Effect of Parent rock on Liquid Limits and Compaction Characteristics of Residual Lateritic Soils

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Abstract-* Lateritic soils derived from migmatite-gneiss, granite, charnockite and quartzite from Basement Complex terrain in Southwestern Nigeria were investigated for their basic geotechnical properties. This is with a view to analyzing variations in liquid limits, dry densities and moisture contents of the soils between and within parent rock groups. The significance of mean group (parent rock) differences was tested at 5% level of significance (p = 0.05) using one-way multivariate analysis of variance (one-way MANOVA). Results obtained indicate significant main effects of parent rock on liquid limit (F (3, 8) = 56.11, $p < 0.001$, partial $\eta^2 = 0.955$), moisture content (F (3, 8)= 5.17, $p = 0.028$, partial $\eta^2 = 0.660$), and dry density (F (3, 8)= 6.88, $p < 0.013$, partial $\eta^2 = 0.721$). Calculated effect size for each variable reveals 96, 72 and 66 % of variance in liquid limit, dry density and moisture content respectively are accounted for by mean group (parent rock) differences. Scheffe post hoc test compared the dependent variables among the four parent rock groups in a multiple pair-wise manner. It indicates that liquid limit is the most sensitive to parent rock difference among the three variables investigated.

***Indexed Terms* - Basement complex rocks, dry density, moisture content, one-way MANOVA, southwestern Nigeria**

I. INTRODUCTION

Lateritic soils are common weathering products in the tropics. Their formation is enhanced by the tropical climate characterized by distinct dry and wet seasons which alternate annually. The reddish soils are abundant in Nigeria and are developed on all rock types, basement complex (igneous and metamorphic) rocks as well as sedimentary Formations. They are one of the major engineering materials in high demand in the construction industry. Different lateritic soils exhibit varied geotechnical characteristics and engineering performances. There are several techniques for univariate and multivariate data analysis in earth sciences including comparison of two samples as well as for problems involving groups of observations (Montgomery and Runger, 2003; Davis, 1973). In the current study, causal-comparative research process was followed to estimate the effect of parent rock differences on the geotechnical behaviour of the genetically different soils under investigation. Through the use of statistical tools, the study tests the significance of the differences between means of some geotechnical parameters (dependent variables) as a result of parent rock group differences (independent variable). Causal-comparative research is an examination which ascertains a provisional cause-effect association that may afterwards become a subject of future investigation (Oloyo, 2001).

II. MATERIALS AND METHODS

2.1 Lateritic Soils

Bulk representative residual lateritic soils derived from migmatite gneiss, granite, charnockite and quartzite were sampled at a depth of about 1.0 m from test pits in Akure metropolis, southwestern Nigeria (Figure 1). Basic geotechnical properties of the soils were determined by laboratory analysis according to British BS 1377: Part 2 (1990) and ASTM D4318 standards.

2.2 Research Design

The research question which the current research is expected to answer is, "Does parent rock (one independent variable) significantly affect the liquid limits, dry density and moisture contents (three dependent variables) of basement rock derived lateritic soils?" Therefore, a 1 x 3 factor design was adopted.

The null hypothesis in a one-way multivariate analysis of variance (one-way MANOVA) states that there is no significant difference in liquid limit and compaction characteristics among the parent rock groups. Using statistical notation, the null hypothesis is further expressed as follows,

$$H_0: \mu_{\text{migmatite}} = \mu_{\text{granite}} = \mu_{\text{charnockite}} = \mu_{\text{quartzite}}$$

Where μ represents the various parent rock group means.

2.3 Laboratory Tests

The soil samples were tested for some basic geotechnical properties which include specific gravity, Atterberg consistency (liquid, plastic and shrinkage) limits, grain sizes, compaction parameters (dry density and moisture contents), California Bearing Ratio (CBR), Unconfined compressive strength (UCS), permeability coefficients and shear strength.

