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Empirical Prediction of Compaction Parameters of Soil of South-Eastern Ngeria Based on Linear Relationship Between Liquid Limit and Compaction Curve

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Abstract - Ten samples of Nigeria South-Eastern tropical soils were classified using the Unified Soil Classification method (USC) and the American Association of State Highway and Transport Officials (AASHTO) method and their compaction properties were determined in the laboratory using three compactive efforts of British standard light, West African standard and British standard heavy. These compaction properties were further used to develop the mathematical models that were used in making reasonable predictions of the compaction properties of the natural soils. A mathematical expression was derived and validated to be used in estimating the optimum moisture content and the maximum dry unit weight of tropical soils exhibiting various engineering properties. The method employed the use of a liquid limit and one compaction curve for the estimation based on a near linear relationship that exists between compaction energy, Log E and γ_{dmax} & W_{opt} as determined in the laboratory.. The mathematical models gave satisfactory results with maximum error of ±1.36% for the maximum dry unit weight and ±1.2% for the optimum moisture content.

Keywords: Compactive Energy, Liquid Limit, Maximum Dry Density, Optimum Moisture Content, Tropical Soils.

1. Introduction

The incessant failures of recently constructed pavements in Nigeria and the rate at which contractors abandon their projects have been on the increase in recent times. This has been identified to be as a result of the soil challenges they face during construction coupled with the weather conditions existing on site. One of the major causes of the problem has been identified as inadequate stabilization methods employed on soils with poor engineering properties encountered during construction. This research work is geared at developing simplified mathematical equations that construction personnels can use to make good predictions to determine the maximum dry density and optimum moisture contents of natural soils.

Amidst other factors identified to play a role in contributing to the delay construction time and pavement failure shortly after construction, compaction control has been identified as the most significant factor. In many cases, requirements for compaction water content and dry unit weight are referenced to an optimum water content and maximum dry density corresponding to a particular compactive method. Daniel and Benson (1990) and Othman and Luettich, (1994) observed that the line of optimum is used for compaction control. Some authors (e.g., Jumiks, 1958; Huang, 1904) have described methods to estimate the optimum water content and maximum dry unit weight of clayey soils. They used index properties to estimate the optimum moisture content corresponding to a particular compactive effort given. (Blotz and Benson, 1997) estimated the optimum moisture content and maximum dry unit weight of compacted clayey soils but did not take account of other soils found in the tropics that could be used for engineering construction works. This research work made effort to address this limitation by taking up similar study on random soil samples of soils found in the tropics.

Benson and Boutwell, 1992, reports that a linear relationship exists between maximum dry unit weight (γ_{dmax}) and the base 10 logarithm of compaction energy (log E) based on the tests he conducted on a micaceous silt fine sand. Review of other data in the literature also reveals that a linear relationship between Log E and dry unit weight as well as Log E and optimum moisture content also exists (Blotz and Benson, 1997). From these findings, it was then investigated in this report to see if these relationships also characteristics of compacted tropical soils and if these relationships can be used to estimate their maximum dry unit weight and its optimum water content. This report describes the findings and presents a simple method to predict the W_{opt}. and Υ_{dmax} for a given compactive effort based on the liquid limit and one compaction curve.

2. Location and Geology of the Study Area

The lateritic soil sample for this research work were disturbed samples collected across various locations within Anambra and Enugu States. The table below gives the geological location of the soil samples with their cordinates within Anambra and Enugu States.

Table 1: Coordinate of Soil Samples.

S/N	Samples No.	Soil type	Latitude	Longitude
1	Sample 1	Laterite	6^o 15’ 25” N	7^o 10’ 9” E
2	Sample 2	Silty-clay	6^o 15’ 23” N	7^o 8’ 43” E
3	Sample 3	Silty-clay	6^o 14’ 36” N	7^o 7’ 43” E
4	Sample 4	Silty-clay	6^o 14’ 21” N	7^o 7’ 22” E
5	Sample 5	Laterite	6^o 21’ 15”N	7^o 09’17”E
6	Sample 6	Silty-clay	6^o 12’ 14”N	7^o 06’48”E
7	Sample 7	Silty-clay	6^o 11’ 32”N	7^o 05’43”E
8	Sample 8	Laterite	6^o 31’ 14”N	7^o 09’ 16” E
9	Sample 9	Laterite	6^o 21’15” N	7^o 09’18” E
10	Sample 10	Clay	6^o 04’25” N	7^o 11’28” E

3. Sample Preparation

Ten different soil samples were selected for the various testing techniques. These samples comprised of four lateritic soils and six non lateritic soils. Fresh soil samples (i.e. samples collected and tested within three months) as suggested by Madu (1975) were used because long storage in the laboratory or in the open air may alter the properties of residual soils, an example of which is the tropical soil. The Atterberg limits were determined using fresh samples for each test. All the samples for the tests and linear shrinkage were air dried for 1 day before testing to stimulate field condition as suggested by Peck (1971).

