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Variability in the Geotechnical properties of some residual clay soils from southwestern Nigeria

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Abstract— Some residual clay soils from southwestern Nigeria have been investigated with a view to elucidating their geotechnical properties and determine the possible variations in these properties in relation to the sampling distance.
Eight bulk residual soil samples from two test pits separated 30m apart at intervals of 0.5m up to a depth of 2.0m were analyzed in the laboratory to determine specific gravity, grain size distribution, consistency limits, linear shrinkage, unconfined compressive strength and compaction characteristics. The data generated were subsequently subjected to statistical analysis.
The investigations revealed that the soils are generally well graded, inorganic, with medium to high plasticity and hence compressibility and are of the same geologic origin. Statistical T-test showed no significant difference exists between the soils in terms of specific gravity, liquid limit, plastic limit, plasticity index, linear shrinkage, % clay size fraction, amount of fines, unconfined compressive strength and optimum moisture content. However the maximum dry density of the soils from both pits differed significantly.
Although most of the parameters examined are not as varied and showed insignificant difference, the equations generated provide an option in the estimation of properties considering the close sampling distance.

Index Terms— Clay, Geotechnical properties, Insignificant difference, Investigated, Residual soil, Statistical analysis, Variability.

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1 INTRODUCTION

The relationship between all engineering infrastructure and their foundation soils is too important to be ignored. A considerable increase in soil utility for engineering works is expected as the country aspires towards improved infrastructural development. Incessant occurrence of road pavement failure and building collapse has made it imperative for a proper understanding of the geotechnical properties of residual clay soils. Clay is predominant in most of the subgrade soils of Nigeria. Due to the relative abundance of these soils and ease of acquisition they have found wide application in engineering construction works. Clay soils used in the production of ceramic materials and burnt bricks are found in abundance in Omi-Adio, Ipetumodu, Ara Ijero, Isan Ekiti, Igbara Odo and Okitipupa areas of southwestern Nigeria [20]. Several researchers including [6] studied the potential use of Tunisian clays as pozzolanic material and concluded that geotechnical and physicochemical tests are useful to predict pozzollanic activity of the clays and clays rich in kaolinite have the highest strength and therefore the best pozzolanic activity. Que et al. [22] investigated the geotechnical properties of the soft soil in Guangzhou college city in China which were found to be difficult both to sample and test. The authors developed equations using statistical and linear regression analysis and confirmed that using these equations, the mechanical indices of the soils could be estimated from the physical indices determined by routine testing.

Adesunloye [1], has through standard laboratory testing procedures, identified the problem soils in the Lagos area as peaty clays. Wu and El –Jandali [27], [25] used statistical analysis to carry out systematic studies of the variability of rock and soil parameters. Dazhao ([8], [9]) achieved good results using statistical analysis to better define the engineering geological properties of soil. However little has been done to understand the variations which exist in the geotechnical properties of residual clay soils from southwestern part of Nigeria in terms of sampling distance using statistical analysis. As a result of the extremely variable nature of geologic materials, this paper is a bid to determine the variation in the geotechnical properties of some residual clay soils from two test pits 30m apart.

2 STUDY AREA

The study area, Ibadan, forms part of the area underlain by the Precambrian Basement Complex rocks of southwestern Nigeria (Fig. 1) which comprises igneous and metamorphic rock units such as gneisses, migmatites, pelitic and semi pelitics schists, psammitic rocks, matebasites, intrusives and associated masses including older granite ridges and pegmatites. Essentially, metamorphic rocks and igneous intrusions such as veins, dykes and pegmatites underlie the area. These rocks occur either directly exposed or covered by the shallow mantle of superficial deposits. Though the assemblages have been variedly classified, they may be broadly subdivided into the ancient gneiss-migmatite complex, the schist belts and the Pan-African (ca. 0.6ga) intrussive series or the older granites plus minor rocks.

Radiometric ages obtained from the ancient migmatite gneisses are notably between ca. 2.8 and 2.0ga [23] older dates (≥ 3.0ga) have more recently been derived from some. The schist belts occur prominently within the western half of the country though a few have more recently been highlighted in the central and southern [10].

