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Original Research Article

Establishing Predictive Relationships Between the Index Properties and Strength Properties of the Tropical Soil in the South East of Nigeria

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Abstract: Soil investigation reports form basis of decision making in the choice of site and design of foundation, with a view to avoiding failures in foundations. Unfortunately, detailed tests are most often time not carried out either as a result of huge financial involvement or scarcity of good laboratory equipment. The study therefore, establishes relationships between the index properties and the strength (detailed) properties of the tropical soil in the South-east. For the purpose of the study data on the various laboratory tests of the tropical soil samples sourced from different construction sites in the South-east of Nigeria were collated. With the results of the mechanical and physical properties of the respective soil samples eight regression models were therefore formulated, which explain the relationships of the respective soil properties to one another. In order to ensure reliability of the models, tests for significance of coefficients of the respective predictive variables and fitness of the models were carried out hence; only three of them were proven adequate. These final models as **(i)** $\mathbf{Y_{CBR1}}$ = 6.09 + 0.79G - 0.08S + 0.03M - 0.09C + 0.24 L_L - 0.30P_L **(ii)** $\mathbf{Y_{CBR2}}$ = 0.42 + 0.93G + 0.05M and **(iii)** $\mathbf{Y^1_{UCS}}$ = 14.12 + 2.40CBR were finally established. By this development in tropical region of Nigeria, when test values of the index properties are obtained, CBR properties would be calculated using the first model. Having obtained the CBR value, the unconfined compressive strength (UCS) can therefore be calculated using last model. Base on this analysis it is therefore concluded that the Index properties of the soil have significant relationships with its Strength properties.
Keywords: Tropical Soil, Laboratory Test, Index and Strength Properties, Regression Modeling and Foundations.

INTRODUCTION
Background to the Study

Suitability of soil for the foundation of a particular construction project is confirmed by assessing the geotechnical parameters of the foundation soil. Various soil tests are usually conducted on the soil samples to achieve this goal. Some of the major soil tests commonly in use in foundation works are; California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), Triaxial, Atterberg's limits, Grain Size Distribution (Gradation) and Compaction tests. These properties are categorized into two major groups as Index properties test (Atterberg limits, Gradation and Compaction tests) and Strength properties test (California Bearing Ratio, Unconfined Compressive Strength and Triaxial tests).

The results of these soil tests based on their respective properties show the condition and characteristics of the soil samples, which when analyzed would explain the soil bearing capacity or the amount of treatment the foundation requires for managing effectively the effects of the designed load under different conditions. A wide variety of laboratory tests can be performed on soil to measure a wide variety of soil properties. According to Arora [5], some soil properties are intrinsic to the composition of the soil matrix and are not affected by sample disturbance, while other properties depend on the structure of the soil as well as its composition, and only be effectively tested on relatively undisturbed samples. Some soil tests measure detailed properties of soil, while others measure index properties which provide useful information about the soil without measuring the desired strength property. The value of any of these properties may relate in a particular way to other properties respectively, which explains the implication of the results to the foundation with regard to the condition of the soil.

The strength properties of soil form important engineering parameters in the design of numerous geotechnical and geo-environmental structures, such as earth dams, retaining walls, pavements, liners and covers, (Oluwapelumi, 2012). Unconfined Compressive Strength (UCS) therefore, measures the resistance of soil by compressibility or shear deformation while, California Bearing Ratio (CBR) value is the rate of resistance to a penetration of 2.5 mm of a standard cylindrical plunger of 50mm diameter expressed as percentage to a standard penetration resistance. Thus, to predict the shear strength of the layer according to Oluwapelumi (2012), explained that soil-water characteristic curve is mostly used as a tool either directly or indirectly along the saturated shear strength parameters, cohesion (c), and angle of internal fraction (ᵟ), to predict the shear strength function of the soil. No wonder Bello, [1] opined that the wide applications of index properties in geotechnical engineering practice makes them common to be used in predicting the engineering behaviors of soil.

From the forgoing information, it can therefore be seen that test result of any of the soil properties has resultant relationship to other respective properties. Hence, one can logically predict within a considerable confidential interval the implication of test result of one property to other respective properties that are not tested [2]. In a study carried out by Bello [1], he attempted to establish correlations between California Bearing Ratio values and Index Properties of the soil samples using linear expression analysis in Oshogbo, Osun state. In his study, it is concluded therefore that there is a close relationship between CBR values, compaction and index properties of the soil mass.

