Original Research Article

EXPERIMENTAL INVESTIGATION OF THE INFLUENCE OF GRADATION PARAMETERS ON ATTERBERG LIMITS OF SOIL

Abstract

This study investigated the influence of gradation parameters on Atterberg Limits of soil. This was with a view to establishing a relationship between the two geotechnical properties. Disturbed soil samples were collected from selected locations. The natural moisture contents, grain size analysis and Atterberg Limits tests were conducted on the collected soil samples, following standard procedures. From the particle size analyses, effective sizes, sorting coefficients, coefficient of uniformity and coefficient of gradation were determined. Regression analysis was then used to investigate and establish relationships between gradation parameters and Atterberg Limits. The study concluded that gradation has effect on the Atterberg Limits of the selected soil samples. The developed model for Liquid Limit ($LL = -5.88x10^{-1}C_u^2 + 3.71C_uS_o - 19.41S_o^2 + 6.44C_u + 29.25S_o + 0.53$) is the best model with R^2 value of 0.95 and RSS (Residual Sum of Squares) value of 23.92.

Keywords: Gradation, Liquid Limit, Plastic Limit, Sorting coefficient, Uniformity

INTRODUCTION

The civil engineer is mainly interested in the engineering behavior of soils as foundation and construction material. He has the responsibility of studying the properties of soil, such as its origin, particle-size distribution, ability to drain water, compressibility, shear strength, sensitivity and load-bearing capacity. There is therefore the need for a classification system that would establish boundaries between differently soils on the basis of their properties (Das, 2001).

Gradation and Atterberg limits are some of the index properties of soil, which play significant role in the classification and engineering application of soils. Index properties have been employed severally to predict some geotechnical properties of soil for engineering purposes.

Soil gradation gives an idea of the particle distribution of the soil. Commonly used measures of soil gradation, obtained from the particle size distribution curve, include D_{10}, C_u, C_c and S_o which are defined as shown in Equations 1 to 3.

$$C_u = D_{60}/D_{10} \quad (1)$$
$$C_c = D_{30}^2/(D_{60} \text{ x } D_{10}) \quad (2)$$
$$S_o = (D_{75}/D_{25})^{0.5} \quad (3)$$

Where D_{10} = Effective size or grain size for which 10% of the sample is finer
D_{30} = Grain size for which 30% of the sample is finer
D_{60} = Grain size for which 60% of the sample is finer
S_o = Sorting coefficient

Sorting coefficient is the quantitative measure of sorting. Sorting of soil is usually expressed as qualitatively ranging from extremely well sorted to very poorly sorted (Folk and Ward, 1957).

To get a clear concept of range of water contents of soil in the plastic state, Atterberg (1911) proposed the limits of soil consistency. These limits of consistency, also known as the soil Atterberg limits, are plastic limit and liquid limit. Plastic limit is the boundary between semi-solid and plastic state, and liquid limit separates plastic state from liquid state (Campbell, 2001).

Casagrande (1932, 1958) developed methods for determining the liquid and plastic limits of soil. These methods have been considered and accepted as standard international tests. The plasticity index (which is the arithmetic difference between liquid limit and plastic limit) has been found useful for characterisation, classification and prediction of the engineering behavior of fine soils. Several researchers (Shahminan *et al.*,2014; Rashid *et al.*, 2014; Baver, 1930; Jong *et al.*, 1990; Archer, 1975; Wroth and Wood, 1978; McBride, 2008; Zolfaghari *et al.*, 2015; Stanchi *et al.*, 2015; Curtaz *et al.* (2014); Vacchiano *et al.* (2014) have identified the relationship between Atterberg limits and some geotechnical properties of soil, and thus emphasised the usefulness of these limits in civil engineering applications.

Consideration for the importance of gradation and Atterberg limits of soil has stimulated an interest to investigate the relationship between gradation and Atterberg limits of selected soils. The aim of this study was to study the influence of gradation on the Atterberg limits of selected soils. The specific objectives of the study were to: (i) determine the index properties, including gradation and Atterberg limits, of selected soils; (ii) relate gradation and Atterberg limits of the soils; and (iii) evaluate the relationship developed in (ii).