2.4 Statistical Data Analysis

Pre-analysis data screening was conducted prior to multivariate analysis. This was to address the effects of missing data as well as extreme values (outliers). It also assessed the adequacy of fit between data and assumptions on which the multivariate statistical procedures adopted are based (Brace *et. al.*, 2006). For one-way MANOVA used in this study, the following assumptions were made and validated in performing the test (Mertler and Vannatta, 2005),

(i) Normality: A measure of normal sample distribution. The distributions of observations on the dependent variables are normal in the populations from which the data were sampled. Randomization: The observations within each sample are randomly sampled.

(ii) Homoscedasticity: The distributions of observations on the dependent variables have equal variances. This assumption was tested by means of Levene's test.

The significant level of 5% ($p = 0.05$) was adopted.

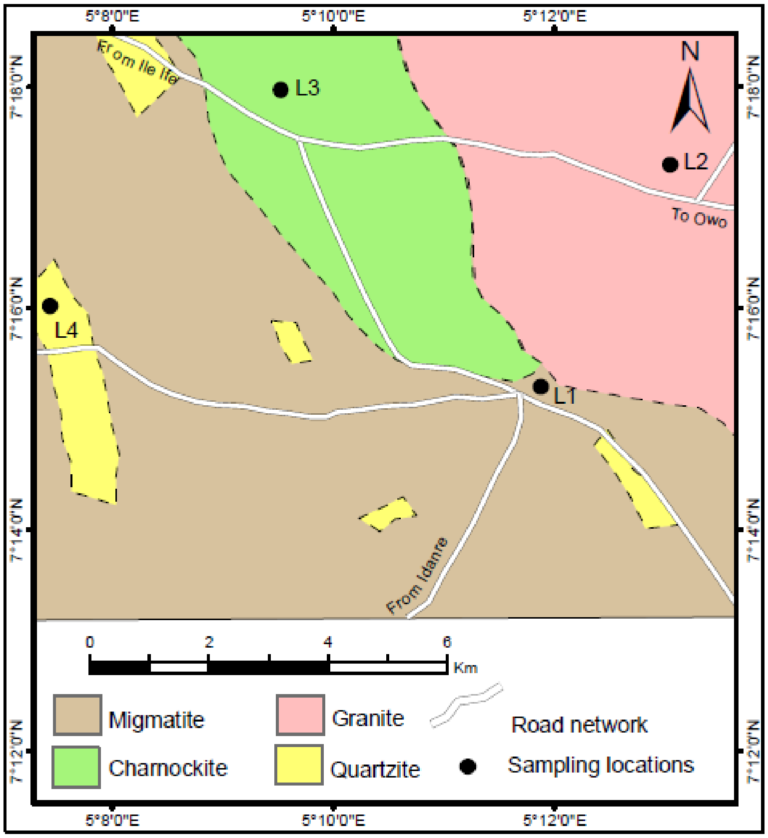

Fig. 1 Geological map of the study area

III. RESULTS AND DISCUSSION

3.1 Basic Geotechnical Properties

The results of the basic geotechnical tests conducted on the lateritic soils are summarized on Table 1. The specific gravity of soil grains indicates the granite-derived soil had the highest degree of maturity and laterization while the migmatite-derived soil had the least level of maturity and laterization. The migmatite-derived soil exhibits the highest percentage fines (about 67 %) while quartzite-derived soil shows the least amount of fines (approximately 19 %). This may be responsible for the trend observed in compaction characteristics in which the quartzite-derived soil records the highest maximum dry density (MDD = 1897 kg/m^3) and minimum optimum moisture content (OMC = 11.25 %) whereas the migmatite-derived soil registered the least MDD (1590 kg/m^3) and relatively higher OMC (16.42 %). Since the engineering performance of most lateritic soils is inversely proportional to the percentage fines (Adewoye and Adeyemi, 2004; Owoseni *et. al.,* 2012), the quartzite-derived soil is expected to have the best engineering performance among the four genetically different soils. All the residual soils are non-plastic except the charnockite-derived soil which has a plastic index of 17.6 %.

