC/S_dC' were used to predict the MDUW for compactive efforts, WAS and BSH. Then, the 'FC/S_dC' only was used to predict the MDUW for same compactive efforts, WAS and BSH. The summary of predicted values for WAS only are shown in Table 3. Root mean square error (RMSE) was also provided in this Table to show the overall prediction accuracy. For Check A, the RMSE values range from 0.025 to 0.376 for MDUW and 0.005 to 0.469 for OMC for prediction using BSL and FC/S_dC. There is not significant margin between the range produced using this model and the model employing only FC/S_dC for WAS (Table 3). Generally, the lower the RMSE, the better the prediction accuracy. Similar precision were obtained when the values of BSH were predicted. It is expected that these predictions would give a good fit because the data were used to develop the models.

3.6 Discussion of results

The results were discussed based on the prediction outcome of MDUW/OMC and predicted errors from the two Checks carried out as shown in Tables 3 and 5. Figures 9-16

Table 3. Summary of results for Check A (WAS).

Sample ID	m, c, n, d calculated from 'FC/SC'				BSL and 'FC/S _d C'				FC/S _d C' only			
					predicted for WAS		Root Mean Square Error (RMSE)		predicted for WAS		Root Mean Square Error (RMSE)	
	m	c	n	d	MDUW	OMC	MDUW	OMC	MDUW	OMC	MDUW	OMC
1	2.678	10.485	-3.347	23.347	18.054	12.758	0.046	0.037	18.529	13.291	0.152	0.047
2	2.638	10.682	-3.418	23.356	19.315	12.242	0.117	0.058	18.607	13.088	0.041	0.131
3	2.790	9.927	-3.148	23.322	18.378	14.302	0.062	0.044	18.309	13.866	0.047	0.142
4	2.686	10.442	-3.332	23.345	19.425	11.461	0.044	0.121	18.512	13.336	0.161	0.299
5	2.744	10.159	-3.231	23.332	18.208	13.684	0.088	0.041	18.400	13.627	0.045	0.028
6	2.574	10.999	-3.532	23.370	18.391	13.017	0.074	0.116	18.732	12.762	0.003	0.059
7	2.418	11.772	-3.808	23.406	19.086	10.756	0.099	0.166	19.036	11.967	0.110	0.104
8	2.088	13.410	-4.394	23.480	18.783	10.826	0.227	0.039	19.682	10.280	0.026	0.161
9	2.778	9.987	-3.169	23.324	18.396	15.097	0.106	0.469	18.333	13.804	0.120	0.180
10	2.875	9.507	-2.997	23.303	17.587	15.836	0.025	0.008	18.143	14.298	0.099	0.336
11	2.754	10.107	-3.212	23.330	17.410	16.788	0.121	0.047	18.380	13.680	0.096	0.742
12	2.178	12.964	-4.235	23.460	19.083	10.261	0.227	0.098	19.506	10.739	0.133	0.009
13	2.385	11.935	-3.866	23.413	17.699	12.443	0.376	0.013	19.100	11.799	0.063	0.157
14	2.572	11.008	-3.535	23.371	18.640	13.017	0.036	0.160	18.735	12.753	0.015	0.101
15	2.026	13.719	-4.505	23.494	19.399	11.801	0.089	0.313	19.804	9.962	0.180	0.098
16	2.344	12.141	-3.940	23.422	19.800	11.527	0.051	0.006	19.182	11.587	0.190	0.019
17	2.574	10.999	-3.532	23.370	19.421	11.617	0.027	0.093	18.732	12.762	0.127	0.349
18	2.185	12.930	-4.222	23.458	19.934	10.864	0.050	0.238	19.493	10.774	0.049	0.218
19	2.332	12.201	-3.961	23.425	19.357	11.522	0.040	0.005	19.205	11.525	0.006	0.006
20	2.264	12.535	-4.081	23.440	19.892	11.095	0.030	0.222	19.337	11.181	0.095	0.242

In Check B, Six (6) different samples (Table 4) were used to validate the models. These soils fall under classes, clayey sands, *SC*, inorganic clay of low compressibility, *CI* and inorganic silt of medium compressibility, *MI* respectively based on USCS. Just as in Check A, RMSE values fall within close range and all values are low. The prediction outcome for WAS only was shown here (Table 5).