Description and Geology of the Study Area

The study area is the Obafemi Awolowo University (OAU) campus, Ile-Ife, Southwestern Nigeria. Ile –Ife lies between Latitudes 7°28’0’’N and 7°45’0’’N and Longitudes 4°30’0’’E and 4°34’0’’E. The OAU campus is located within the Ife-Ilesha Schist Belt. The campus falls within the Basement Complex area of Nigeria (Durotoye, 1983). The rock types are primarily made up of Gneisses and Mica Schists into which some minor granitic and basic rocks have intruded (Boesse, 1989; Adunoye, 2017).

MATERIALS AND METHODS

Materials and Equipment

The main material used for this study was lateritic soil samples obtained from eight selected locations on OAU campus, Ile-Ife. Figure 1 is a map of the study area showing the sampling locations. The list of equipment used for the study is presented in Table 1. All the equipment were available at the Geotechnical Engineering Laboratory of the Department of Civil Engineering, OAU, Ile-Ife.

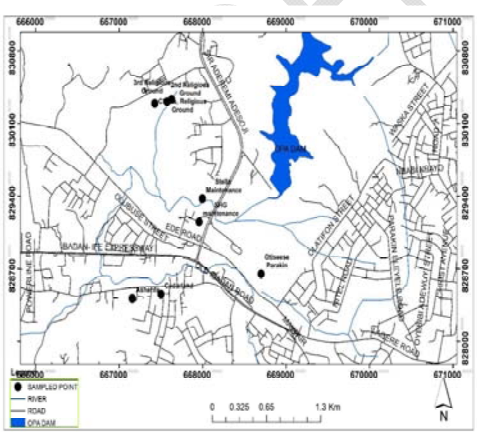

Figure 1: Map of OAU campus showing sampling locations (Department of Geography, OAU, Ile-Ife, 2018)

Methods

Soil sampling and preparation

A trial pit was dug in each of the eight identified sampling locations. About 25 kg of soil was collected in each location and properly wrapped in nylon sacks for onward transportation to the Geotechnical Engineering Laboratory of the Department of Civil Engineering, OAU, Ile-Ife for analyses. At the Laboratory, representative samples were immediately taken for the determination of natural moisture content. The remaining soils were then air-dried for further analyses.

Table 1: List of equipment

Equipment	Purpose
Set of standard sieves	Sieve analysis
Atterberg apparatus	Determination of Atterberg limits
Sensitive balance	Weighing
Electric oven	Drying of soil samples
Specific gravity bottle	Determination of specific gravity
Measuring cans	Containing soil samples for measurement
Wash and separating bowls	Washing and separation of soil particles
Standard proctor compaction apparatus	Compaction
Mechanical balance	Weighing

Laboratory tests on soil samples

The following laboratory tests were conducted on the soil samples: specific gravity test, particle size analyses and Atterberg limits tests. All tests were conducted in accordance with BS 1377 (1990). The natural moisture content had been determined in the laboratory immediately after collection of soil samples.

The results of the particle size analyses (dry and wet sieve) were used to determine the grain size distribution of the soil samples, having plotted the particle size distribution (psd) curves. From the psd curves, sorting coefficients were determined using Equation 3. Plasticity Index was determined from Equation 1. Thereafter, the soil samples were classified.

$$PI = LL - PL \qquad (4)$$

Where: PI = Plasticity Index
LL = Liquid Limit
PL = Plastic Limit

Development of relationship between sorting coefficient and Atterberg limits

Data obtained from the tests described in the preceding section were used to investigate and establish relationships between gradation parameters and Atterberg limits of soil samples, thus determining the influence of gradation on Atterberg limits of the selected soils. The relationships between gradation parameters and Atterberg limits were established using multiple polynomial regression. Atterberg limits were the dependent variables, while gradation parameters were the independent variables. In the choice and combination of independent variables, caution was exercised so as not to include two or more parameters that are directly related. This was done in order to avoid a situation referred to as multicollinearity (Dunlop and Smith, 2003).The Regression Tool employed was obtained from the Xuru's website (2018).

