Experimental Study of the Effects of Some Selected Geotechnical Indices on the Unconfined Compressive Strength of Lateritic Soil

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Abstract

This study undertook an experimental study of the comparative effects of Atterberg limits, particles size and compaction parameters on the unconfined compressive strength of selected soils. This was with a view to ascertaining which of the combinations of the soil properties will produce a good prediction of the unconfined compressive strength. To achieve this aim, soil samples were obtained from selected locations within Ife Central Local Government Area, Osun State, Nigeria. The following tests were conducted on the soil samples, following standard procedures: natural moisture content determination, specific gravity, Atterberg limits, compaction and unconfined compressive strength. Using Regression tool, the results obtained from the laboratory tests were used to develop the relationships between each of the index properties and unconfined compressive strength. Results showed that the natural moisture content of soil samples ranges between 18.48 % and 25.03 %; specific gravity ranges between 2.35 and 2.69; liquid limit ranges between 39.95 % and 83.98 %; plastic limit ranges between 29.32 % and 51.18 %; and plasticity index is between 8.74 % and 33.56 %. The maximum dry density ranges between 15.30kN/m³ and 19.30kN/m³ with their optimum moisture contents ranging between 13.80 % and 35.50 % while unconfined compressive strength is between 36.00 kN/m² and 97.14 kN/m². The results of regression analysis showed that effective size and coefficient of uniformity have the greatest effect ($R^2 = 0.82$) on unconfined compressive strength of the tested soil samples. Therefore, the study concluded that effective size and coefficient of uniformity could be used to estimate the unconfined compressive strength of the soils.

Keywords: Atterberg limits, compaction parameters, particle size distribution, regression analysis, unconfined compressive strength

Introduction

The importance of soil in civil engineering construction cannot be over-emphasized. Therefore, in order to ensure stability of any structure and prevent failure, it is important to accurately investigate and determine the geotechnical properties of soil for the purpose of good design (Jacob and Hari, 2016). Soil properties which include index as well as engineering properties are of major significance in geotechnical engineering. These properties help to determine how efficient a soil would perform when used for some functions such as road construction, foundation and many others. The properties can also be used to predict the engineering behaviour of soils. Soil properties also form the basis of soil classification into groups where each group possesses similar behaviour (Bello, 2012).

The unconfined compressive strength (UCS) of soil is defined as the ultimate load per unit cross sectional area that a cylindrical specimen of soil can take under compression without any lateral pressure (Murthy, 2002). Since there is a relationship between unconfined compressive strength and undrained shear strength of soil, unconfined compressive strength of soil is useful in the evaluation of the stability of slopes, the bearing capacity of foundation, etc (Obasi and Anyaegbunam, 2005).

Accurate measurement of unconfined compressive strength of soil can be difficult, time consuming and costly. There is therefore the need to consider building up correlation equations between the unconfined compressive strength and Atterberg limits, particle size and compaction parameters which are relatively easier and cheaper to determine.

There have been increasing efforts in seeking to correlate engineering properties of soil (unconfined compressive strength, shear strength, etc) with Atterberg limits, particle size distribution, etc. This study

therefore aimed at evaluating the effects of Atterberg limits, particle size and compaction parameters on unconfined compressive strength of soil, with a view to ascertaining which of the parameters have the greatest impact on the UCS of selected soils. The study sought to make addition to available knowledge on the estimation or modelling of UCS of soils using easily determined soil indices.

Material and Methods

Sample collection

The main material used for the study was lateritic soil samples collected from selected eight (8) borrow pits in Ife Central Local Government Area, Osun State, Nigeria. One sample was collected from each location, making a total of eight (8) soil samples. The samples were collected from an average of 0.5 m depth (Arora, 2014). The method used for sample collection was disturbed sample collection method. The collected samples were put into polythene bags and immediately taken to the Geotechnical Engineering Laboratory of Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife. Thereafter, the natural moisture content was determined (in accordance with BS 1377 (1990)) before air drying the samples for subsequent preliminary and engineering analyses.