Table 4. Index properties of soil used to validate method.

Sample No	Measured MDUW (kN/m ³)			Measured OMC (%)			Fines Content (FC) %	Sand Content (SC) %	FC/SC (%)
	BSL	WAS	BSH	BSL	WAS	BSH			
S1	18.7	19.92	20.2	12.9	11.6	10	25.36	74.64	0.34
S2	18.25	20.4	20.52	10.2	9	8.5	26.05	73.95	0.352
S3	18.52	19.88	20.02	12.4	11.5	9.3	31.08	68.92	0.451
S4	18.72	20	20.07	11	10.8	9.2	29.37	70.63	0.416
S5	17.72	19.45	19.78	13.2	11.6	12	35	65.35	0.536
S6	18.09	19.8	20.06	12.5	10.7	10.5	29.65	70.35	0.421

Table 5. Summary of results for Check B (WAS).

Sample No.	m, c, n, d calculated from 'FC/SC'				BSL and 'FC/SC'				FC/SC' only			
					predicted for WAS		Root Mean Square Error (RMSE)		predicted for WAS		Root Mean Square Error (RMSE)	
	m	c	n	d	MDUW (kN/m ³)	OMC (%)	MDUW (kN/m ³)	OMC (%)	MDUW (kN/m ³)	OMC (%)	MDUW (kN/m ³)	OMC (%)
1	2.188	12.913	-4.216	23.457	19.185	11.965	0.164	0.082	19.486	10.792	0.097	0.181
2	2.209	12.810	-4.179	23.453	18.740	9.274	0.371	0.061	19.446	10.898	0.213	0.424
3	2.380	11.960	-3.875	23.414	19.048	11.541	0.186	0.009	19.111	11.772	0.172	0.061
4	2.320	12.261	-3.983	23.428	19.234	10.117	0.171	0.153	19.229	11.463	0.172	0.148
5	2.527	11.231	-3.614	23.381	18.280	12.399	0.262	0.179	18.823	12.523	0.140	0.206
6	2.328	12.218	-3.968	23.426	18.606	11.621	0.267	0.206	19.212	11.507	0.131	0.180

showed the comparison of measured and predicted values for MDUW/OMC using line of equality plots based on Table 3. The measured and predicted values are quite close to the line of equality which shows that there was not much wide difference between measured values and predicted values especially for OMC. The R-squared values obtained by line of best fit fall within 0.528 and 0.591 for MDUW with one exception and 0.653 and 0.842 for OMC.

The following were considered for discussion; the maximum error, minimum error, average error (mean error/ measure of bias) and the standard deviation (measure of precision) obtained from the prediction outcomes. These are shown in sections 3.6.1 and 3.6.2.

3.6.1 Check A

3.6.1.1 Prediction outcome for West African Standard (WAS)

When 'FC/S_dC' and a compactive effort are known, the maximum error for MDUW was 1.68 kN/m³, the minimum error was -0.53 kN/m³, the mean error or bias was 0.21 kN/m³ and the standard deviation was 0.55 kN/m³. For the OMC, the maximum error was 0.74%, the minimum error was -2.10%, the mean error was -0.21% while the standard deviation was 0.74%. From these results it can be seen that the variation that uses 'FC/S_dC' and one compactive effort is nearly unbiased and show minimal variability. When

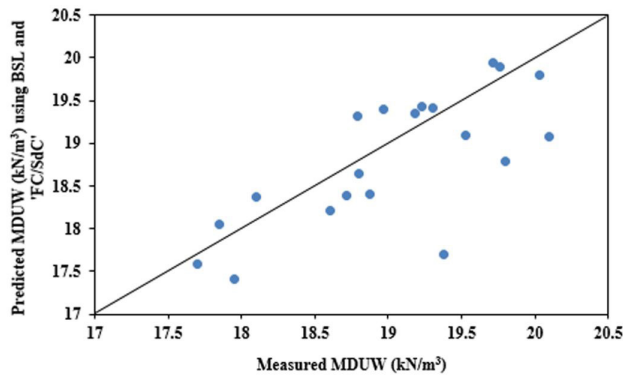


Figure 9. Relationship between measured values and predicted values of MDUW for WAS using BSL and 'FC/S_dC'.