Patel, *et al* [3], in their experimental analysis also developed co-relations between various tests like; maximum dry density (MDD), optimum moisture content (OMC), KPBT, UCS, CBR and DCP of soil in soaked condition. They concluded therefore, that the relations between MDD, OMC, KPBT, UCS, CBR, and with DCP results are in the form: $Z = ax + by$.

Ideally in tropical environments like ours, the upper part of the sub surface which is composed of lateritic soil is commonly used as earth filling materials in foundation works. For this reason and many more, Geotechnical investigation on soils becomes very necessary to obtain information on the physical and mechanical properties of in-situ or imported soil for foundation works.

PROBLEM OF THE STUDY

Test of soil in foundation work is a panacea to foundation failure. Many incidence of building collapse has been traced to foundation problem. This is an indication of neglect in the practice and enforcement of soil test aspect of site investigation and laws regulating the code of practice respectively, in Nigeria as a nation.

Some practioners have made attempt to carry out soil test for some big projects but, lack of well established laboratories with complete facilities and economic hardship have been discouraging the progress. Although a list of soil test is usually required for detailed soil condition analysis, understanding the relations between the respective tests would obviate the problem.

The basic relationships between the respective test results of a particular soil sample therefore, alleviate the challenges confronting the conclusive decision on the soil condition where inadequate fund, time constraint and absence of complete laboratory facilities and experts could not permit easy access to other supplementary tests - having extrapolated the knowledge from one or two soil test reports to deduce the possible values of other properties of the soil not tested.

Absence of this essential knowledge must have contributed significantly to increase in occurrence of foundation failures especially, when there is absence of soil test experts and/or non accessibility to complete laboratory facilities for relevant soil tests.

AIM AND OBJECTIVES OF THE STUDY

In order to address the research gap, the study is aimed at establishing relationships between results of the index and strength tests of the tropical soil in the South-east of Nigeria.

The following specific objectives are therefore targeted. They are to,

i. examine and interpret the results of the respective soil tests.

ii. relate the results of the various soil test to one another and establish their relationships.

METHOD OF THE STUDY

Study Area

The study covers the tropical region of the South-eastern Nigeria. According to Okereke [4], this region is characterized by the hot and warm humid climates for construction purposes in Nigeria. For the purpose of the study, data on soil samples sourced from construction sites of interest in every state within the study area were collated.

Research Design

The study adopted experimental research design approach. Data generated are in quantitative forms, collated, interpreted and analyzed towards arriving at conclusions that will address the contemporal problem in the construction industry. The design is a step by step procedure undertaken to demonstrate a known fact. The results of the individual laboratory test were used therefore to assess and establish relationships between the respective geotechnical tests carried out on the samples of the tropical soil for reference purposes and foundation stability in the study area.

Method of Data Analyses

Data generated in the study were analyzed using regression analysis of both simple and multiple forms in order to establish orders of relationships between the respective soil test results. This analytical approach explains the degree of relationships that exist between predictive variables (independent factors) and the objective function (dependent factor) in the study.

Thus, a single most important condition for the validity of the study was therefore examined in the analysis of data obtained from the laboratory tests, using the following hypothetical assumption.

H_o: There are no significant relationships between the aggregate values of the index properties of the tropical soil and their strength properties.

DATA PRESENTATIONS, ANALYSES AND DISCUSSION OF FINDINGS

Laboratory results of the respective soil samples from atleast two sites of various construction activities from each states of the South-east on the respective tests were collated and presented in Table 1.

Table 1: Results of the Laboratory Tests on the Tropical Soil

States	S/N	X_1 (G) Gravel	X_2 (S) Sand	X_3 (M) Silt	X_4 (C) Clay	X_5 (L_L)	X_6 (P_L)	Y_1 (CBR)	Y_2 (UCS)	Remarks
Abia	1	2.50	52.50	25.00	20.00	40.00	32.00	3.50	78.00	
	2	4.50	44.50	24.00	27.00	42.00	36.00	4.80	90.00	
Anambra	3	4.50	80.00	3.00	12.50	25.00	17.00	4.00	68.40	
	4	4.80	72.00	11.00	12.50	30.00	25.00	4.50	90.00	
Ebonyi	5	9.00	51.00	20.00	20.00	46.00	40.00	8.80	112.00	
	6	8.50	81.00	6.00	5.00	28.00	22.00	8.00	127.00	
Enugu	7	7.00	78.00	4.50	10.00	30.00	21.00	7.50	110.00	
	8	6.50	55.00	17.50	21.00	17.50	21.00	6.60	93.00	
Imo	9	5.00	34.00	31.00	30.00	35.00	30.00	6.00	88.00	
	10	8.00	56.00	20.00	26.00	35.00	27.00	8.20	112.00	

Source: Authors' Field Work (2016).

