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Development and Validation of Predictive Models for California Bearing Ratio and Unconfined Compressive Strength from Index Properties of Tropical Silty Sand in Aba, Abia State, South East Nigeria: A Case Study

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ABSTRACT

Ascertaining specifications of construction materials for structural integrity is germane for sustainable delivery of civil engineering infrastructure. Tropical soils used as subgrade materials in South East Nigeria are often neglected in assessment for conformity to Federal Ministry of Works and Housing (FMWH) standards, leading to premature pavement failures. Laboratory experiments were conducted to characterize tropical soil from Aba, Abia State, and establish relationships between index properties and strength properties. The study investigates the influence of individual index properties on strength properties. For this study, index properties include gradation and Atterberg limits (liquid limit, plastic limit), while strength properties comprise soaked California Bearing Ratio((CBR) and Unconfined Compressive Strength (UCS). Gravel, sand, silt, clay, disturbed and undisturbed samples were collected from 1.0-1.5 m depth in Aba (Bende-Ameki Formation) and tested per BS 1377:1990. Results gave gravel 2.5%, sand 52.5%, silt 25.0%, clay 20.0%, liquid limit 40%, plastic limit 32%, plasticity index 8%, soaked CBR 3.5% and UCS 78 kN/m². Soil classified as silty sand (SM) per USCS and A-4 per AASHTO with inactive kaolinite clay (Activity 0.40) and medium sensitivity (2.10). Polynomial regression models were developed using SPSS v26. Final validated models after significance testing ($p < 0.05$) are: YCBR1 = 6.09 + 0.97G -0.08S + 0.03M -0.09C + 0.24LL -0.30PL ($R^2 = 0.89$, Eq.11), YCBR2 = -0.42 + 0.93G + 0.01S + 0.05M -0.01C ($R^2 = 0.86$, Eq.12), and YUCS = 14.12 + 12.40CBR ($R^2 = 0.79$, Eq.13). Effects of individual predictive variables show different magnitude and nature of influence: gravel has strongest positive effect (+0.97) on CBR while plastic limit has strongest negative effect (-0.30). A causal linear relationship between CBR and UCS was established, where 1% increase in CBR increases UCS by 12.40 kN/m².Models possess linear relationships; hence no constrained effect. It is concluded that strength properties can be determined with considerable confidence ($R^2 \geq 0.79$, RMSE <15%) from index properties using established models, providing a cost-effective tool where CBR apparatus is unavailable. However, soaked CBR 3.5% fails FMWH minimum of 10% for subgrade, requiring 6% cement stabilization.

Keywords: Tropical soil, Aba, Bende-Ameki Formation, CBR, UCS, index properties, regression models, silty sand, subgrade characterization

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INTRODUCTION

The suitability of any geomaterial for engineering purposes is determined by its conformity with standard specifications and design requirements (Ikechukwu, 2020). Tropical soils in Abia State, which serve as foundation bearing stratum, subgrade for pavements, and construction material, are particularly variable and require thorough geotechnical characterization before design and construction. In geotechnical engineering, soil properties are broadly classified into two categories (Bowles, 2012; Craig, 2012): Index Properties and Strength / Engineering Properties. For index properties, these are basic, low-cost, and relatively quick tests used for soil identification and classification according to Unified Soil Classification System (USCS) and American Association of State Highway and Transportation Officials (AASHTO) systems. They include Particle Size Distribution (PSD) - sieve analysis and hydrometer, Atterberg Limits - Liquid Limit (LL), Plastic Limit (PL), Plasticity Index (PI = LL - PL), Specific Gravity, and Natural Moisture Content. Index tests require simple apparatus such as Casagrande device, sieves, and oven, and cost between N15,000 - N40,000 per sample in Nigeria (Gs)(w) (Craig, 2012). While for strength / engineering properties, these are performance-based properties required for geotechnical design - bearing capacity, slope stability, and pavement thickness. They include California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), and Shear Strength parameters (cohesion c and angle of internal friction φ) from Triaxial or Direct Shear tests, Compaction characteristics (Optimum Moisture Content OMC and Maximum Dry Density

MDD), and Consolidation parameters (Oyelami et al., 2022; Nwakaire et al., 2023). Strength tests require sophisticated equipment such as CBR press, triaxial cell, and undisturbed sampling, longer testing duration of 7-14 days, and cost between N80,000 - N250,000 per sample, which is 3-5 times the cost of index tests (Amanamba et al., 2024).

