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Shear strength/moisture content models for a laterite soil in Ilorin, Kwara State, Nigeria

Shear strength eu humidité teneur modelé pour un sol latérite a Ilorin état de Kwara au Nigeria

Yinusa A. Jimoh
Department of Civil Engineering, University of Ilorin, Ilorin – Nigeria
yolasilorin @ yahoo.com

ABSTRACT

This paper presents various models for the relationship between the cohesion (c) and frictional angle (ϕ) and the moisture content of a laterite soil. Conventional laboratory shear box test was performed on sample of a laterite soil in Ilorin, Kwara State Nigeria. It was carried out at various moisture contents ranging from 0% - 30% at intervals of 2% - 4%. The c and ϕ values were found to decrease with increasing moisture content in linear and parabolic forms, respectively and reaching zero values at the liquid limit. The modular of elasticity were also found to exhibit a parabolic model. The implication of the formulated models for the c (w) and ϕ (w) on the variation of bearing capacity at prevailing moisture contents was quantitatively demonstrated in the paper.

RESUME

Ce texte présent différent models de la relation entre la cohésion (c) et l'angle frictionnel (ϕ) et la taleur eu humidité du sol latérite. Les laboratoire conventionnels "Shear box Test" a ete fait dan l'exemple du sol latérite a Ilorin dau l'etat du Kwara au Nigeria. Cela était meue a différentes teneur en eu humidité allant de 0% a 30% a intervals de 2% a 4%. Les valuers de la (c) at (ϕ) out été ameler a eliminuer avec augmentation de la teneur eu humidité dans les formes linéaires et paraboliques respectivement et attendent les valeur zero a la limite – liquide. Le module de l'élasticité était aussi mener a exhiber un model parabolique. L'implication des models formules pour la c(w) et ϕ(w) daus la variation de la capacité de la teneur eu humidité du dit sol était quantitativement de montrée daus le texte

1 INTRODUCTION

The current procedure that attempts to reflect the influence of moisture content on the bearing capacity of soils computed with Terzaghi's Theory is the water table correction factor reflecting the buoyancy effects on the density of the wet soil.Das (1999).This is often translated to the expression "0.5 $\{1+{}^{D}w/_{B}\}$" whereby D_w is the separation of the footing invert and the water table and B is the least lateral dimension of the footing . In deriving this factor, it was assumed that the bearing capacity is halved when the footing rests directly on saturated subsoil whose shear strength parameters were used in Terzaghi's equation but unaffected once the water table is up to the footing breadth down below, ($D_w \geq B$).

Whereas and also based on pressure bulb analysis, the subsoils within twice the footing width is assumed to be unaffected by the footing loads. This is one of the criteria used in determining the depth of probe in standard subsoil investigation practice. Thus in setting up the geotechnical investigation for shallow spread footing, the depth of probe is usually extended to at least twice the width of a possible foundation; BS5930 (1981), Robb (1982). Hence intuitively and in order to eliminate the identified discrepancies between the two above facts, the correction factor could be "0.5 $\{1+0.5D_W/B\}$" which would imply a conservative footing design and a higher factor of safety. Although this observation still needs to be proved empirically in Nigeria. However it is obvious that the saturation level of the subsoil is directly dependent on the prevailing level of the water table in the location. As a matter of fact, the soil below the water table is completely saturated but partially, upwards above as water moves up by either surface tension, suction and or capilarity phenomenon. Hence an attempt at actually determining, in absolute quantitative terms, the influence of the moisture content on the shear strength parameters of a soil should be a more accurate method of correcting Terzaghi's bearing capacity values with respect to saturation level. This is the import of this paper which is meant to establish and analyze various models for the shear strength parameters (cohesion and internal angle of friction) for a typical Nigerian lateritic soil and at shallow depths.