Analysis of the Laboratory Tests Results

Results of the Laboratory experiments on the respective index and strength properties of the soil samples were clearly study empirically to establish their relationships to one another. For this purpose, data from the laboratory experiments were transformed into regression models.

These regression models were obtained and analyzed by checking for adequacy (fitness) of the models using the Fisher statistics of criteria, $F_{cal} > F_{tab.}$

Table 2: Analysis of Results from Laboratory Test Experiments

States	S/n	X_1 (G)	X_2 (S)	X_3 (M)	X_4 (C)	X_5 (L_L)	X_6 (P_L)	Y_1 - CBR	Y_1 - UCS	Y_2 – CBR	Y_2 - UCS	Y_3 - CBR	Y_3 - UCS	Y^1 - CBR	Y^1 - UCS
Abia	**1**	2.5	52.5	25.0	20.0	40.0	32.0	3.5	78.0	3.5	78.0	3.5	78.0	3.5	78.0
	2	4.5	44.5	24.0	27.0	42.0	36.0	4.8	90.0	4.8	90.0	4.8	90.0	4.8	90.0
Anambra	**3**	4.5	80.0	3.0	12.5	25.0	17.0	4.0	68.4	4.0	68.4	4.0	68.4	4.0	68.4
	4	4.8	72.0	11.0	12.5	30.0	25.0	4.5	90.0	4.5	90.0	4.5	90.0	4.5	90.0
Ebonyi	**5**	9.0	51.0	20.0	20.0	46.0	40.0	8.8	112.0	8.8	112.0	8.8	112.0	8.8	112.0
	6	8.5	81.0	6.0	5.0	28.0	22.0	8.0	127.0	8.0	127.0	8.0	127.0	8.0	127.0
Enugu	**7**	7.0	78.0	4.5	10.0	30.0	21.0	7.5	110.0	7.5	110.0	7.5	110.0	7.5	110.0
	8	6.5	55.0	17.0	21.0	17.5	21.0	6.6	93.0	6.6	93.0	6.6	93.0	6.6	93.0
Imo	**9**	5.0	34.0	31.0	30.0	35.0	30.0	6.0	88.0	6.0	88.0	6.0	88.0	6.0	88.0
	10	8.0	56.0	20.0	26.0	35.0	27.0	8.2	112.0	8.2	112.0	8.2	112.0	8.2	112.0
						B_0		6.09	-1.14	-.42	-139	4.98	65.75	2.31	14.12
						B_1		0.97	12.37	0.93	12.39				
						B_2		-0.08	1.73	0.005	1.72				
						B_3		0.03	6.25	0.05	6.27				
						B_4		-0.09	-2.71	-0.01	-2.72				
						B_5		0.24	0.055			0.036	-2.21		
						B_6		-0.30	- 0.018			0.7E	3.69		
						B_{UCS}								0.043	12.40
						B_{CBR}									
						C_1		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
						S_e		0.31	29.8	0.49	23.1	2.15	34.4	1.39	23.7
						t_∞ f_1		2.02	2.02	2.35	2.35	6.31	6.31	6.31	6.31
						b_i		0.01	0.72	0.01	0.65	0.16	2.60	0.11	1.80
						F_{cal}		56.3	1.30	33.3	3.28	-	.0.53	-	8.99
								>	<	>	<	-	<	-	>
						F_{tab}		3.2	5.99	4.10	5.99	-	4.11	-	4.96
						Remarks		Adqt	Inadqt	Adqt	Inadqt	-	Inadqt	-	Adqt

Source: Authors' Laboratory Test Results and Analyses, (2016).
Legend: L_L= Liquid Limit, P_L= Plastic Limit, Adqt = Adequate, Inadqt = Inadequate

Laboratory tests on the respective Index and Strength properties were clearly studied empirically on the tropical soil of the south-east as contained in Table 2, to define their inter relationships between the index properties and the strength properties of the soil for the purpose of construction works. The benefit of this analysis pave way for establishing standard relationship for obtaining the strength properties of the soil without direct laboratory tests on them.