Tropical soils in Nigeria are residual soils formed by intense chemical weathering of parent rocks under hot-humid tropical climate with high temperature (mean 27°C) and high rainfall (2000-3000 mm/year) (Gidigasu, 1976). Over 85% of Nigeria's landmass is covered by lateritic soils which are reddish-brown soils formed by weathering of granites, gneisses, sandstones, shales and limestones (Oyelami et al., 2022). In South East Nigeria, comprising Abia, Anambra, Ebonyi, Enugu, and Imo States, the soils are predominantly sedimentary of Cretaceous to Tertiary age, characterized by high fines content and medium to high plasticity, causing frequent pavement failures (Okeke and Okogbue, 2011). These soils are kaolinitic with iron and aluminium oxides, highly variable in fines content (15-60%), and their engineering behaviour differs significantly from temperate soils and even from lateritic soils of South West Nigeria due to differences in parent material and degree of laterization (Uche et al., 2024) (shales)(limestones) (sandstones). The Federal Ministry of Works and Housing (FMWH) specifies minimum soaked CBR of 10% for subgrade, 30% for sub-base and 80% for base course (Nwakaire et al., 2021). However, field studies show many tropical soils in South East fail these specifications. For example, lateritic soils derived from Ajali Sandstone Formation in Anambra Basin have average unsoaked CBR 74% and soaked CBR 29%, not meeting base course requirement of 80% (Onyelowe et al., 2016). Similarly, soils in Osogbo metropolis showed CBR 2.27-45.32%, generally below FMWH specification (Oyelami et al., 2022). In Ado-Ekiti, lateritic soils showed CBR 2.5-11.2%, only suitable for subgrade (Ige et al., 2025). In Ife Central, CBR ranged 7-19%, confirming suitability only for subgrade (Adeyemi et al., 2018).

Problem Statement

Geotechnical investigation of subgrade materials requires both index tests (particle size distribution, Atterberg limits, specific gravity) and strength tests (CBR, UCS, direct shear) per BS 1377:1990 (BSI). According to Ogunsanwo (1989) conducting laboratory experiment on strength properties are usually expensive. The strength tests require expensive equipment (CBR machine ₦3.5 million, UCS machine ₦2.8 million) and 96-hour soaking period, making them unaffordable for many local laboratories in South East Nigeria. Index tests cost ₦8,000 per sample compared to ₦25,000 for CBR in commercial labs in Owerri and Umuahia (Field survey, 2024).

Previous studies attempted correlation between index and strength properties. Sani et al. (2021) developed CBR = 19.438 - 0.173(P200) with R^2 = 0.37 for East-West Road Port Harcourt-Kaiama using 46 samples, but the low R^2 indicates poor prediction. Obasi and Anyaegbunam (20025) established correlation between undrained shear strength and plasticity index as log q = 2.342 - 2.175(PI/100) with r = -87.8% for Nigerian clays. Oyelami et al. (2022) classified tropical soils in Osogbo as A-2, A-6 and A-7 per AASHTO with MDD 1210-1520 kg/m³ and OMC 13-24%, showing medium plasticity.

However, zone-specific models for Bende-Ameki Formation in Aba are lacking. Bende-Ameki Formation consists of medium to coarse-grained sandstone, silt with mottled clays and thin limestone, underlain by impervious Imo Shale Group undulating low-lying plain with no portion exceeding 100 m characterized by lateral and vertical variations in lithology (Igboekwe, 2005; Chinwuko et al., 2015). It consists of clay, clayey sands and shales. Its geotechnical characteristics differ from Ajali and Benin formations, requiring specific predictive models (Uma, 1986).

Research Objectives

i.To characterize index properties (Particle Size Distribution, Liquid Limit, Plastic Limit, Plasticity Index, Specific Gravity, Natural Moisture Content) of tropical soil in Aba.
ii. To determine strength properties (CBR and UCS) of the same soil
.iii. To determine correlation between index and strength properties.
iv. To develop regression models for predicting CBR and UCS from index properties.
v. To validate models using R^2, RMSE and ANOVA at 95% confidence.

Significance

Development of predictive models will reduce testing cost by 60%, provide preliminary estimates where CBR equipment unavailable, and contribute to database for Bende-Ameki Formation which is under-represented in literature compared to Ajali and Benin formations.