2 MATERIAL AND METHODS

2.1 *Materials*

Nigeria, which lies between Lat.4^0 and 14^0 and Long. 2^0 and 15^0E is in the subtropics whose humidity, high temperatures, around 25^0C or more; and seasonal heavy rainfalls promote laterization, the condition extensively associated with the middle Niger, Benue and Upper Benue areas; Durotoye, (1983). Kwara State is in the Niger Basin areas. Apart from the 10-15km stretch of marine deposits along the coast of Nigeria and the black cotton soil deposits at the north eastern corner (around Chad Basin), the rest portion of the country is characterised by laterites, which have been reported to exist in 1 – 6 metres in thickness in this humid tropical climate; Durotoye (1983). Also it is a truism that it is only the few commercial centres of Lagos, Kano, Port Harcourt and the federal capital city of Abuja that are characterised by high-rise buildings or structures on probably deep footings. The other areas whose proportion is greatly substantial are dotted with small structures constructed on shallow spread footings. Hence the choice of the material for this study is the typical lateritic soil deposit in the mid region of Nigeria and situates at a shallow depth, about three metres. Four (4) material samples were sourced within 3meter depth below the grounds surface from two positions in Tanke area in Ilorin, Kwara State capital. All the samples are of the mottled colours of yellow, light to dark brown and black which are reminiscent of reported description for Nigeria laterites; Ola (1983). The preliminary geotechnical properties of these four samples are presented in Table 1.

Table 1 - Preliminary geotechnical properties of the materials

Model	Sample 1 [a]	Sample 2 [b]	Sample 3 [b]	Sample 4 [b]	Nigerian [c] Laterite
W_n (%)	4	3.0	4.0	5.7	0.9-14
W_L(%)	25	16	18	23	NP – 42
W_p	14	8.4	9.5	12.1	NP – 25
PI (%)	9.0	7.6	8.6	10.9	0 – 15
FI (%)	40	-	-	-	-
Cc	2.37	0.84	0.75	1.16	-
Cu	6.6	5.5	8.4	6.4	-
Gs	2.77	2.70	2.73	2.80	2.70
MDD kgm^{-3}	1950	1750	1760	1520	
Omc (%)	10.0	6	8	16.5	
N %	1.81	0.8	1.0	2.8	2.8 – 6.5
DD	1645	1770	1697	1520	

Source: [a] Mansour, [b] Mumini, [c] Ola

2.2. *Methods*

Conventional Quick laboratory shear strength tests, BS 1377:1990; were performed on these samples at varying values of moisture content from 0% until completely fluidised (no shear strength) and at intervals of 2%. The corresponding shear strength parameters at the various moistures were noted. The samples were tested up to 24-30% moisture. Also Standard BS compaction test was done in order to determine their optimum moisture (omc) and maximum dry density (mdd)

2.3 *Results*

The outcome of the experimental work which form the basic input into the development of the various models for the two shear parameters (cohesion and frictional angle) were displayed in following table, Table 2.

Table 2 - Shear Strength Parameters at varying Moisture Content

	Sample 1		Sample 2		Sample 3		Sample 4	
W (%)	C(kN/m^2)	ϕ (^{0})	C(kN/m^2)	ϕ (^{0})	C(kN/m^2)	ϕ (^{0})	C(kN/m^2)	ϕ (^{0})
0	110	50	0	37.2	63	33.9	19	36.6
2	140	39	75	29.7	73	37.6	34	36.3
4	100	36	73	33.6	100	29.9	57	36.0
6	100	36	66	35.1	56	38.9	62	30.0
8	35	27	45	34.2	53	37.0	18	38.7
10	3	27	60	28.4	35	39.2	24	38.4
14	0	27	13	32.3	51	34.5	100	34.8
16	0	26					99	33.4
20	5	26					64	29.2
22	0	23					91	17.4
24	0	21					38	20.3
26	0	19					57	13.4
28	0	13					33	17.1
30	1	12						
	4	10						

Sample 1 was obtained from Tanke Iledu at 1.5 m; Samples 2, 3 and 4 were obtained from Tipper Garage Area, Tanke but at 0-1m, 1-2m and 2-3m depths respectively.