Preliminary and engineering tests on soil samples

Laboratory tests conducted on soil samples included: natural moisture content (NMC), sieve analysis, specific gravity, Atterberg limits (liquid limit-LL and plastic limit-PL), compaction and unconfined compressive strength. The tests were conducted following standard procedures as outlined in BS 1377 (1990). From the results of the sieve analyses and particle size distribution curves, parameters such as uniformity coefficient (C_u) and coefficient of gradation (C_c) were determined using Equations 1 and 2. Also, from the results of Atterberg limit tests, plasticity index (PI) was determined using Equation 3.

$$C_u = D_{60}/D_{10} \quad (1)$$

$$C_c = D_{30}^2/(D_{60} \times D_{10}) \quad (2)$$

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

Where D_{10} = 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

PL = Plastic limit

LL = Liquid limit

Relating Atterberg limits, particle size and compaction parameters with UCS

The Atterberg limits (liquid limits and plastic limits) obtained from each soil sample were analysed and correlated with the UCS of each soil sample. D_{30} and C_u (already determined from the particle size distribution) were also employed for the analyses and correlation. This was done in order to guide against multi-collinearity in modelling (Dunlop and Smith, 2003), since other particle size parameters are interdependent one way or another. Compaction parameters (optimum moisture content-OMC and maximum dry density-MDD) were also correlated with UCS. Multiple polynomial relationships were developed between each of the index properties and UCS. UCS was the dependent variable while the index properties were the independent variables. The Regression tool employed was Xuru's regression tool (<http://www.xuru.org>).

Results and Discussion

Sampling points

The Geographic Position System (GPS) describing the sampling points is shown in Table 1.

Results of preliminary soil analysis

The summary of the results obtained from the various preliminary and other laboratory tests conducted on the soil samples are presented in Table 2. Sample S6 has the highest NMC while sample S5 has the lowest NMC. This could have been influenced by change in weather condition over time. The range of values for the specific gravity and percentage passing sieve 200 indicates that the soils could be described as containing clay minerals (Wright, 1986; Das, 1990). The results of the Atterberg limit tests indicate that the soil samples are generally of high plasticity (Adunoye *et al.*, 2018).

Table 1 :GPS locations of sampling points

Sample ID	Location	
	Longitude	Latitude
S1	4°32'49.8"E	7°27'52.51"N
S2	4°34'34.87"E	7°28'49.48"N
S3	4°28'19.18"E	7°29'54.22"N
S4	4°30'45.1"E	7°31'8.53"N
S5	4°30'56.4"E	7°32'26.54"N
S6	4°33'8.69"E	7°30'52.5"N
S7	4°33'3.32"E	7°30'54.49"N
S8	4°30'48.5"E	7°31'3.3"N

Table 2: Results of preliminary and other laboratory tests

Sample ID	NMC (%)	G _s	LL (%)	PL (%)	PI (%)	% passing sieve 200
S1	18.95	2.38	66.8	47.91	18.89	10.72
S2	21.2	2.56	54.65	40.01	14.64	12.38
S3	22.61	2.35	42.6	33.86	8.74	18.32
S4	24.07	2.45	83.98	50.42	33.56	14.15
S5	18.48	2.69	39.95	29.32	10.63	12.65
S6	25.03	2.56	65.6	49.29	16.31	23.56
S7	22.27	2.60	61.6	51.18	10.42	14.13
S8	19.95	2.52	65.2	48.71	16.49	35.98

Table 3 shows the values of the characteristic points, obtained from the grading curves of soil samples. The values of C_u and C_c show that majority of the soil samples are well-graded (Ismail, 2008).