3.2 Statistical Pre-Analysis Data Screening

The significance levels observed (Table 2) for Levene's test is high (i.e. $p > 0.05$) for all the three dependent variables, indicating homogeneity of variance. Therefore the null hypothesis that the variances are equal was not rejected.

Table 1: Results of grain-size analysis, specific gravity, permeability, compaction, compression and consistency limit tests on the soils.

Location (Parent Rock)	Specific gravity	Particle size distribution (%)		Perme-ability (cm/s)	Compaction parameters (%)		UCS (kPa)	Shear strength (kPa	Atterberg limits (%)		
		(Gravel + Sand)	(Silt + Clay)		MDD (kg/m^3)	OMC (%)			W_L	W_P	L.S
L1 (Migmatite)	2.61	33.03	66.97	0.0678	1590	16.42	16.42	24.50	53.44	NP	9.29
L2 (Granite)	2.66	48.45	51.55	0.0038	1791	23.75	52.06	61.00	54.68	NP	13.57
L3 (Charnockite)	2.65	46.06	53.94	0.0678	1830	15.20	18.31	26.60	38.91	17.6	8.58
L4 (Quartzite)	2.64	80.71	19.29	0.0975	1898	11.25	15.92	13.80	44.37	NP	8.56

W_L = liquid limit, W_P = plastic limit, L.S = linear shrinkage

3.3 Multivariate Analysis of Variance (MANOVA)

The one-way multivariate analysis of variance was conducted to investigate the effect of parent rock differences on liquid limits, moisture contents and dry densities at Proctor compaction level. MANOVA summary table (Table 3) indicated a significant main effect of parent rock on liquid limit ($F(3,8)= 56.11$, $p < 0.001$, partial $\eta^2 = 0.955$), optimum moisture content ($F(3,8)= 5.17$, $p = 0.028$, partial $\eta^2 = 0.660$) and dry density ($F(3,8)= 6.88$, $p < 0.013$, partial $\eta^2 = 0.721$). Also, calculated effect size for each variable indicates 96, 72 and 66 % of variance in liquid limit, dry density and moisture content respectively, are accounted for by parent rock differences. The Scheffe post hoc test, also known as multiple comparisons was conducted to determine which parent rock types were significantly different (Table 4). The results of the pair-wise comparisons revealed that,

(i) migmatite-derived soil is not significantly different in liquid limit values from granite-derived soil. Similarly, charnickite-derived soill is not significantly different in liquid limit values from quartzite-derived soil;

(ii) migmatite-derived soil is not significantly different in moisture content at Proctor level of compaction from soils derived from all other parent rocks except quartzite;

(iii) quartzite-derived soil is significantly different in dry density from both migmatite- and granite-derived soils.

Table 2: Levene's test for equality of error variances

	F	df1	df2	Sig.
Liquid limit	0.331	3	8	0.803
Moisture content	0.199	3	8	0.894
Dry density	4.013	3	8	0.052

VI. CONCLUSION

From the foregoing, there is a statistically significant effect of the parent rock group differences on the liquid limits as well as moisture contents and dry densities (at Proctor compaction energy level) of the lateritic soils derived from four genetically varied basement complex parent rocks under investigation. The effect of parent rock difference is most pronounced in the liquid limit while it is least in the moisture contents of the soils. The dry density is more sensitive to parent rock affects than the moisture content. In short, the degree of sensitivity of the three geotechnical variables to parent rock differences is in the following order,

Liquid limit > Dry density > Moisture contents.