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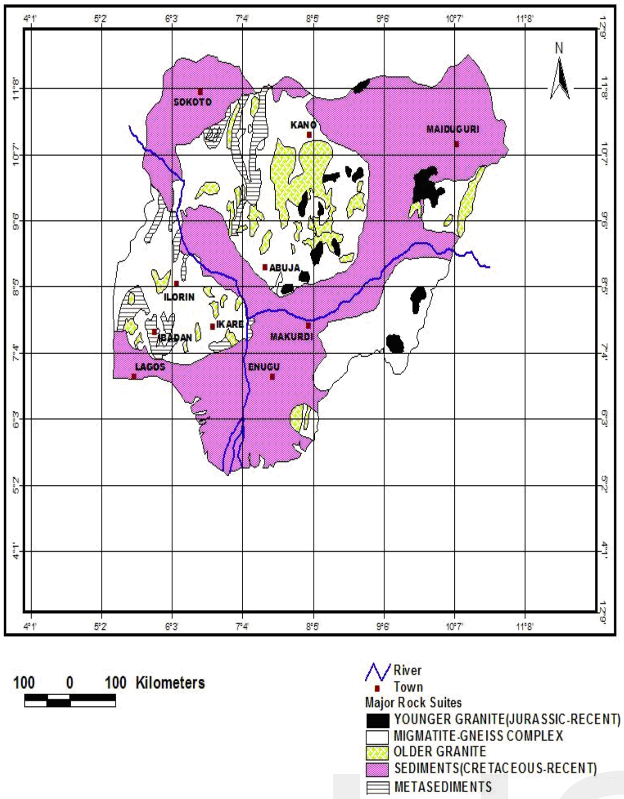

Fig. 1. Generalized geological map of Nigeria [12].

3 Materials And Methods

Eight bulk residual clay soils were obtained from two test pits spaced 30m apart at intervals of 0.5m up to a depth of 2.0m. The disturbed soils were air dried for two weeks and later subjected to geotechnical tests including specific gravity, grain-size distribution, consistency limits, linear shrinkage, unconfined compressive strength and compaction. All the geotechnical tests were done in accordance with BS1377 [5] test procedures. However to ensure effective segregation of soil grains, the soils were soaked and regularly agitated in a calgon solution for a period of 24hrs before wet sieving. Subsequently the results were subjected to statistical analysis to better evaluate and understand the variations and relationships which exists.

4 Results And Discussion

4.1 Specific gravity

The results of the specific gravity of the soils (Table 1) range from 2.69 - 2.72 with an average of 2.71 for pit "A" and 2.70 - 2.87 with an average of 2.79 for pit "B". Specific gravity is an important index property of soils that is closely linked with mineralogy and/or chemical composition. Soils from pit B exhibit higher degree of laterization than the soils from pit "A" according to Maignien[19] who established a positive correlation between the specific gravity of soils and their degree of laterization. On the basis of the classification by [24] the soils fall within either sand, silt or clay type of soil with some containing mica or iron. The soils are also not organic.

TABLE 1. SPECIFIC GRAVITY OF STUDIED SOILS

SAMPLE	SPECIFIC GRAVITY	
	PIT A	PIT B
1	2.70	2.73
2	2.69	2.85
3	2.72	2.70
4	2.71	2.87
AVERAGE	**2.71**	**2.79**

4.2 Consistency Limits

The consistency limits of the soils which relates to the relative ease to which a soil can be deformed based on the relationship or interaction with water are presented in Table 2. The consistency limits have been repeatedly shown to be useful indicators of clay behavior [15]. Certain types of clayey soils expand when they are wetted and shrink when dried. Adeyemi et al. [2] indicated that clay should be plastic in order to be easily manipulated. However excessive plasticity can be detrimental. Based on the specification of maximum liquid limit of 40% by Federal Ministry of Works and Housing [11] for soils used as highway subgrade materials, the average liquid limit of the soils under consideration shows they are not suitable for use.

Casagrande chart classification of all the soils (Fig. 2 and 3) show that they are of medium to high plasticity and hence compressibility. The soils all fall above the A-line and can be said to be inorganic plastic clays. This corroborates the classification of Ramamurthy and Sitharam [24] on the basis of specific gravity which indicated that the soils are not organic. Furthermore the soils also plot parallel to the A-line on the chart indicating soils of the same geologic origin. Average values of liquid and plastic limits are higher for soils from pit "A"

The plasticity index of the soil which is the difference in water content between the liquid and plastic limits is a measure of the affinity of a soil for water. It is an indicator of the plasticity of a soil.