2.4 *Model development*

A three stage procedure was adopted: (i) the determination of appropriate models based on the closeness to ± 1 of the correlation coefficient (R) of empirical data for sample1 (ii) trial and confirmation of such choice with data of samples 2, 3 and 4; and (iii) deduction of the most appropriate models using the global data for all the samples.

2.4.1 *Stage One*

The data from Table 2 exclusively for sample 1 were subjected to statistical correlation analysis in Micro Soft Excel to generate various model types: linear, 2nd and 3rd degree polynomial; log-log, exponential and index (power) equations. Some adjustments were made to the data, especially the zero values so as to accommodate all the enumerated models. Tables 3&4 give the summary of probable models respectively for the cohesion and frictional angles for the unmodified data while Tables 5 & 6 give those when data were modified. See figures1, 2, 3 & 4 for development of these models.

Table 3 - Developed Cohesion Models (Unmodified data)

S/No	Model Name	Expression c = f (w)	R^2	R	Rem.
1	Linear	-4.1w + 94	0.627	0.79	Low
2	2^0 Polynomial	$0.324w^2 - 13.9w+139$	0.872	0.93	High
3	3^0 Polynomial	$0.003w^3+0.47w^2 - 15.9w+142$	0.874	0.93	High

Table 4 – Frictional Angle Models unmodified data

S/No	Model Name	Expression ϕ = f(w)	R^2	R	Rem
1	Linear	-0.94w + 39.43	0.9474	0.97	High
2	2^0 Polynomial	$-0.0003w^2 - 0.93w+39.4$	0.947	0.97	High
3	3^0 Polynomial	$-0.002w^3+0.088w^2-194w+4.56$	0.946	0.97	High
4	Exponential	43.56 exp (-0.040w)	0.904	0.95	High

Table 5 - Cohesion model with modified data

S/No	Model Name	Expression c = f(w)	R^2	R	Remarks
1	Linear	-3.89w+89.3	0.559	.75	Low
2	2^0 Polynomial	$0.41w^2 - 17.0w+162.2$	0.895	.95	High
3	3^0 Polynomial	$-0.002w^3+1.38w^2-29.8w+201$	0.945	.97	High
4	Log-Log	Log C= - 54 logw+164.4	0.818	.90	High

Table 6 - Frictional Angle Models with modified data

S/No	Model Name	Expression ϕ = f(w)	R^2	R	Rem.
1	Linear	-0.935w +39.25	0.9365	.97	High
2	2^0 Polynomial	$-0.002w^2 -0.867w +38.88$	0.9368	.97	High
3	3^0 Polynomial	$-0.003w^3+0.129w^2-2.58w+44.1$	0.9628	.98	High
4	Log-Log	Log ϕ= -10.29 logw +50.4	0.858	.93	High
5	Exponential	44.68 exp (-0.043w)	0.896	.95	High
6	Index (Power)	$69.286w^{-0.44}$	0.723	.85	High

