International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 8 Issue 1, January-February 2024 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Study of Relationships Between Compaction Characteristics and Selected Index Properties of Soil

G. O. Adunoye

Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria

ABSTRACT

The cost and amount of time involved in carrying out compaction for mega construction projects have made it imperative to find quicker and cheaper methods of determining the compaction characteristics of soils. This study therefore aimed at studying the effects of index properties on compaction characteristics of lateritic soils, with the aim of developing empirical relationships between these properties. To achieve this aim, soil samples were collected from selected locations within Ife North Local Government Area, Osun state, southwest Nigeria. Preliminary, index property and compaction tests were conducted on the soil samples, using standard procedures. Using Microsoft Excel tool, the laboratory test results were used to develop relationships between compaction characteristics (optimum moisture content and maximum dry density) and index properties. Results of index property tests showed that the soils are excellent to good subgrade materials. The optimum moisture content ranged between 5.38 % and 22.62 %, while the maximum dry density ranged between 1648 kN/m^3 and 2150 kN/m^3. Regression analysis showed that, liquid limit (LL) and plastic limit (PL) had a good correlation with optimum moisture content (for LL, R^2 = 0.540; for PL, R^2 = 0.50); plasticity index (PI) showed a strong correlation with optimum moisture content (R^2 = 0.810). However, each of the index properties (specific gravity, effective sizes, liquid limit, plastic limit and plasticity index showed a very weak correlation with maximum dry density. The study concluded that plasticity index could be used to estimate the optimum moisture content of the soils, by applying the developed equations.

How to cite this paper: G. O. Adunoye "Study of Relationships Between Compaction Characteristics and Selected Index Properties of Soil" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-8 | Issue-1, February 2024, pp.559-564, URL: www.ijtsrd.com/papers/ijtsrd63428.pdf

IJTSRD63428

KEYWORDS: *Compaction, correlation, index properties, maximum dry density, optimum moisture content*

INTRODUCTION

Compaction of soil is the densification of soil by removal of air, which requires mechanical energy. The process of soil compaction increases the density of soil, increases the stability of slopes, and reduces the permeability of the soil. Compaction is used in waste impoundment sites to make them relatively impermeable to leachates and thus reduce the threat of groundwater contamination. The degree of compaction of a soil is measured in terms of its dry unit weight or dry density. (Das, 2010).

In order to evaluate compaction in the field, laboratory compaction characteristics are required and determined. Compaction characteristics of soil have great importance for practically achieving the desired strength, permeability and compressibility of soil during construction (Budhu, 2015; Powrie, 2014). The two characteristics which are determined in the process of soil compaction are: optimum moisture content (OMC) and maximum dry density (MDD). They are referred to as compaction parameters. The OMC is the water content at which the soil attains its maximum density.

Index properties of soil are the properties of soil that help in the identification and classification of soil. They are properties of soil that indicate the type and conditions of the soil, and provide a relationship to structural properties. Soil index properties are used extensively by engineers to discriminate between the different kinds of soil within a broad category (ELE, 2013). A good knowledge about a site including its subsurface conditions is very important in its safe and economic development. Determination of index properties of soil is therefore an essential preliminary to the construction of any civil engineering work such as roads, buildings, dams, bridges, foundations, etc. (Adeyeri, 2015).

Laboratory compaction (for the determination of OMC and MDD) of soils involves collection of numerous samples, laborious efforts, and considerable time. Therefore, for a preliminary assessment of the suitability of soils for large projects, it is desirable to develop correlations of engineering properties (compaction parameters in this case) with simple physical properties (index properties) of soils, which are easily determined through simple tests (Tsegaye *et al*., 2017).

Attempts have been made to determine a relationship between compaction parameters and plasticity of soil (Sridharan and Nagaraj, 2005). Nerea (2012) also found that compaction characteristics can correlate well with plastic limit in comparison with liquid limit and plasticity index for a specific type of soil. He stated that plastic limit alone can be used to determine compaction parameters. Further, Tsegaye *et al.* (2017) observed that there is a relatively good correlation between optimum moisture content and plastic limit, and similarly, a good correlation was observed between maximum dry density and liquid limit, and plastic limit and plasticity index together.

Adunoye *et al*. (2020) studied the correlation potential of compaction characteristics and Atterberg limits of selected lateritic soils. They found that: the combination of liquid limit and plastic limit has a strong correlation with optimum moisture content; and the combination (of liquid limit and plastic limit) showed a weak correlation with maximum dry density. They concluded that liquid limit and plastic limit could be used to estimate the optimum moisture content of the soils, by applying the developed relationship/equation.