The compaction tests was carried out using BSL, WAS and BSH compactive efforts because the BSL is easily achieved in the field, the WAS compaction is the conventional energy commonly used in our region (Osinubi and Oyelakin, 2012) and the BSH energy level is used to simulate the maximum expected strength gain that can be achieved on site (Oyelakin, 2014). All tests were carried out in accordance with BS 1377 (1990) and they were analyses at the Civil Engineering Department’s Laboratory, Nnamdi Azikiwe University, Awka.

4. Results and Discussions

Preliminary tests conducted to determine the natural properties of the soil revealed that the soil has very relatively low moisture content. The moisture contents were all below 17% with sample No. 2 having the least moisture content of 5.2% which was due to the period of its collection (in December during the dry season). The index and compaction properties are summarized in Table 2.

Table 2: Index and Compaction Properties of the Natural Soil.

Properties	Sample No 1	Sample No 2	Sample No 3	Sample No 4	Sample No 5	Sample No 6	Sample No 7	Sample No 8	Sample No 9	Sample No 10
Natural moisture Content (%)	11.368	16.399	5.2231	14.334	13.708	7.924	10.931	7.1976	8.5601	7.4825
Liquid limit (%)	39.5	26.2	24.2	30.8	35.2	27.0	27.65	36.3	33.36	43.2
Plastic limit (%)	21.32	15.48	13.83	13.374	24.6	14.2	14.16	20.33	19.21	18.79
Plasticity index (%)	18.18	10.72	10.371	17.426	10.6	12.8	13.49	15.97	14.15	24.41
Percentage passing No 200 sieve	38.11	37.06	25.57	34.26	37.45	22.17	26.60	40.7	38.185	64.17
Coeff. Of UniformIty. (Cu)= D_{60}/D_{10}	NIL	NIL	3	NIL	NIL	NIL	NIL	NIL	NIL	NIL
AASHTO Classification	A-6	A-6	A-2-6	A-2-4	A-6	A-2-4	A-2-4	A-6	A-6	A-7-6
USCS classification	SC	SC	SC	SC	SC	SC	SC	SC	SC	CL
Specific gravity	2.45	2.36	2.459	2.41	2.51	2.45	2.48	2.61	2.6	2.33
MDD BSL	1780	1925	1880	1855	1910	1860	1895	1810	1920	1512
OMC BSL	13.5	12.0	12.5	14.1	13	13	13	16	12.2	21
MDD BSH	1940	1990	1980	1925	1960	1945	2020	1890	1990	1630
OMC BSH	13.2	9.0	10.5	9.5	12.5	10	9.5	14	9	18
MDD WAS	1820	1950	1942	1875	1915	1910	1935	1845	1960	1555
OMC WAS	13.5	12.5	12.5	10.5	12.5	12	10.5	13.5	12	19

The particle size analysis for the lateritic samples shows that the cumulative percentage retained on No. 200 BS sieve were in the range of 59.30% and 77.83% except for sample No 10 which is 32.83%. From the results also, the cumulative percentage passing on No: 200 BS sieve are in the range of 22.17% and 40.70% except the same sample No 10 which is 64.17%. From the analyses, it is clear that there is higher percentage of sand than fines (silt and clay) in samples No 1 to sample No 9. Sample No 10 has higher percentage of fines (silt and clay) than sand.