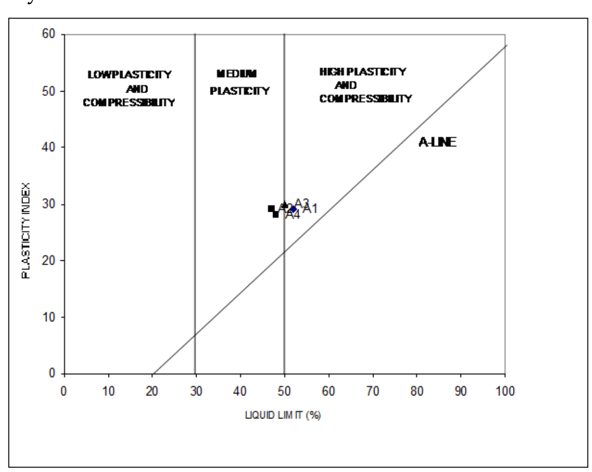

Fig. 2. Casagrande chart classification of soils from pit A

International Journal of Scientific & Engineering Research Volume 2, Issue 9, September-2011
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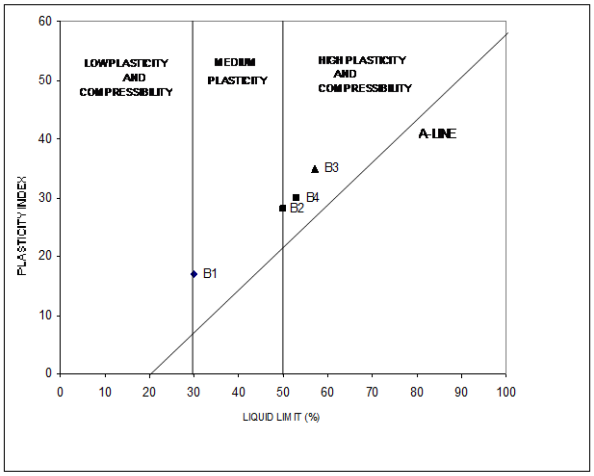

Fig. 3. Casagrande chart classification of soils from pit B

The greater the plasticity index, the more plastic and compressible and the greater the volume change characteristics of the soil. The average plasticity index of the soils from pit "A" was found to be greater than for soils from pit B. However soils from pit "A" all exhibit high swelling potential according to the classification by [21] while the soils from pit B exhibit medium to high swelling potential. The linear shrinkage of soils from pit "A" showed no regular pattern while the linear shrinkage of soils from pit "B" increased with depth. The average linear shrinkage for the soils in pit "A" are lower than for the soils in pit "B". All the soils from the two pits show higher linear shrinkage than the maximum 8% specified [18] for highway sub grade soils.

TABLE 2. CONSISTENCY LIMITS OF STUDIED SOILS

PITS	SAMPLE	CONSISTENCY LIMITS (%)			
		LL	PL	PI	LS
PIT A	1	52.0	23.0	29.0	13.6
	2	47.0	18.0	29.0	9.3
	3	50.0	20.0	30.0	11.4
	4	48.0	20.0	28.0	10.0
	AVE.	**49.3**	**20.3**	**29.0**	**11.1**
PIT B	1	30.0	13.0	17.0	8.6
	2	50.0	22.0	28.0	10.0
	3	57.0	22.0	35.0	12.9
	4	53.0	23.0	30.0	15.0
	AVE.	**47.5**	**20.0**	**27.5**	**11.6**

LL=Liquid Limit, PL=Plastic Limit, PI=Plasticity Index, LS=Linear Shrinkage.

4.3 Grain size Analysis

The results of the grainsize distribution analysis are summarized in Table 3. Gidigasu [13] indicated that textural and plasticity characteristics of clays are to some extent dependent on the parent materials and the degree of laterization. Lee [17] noted that the colloidal content of clays provides the necessary plasticity or workability while Akinmusuru and Adebayo [3] indicated that the sand size particles contribute to the mechanical strength. The average amounts of clay, silt, sand and gravel are 15.50%, 44.00%, 28.50%, 4.25% and 19.50%, 44.75%, 21.00%, 11.75% respectively for soils from pits "A" and "B".