Abdulazeez *et al* (2020) studied the effects of selected index properties on the California bearing ratio of selected soils. Their results showed that combination of plasticity index (PI) and uniformity coefficient gave the best model for unsoaked CBR, while PI and coefficient of gradation gave the best model for soaked CBR. The study concluded that useful relationships exist between the selected index properties and CBR. The developed models could therefore be employed in the determination of the CBR of tested soils for preliminary analysis/assessment.

Ojo *et al*. (2022) studied the effects of particle size characteristics on compaction parameters of fine-grained soils. After the laboratory results and analysis, they found that: the combination of D_{30} and C_u has a strong correlation with MDD; and the combination of D_{30} and D_{60} showed a fair correlation with OMC. They concluded that D_{30} and C_u could be used to estimate the MDD of the soils, by applying the developed equation.

As at the time of carrying out this study, there was no documented evidence of correlation between compaction parameters and index properties of lateritic soils in the study area; hence, this study.

Description and geology of the study area

The study area is Ife-North Local Government Area in Osun State, Southwestern Nigeria (see Figure 1). Its headquarters is at Ipetumodu town. The Loral Government covers an area of about 889 km^2 and has a density of about 237.5/km^2 (National Bureau of Statistics, 2019). The study area falls within the basement complex of Southwestern Nigeria (Anukam, 1997). It forms part of the African crystalline shield which consists predominantly of migmatised and undifferentiated gneisses and quartzite (Akintola, 1982; Areola, 1982; Adunoye and Agbede, 2013; Adeyemi *et al.*, 2019).

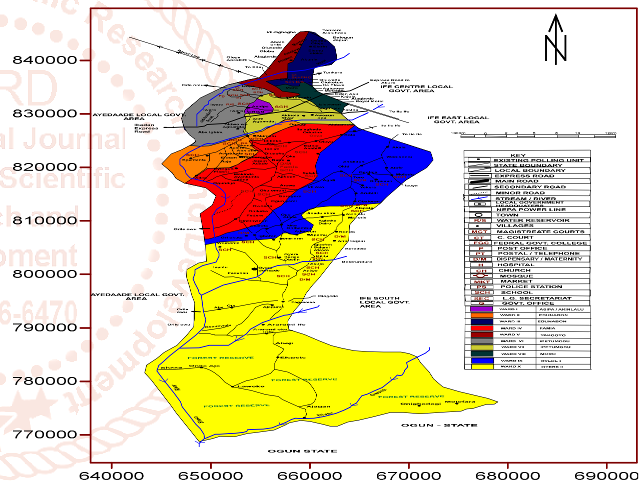

Figure 1: Map of Ife North Local Government Area (Ife North LGA, 2018)

MATERIALS AND METHODS

Materials and equipment

The soil samples used for this study were collected from twelve identified locations in Ife North Local Government Area of Osun state, southwest Nigeria. Equipment used for laboratory tests included equipment and tools for preliminary, index properties and compaction test

Soil sampling and preparation

The study area was randomly divided into six areas thus: Moro Junction Ife North Area, Babalakin close central mosque, Yakoyo house, Asipa express way, Akinlalu junction and Oduduwa University, Ipetumodu area. Subsequently, two soil samples were collected from each of the identified divisions – making a total of 12 samples. The Global Positioning

System (GPS) descriptions of the sampling locations are presented in Table 1. The method of sampling used was disturbed sampling. Making use of the hand auger, 25 kg of soil was collected from each location, placed in nylon bag, properly sealed and labelled for onward transportation to the Geotechnical Engineering Laboratory of the Department of Civil Engineering Obafemi Awolowo University (OAU), Ile-Ife for analysis. At the laboratory, natural moisture content was immediately determined for the soil samples. Subsequently the soils were spread and air-dried for further laboratory analysis.