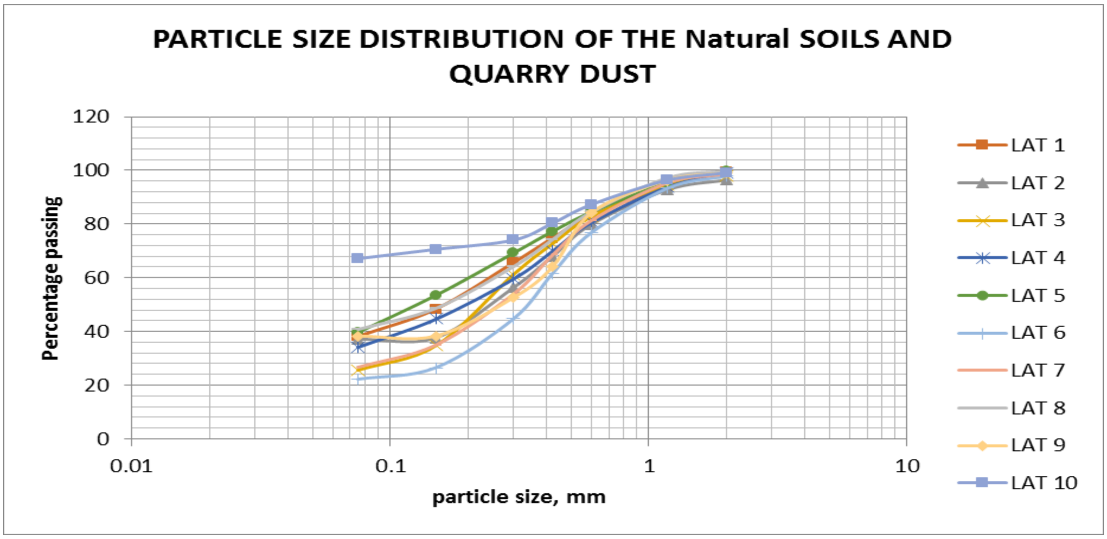

Fig. 1: Particle Size Distribution of the soil samples

According to the Federal Ministry of Works and Housing (1997) specification (Bello and Adegoke, 2010), it can be deduced that only the samples that have percentage passing on No 200 BS sieve less than 35% is suitable for sub base and base materials. Therefore it can be affirmed that the following sample Nos; 3, 4, 6, and 7 with percentages passing on No 200 BS sieve as 25.57%, 34.26%, 22.17% and 26.60% respectively satisfy this criteria and therefore are sufficient to be used as sub base and base materials. With this regard the remaining samples will require further soil improvement techniques performed on them before they could be use as base and sub base materials.

Since all the soils samples except sample No 10 have more than 50% of the soil retained on the No. 200 BS sieve, the soils are coarse grained, and the soils are identified as sand. Also, since Sample Nos 1 to 9 have plasticity index greater than 7, they may be referred to as inorganic clays with medium plasticity and group name SC. While sample 10 with plasticity index of 24.41% and liquid limit 43.2% which is less than 50% is regarded inorganic clay of low to medium plasticity with group name CL.

Establishing Linear Relationships

Table 3: Relationship between LL and Compaction Characteristics

Sam. No	Liq. Limit	Plast. Index	BSL		WAS		BSH		Equ1			Equ 2		
			Υd_{max}	W_{opt}.	Υd_{max}	W_{opt}.	Υd_{max}	W_{opt}.	β	δ	R^2	A	E	R^2
1	39.5	21.3	17.46	13.5	17.85	13.5	19.03	13.2	7.4	-18.3	0.9921	-0.5	14.9	0.988
2	26.2	15.48	18.88	13	19.12	12.5	19.52	9	19.8	-55.4	0.997	-7.1	33.4	0.983
3	24.2	13.83	18.44	12.5	19.05	12.5	19.42	10.5	12	-32.2	0.8965	-3.3	21.9	0.988
4	30.8	13.4	18.19	12.1	18.39	10.5	18.88	9.5	17.4	-47.7	0.9969	-3.8	22.2	0.904
5	35.2	24.6	18.73	13	18.79	12.5	19.23	12	22.6	-63.5	0.9395	-1.4	17.1	0.966
6	27	14.2	18.25	13	18.74	12	19.08	10	14.2	-38.4	0.9178	-4.6	25.8	0.999
7	27.7	14.2	18.59	13	18.98	10.5	19.82	9.5	10.2	-27	0.9998	-4.9	26.2	0.929
8	36.3	27.3	17.76	15	18.1	14.5	18.54	14	15.2	-46	0.9864	-1.5	19.1	0.966
9	36.6	23.7	18.83	12.2	19.23	12	19.52	9	17.8	-49.5	0.9287	-5.1	26.9	0.921
10	43.2	18.8	14.83	20	15.25	19	15.99	18	8.7	-20.8	0.9986	-2.9	28.1	0.967

A near linear relationship between $\gamma_{dmax.}$ and log E for the ten soil samples are listed in Table 3 above. The regression lines fit the data well with the coefficient of determination ranging from 0.8965 to 0.9998 with an average of 0.9653. The equation of the line is represented as;

$$\gamma_{dmax} = \beta \log E + \delta \text{ ……………………………………. (1)}$$

Where; β = slope and δ = intercept.