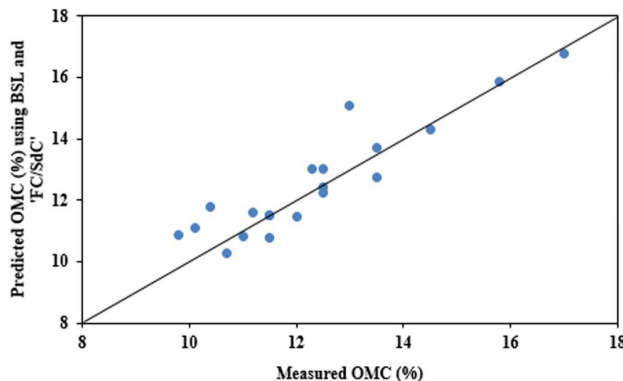


Figure 10. Relationship between measured values and predicted values of OMC for WAS using BSL and 'FC/S_dC'.

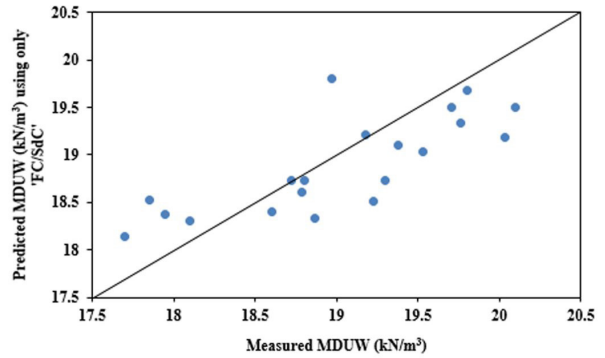


Figure 11. Relationship between measured values and predicted values of MDUW for WAS using only 'FC/S_dC'.

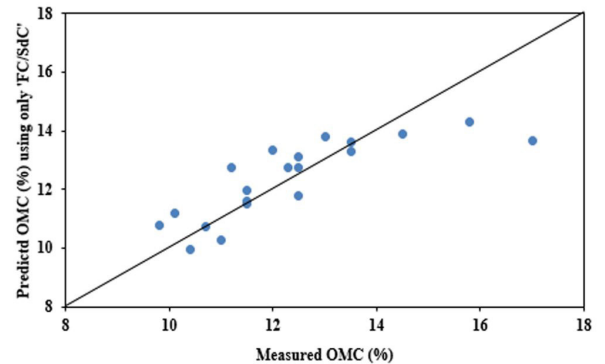


Figure 12. Relationship between measured values and predicted values of OMC for WAS using only 'FC/S_dC'.

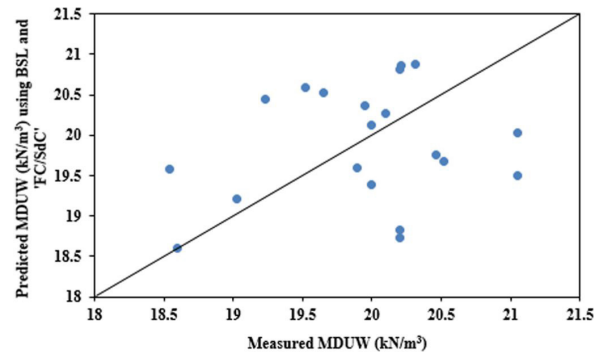


Figure 13. Relationship between measured values and predicted values of MDUW for BSH using BSL and 'FC/S_dC'.