Preliminary and geotechnical analysis of soil samples

The following preliminary and geotechnical tests were conducted on the soil samples: particle size analysis, specific gravity, Atterbrg limits and compaction tests. All the tests were conducted in accordance with standard procedures as stated in BS 1377 (1990). Particle size characteristics were also determined from the particle size curves which were plotted from the particle size analysis, using equations (1) and (2). Plasticity index was also obtained using equation (3)

$$Cu = \frac{D_{60}}{D_{10}} \quad (1)$$

Where,
C_u = Coefficient of uniformity.
D_{10} = diameter corresponding to 10% finer.
D_{60} = diameter corresponding to 60% finer.

$$Cc = \frac{D_{30}^2}{D_{10} \, x \, D_{60}} \quad (2)$$

Where,
D_{10} = diameter corresponding to 10% finer
D_{30} = diameter corresponding to 30% finer.
D_{60} = diameter corresponding to 60% finer

$$PI = LL - PL \quad (3)$$

Where,
PI = plasticity index
LL = liquid limit;
PL = plastic limit

Table 1: Description of sampling locations

Sample ID	Latitude	Longitude
S1	N70 28’ 29.1”	E40 20’ 33.8”
S2	N70 27’ 12.0”	E40 20’ 48.6”
S3	N70 28’ 46.2”	E40 20’ 27.7”
S4	N70 28’ 45.5”	E40 20’ 26.4”
S5	N70 28’ 40.9”	E40 20’ 26.4”
S6	N70 28’ 41.2”	E40 20’ 33.8”
S7	N70 29’ 25.5”	E40 21’ 11.0”
S8	N70 29’ 24.7”	E40 21’ 11.6”
S9	N70 29’ 12.0”	E40 20’ 48.9”
S10	N70 29’ 09.6”	E40 20’ 33.8”
S11	N70 29’ 14.2”	E40 20’ 43.4”
S12	N70 29’ 08.1”	E40 20’ 53.2”

Correlating compaction parameters and index properties

Variations of compaction characteristics (OMC and MDD) with the index properties (particle size characteristics, specific gravity, Atterberg's limit) of the soils were studied. Using Microsoft Excel Regression Tool, empirical relationships were then developed between the compaction characteristics and index properties thus: OMC and index properties; and MDD and index properties.

RESULTS AND DISCUSSION

Results of preliminary and index property tests

Results of preliminary and index property tests are presented in Table 2. Sample S1 had the highest natural moisture content, *w* (19.02 %) while Sample S11 had the lowest natural moisture content (5.23 %). Seven soil samples, representing 58 % of the samples, had natural moisture content higher than 10 %, while the other 42 % had theirs lower than 10 %. Six of the samples, representing 50 %, had natural moisture content between 8 % and 15 %. Generally speaking, the soils could be said to have relatively low natural moisture content. This is attributed to the fact that the soil samples were collected at a period which fell within early rainy season (i.e. March).

Similarly, Sample S4 had the highest specific gravity (G_s) value of 2.85 while Sample S5 had the lowest specific gravity of 2.30. Also, 90 % of the soil samples had their specific gravity greater than 2.60 while the rest had theirs less than 2.60. According to Bowles (2012), the specific gravity of clayey and silty soils may vary from 2.60 to 2.90 while for organic soils the value ranges between 1.00 and 2.60. It can therefore be deduced that majority of the tested soil samples are silty-clayey in nature.

Table 2: Results of index property tests

Sample ID	*w* (%)	G_s	Fine content (%)	C_u	C_c	LL (%)	PL (%)	PI (%)
S1	19.02	2.77	0.2	6.3	1.34	47.71	28.82	18.89
S2	10.48	2.82	0.32	11.48	0.66	33.26	17.06	16.19
S3	14.59	2.63	0.18	11.23	0.97	29.99	16.48	13.51
S4	10.76	2.85	0.9	8.43	0.9	35.42	21.14	14.28
S5	13.9	2.31	0.47	7.8	1.17	26.09	20.5	5.58
S6	11.61	2.6	0.69	10.41	1.12	31.16	20.13	11.03
S7	7.25	2.58	0.5	5.24	0.6	20.21	12.3	7.92
S8	8.26	2.63	0.73	8.02	0.68	22.53	18.11	4.42
S9	12.51	2.72	0.28	9.46	1.26	44.32	31.09	13.23
S10	5.64	2.64	0.21	10.02	0.83	47.77	26.07	21.69
S11	5.23	2.73	0.62	11.24	0.62	42.27	27.08	16.2
S12	18.2	2.63	1.05	11.74	0.93	38.13	25.39	12.75

The soil with the highest percentage of fine content was Sample S12, with a value of 1.05 %, while sample S3 had the lowest value of 0.18 %. The average percentage fines in the soils is 0.518 %. Also, sample S12 had the highest coefficient of uniformity (C_u) of 11.74 while sample S7 had the least value of 5.24. Sample S1 had the highest coefficient of curvature (C_c) of 1.34 while the lowest C_c was 0.60 (sample S7). Jumikis (1962) opined that, on the average, the soil is sandy, if C_u is between 10 and 20; silty, if C_u is between 2 and 4. It can therefore be said that 50 % of the soil samples is silty and the other 50 % is silty-sandy.