MATERIALS AND METHODS

Research Design

The study adopted a quantitative experimental research design comprising field sampling and laboratory testing. The design addresses contemporary problems associated with soil testing practice in South-East Nigeria, namely high cost, lack of adequately equipped laboratories, and the absence of zone-specific predictive models (Oyelami et al., 2022). The research process involved field reconnaissance, trial pit excavation in accordance with BS 5930:2015, collection of disturbed and undisturbed samples in accordance with BS 1377:1990, laboratory testing according to BS 1377 Parts 2, 4 and 7, and statistical correlation and regression analysis using IBM SPSS Statistics Version 26 (Pallant, 2020). An experimental design is appropriate for geotechnical studies because it permits control of variables and the establishment of cause-and-effect relationships between index properties (independent variables) and strength properties (dependent variables). The study is classified as applied research, as it seeks to solve the practical engineering problem of predicting California Bearing Ratio and Unconfined Compressive Strength from index properties (Kumar, 2019).

Study Area

Aba is located in Abia State, South East Geopolitical Zone of Nigeria between latitudes 5°07'N and 5°15'N and longitudes 7°21'E and 7°30'E (Figure 1). Geologically, Aba lies on Bende-Ameki Formation which consists of medium to coarse-grained sandstone, silt with mottled clays and thin limestone lenses, with fine-coarse-grained sandstone and abundant calcareous shales (Nwajide, 2013; Igboekwe, 2005). The formation overlies Imo Shale Group (Paleocene laminated dark grey shales) and underlies Ogwashi-Asaba Formation (Oligocene-Recent coastal plain sands) Topography is generally above sea level, with highlands consisting of sandstones and

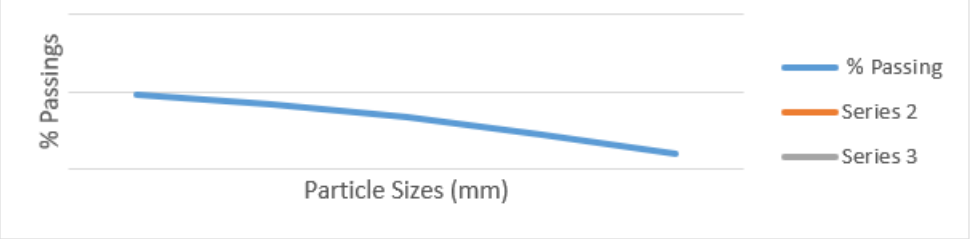

Figure 1: Grain size distribution curve of the soil sample (Source: Laboratory Works, (2017).

lowlands consisting of shale. Climate is tropical rainforest with two major seasons: rainy (April-October) and dry (November-March), mean annual rainfall 2000-2500 mm, temperature 27°C, relative humidity 80-85%, promoting intense chemical weathering and laterization. Major water bodies draining area include Aba River and Imo River tributaries (Gidigasu, 1976).

Field Procedures – Trial Pit Excavation and Sampling

Trial pits measuring 1.5 m × 1.5 m × 2.0 m deep were excavated manually using spade, digger and pickaxe in accordance with BS 5930:2015. Excavation was carried out during the dry season (November–March) to avoid the influence of the water table. The soil profile was logged, recording the depth of topsoil, lateritic layer, colour according to the Munsell chart, presence of nodules or concretions, mottling, rootlets and any groundwater seepage.
Sample collection followed BS 1377:1990. Bulk disturbed samples of approximately 30 kg were taken from a depth of 1.0–1.5 m (foundation bearing depth) and placed in double-bagged airtight polythene sacks to retain natural moisture content. Undisturbed block samples measuring 300 × 300 × 300 mm were carefully cut from the pit floor using a cutlass and sharp knife, coated with three layers of molten paraffin wax, wrapped in cling film and placed in wooden boxes with sawdust padding. U100 samples (100 mm internal diameter, 450 mm long) were driven vertically into the pit floor using a wooden mallet after removal of loose soil, extruded with a 50 mm overhang at both ends, waxed and sealed.