The validity of each model was verified by the coefficient of determination (R^2), which compares estimated and actual y-values, and ranges in value from 0 to 1. If it is 1, there is a perfect correlation in the sample, i.e. there is no difference between predicted value and the experimental value. At the other extreme, if the R^2 is 0, the regression equation is not helpful in predicting y-value. Thus, the closer R^2 to 1, the better the representation of the relationship between the dependent and independent variables by the models developed (Shahin *et al.*, 2009). In addition, Residual Sum of Squares was also used to assess the developed models. the lower the RSS, the better the performance of the model.

RESULTS AND DISCUSSION

Results of Laboratory Tests on Soil Samples

The summary of the results obtained from laboratory tests conducted on the soil samples are shown in Table 2. The natural moisture content (nmc) describes the amount of moisture present in the soil at the time it was brought to the laboratory from the site. The nmc ranges between 5.95 % (S1) and 27.78 % (S2). The high moisture content of most of the samples was due to the site condition, with water table being high at the time of obtaining the samples. The values of the sorting coefficients, obtained from particle size analyses indicate that sample S1 is the most well-graded, while sample S5 is the least well-graded sample. This is because, the larger the sorting coefficient, the more well-graded the soil (Craig, 2004).

With liquid limits less than 35%, samples S1, S2 and S7 are of low plasticity; and with liquid limits ranging between 35 % and 50 %, samples S3, S4, S5, S6 and S8 highly plastic (Das, 1990).

Table 2: Results of geotechnical tests on soil samples

Property	S1	S2	S3	S4	S5	S6	S7	S8
nmc (%)	5.95	27.78	16.19	13.23	18.12	8.78	18.37	17.31
D_{10}	0.18	0.25	0.23	0.27	0.22	0.21	0.23	0.25
C_u	8.33	2.20	7.83	9.26	15.91	3.57	5.65	8.00
C_c	0.62	1.11	0.60	0.90	7.48	1.17	0.77	0.95
S_o	2.88	1.51	2.85	2.59	1.35	1.68	2.26	2.34
Liquid Limit (%)	27.00	23.00	39.00	42.00	38.00	35.00	30.00	48.00
Plastic Limit (%)	19.00	15.00	25.00	16.00	15.00	29.00	14.00	31.00
Plasticity Index (%)	8.00	8.00	14.00	26.00	23.00	6.00	16.00	17.00
AASHTO Classification	A-2-7	A-2-6	A-2-5	A-2-6	A-2-4	A-2-5	A-2-4	A-2-5

Effect of sorting gradation parameters on Atterberg limits

Figures 2 to 5 present graphical display of the relationships between gradation parameters and Atterberg limits of the soil samples. From the Figures, it is clear that there is no regular pattern or any particular order in the change in each of the Atterberg limits and gradation parameters. Table 3 shows the Equations (5 – 10) derived from multiple polynomial regression analyses of the parameters. The Equations show that the correlated variables have relationships ranging from moderate correlation (Equation 7, with $R^2 = 0.336$ and RSS = 217.68) to very strong correlation (Equation 6, with $R^2 = 0.95$ and RSS = 23.92) (Shahin *et al.*, 2009).

CONCLUSION

This study has shown, as expected, that gradation has effect on the Atterberg limits of selected soil samples. Validation of the developed models showed that all the models were valid for the soil samples, with model for Liquid Limit ($LL = -5.88x10^{-1}C_u^2 + 3.71C_uS_o - 19.41S_o^2 + 6.44C_u +$

29.25S_o + 0.53) being the best model with the highest R^2 value (0.95) and the least RSS value (23.92). The results are valid within the tested materials and the procedure outlined in this paper. It is recommended to perform more experiments to further validate the finding in this research.