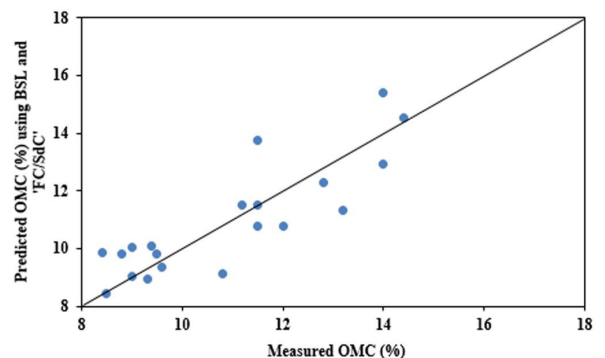


Figure 14. Relationship between measured values and predicted values of OMC for BSH using BSL and 'FC/S_dC'.

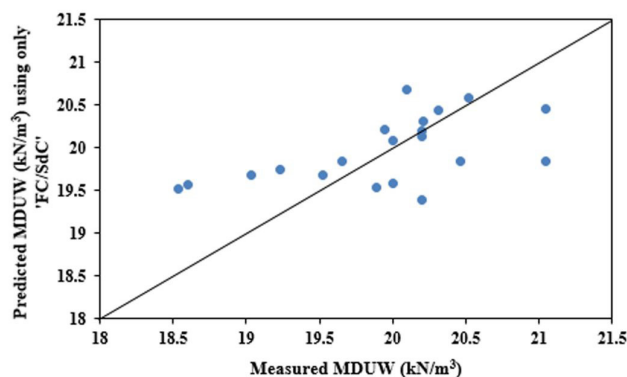


Figure 15. Relationship between measured values and predicted values of MDUW for BSH using only 'FC/S_dC'.

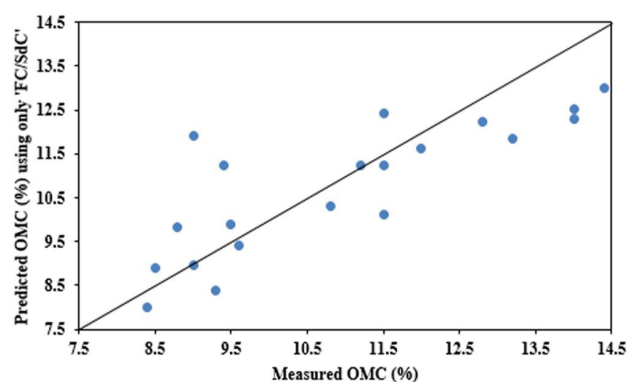


Figure 16. Relationship between measured values and predicted values of OMC for BSH using only 'FC/S_dC'.

only 'FC/S_dC' was used in the prediction, similar bias was also observed with almost the same range of standard deviation, the maximum error for MDUW was 0.85 kN/m³, the minimum error was -0.80 kN/m³, the mean error was 0.13 kN/m³ while the standard deviation was 0.46 kN/m³. For the OMC, the maximum error was 3.32%, the minimum error was -1.56%, the mean error was -0.01% while the standard deviation was 1.09%. The maximum error represents the maximum difference between predicted values and corresponding measured values while the minimum error represents the minimum difference between predicted values and corresponding measured values. The standard deviation shows how far the predicted values are from the mean. For MDUW, the standard deviation show low variation since it is less than 1 but for OMC, the variation is slightly high. The error values (maximum, mean and minimum) are in accordance with the most used compaction control values, that is, it is within the allowed variation, in projects or standards, for MDUW and for OMC. Similar prediction outcome was obtained for BSH.

3.6.2 Check B

3.6.2.1 Prediction outcome for West African Standard (WAS)

When using 'FC/S_dC' and BSL, the maximum error for MDUW was 1.66 kN/m³, the minimum error was -0.74 kN/m³,