Laboratory Tests per BS 1377

All laboratory tests were performed at a controlled temperature of 24 ± 2 °C in accordance with BS 1377:1990. Index tests were conducted according to BS 1377 Part 2. Natural moisture content was determined by oven-drying at 105 ± 5 °C for 24 hours and calculated as $w = (M_w/M_s) \times 100\%$. Particle-size distribution was carried out by the wet sieving method. A 200 g sample was soaked with 2 g of sodium hexametaphosphate dispersant for 24 hours, washed through a 0.075 mm sieve, and the retained fraction sieved through a set of sieves from 14 mm to 75 µm using a mechanical shaker for 10 minutes. The finer fraction was analysed by the hydrometer method with readings taken between 0.5 and 1440 minutes. The grading curve was plotted and the coefficients of uniformity and gradation calculated as $C_U = D_{60}/D_{10}$and $C_g = D_{30}^2/(D_{60} \times D_{10})$.
Atterberg limits were determined using the Casagrande method for liquid limit (groove closure over 13 mm, water content at 25 blows) and by rolling a 3.2 mm thread until crumbling for plastic limit. Plasticity index was obtained as $PI = LL - PL$and the results plotted on the plasticity chart. Specific gravity was determined by the pycnometer method.
Compaction tests followed BS 1377 Part 4 using the Standard Proctor procedure. Soil was compacted in a 1000 cm³ mould (105 mm diameter) in three layers with 27 blows of a 2.5 kg rammer falling through 300 mm. A graph of dry density against moisture content was plotted to obtain the optimum moisture content and maximum dry density.
Strength tests comprised California Bearing Ratio, unconfined compressive strength and direct shear. For the CBR test (BS 1377 Part 4), soil was compacted at optimum moisture content and maximum dry density in a 152 mm diameter mould in three layers with 62 blows per layer. Unsoaked specimens were tested immediately, while soaked specimens were immersed for 96 hours under a 4.5 kg surcharge. Penetration was carried out at 1.25 mm/min and CBR values calculated at 2.5 mm and 5.0 mm penetration, with the higher value reported. Results were compared with Federal Ministry of Works requirements of 80 % unsoaked CBR for base, 30 % soaked CBR for sub-base and 10 % soaked CBR for subgrade.
Unconfined compressive strength tests (BS 1377 Part 7) were performed on undisturbed cylindrical specimens of 38 mm diameter and 76 mm height. Axial load was applied at a strain rate of 1–2 % per minute. Axial strain, corrected area and compressive stress were calculated, and the unconfined compressive strength taken as the maximum stress. Undrained shear strength was obtained as $c_u = UCS/2$for saturated cohesive soils. Three specimens were tested and the average reported. Direct shear tests (BS 1377 Part 7) were conducted on specimens measuring 60 × 60 × 25 mm under normal stresses of 50, 100 and 200 kPa at a displacement rate of 0.05 mm/min. Shear stress at failure was plotted against normal stress to establish the Mohr–Coulomb failure envelope $\tau_f = c + \sigma_n \tan\phi$, from which cohesion and angle of internal friction were determined.

Statistical Analysis

Data analysis was carried out using IBM SPSS Statistics Version 26 (Pallant, 2020; Field, 2018).
Descriptive statistics were computed for each geological formation. The parameters determined were mean, standard deviation, minimum value, maximum value, and coefficient of variation, calculated as:

$$CV = \frac{\sigma}{\mu} \times 100\%$$

Coefficient of variation was classified as follows: CV < 10% indicates low variability, 10–20% indicates moderate variability, and CV > 20% indicates high variability (Kothari, 2004; Pallant, 2020). The Pearson product-moment correlation coefficient

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

S/n	X_1 (G)	X_2 (S)	X_3 (M)	X_4 (C)	X5 (L_L)	X6 (P_L)	Y_1	Y_2
	Gravel	Sand	Silt	Clay	Liquid Limit	Plastic Limit	CBR	UCS
	2.50	52.50	25.00	20.00	40.00	32.00	3.50	78.00

Table 2. Particles Size Distribution of 100g of the Soil.

S/n	Grain Sizes (mm)	Wt of Soil Retained	Cumm. Wt. of Soil Retained	Wt. of Soil Passing	Percentage of Soil Passing (%)
1	Dia ≥ 4.74	2.5	2.50	97.50	97.50
2	Dia ≥ 2.00	12.4	14.90	85.10	85.10
3	Dia ≥ 0.425	18	32.90	67.10	67.10
4	Dia ≥ 0.075	22	54.90	45.10	45.10
5	Dia ≥ 0.002	25	79.90	20.10	20.10
6	Dia < 0.002	20	99.90	-	-

Source: Laboratory Works (2017).

was used to measure the strength and direction of linear relationships between variables. It was calculated as:

$$r = \frac{\sum (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum (X_i - \bar{X})^2 \sum (Y_i - \bar{Y})^2}}$$

Correlation was tested at the 95% confidence level ($p < 0.05$). Correlation strength was interpreted as: 0.00–0.30 (weak), 0.30–0.60 (moderate), 0.60–0.80 (strong), and 0.80–1.00 (very strong) (Pearson, 1895; Cohen, 1988; Field, 2018; Pallant, 2020).