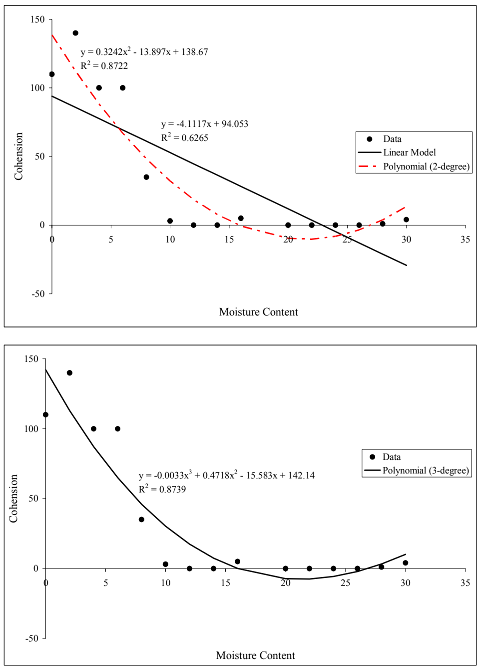


Figure 1: Cohesion - Moisture Models (Raw Data) For Sample 1

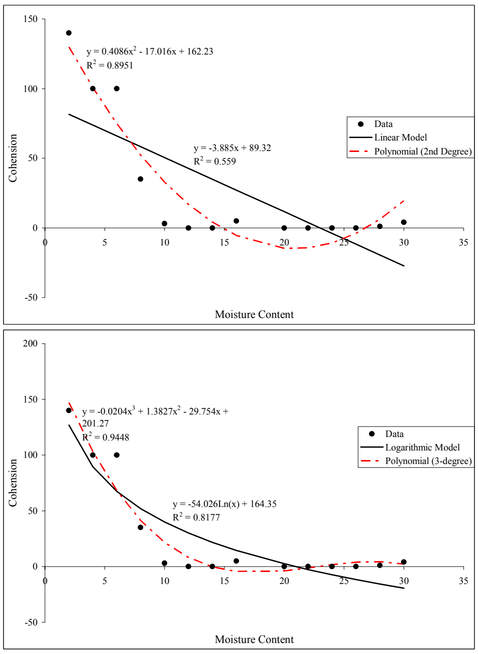


Figure 2: Cohesion- Moisture Content Models (Modified data) for Sample 1

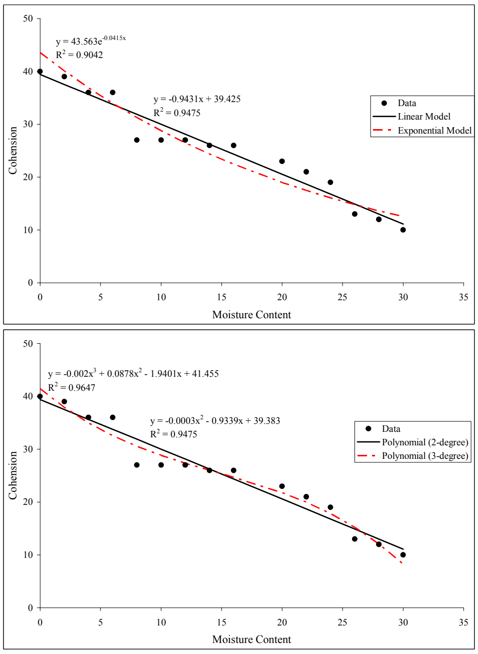
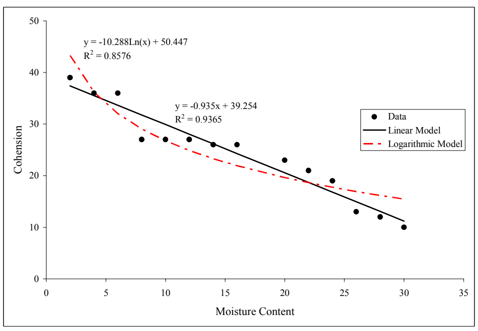


Figure 3: Angle Friction - Moisture Content Models (Raw Data)