Each soil has its unique β and δ values which are listed in Table 3 above. Since the optimum point normally occurs at a saturation near 85% (Benson and Boutwell, 1992) a relationship between W_{opt}. and logE is also approximately near linear. The line fits to the data are good with R^2 ranging from 0.921 to 0.999. The equation of each line is represented as;

$$W_{opt}. = \alpha \log e + \varepsilon \text{ …………………………………… (2)}$$

Where; α = slope and ε = intercept.

The α and ε values for each soil are listed in Table 4 with $W_{opt.}$ in percent and E in kilojoules.

Correlation with Liquid Limit

An attempt was made in the course of this study to see if α , β , δ and ε could be related with easily measured index properties such as liquid limit similar to the work done by (Benson and Boltz, 1997). It was established that a good correlation existed between these values and their liquid limit and this was used for further analysis. Fig. 2 is a graph of β vs LL. A logarithmic curve was fitted using least square regression. The equation of the curve is;

$$\beta = -18.15 \log LL + 26.753 \text{ ……………………………………………. (3)}$$

The fit to this curve is good with $R^2 = 0.71$.

Fig. 3 shows the relationship between δ and LL, the equation for this curve is

$$\delta = 2.9563LL - 3.4207 \quad \ldots\ldots (4)$$

With $R^2 = 1$.

Fig. 4 shows the relationship between α and LL, the equation for this curve is;

$$\alpha = 2.326 \log LL - 4.787 \quad \ldots\ldots (5)$$

With $R^2 = 0.9943$.

Fig. 5 shows the relationship between ε and LL, the equation for this curve is;

$$\varepsilon = -0.2828\, LL + 26.753 \quad \ldots\ldots (6)$$

With $R^2 = 0.7856$.

Applications

If the liquid limit and a single compaction curve are known, (i.e. compaction curve for a effort E_k having γ_{dmaxk} and W_{optk}) then γ_{dmaxE} and W_{optE} for compactive effort E can be estimated by combining equations (1) and (3) or (2) and (5) as;

$$\gamma_{dmaxE} = \gamma_{dmaxK} + (-18.15 \log LL + 26.753) \log (E/E_K) \quad \ldots\ldots (7)$$

and;

$$W_{optE} = W_{optk} + (2.2783 \log LL - 4.787) \log (E/E_K) \quad \ldots\ldots (8)$$

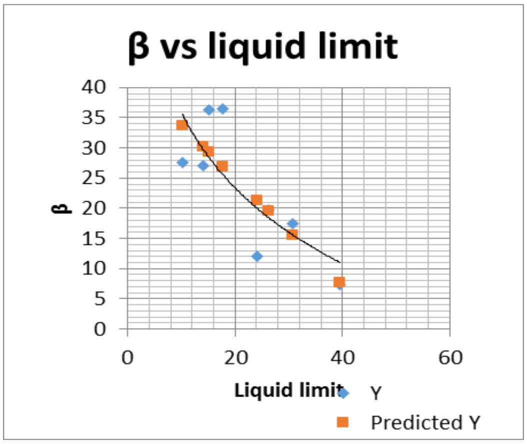

FIG. 2: beta values vs liquid limit.

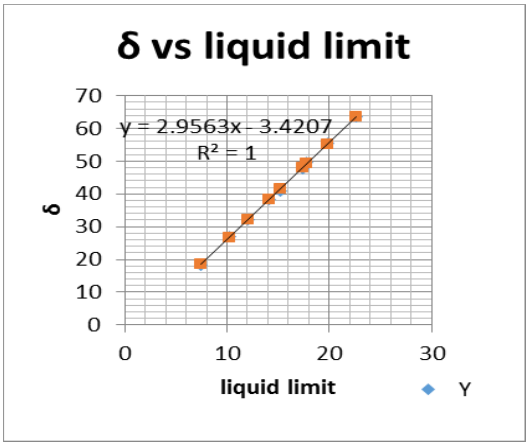

FIG. 3: delta values vs LL.