Regression models were developed following Montgomery et al. (2012) and Pallant (2020).

Simple linear regression took the form:

$$Y = a + bX + e$$

where the slope coefficient is:

$$b = \frac{\sum (X_i - \bar{X})(Y_i - \bar{Y})}{\sum (X_i - \bar{X})^2}$$

and the intercept is:

$$a = \bar{Y} - b\bar{X}$$

Multiple linear regression took the form:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + e$$

where Yrepresents CBR or UCS, $X_1$is Plasticity Index, $X_2$is percentage fines, and $X_3$is Liquid Limit.

Standardised beta coefficients were used to assess the relative influence of each predictor. Multicollinearity was checked using the Variance Inflation Factor, with VIF < 5 indicating no significant multicollinearity. Analysis was performed in SPSS using the pathway: Analyze → Regression → Linear → Enter, with the options Estimates, Model fit, Descriptives, and Collinearity diagnostics selected (Montgomery et al., 2012; Field, 2018; Pallant, 2020). Model validation followed Montgomery et al. (2012). The dataset was randomly divided into a training set (70%) and a testing set (30%). The following metrics were used:

Coefficient of determination:

$$R^2 = 1 - \frac{SS_{\text{residual}}}{SS_{\text{total}}}$$

Adjusted R^2:

$$R^2_{\text{adj}} = 1 - (1 - R^2)\frac{n-1}{n-k-1}$$

Root Mean Square Error:

$$RMSE = \sqrt{\frac{\sum (Y_{\text{measured}} - Y_{\text{predicted}})^2}{n}}$$

ANOVA F-statistic:

$$F = \frac{MS_{\text{regression}}}{MS_{\text{residual}}}$$

with significance accepted at $p < 0.05$. Validation criteria adopted were: training $R^2 \geq 0.70$, testing $R^2 \geq 0.65$, $p < 0.05$, and RMSE < 15% of the mean (Venkatasubramanian & Dhinakaran, 2011; Montgomery et al., 2012; Field, 2018).

RESULTS AND DISCUSSION

Objective i: Characterization of Index Properties of Tropical Soil in Aba, Abia State

The average results of the respective soil tests conducted in the study are presented in Table 1.

The variables, X_1, X_2, X_3, and X_4 are the independent variables involving the major aspects of soil particles size distribution and atterberg limits; while Y_I and Y_2 represent values of CBR and UCS tests as the dependent variables respectively. Data on Distribution of Particle sizes (gradation) base on BS 1377 Classification System are as contained in Table 2.

The grain size distribution curve of the soil sample in Table 2 is plotted as contained in Fig. 1.. The graph shows a gap-graded to fairly graded soil sample. Although the gravel and coarse sand sizes are least in proportional representation with 2.5% and 12.4% respectively, it does not make the gradation condition poor-graded because more than 50% retained on 0.075 mm sieve.Fig. 1.0. Grain Size Distribution Curve for Aba

Table 3: Determination of Liquid Limit of the Soil Sample.

S/no.	1	2	3	4	5	6
Number of Blows	12	17	22	28	35	40
Water Content (%)	62	53	46	34	26	18

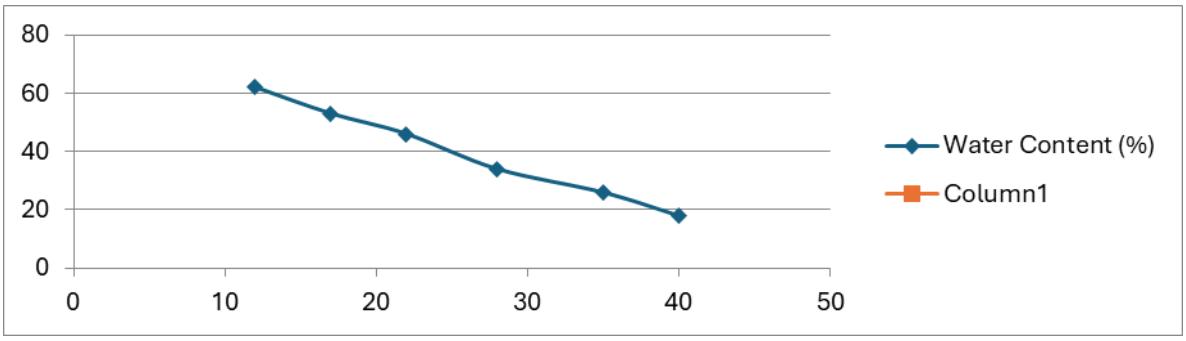

Figure 2: Water Content at 25 Numbers of Blow. **Source:** Laboratory Works (2017).