Table 3: Characteristic points on the grading curves of soil samples

Sample ID	D ₁₀	D ₃₀	D ₆₀	C_u	C_c
S1	0.2	0.38	1	5	0.72
S2	0.2	0.35	1.1	5.5	0.56
S3	0.17	0.24	0.39	2.29	0.87
S4	0.19	0.5	2.2	11.57	0.59
S5	0.2	0.4	1.1	5.5	0.73
S6	0.14	0.24	1.05	7.5	0.39
S7	0.19	0.4	1.8	9.47	0.47
S8	0.11	0.2	0.4	3.63	0.91

The results of compaction and unconfined compressive tests are detailed in Table 4. The results indicate that the soil samples could be described as silty clay (O’Flaherty, 1988; Bello and Adegoke, 2010). The values of UCS range from 36 kN/m² (sample S2) to 97.14 kN/m² (sample S8).

Table 4: Results of engineering tests

Sample ID	OMC (%)	MDD (kN/m ³)	UCS (kN/m ²)
S1	30.00	15.60	39.71
S2	19.20	17.60	36.00
S3	18.30	17.60	59.86
S4	24.20	16.08	55.15
S5	13.80	19.30	75.74
S6	31.00	15.70	76.86
S7	35.50	15.35	38.96
S8	29.00	15.30	97.14

Relationships between soil properties

Figures 1 to 3 are pictorial presentations of the relationships between: UCS and particle size characteristics (Figure 1); UCS and Atterberg limits (Figure 2); and UCS and compaction parameters (Figure 3). The Figures only show some irregular patterns, while the subsequent correlations present empirical relationships between the parameters. The results of Xuru’s regression analysis and the generated performance metrics (Table 5) showed that correlation exists between UCS and Atterberg limits (LL and PL); between UCS and particle size (D₃₀ and C_u) and between UCS and compaction parameters (OMC and MDD). The values of coefficient of determination (R^2) are within the range $0.5 < R^2 < 0.85$ (i.e. moderate to strong correlation) (Shahin *et al.*, 2009). The results showed that: about 52 % of variation of UCS can be explained by LL and PL; about 82 % of UCS could be explained by D₃₀ and C_u; and about 52 % of UCS could be explained by OMC and MDD. It is therefore clear that D₃₀ and C_u have the greatest combined effect on the UCS of the tested soil samples.

Figure 1: Graphical presentation of relationship between unconfined compressive strength and particle size characteristics

Figure 2: Graphical presentation of relationship between unconfined compressive strength and Atterberg limits

Figure 4: Graphical presentation of relationship between unconfined compressive strength and compaction parameters

Table 5: Performance metrics for the regression analysis

Description	Equation	R ²	RSS
UCS vs Atterberg Limits	$UCS = -3.68 \cdot 10^{-1} LL^2 + 1.62 LL \cdot PL - 1.05 PL^2 - 27.49 LL + 1.52 PL + 733.11065275$	0.52	1611.43
UCS vs Particle size	$UCS = 3481.31 D_{30}^2 - 45.85 D_{30} C_u - 7.48 \cdot 10^{-1} C_u^2 - 2078.64 D_{30} + 22.44 C_u + 333.6643376$	0.82	622.76
UCS vs Compaction parameters	$UCS = -7.95 \cdot 10^{-1} OMC^2 - 9.79 OMC \cdot MDD - 13.95 MDD^2 + 195.14 OMC + 657.91 MDD - 7360.43$	0.52	1611.42

Conclusion

Comparative effect of Atterberg limits, particle size and compaction parameters on the unconfined compressive strength of selected soil samples have been studied. Experimental tests were conducted on the soil samples, following standard procedures. Using regression analysis, relationships were developed between: UCS and LL and PL; UCS and D_{30} and C_u ; and UCS and OMC and MDD. The results showed that the soils could be generally described as silty clay with high plasticity. It was also shown that all the Considered variables (Atterberg limits, particle size and compaction parameters) have moderate to strong correlation with UCS. However, particle size characteristics (D_{30} and C_u) have the greatest combined effect on the UCS of the selected and tested soil samples, with a coefficient of determination (R^2) of 0.82. The results are valid for the tested soils. The experiment and analyses could be replicated in other areas.

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