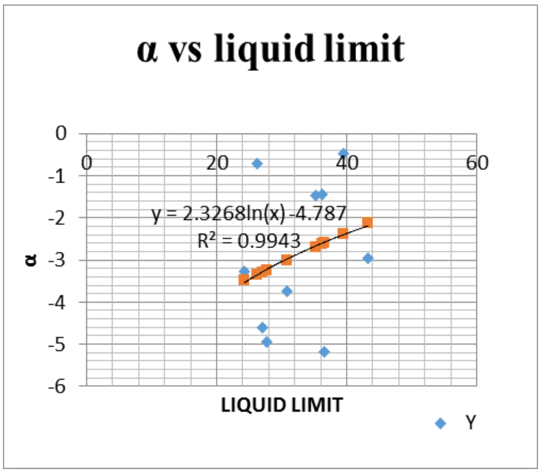

FIG. 4: alpha values vs liquid limit.

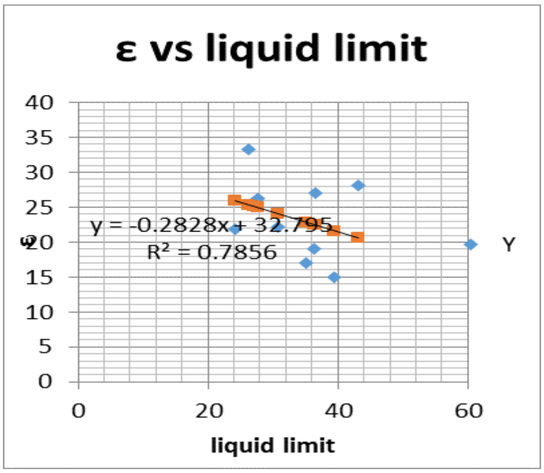

FIG. 5: ε values vs liquid limit.

Validation

A check was carried out on the equations to ascertain its degree of accuracy in estimating the Optimum moisture content and maximum dry unit weight of tropical soils. The results are shown in Table 4.

TABLE 4: α, β, δ and ε values with predicted compaction characteristics values

Sam No.	α	B	Δ	ε	Predicting $\Upsilon d_{max.}$ using the liquid limit and one compaction curve. (KN/M^3)				Predicting W_{opt}. using the liquid limit and one compaction curve.(%)			
					West African std.		British standard heavy		West African std.		British standard heavy	
					Predicted Υd_{max}	error	Predicted Υd_{max}	error	Predicted W_{opt}. (%)	error	Predicted W_{opt}.(%)	error
1	-0.5	7.4	-18.3	14.9	18.29	0.4	19.5	0.52	13.25	0.04	12.75	-0.44
2	-7.1	19.8	-55.4	33.4	19.1	0.05	19.5	0.01	12.6	0.15	11.98	0.88
3	-3.3	12	-32.2	21.9	18.8	-0.2	19.5	0.06	12.14	-0.35	11.43	-0.37
4	-3.8	17.4	-47.7	22.2	18.1	-0.3	18.0	-0.8	11.79	1.29	11.19	0.91
5	-1.4	22.6	-63.5	17.1	18.4	-0.3	17.5	-1.7	12.72	0.2	12.17	-0.8
6	-4.6	14.2	-38.4	25.8	18.4	-0.3	18.7	-0.3	12.66	0.66	12	1.2
7	-4.9	10.2	-27	26.2	18.7	-0.3	18.9	-0.8	12.67	2.17	12.02	2.52
8	-1.5	15.2	-46	19.1	17.4	-0.6	16.7	-1.4	14.736	0.2	14.1	0.2
9	-5.1	17.8	-49.5	26.9	18.5	-0.7	17.7	-1.5	11.9	-0.06	11.40	0.4
10	-2.9	8.7	-20.8	28.1	14.2	-1.6	12.9	-3.1	19.76	0.76	19.3	0.8

5. Conclusion

A simple empirical method has been described for estimating maximum dry unit weight (γdmax) and optimum water content (Wopt) for tropical soils at compactive effort E using the liquid limit and a compactive curve. The method is based on the linear relationship between Log E and Wopt. as determined in the laboratory. Their linear relationships correlated well with the liquid limit.

6. Recommendation

The results of 10 tropical soils selected randomly around the south east geopolitical zones of Nigeria were used to develop this method. The method was found to be relatively consistent with slight deviations from the actual parameters measured in the laboratory. Nevertheless, we recommend that in a particular project, results from the procedure should be checked against atleast one compaction curve to ensure that the method is acceptable for the soil been used. The mehod is currently restricted to soils with liquid limits ranging from 18% to 40%.

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