For this purpose, data from the test experiments were also tested for significance of coefficients of the independent variables (G, S, M, C, L_L and P_L). Besides, the adequacies of the models themselves were also checked.
The Regression Modeling and Analysis involved the following stages.

i) Obtaining Regression Models - Regression Models of the first order (linear regression) for each of the strength property of interest (CBR and UCS) were obtained in the forms:

$$Y_i = b_o + b_1 X_1 + b_2 X_2 + b_3 X_3 \ldots\ldots\ldots + b_n X_n \qquad \ldots\ldots(\mathbf{1.10})$$

Where b_o is the intercept, b_i are the regression coefficients and x_i - the independent variables (G, S, M, C, L_L, P_L) or factor (i = 1,2,3,4,5, and 6)

ii) Carrying out Regression Analysis – This stage involves checking for adequacy (fitness) of the models using fisher statistics with the student't' criteria test.

The decision rule for adequacy of the models is $F_{cal} > F_{tab}$, otherwise the null hypothesis will be rejected.

REGRESSION MODELS FOR THE STRENGTH PROPERTIES OF THE TROPICAL SOIL IN THE SOUTH-EAST OF NIGERIA

i. For the Index Properties as the Independent Variables on the Respective Strength Properties of the Soil.

$Y_{CBR1} = b_o + b_1 G + b_2 S + b_3 M + b_4 C + b_5 L_L\ b_6 P_L$ …….(**1.20**)

$= 6.09 + 0.97G + (-0.08)S + 0.03M + (-0.09)C + 0.24L_L + (-0.30)P_L$

$Y_{UCS1} = b_o + b_1G + b_2S + b_3M + b_4C + b_5 L_L + b_6P_L$ …….(**1.30**)

$= -141.088+12.366G +1.729S + 6.253M + (-2.71)C$

$+ 0.055\ L_L + (-0.018)PL$

ii. For the Gradation as Index Property on the Strength Properties of the Soil.

$Y_{UCS2} = b_o + b_1G + b_2S + b_3M + b_4C$ …….(**1.40**)

$= -0.416 + 0.926G + 0.005S + 0.049M + (-0.005)C$

$Y_{UCS2} = b_o + b_1G + b_2S + b_3M + b_4C$ …….(**1.50**)

$= -139.42 + 12.39G + 1.72S + 6.27M + (-2.72)C$

iii. For the Atterberg Limits as Index Property only on the Strength Properties of the Soil

$Y_{UCS3} = b_o + b_5 L_L + b_6\ P_L$ …….(**1.60**)

$= 4.98 + 0.036L_L + (-0.00007)\ P_L$

$Y_{UCS3} = b_o + b_5L_L + b_6P_L$ …….(**1.70**)

$= 65.74 + (-2.241)\ L_L + 3.69P_L$

iv. For each of the Strength Property as an Independent Variable on the Other Respectively.

$Y^1_{CBR1} = b_o + b_1\ UCS = 2.31 + 0.043\ UCS$ …….(**1.80**)

$Y^1_{UCS1} = b_o + b_1CBR = 14.12 + 12.40\ CBR$ …….(**1.90**)

Tests for Significance of the Models Coefficients

Significance of the coefficients was tested using the following condition:

$|B_i| \geq b_i$, for significance of the coefficients in the model otherwise, if $|B_i|$ is < $b_{i,}$ the coefficient of that particular independent variable is insignificant hence, should be discarded entirely.

Where,

B_i is coefficients of the respective independent variables

b_i - the tabulated coefficient parameter

Thus, $b_i = C_1 S_e t_\infty f_1$

By applying the rule, the following models therefore bear the significant coefficients only.

$\mathbf{Y_{CBR1}} = b_o + b_1G + b_2 S + b_3M + b_4 C + b_5 L_L + b_6P_L$ …….(**1.10**)

$= 6.09 + 0.97G - 0.08S + 0.03M - 0.09C + 0.24L_L - 0.30\ P_L$

$\mathbf{Y_{UCS1}} = b_o + b_1G + b_2S + b_3 M + b_4C$ …….(**1.11**)

$= -141.09 + 12.37G + 1.73S + 6.25M - 2.71C$

$\mathbf{Y_{CBR2}} = b_o + b_1 G + b_3 M = -0.416+0.926G+0.049M$ …….(**1.12**)

$\mathbf{Y_{UCS2}} = b_o + b_1 G + b_2 S + b_3 M + b_4 C$ …….(**1.13**)

$= -139.42 +12.39G +1.725 + 6.27M - 2.72C$

$\mathbf{Y_{CBR3}}$ = The entire coefficients of the respective factors are insignificant,

Therefore, the model does not exist.