the mean error was 1.06 kN/m³ while the standard deviation was 0.36 kN/m³. For the OMC, the maximum error was 0.68%, the minimum error was -0.92%, the mean error was -0.29% while the standard deviation was 0.58%. Using only 'FC/S_dC' variation, the maximum error for MDUW was 0.95 kN/m³, the minimum error was 0.43 kN/m³, the mean error was 0.69 kN/m³ while the standard deviation was 0.18 kN/m³. For the OMC, the maximum error was 0.81%, the minimum error was -1.90%, the mean error was -0.63% while the standard deviation was 0.89%. The definition of maximum error, minimum error and standard deviation as shown in section 3.6.1 also applies here. The standard deviation for both MDUW and OMC are less than 1 which generally depicts low variation. However, MDUW was more distinct in this category. The error values (maximum, mean and minimum) are in accordance with the most used compaction control values, that is, it is within the allowed variation, in projects or standards, for MDUW and for OMC. Just as in Check A, the prediction outcome for BSH was also good with negligible differences.

4. Conclusion

Twenty (20) lateritic soils collected from different borrow pits in different parts of Anambra state in Nigeria were subjected to laboratory compaction tests using three common laboratory compaction methods namely: BSL, WAS and BSH. Linear regression was used to establish the relationships between MDUW/OMC, log E and 'FC/S_dC'. The equations obtained in these relationships were used to develop two models, one model based on one compactive effort and 'FC/S_dC' and the other model based on 'FC/S_dC' only. The models were used to predict MDUW/OMC when log E and 'FC/S_dC' were known for the twenty (20) soils used to develop the models. Six (6) other lateritic soils that were not used in the development of the models were used to validate the models. Owing to the variations in error values obtained which are within values mostly used in compaction controls, it would be accepted that the models are quite unbiased and robust. The models quite agree with similar work done by (Benson et al., 1998) using liquid limit for some clayey soils. For the model employing 'FC/S_dC' and one compactive effort for the prediction of BSH, standard (typical) errors of ±0.63 kN/m³ and ±0.76% were observed for MDUW and OMC respectively while for the prediction of WAS, standard errors of ±0.39 kN/m³ and ±0.52% were observed. This is quite precise and this model is preferred because it has wider application. For the model employing only 'FC/S_dC', standard errors of ±0.4 kN/m³ and ±0.83% were observed for MDUW and OMC respectively for the prediction of BSH while the standard errors of ±0.33 kN/m³ and ±0.77% for MDUW and OMC respectively were observed for the prediction of WAS. The note further shows how the fines content and sand content of soils influence their compaction behaviour. Even though these models are quite robust, it is recommended that the method should be checked

against at least one series of compaction curve to ensure the result is acceptable for soils being used. The method should be limited to lateritic soils with $0.246 \leq 'FC/S_dC' \leq 0.737$ and laterites with fines content less than 50%.

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Declaration of interest

There is no conflict of interest associated with the work.

Author's contributions

Charles M. O. Nwaiwu: Conceptualization and methodology. Ethelbert O. Mezie: Writing-reviewing and editing.

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List of symbols

γ_{dmax} Maximum Dry Unit Weight
 w_{opt} Optimum Moisture Content
 $\gamma_{dmax,u}$ Maximum Dry Unit Weight for unknown compactive effort
 $\gamma_{dmax,k}$ Maximum Dry Unit Weight for known compactive effort
 $w_{opt,u}$ Optimum Moisture Content for unknown compactive effort
 $w_{opt,k}$ Optimum Moisture Content for known compactive effort
E Compactive effort
 E_u Unknown compactive effort
 E_k Known compactive effort
m Slope of maximum dry unit weight versus log of compactive effort
n Slope of optimum moisture content versus log of compactive effort
c Intercept of maximum dry unit weight versus log of compactive effort
d Intercept of optimum moisture content versus log of compactive effort
MDUW Maximum Dry Unit Weight
OMC Optimum Moisture Content
FC/S_dC Fines content-Sand content ratio
BSL British Standard Light
WAS West African Standard
BSH British Standard Heavy
LL Liquid Limit
PL Plastic Limit
PI Plasticity Index
S_dC Sand Content
GC Gravel Content
FC Fines Content
SG Specific Gravity
SC Clayey Sands
CI Inorganic clay of medium compressibility
CL Inorganic clay of low compressibility
MI Inorganic silt of medium compressibility
RMSE Root Mean Square Error