The highest value of liquid limit that was obtained was 47.77 % (S10), and the least was 20.21 % (S7). Also, the plastic limit had a maximum value of 31.09 % (S9) and the minimum value of 12.3 % (S7). In addition, 21.69 % (for S10) was the highest plasticity index value, while the lowest value was 4.42 % (S8). The mean liquid limit, plastic limit and plasticity index for the soil samples were 34.91 %, 21.93 % and 12.98 %, respectively. According to Whitlow (1995), a soil having liquid limit less than 35 % has low plasticity, between 35 % and 50 % has intermediate plasticity, 50 % to 70 % liquid limit has high plasticity and 70 % to 90 % indicates very high plasticity in a soil. On this basis, 50 % of the soil samples has low plasticity; the other 50 % has intermediate plasticity.

The soil classification using the results of the index properties, according to American Association of State Highway and Transportation Officials (AASHTO) and Unified Soil Classification System (USCS), is presented in Table 3. AASHTO classification shows that 25 % of the soils are A-2-4, 42 % are A-2-6 and the remaining 33 % are A-2-7. In the same vein, USCS classification indicates that 33 % of the soils are well graded sand, fine to coarse (SW) and the remaining 67 % are poorly graded sand (SP). The soils can therefore be described as excellent to good subgrade materials (Das, 2010).

Table 3: Soil classification

Sample ID	AASHTO	USCS
S1	A-2-7	SW
S2	A-2-6	SP
S3	A-2-6	SP
S4	A-2-6	SP
S5	A-2-4	SW
S6	A-2-6	SW
S7	A-2-4	SP
S8	A-2-4	SP
S9	A-2-7	SW
S10	A-2-7	SP
S11	A-2-7	SP
S12	A-2-6	SP

Results of compaction tests

Results of compaction tests showing the values of maximum dry density (MDD) and optimum moisture content (OMC) are presented in Table 4. The highest value of OMC was 22.62 % (S1), and the lowest OMC value was 5.38 % (S7). Also, the highest MDD was 2150 kg/m^3 (S4); the lowest MDD was 1648 kg/m^3 (S12). 75 % of the soil samples had OMC within the range 10 % - 20 %; 17 % of the samples had OMC below 10 %; while the remaining 8 % had OMC values ranging between 20 % and 30 %. In addition, 67 % of the soils had MDD within the range 1000 kg/m^3 – 1800 kg/m^3, and the remaining 33 % had MDD within 1800 kg/m^3 – 2200 kg/m^3. With the results of the compaction tests, the soils could be said to fall between silty clay and sandy clay, as earlier established (O'Flaherty, 1988; Bello and Adegoke, 2010; Adunoye and Agbede, 2013).

Table 4: Results of compaction test

Sample ID	MDD (KN/m^3)	OMC (%)
S1	1703	22.62
S2	1680	15.2
S3	1918	10.7
S4	2150	14.2
S5	1810	10.4
S6	1733	9.54
S7	1694	5.38
S8	1650	10.38
S9	1729	11.44
Sample S10	1690	13.85
S11	1928	18.5
S12	1648	11.00

Effects of index properties on compaction parameters

After examining different combinations, a summary of the results of regression analyses on index properties and compaction characteristics is presented in Table 5. OMC had good correlation with liquid limit and plastic limit (R^2 = 0.54 and 0.5 respectively). On the other hand, a very strong correlation was observed between OMC and plasticity index (R^2 = 0.81). From the observed relationships of OMC with the selected index properties, it can be said that the assessment of soil moisture content of over compacted lateritic soils can be predicted from plasticity index, with little significant error, as earlier observed by Nerea (2012).

It was also observed that there was a very weak relationship between MDD and each of the selected index properties, with very low R^2 values (all less than 1).

Table 5: Results of correlation

Index property	Equation	R^2
LL	OMC = 1.52LL + 15.45	0.54
PL	OMC = 0.81PL + 11.35	0.5
PI	OMC = 0.51PI – 4.52	0.81

CONCLUSION

Relationships between compaction characteristics and index properties of selected soils have been studied. The tested soils generally fall between silty clay and sandy clay and were found to be excellent to good subgrade materials. Maximum dry density did not show either fair, good or excellent relationship with any of the index properties. However, a very strong relationship was observed between optimum moisture content and plasticity index, for the tested soil samples. This conforms, to some extent, with the results of earlier work by Adunoye *et al* (2020). Therefore, the empirical equation (relationship between optimum moisture content and plasticity index) could be used to predict the optimum moisture content of the soils. the result could also be said to be valid for the tested soil samples and regression model used.