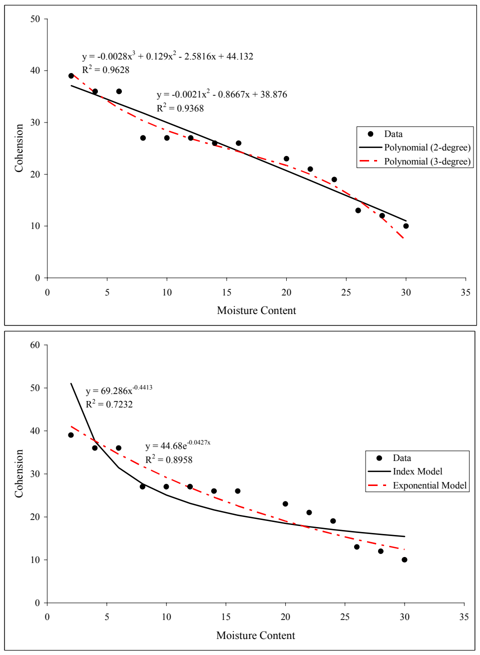


Figure 4: Angle Friction - Moisture Content Models (Modified) Data For Sample 1

From Tables 3 & 4, R-values of 0.93 – 0.97 are high enough to suggest that the 2nd or 3rd degree polynomials are applicable cohesion models while the linear and exponential (additionally, to make four) are friction models for the studied laterites. They can now be refered to as the models. An inspection of Tables 5 & 6 also confirm that the models are probable but the idea of adjusting the data just to force an empirical model may not be realistic, especially when considering for practical engineering purposes. The models that have passed the initial test were employed to analyse the data for samples 2-4 as the second stage of the model development.

2.4.2 *Stage 2- Confirmatory*

The data for samples 2 to 4 were analyzed for the empirical model selected from stage one for confirmatory purposes. These are the polynomials for cohesion but linear plus the polynomial for the friction angle. Tables 7 & 8 summarized the reported outcome of this exercise, which can be said to have confirmed the models. The correlation coefficients are in the ranges 0.62 to 0.99, meaning that over 60% of the data have explained these models.

2.4.3 *Stage 3- Cohesion and Friction Model for Studied Laterite.*

Figures 5&6 display the development of the global model for the Ilorin laterite soil. The high correlation levels strongly support the developed models. But for computational conveniences and simplicity, the second degree polynomial is preferred for the cohesion while the linear is for the friction angle model. Thus the applicable equations for further analysis as examples:

$$C = -0.25w^2 - 1.54w + 68.5; \qquad (R=0.50) \qquad (1)$$

$$\phi = -0.8653w + 38.86; \qquad (R = 0.86) \qquad (2)$$

Table 7 Correlation Coefficient for Cohesion models, samples 2 – 4

Model	Sample 2	Sample 3	Sample 4	R-Range	Rem.
2^0 Poly	0.6472	0.333	0.325	0.58 – 0.80	Model
3^0 Poly	0.9976	0.7455	0.3829	0.619-0.999	well
Exponential	0.34	0.345	0.1114	0.33 – 0.588	explained Low.

Table 8: Correlation coefficient for Friction Angle Models, Samples 2-4

Model	Sample 2	Sample 3	Sample 4	R-Range	Rem.
Linear	0.47	0.078	0.545	0.216-0.738	Ok
Exponential	0.032	0.078	0.5327	0.179-0.73	Ok
2^0 Poly	0.475	0.1155	0.5228	0.34-0.72	Ok
3^0 Poly	0.1521	0.2796	0.5284	0.39-0.727	Ok