TABLE 3. GRAIN SIZE CHARACTERISTICS OF STUDIED SOILS

PIT	SAMPLE	GRAINSIZE DISTRIBUTION (%)				
		G	S	SI	C	F
PIT A	1	2.0	41.0	36.0	17.0	53.0
	2	3.0	41.0	36.0	17.0	53.0
	3	6.0	6.0	45.0	20.0	65.0
	4	6.0	26.0	59.0	8.0	67.0
	AVE.	**4.3**	**28.5**	**44.0**	**15.5**	**59.5**
PIT B	1	G	S	SI	C	F
	2	22.0	16.0	32.0	24.0	57.0
	3	9.0	17.0	55.0	19.0	74.0
	4	10.0	30.0	36.0	21.0	57.0
	AVE.	**6.0**	**21.0**	**56.0**	**14.0**	**70.0**

G=Gravel, S=Sand, SI=Silt, C=Clay, F=Amount of Fines

The soils are generally well graded (Fig. 4 and 5) with no noticeable trend with depth common to the pits. Whereas soils from pit "A" showed noticeable increase in size fractions with depth for gravel, silt and amounts of fines, soils from pit "B" exhibited none. However the average size fractions are higher for soils from pit "B" when compared to the corresponding size fraction for soils from pit "A" with the exception of the sand size fraction.

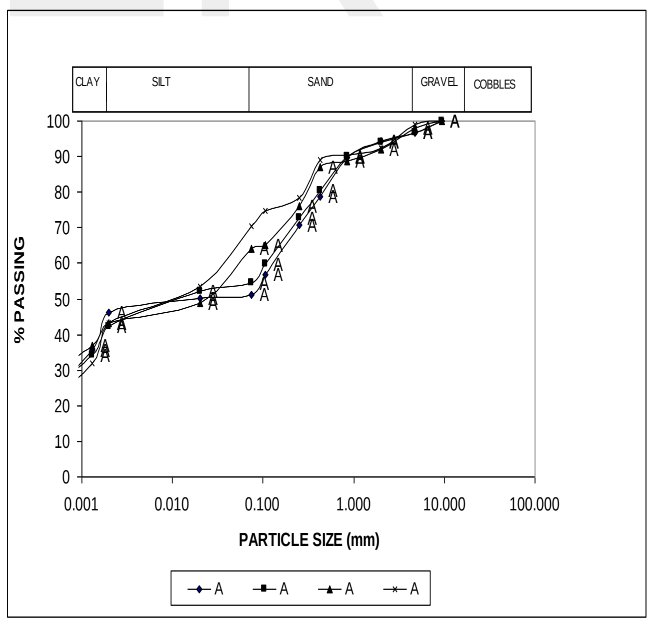

Fig. 4. Grading curves of soils from pit A

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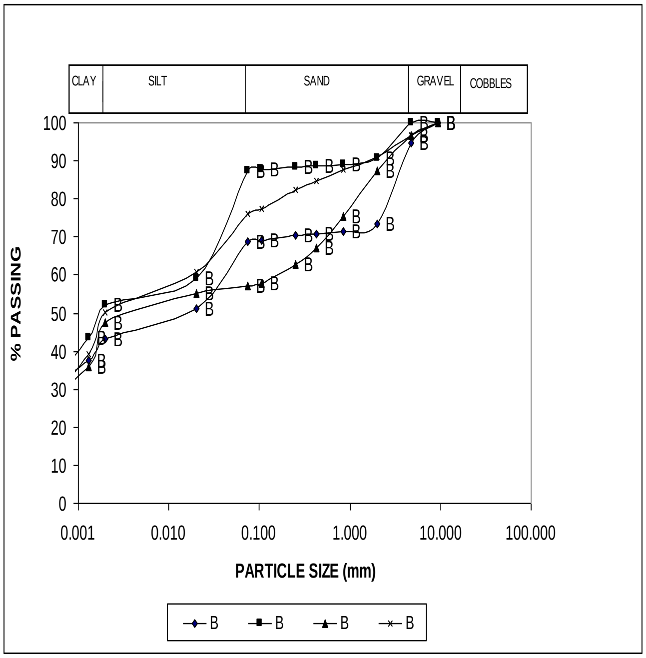

Fig. 5. Grading curves of soils from pit B

The average amount of fines 59.50 and 64.50% indicative of soils with poor engineering properties since the amount of fines are greater than 50%. Although soils from pit "A" lower amounts of fines and are expected to be better than those from pit "B".