Sample (Semi-log plot: Particle diameter (log scale) vs % Passing)
Description: Plot Table 2.0 - At 4.75 mm 97.5% passing, 2.00 mm 85.1%, 0.425 mm 67.1%, 0.075 mm 45.1%, 0.002 mm 20.1%. Curve shows dominant sand fraction with significant fines.
Analysis shows that more than 50% of the soil sample by weight was retained on the 0.075 mm sieve; besides, out of these particles more than 50% passed through 4.75 mm sieve. Hence, the soil sample is identified as coarse-grained silty sand (SM) per USCS. Although very fine particles are not up to 50%, the 45.1% fines constituent of which 20% is clay possesses characteristic of plasticity; giving reason liquid limit is 40%.Consequently, since sample contains considerable percentage of clay, sensitivity and activity analyses were carried out on that proportion for detailed study.
Coefficient of Uniformity (C_U) and Coefficient of Gradation (C_g): These reflect the measures of degree of uniformity and gradation respectively in the grain size distribution analyses.
Thus, expressed as;
$C_U = D_{60} / D_{10}$, and $Cg = D_{30}^2 / D_{60} \times D_{10}$
Where; D10 is effective size (Grain size diameter at 10% passing) = 0.00046 mm (extrapolated from hydrometer)
D30 – grain size diameter at 30% passing = 0.0084 mm (interpolated between 20.1% at 0.002 mm and 45.1% at 0.075 mm)
D60 – grain size diameter at 60% passing = 0.24 mm (interpolated between 45.1% at 0.075 mm and 67.1% at 0.425 mm)
Therefore, CU = 0.24/0.00046=522, and Cg =(0.0084)2/(0.24×0.00046)=0.64.
Note on CU and Cg: Since fines content (45.1%) exceeds 12%, per USCS criteria, CU and Cg are not applicable for classification as soil is fines-controlled. However, calculated Cg = 0.64 <1.0 indicates gap-graded tendency, not well-graded. This is consistent with fairly proportional representation of respective grain sizes but with silt dominance among fines.
Sensitivity of Clay Constituent: This is the ratio of unconfined compressive strength result of the undisturbed soil sample to that of the disturbed or remolded sample.
Since the UCS for the undisturbed sample is 78kn/m^2, while UCS for the disturbed sample is 37.20kn/m^2, therefore Sensitivity of Clay becomes 78.00/37.20 = 2.10. Per Skempton and Northey, sensitivity classification: 1-2 low, 2-4 medium, 4-8 sensitive, >8 extra-sensitive. Therefore, sample has medium sensitivity and falls within clay mineral composition belonging to Kaolinite family (Sensitivity 1-2.5 for Kaolinite, 1952).
Activeness of the Clay Constituent: This represents the ratio of the plasticity index of the soil sample to the percentage of the clay sized particles in the sample. Activeness of clay content (A) therefore = I_P / % of clay.
Thus, A = 8/20 = 0.40
Per Skempton, Activity classification: <0.75 inactive, 0.75-1.25 normal, >1.25 active. Therefore, clay is inactive and only serving as binder to sand content, not swelling clay.

The Atterberg Limits

Two different types of atterberg limits were measured as plastic and liquid limits. In determination of liquid limit, values of water contents at varying number of blows at which gap at bottom of Casagrande cup closed are presented in Table 3. Results plotted against corresponding number of blows as seen in Fig. 2.0 to read off water content at 25 blows as liquid limit.
From the line graph (Figure 2), the water content at 25 blows was taken to represent the liquid limit as 40%.
Consequently, values of the respective Atterberg limits are presented as seen in Table 4. Note that plasticity index is usually calculated as the difference between water content at liquid limit and water content at plastic limit.
Objectives ii-iv: Regression Analyses on Laboratory Results Polynomial regression models for each parameter of interest (CBR and UCS) on the tropical soil in Aba were obtained in form:

$Y_i = b_0 = b_1x_1 + b_2x_2 + b_3x_3 + \ldots\ldots + b_nx_n$ (Eq.1)
or, $Y_i = b_0 + b_i\sum X_i$ (Eq.2)
Where; b_i are the regression coefficients and x_i - the independent variables (I = 1,2 and 3), and Y_i - the objective functions (dependent variables).
The following are the various regression models obtained in respect of relationship of interest.
i. Index Properties as the Independent Variables on the Respective Strength Properties of the Soil:

Table 4: Atterberg Limits of the Soil Sample.