$\mathbf{Y_{UCS3}} = b_o + b_5 L_L + b_6 P_L = 65.74 - 2.24L_L + 3.69P_{L.}$ …….(**1.14**)

$\mathbf{Y^1_{CBR}}$ = the coefficient of the UCS factor is insignificant,

therefore the model seizes to exist

$\mathbf{Y^1_{UCS}} = b_o + b^1\ CBR = 14.12 + 12.40CBR.$ …….(**1.15**)

Check for Adequacy of the Models

In the study, the following hypothesis was formulated and tested in the respective derived models, for Adequacy of the models.

H_o: There are no significant relationships between the aggregate values of the index properties of the tropical soil and their strength properties.

Thus, When $F_{cal} > F_{tab}$, it explains that there is significant difference in the variability of the comparable mean populations. If however, $F_{cal} \leq F_{tab}$, there exist insignificant difference between the two variances in the study, hence the hypothesis is rejected.

Based on this assumption, the following models are therefore confirmed adequate and the alternatively hypotheses (H_1) accepted in their cases for the study, since their $F_{cal} > F_{tab}$.
Thus, the final derived models therefore are as follows:

Y_{CBR1} = 6.09 + 0.97G - 0.08S + 0.03M - 0.09C + 0.24L_L- 0.30 $P_{L.}$ ….(1.16)
Since F_{cal} (56.31) > F_{tab} (3.22)

Y_{CBR2} = - 0.42 + 0.93G + 0.049M, ……….(1.17)
Since F_{cal} (33.33) > F_{tab} (4.10)

Y^1_{UCS} = 14.12 + 2.4O CBR, ……….(1.18) Since F_{cal} (8.99) > F_{tab} (4.96)

Other derived models with significant coefficients in the study however, have their $F_{cal} < F_{tab}$ hence, they are confirmed inadequate which made them invalid in the study.

CONCLUSIONS

Laboratory experiments were carried out on soil samples of the South-east of Nigeria with strong emphasis on establishing relationships between the index properties and the strength properties of the soil. The relationships show that changes in the index properties of the soil samples affect the values of the strength properties,

In the analyses of the various test results of the tropical soil with regard to one another it was discovered therefore, that the index properties (gradation and atterberg limits) have strong relationships with its strength properties. Among the eight models formulated in the study, only three of them are confirmed to have significant and adequate relationships between their respective independent and dependent variables. They are as follows:

i) Y_{CBR1} = 6.09 + 0.79G - 0.08S + 0.03M - 0.09C + 0.24 L_L - 0.30 P_L
ii) Y_{CBR2} = 0.42 + 0.93G + 0.049M
iii) Y^1_{UCS} = 14.12 + 2.40 CBR

By this development, when test values of the index properties are obtained, CBR properties would be calculated using model in Equ.1.16. Having obtained the CBR value, the unconfined compressive strength (UCS) can therefore, be calculated using model in Equ.1.18. These models will to a greater extent help to provide easily reliable values for the strength properties of the tropical soil in the south eastern Nigeria when the index properties of the soil would have been found experimentally.

RECOMMENDATIONS

In targeting means of accessing the values of strength properties of the tropical soil without actually carrying out the various detailed tests for sustainable design of the sub-base/foundation, the following suggestions are therefore made.

They are:

i) Awareness on the importance of geotechnical investigation should be created by government and the stake holders in the construction industry by way of media discuss and link programme, seminars and training workshops in Nigeria.
ii) Effort should be made by government at both state and federal levels to establish standard laboratory test centers for construction work purposes across the nation, and at an affordable cost.
iii) It is also recommended that the models established in this study be used as guide in determining the approximate strength properties of tropical soil in the South-east.
iv) Thorough laboratory tests will as well be carried out on different geological formations both in the tropical zone and on other formations in Nigeria, in order to develop standard models for determining approximate values of strength properties of the respective formations.

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