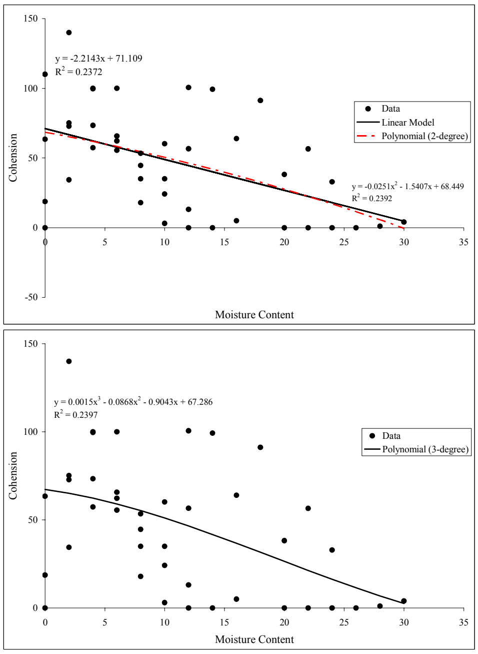


Figure 5 : Cohesion - Moisture Content

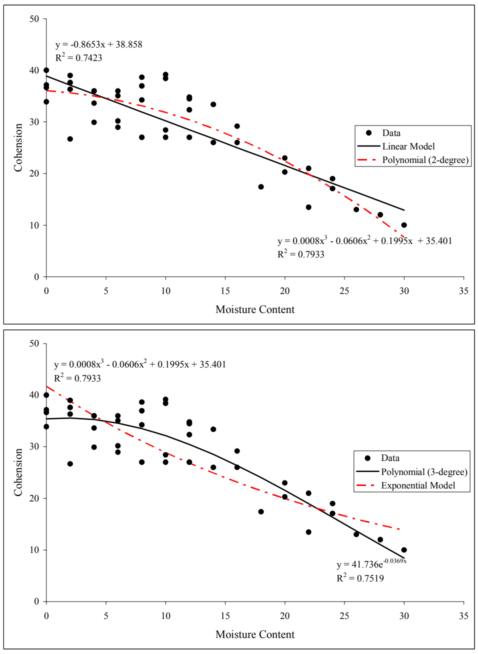


Figure 6: Angle Friction Model For Ilorin

2.5 Analysis of the model and moisture influence on bearing capacity

The distinct level of influence of water on behaviour of a soil deposit can be described by the moisture condition; such as dry state (0% moisture content), plasticity (liquid- plastic limits), prevailing moisture, optimum and saturation conditions. Obviously the bearing capacity of a soil will experience drastic changes once the soil also experiences change in moisture in consonance with the developed models. These change were analysed and indicated that the ultimate bearing capacity of a strip footing (Tazaghi;s expression) dropped from 100% when dry (w=0%) to31%, 33% and 10% respectively at the optimum moisture (w=10%), plastic (w=11%) and liquid limits(w=24%). In other words, at complete saturation, possibly moisture is at the liquid limit and /or water table directly beneath the footing, the correction factor should be 0.10. From quantitative model, the limits of the parameters can be determined. For instance, the maximum value of the cohesion occurs when the sample is completely dry and least (Zero) when the moisture condition is near the liquid limit. Frictional parameter demonstrate similar trend.

3 DISCUSSION

It has already been observed; Smith (1989) that there is a direct relationship between soil's shear strength parameters and its moisture content. This is understandable because water added or expelled from a soil mass depends on the magnitude of forces (van der Waal) and energy of formation, the intergranular spacing and structural (geometric) arrangement; Michel (1976), Carmichell, (1989). Hence most waterlogged soils settle quickly or fails completely under an in-significant loads at shorter time intervals, Michel (1976). Thus in the light of recentdevelopments there is the need to probe further so that these models could be more defined in quantitative terms. Thus the High correlation coefficients obtained for the models prove that the data appropriately explain them for the laterite deposit examined, which also supports earlier findings. Though have been qualitative only. It could also be observed that the bearing capacity of the soil is the same (30%) at both the optimum, and plastic limit conditions. Hence a monitoring of the moisture content can predict appropriately the changes in the values of the soils bearing capacity. This has safety implication for engineering practice.

4. CONCLUSIONS AND RECOMMENDATIONS

The relationship between the shear strength parameters of a soil and its prevailing water condition can be quantitatively explained. In fact two models the second and third degree polymonials are appropriate for the cohesion while four models (2^{nd} and 3^{rd} polynomials, Linear and exponential) are relevant for the frictional angles of a typical Nigerian laterite. Substantial proportion of the data (60 – 90%) explained these models. Because of the relative ease in monitoring moisture changes in a soil mass, it is therefore strongly recommended that these models should be tried for more laterite deposits in Nigeria and the tropics/subtropics in general.

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