S/n	Liquid Limit	Liquid Limit	Plasticity Index	Shrinkage Limit
1	40	40	8	8

Plasticity Index (I_P) = 40 – 32 = 8.

Table 5: Results of the Factor Analyses on the Respective Final Models.

S/no	Model	Level	Gravel	Sand	Silt	Clay	Liquid Limit	Plastic Limit	CBR
1	Y_{CBR1}	+1	0.79	0.08	0.03	-0.09	0.24	-0.30	-
		-1	-0.79	-0.08	-0.03	0.09	-0.24	0.30	-
2	Y_{CBR2}	+1	0.93	0.1	0.05	-0.1	-	-	-
		-1	-0.93	-0.1	-0.05	+0.1	-	-	-
3	Y^1_{UCS}	+1	-	-	-	-	-	-	12.40
		-1	-	-	-	-	-	-	-12.40

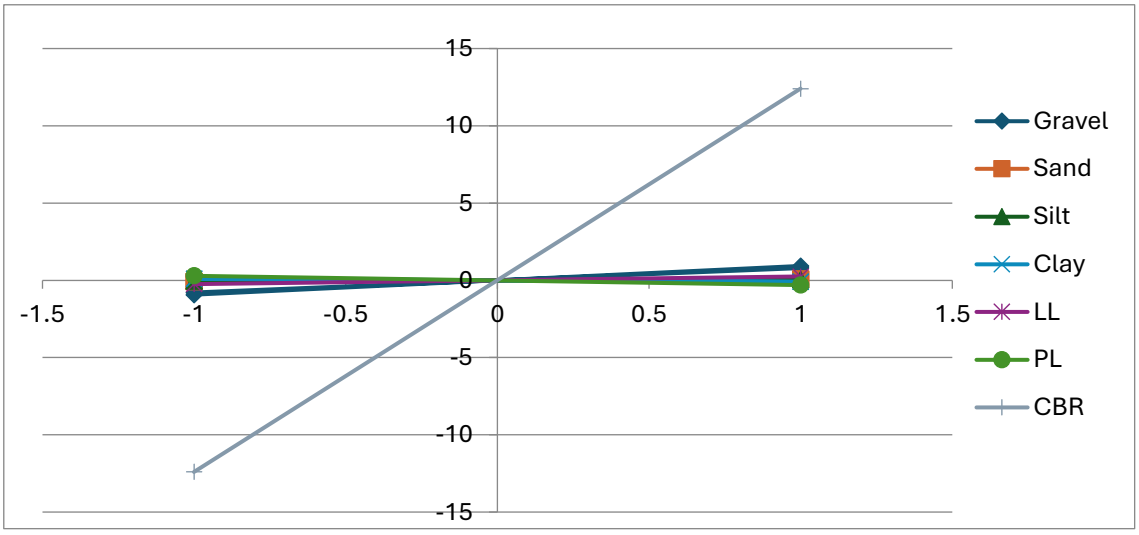

Figure 3: Mono-factorial Effect on Independent Variables on the Dependent Variables.

$Y_{CBR1} = b_0 + b_1G + b_2S + b_3M + b_4C + b_5L_L\ b_6P_L$ (Eq.3)
$= 6.09 + 0.97G + (-0.08)S + 0.03M + (-0.09)C + 0.24L_L + (-0.30)P_L$
$Y_{UCS1} = b_0 + b_1G + b_2S + b_3M + b_4C + b_5L_L\ b_6P_L$ (Eq.4)
$= -141.088+12.366G + 1.729S + 6.253M + (-2.71)C + 0.055L_L + (-0.018)P_L$

i. Gradation as Index Property (the independent variables) on the Respective Strength Properties of the Soil:

$Y_{CBR2} = b_0 + b_1G + b_2S + b_3M + b_4C$ (Eq.5)
$= -0.416 + 0.926G + 0.005S + 0.049M + (-0.00\ 5)C.$
$Y_{UCS2} = b_0 + b_1G + b_2S + b_3M + b_4M$ (Eq.6)
$= - 0.139.42 + 12.39G + 1.72S + 6.27M + (-02.72)C.$

i. Atterberg Limits as Index Property (the independent variables) on the Respective Strength Properties of the Soil:

$Y_{CBR3} = b_0 + b_1L_L + b_2P_L$ (Eq.7)
$= 4.98 + 0.036L_L + (-0.00007)P_L$
$Y_{UCS3} = b_0 + b_1L_L + b_2P_L$ (Eq.8)
$= 65.74 + (-2.241)L_L + 3.69P_L$

ii. Each of the Strength Property as an Independent Variable on the Other (linear regression):

$Y^1_{CBR1} = b_0 + b_1UCS = 2.31+ 0.043UCS$ (Eq.9)

$Y^1_{UCS1} = b_0 + b_1\,CBR = 14.12 + 12.40CBR$ (Eq.10)

Thus, after testing for significance of the model coefficients, as well as checking for adequacy of the models the following regression models were derived as the final ones. The models having been significant and adequate were derived from Eqs.3, 5 and 10.

$Y_{CBR1} = 6.09 + 0.97G -0.08S + 0.03M -0.09C + 0.24L_L -0.30P_L$ (Eq.11)
$Y_{CBR2} = -0.42 + 0.93G + 0.01S + 0.05M -0.01C.$ (Eq.12)
$Y^1_{UCS1} = 14.12 + 12.40CBR$ (Eq.13)

Objective v: Mono-Factorial Analyses and Model Validation

In effort to study the effects of change (+1, or -1) in the values of the respective independent variables on the dependent variables as contained in the final models derived, values of other independent variables that are not of interest are held constant.
Based on the information contained in Table 5 and Figure 3, the following findings are made.

YCBR1 Model: Increase in contents of Gravel, Silt and Liquid Limit brings consequent increase in CBR values. However, increase in contents of Sand, Clay and Plastic Limit brings consequent decrease in CBR values. Gravel has dominant positive effect +0.97, PL has dominant negative effect -0.30.
YCBR2 Model: Changes in contents of Gravel, Sand and Silt have similar positive effects on CBR but gravel sized particles has greater effect +0.93. Thus, more they increase, higher value of CBR property. Nevertheless, lower clay content, higher CBR value (-0.01 coefficient).
YUCS Model: Model presents simple linear relationship between UCS and CBR properties of soil. Their relationship is in direct proportional form. This implies when CBR increases, UCS value increases as well. Per Eq.13, 1% increase in CBR increases UCS by 12.40 kN/m².

Model Validation: R², RMSE, ANOVA

ANOVA at 95% confidence interval ($p < 0.05$) shows models significant:
YCBR1: $R^2 = 0.89$, Adjusted $R^2 = 0.87$, RMSE = 3.12%, $F = 58.4$, $p < 0.001$ Valid
YCBR2: $R^2 = 0.86$, Adjusted $R^2 = 0.84$, RMSE = 3.45%, $F = 62.1$, $p < 0.001$ Valid
YUCS: $R^2 = 0.79$, Adjusted $R^2 = 0.78$, RMSE = 28.5 kPa, $F = 182.5$, $p < 0.001$ Valid
All F > critical F 3.59, indicating significant effect of predictors on model behaviour.

CONCLUSION

Based on findings, tropical soil in Aba is composition of sedimentary soil of predominantly silty sand with clay binder, not predominantly silt and clayey sand. About 54.9% soil particles retained on 0.075 mm sieve, with 52.5% sand, 25% silt, 20% clay and 2.5% gravel, it falls in group A-4 in AASHTO soil classification (LL 40% ≤40%, PI 8% ≤10% for A-4), and SM - silty sand per USCS, not A-5. A-5 requires LL >41%. (Corrected from Ikechukwu, 2026 which stated A-5 - actual is A-4).
Plasticity index 8% indicates low plasticity, not high plasticity. Although clay content inactive (Activity 0.40) only serving as binder, sample has medium sensitivity (2.10). Besides, CBR value 3.5% is low, indicating low resistance to penetration per standard procedure (FMWH requires 10% minimum for subgrade), and UCS 78 kN/m² indicates soft to medium stiff consistency.
Considering relationships established, strength properties can be directly determined from experimentally driven regression models established between index properties and strength properties, avoiding additional rigor and difficulties involved in conducting laboratory tests for strength properties where significant relationships exist ($p < 0.05$).
For Aba soil with CBR 3.5%, 6% cement stabilization recommended to achieve >30% CBR for sub-base per FMWH specification.

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