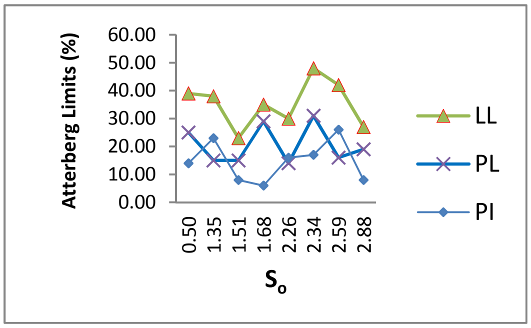

Figure 2: Relationship between Atterberg limits and sorting coefficients

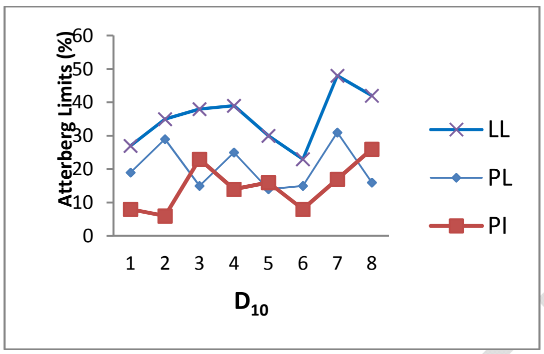

Figure 3: Relationship between Atterberg limits and effective size

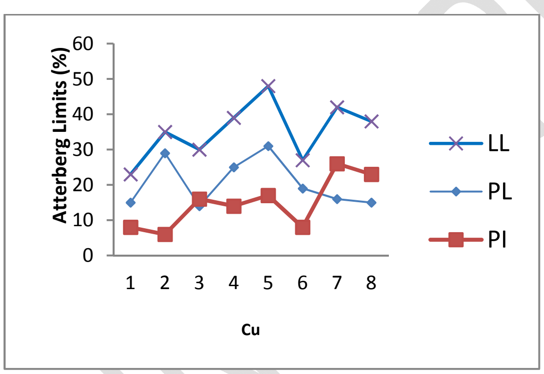

Figure 4: Relationship between Atterberg limits and coefficient of uniformity

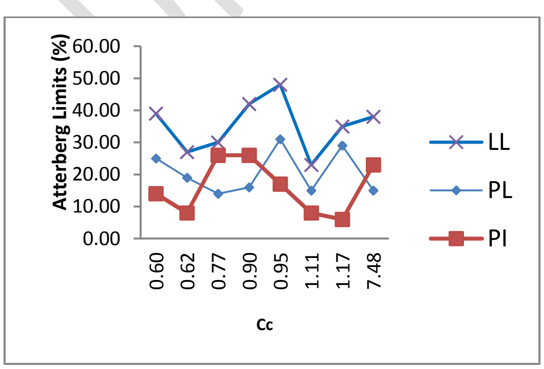

Figure 5: Relationship between Atterberg limits and coefficient of gradation

Table 3: Developed equations

Equation No.	Equation	R^2	RSS
5	$LL = 1.63C_c^2 + 72.68C_cS_o + 5.55S_o^2 - 109.59C_c - 68.72S_o + 115.08$	0.87	60.27
6	$LL = -5.88x10^{-1}C_u^2 + 3.71C_uS_o - 19.41S_o^2 + 6.44C_u + 29.25S_o + 0.53$	0.95	23.92
7	$PL = -2.63C_c^2 + 17.59C_cS_o + 6.93S_o^2 - 2.12C_c - 37.73S_o + 38.58$	0.336	217.68
8	$PL = -3.29x10^{-1}C_u^2 + 1.19C_uS_o - 8.49S_o^2 + 4.02C_u + 14.39S_o + 4.56$	0.382	202.65
9	$PI = 4.26C_c^2 + 55.09C_cS_o - 1.38S_o^2 - 107.48C_c - 30.99S_o + 76.50$	0.867	49.06
10	$PI = -2.59x10^{-1}C_u^2 + 2.52C_uS_o - 10.92S_o^2 + 2.42C_u + 14.86S_o - 4.03$	0.764	87.317

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