Table 3: MANOVA Summary on Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	Liquid_limit	505.288[a]	3	168.429	56.109	.000	.955
	Moisture content	252.000[b]	3	84.000	5.169	.028	.660
	Dry density	226061.583[c]	3	75353.861	6.879	.013	.721
Intercept	Liquid_limit	26402.825	1	26402.825	8795.640	.000	.999
	Moisture content	3468.000	1	3468.000	213.415	.000	.964
	MDD	3.205E7	1	3.205E7	2925.917	.000	.997
Rock_Type	Liquid_limit	505.288	3	168.429	56.109	.000	.955
	Moisture content	252.000	3	84.000	5.169	.028	.660
	Dry density	226061.583	3	75353.861	6.879	.013	.721
Error	Liquid_limit	24.014	8	3.002			
	Moisture content	130.000	8	16.250			
	Dry density	87628.667	8	10953.583			
Total	Liquid_limit	26932.127	12				
	Moisture content	3850.000	12				
	MDD	3.236E7	12				
Corrected Total	Liquid_limit	529.302	11				
	Moisture content	382.000	11				
	Dry density	313690.250	11				

a. R Squared = .955 (Adjusted R Squared = .938)

b. R Squared = .660 (Adjusted R Squared = .532)

Table 4: Scheffe Multiple comparisons of dependent variables for parent rock types

Dependent Variable	(I) Rock_Type	(J) Rock_Type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Liquid limit	Migmatite	Granite	-1.7500	1.41464	.686	-6.6908	3.1908
		Charnockite	13.9267*	1.41464	.000	8.9858	18.8675
		Quartzite	9.3300*	1.41464	.001	4.3892	14.2708
	Granite	Migmatite	1.7500	1.41464	.686	-3.1908	6.6908
		Charnockite	15.6767*	1.41464	.000	10.7358	20.6175
		Quartzite	11.0800*	1.41464	.000	6.1392	16.0208
	Charnockite	Migmatite	-13.9267*	1.41464	.000	-18.8675	-8.9858
		Granite	-15.6767*	1.41464	.000	-20.6175	-10.7358
		Quartzite	-4.5967	1.41464	.069	-9.5375	.3442
	Quartzite	Migmatite	-9.3300*	1.41464	.001	-14.2708	-4.3892
		Granite	-11.0800*	1.41464	.000	-16.0208	-6.1392
		Charnockite	4.5967	1.41464	.069	-.3442	9.5375
Moisture Content	Migmatite	Granite	6.6667	3.29140	.321	-4.8290	18.1624
		Charnockite	8.6667	3.29140	.153	-2.8290	20.1624
		Quartzite	12.6667*	3.29140	.032	1.1710	24.1624
	Granite	Migmatite	-6.6667	3.29140	.321	-18.1624	4.8290
		Charnockite	2.0000	3.29140	.944	-9.4957	13.4957
		Quartzite	6.0000	3.29140	.401	-5.4957	17.4957
	Charnockite	Migmatite	-8.6667	3.29140	.153	-20.1624	2.8290
		Granite	-2.0000	3.29140	.944	-13.4957	9.4957
		Quartzite	4.0000	3.29140	.697	-7.4957	15.4957
	Quartzite	Migmatite	-12.6667*	3.29140	.032	-24.1624	-1.1710
		Granite	-6.0000	3.29140	.401	-17.4957	5.4957
		Charnockite	-4.0000	3.29140	.697	-15.4957	7.4957
Dry density	Migmatite	Granite	-4.3333	85.45402	1.000	-302.7935	294.1269
		Charnockite	-117.0000	85.45402	.619	-415.4602	181.4602
		Quartzite	-338.3333*	85.45402	.027	-636.7935	-39.8731
	Granite	Migmatite	4.3333	85.45402	1.000	-294.1269	302.7935
		Charnockite	-112.6667	85.45402	.645	-411.1269	185.7935
		Quartzite	-334.0000*	85.45402	.029	-632.4602	-35.5398
	Charnockite	Migmatite	117.0000	85.45402	.619	-181.4602	415.4602
		Granite	112.6667	85.45402	.645	-185.7935	411.1269
		Quartzite	-221.3333	85.45402	.161	-519.7935	77.1269
	Quartzite	Migmatite	338.3333*	85.45402	.027	39.8731	636.7935
		Granite	334.0000*	85.45402	.029	35.5398	632.4602
		Charnockite	221.3333	85.45402	.161	-77.1269	519.7935

Based on observed means.

The error term is Mean Square (Error) = 10953.583.

*. The mean difference is significant at the 0.05 level.

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