REFERENCES

[1] Abdulazeez, M. O., Adunoye, G. O. and Adekola, A. A. (2020). Experimental Study on the Effects of Some Index Properties on California Bearing Ratio of Selected Soils. International Journal of Scientific & Engineering Research, 11(1): 1562-1567.

[2] Adeyeri, J. B. (2015). *Technology and Practice in Geotechnical Engineering*: IGI Global Publishers: Advances in Civil and Industrial Engineering (ACIE) Book Series; Pennsylvania, USA.

[3] Adeyemi, E. O., Adunoye, G. O. and Ata, B. T. (2019). Geotechnical Evaluation of Selected Lateritic Soils. UI Journal of Civil Engineering and Technology, 1(1), 32-40.

[4] Adunoye, G. O. and Agbede, O. A. (2013) Geotechnical evaluation of Opa dam, Obafemi Awolowo University, Ile-Ife, Nigeria. The International Journal of Engineering and Science 2(2), 160 – 165.

[5] Adunoye, G. O., Ojo, A. A., Alasia, A. F., and Olarewaju, M. O. (2020). A Study on the Correlation Potential of Compaction Characteristics and Atterberg Limits of Selected Lateritic Soils. International Journal, 8(1), 22-26.

[6] Akintola, F.A. (1982). Geology and geomorphology, in K.M. Barbours (Ed.), Nigeria in maps (London, UK: Hodder and Stoughton.

[7] Anukam, C. L. (1997) Water pollution control - A guide to the use of water quality management principles.

[8] Areola, O. (1982). Soil, in K.M. Barbours (Ed.), Nigeria in maps. London, UK: Hodder and Stoughton.

[9] Bello, A.A and Adegoke, C.W (2010) Evaluation of geotechnical properties of Ilesha East Southwest Nigeria's lateritic soil. Pacific Journal of Science and Technology, 11(2), 617-624.

[10] Bowles J. E. (2012). Engineering Properties of Soils and their Measurements, 4th edition,

McGraw Hill Education (India) Private Limited, New Delhi.

[11] BS: 1377 (1990). British Standard Methods of Tests for Soil for Engineering Purposes, Part 2, BSI, London.

[12] Budhu, M. (2015). Soil Mechanics Fundamentals. 1st ed. John Wiley and Sons, United Kingdom.

[13] Das, B. M. (2010). Principles of geotechnical engineering, 7th ed. Cengage learning, USA.

[14] ELE International (2013), Chartmoor Road, Chartwell Business Park, Leighton Buzzard, Bedfordshire, LU7 4WG

[15] Ife North Local Government (2018). Map of Ife North local Government Area.

[16] Jumikis, R.A. (1962). Soil Mechanics. D. van Nostrand company Inc.

[17] National Bureau of Statistics (2019). Ife North Loal Government, ttps://www.citypopulation.de/en/nigeria/admin/osun/NGA030013__ife_north. Assessed 14/10/2019.

[18] Nerea, A. (2012). Prediction of Compaction Characteristics from Atterberg Limits for Fin grained Soils. MSc. Thesis, Department of Civil Engineering, Addis Ababa University, Ethiopia.

[19] Ojo, A.A., Alasia, A.F., Olarewaju, M.O., Adunoye, G.O. Study on the Effects of Particle Size Characteristics on Compaction Parameters of Fine Grained Soils. New York Science Journal, 15(3), 34-40.

[20] O'Flaherty CA (1988) Highway engineering 2. Edward Arnold Publishers, London, UK.

[21] Powrie, W. (2004). Origin and Classification of soils Soil Mechanics: Concepts and Applications. Spon Press, Oxon. p47-48.

[22] Sridharan, A. and H. A. Nagaraj. (2005). Plastic limit and compaction characteristics of fine grained soils. Ground Improv. 9(1): 17-22.

[23] Tsegaye, T., F. Henok and A. Tadesse. (2017). Correlation between compaction characteristics and atterberg limits for fine grained soils found in Adiss Ababa. Int J. Sci. Eng. Res. 8(6): 357.

[24] Whitlow, R. (1995). Basic Soil Mechanics. 3rd ed. Addison Wesley Longman Limited, Edinburgh Gate.