Generally all the soils from the pits have high amount of fines and will have high specific surface with low leachate migration as soil texture becomes finer [4]. The soils are expected to compact to a low porosity and hence permeability will perform well as they are suitably graded with low clay fraction content. The amount of clay size particles have been found to have some relationship with plasticity and hence the workability of lateritic soils. The lower the clay size fraction the higher the degree of laterization. The soils from both pits possess lower clay size fractions than silt size fractions. Furthermore the soils from pit "A" exhibit lower clay size fractions than those from pit B. This can possibly be attributed to more pronounced sesqui-oxide coating in the pit "A" soils and thus can be said to be more lateritized.

4.4 Unconfined Compressive Strength

The Unconfined Compression test is used to measure the shearing resistance of cohesive soils. Results of the unconfined compressive strength (Table 4) for the pits show a trend which indicates a decrease in the strength with depth of sampling. The average unconfined compressive strength of soils from pit "A" are however higher than for soils from pit "B". The strength values of the soils are however very low when considering the soils as isolation barriers for landfill purposes. Foundation soils must be capable of supporting the landfill's weight. Failures occur when foundation soils beneath or adjacent to the landfill yield because of the applied load. Kabir and Taha [16] specified that soils used in waste containment system as isolation barriers are expected to sustain certain amount of static load exerted by the overlying waste materials. Daniel and Wu [7] mentioned that soil used as barrier material should have minimum unconfined compressive strength of 200 kN/m

TABLE 4. UNCONFINED COMPRESSIVE STRENGTH OF STUDIED SOILS

SAMPLE	UNCONFINED COMPRESSIVE STRENGTH (kN/m²)	
	PIT A	PIT B
1	23.95	22.00
2	23.57	18.85
3	15.40	17.85
4	11.65	10.00
AVERAGE	**18.64**	**17.17**

4.5 Compaction Characteristics

Compaction characteristics of soils are determined to ensure quality of materials used for construction purposes. The soils for the present study were compacted at the modified AASHTO level of compaction. The maximum dry density of the soils (Table 5) varies from 1765.30 to 1825.12 kg/m3 and 1815.13 to 1855.64 kg/m3 respectively for soils from pits "A" and "B" while the optimum moisture content varies from 16.40 to 17.65 % and 16.60 to 20.35 % respectively for soils from pits "A" and "B". However the average MDD and OMC of the soils from pit "B" are higher than for soils from pit "A".

TABLE 5.COMPACTION PARAMETERS OF STUDIED SOILS

SAMPLE	COMPACTION at Modified AASHTO Level			
	MDD (Kg/m³)		OMC (%)	
	PIT A	PIT B	PIT A	PIT B
1	1780.12	1835.11	17.45	16.60
2	1825.12	1855.64	17.65	18.30
3	1765.30	1815.13	17.22	20.35
4	1800.00	1825.03	16.40	20.02
AVE.	**1792.64**	**1832.73**	**17.18**	**18.82**

4.6 Statistical Analysis and Relationships

The results of all the parameters examined were subjected to statistical t- test, correlation coefficient, coefficient of variation and linear regression analysis and the observations are displayed in Table 6.

From the analysis of the data sets observed for soils from pits "A" and "B", statistical t test showed no significant difference exists between the soils obtained from pit "A" and "B" in terms of specific gravity, liquid limit, plastic limit, plasticity index, linear shrinkage, % clay size fraction, amount of fines, unconfined compressive strength and optimum moisture content. However the maximum dry density of the soils from both pits differed significantly. Furthermore in terms of correlation coefficient, strong positive relationship of 0.8242, 0.8761 and

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0.8462 was respectively observed between the soils from both pits for the % clay size fraction, unconfined compressive strength and maximum dry density while strong negative correlation coefficient of -0.8618 in plastic limit exists between the soils from the pits. Specific gravity, linear shrinkage and amount of fines showed weak negative correlation coefficients of -0.4708, -0.4870, -0.0651 for soils from both pits. The coefficient of variation determined showed that the %clay size fraction is the most variable parameter at 16.16% which does not show notable difference as the case may be. The specific gravity, liquid limit, plastic limit, plasticity index, linear shrinkage, amount of fines, unconfined compressive strength, optimum moisture content and maximum dry density were not as varied and hence does not show any significant variation. Linear regression equations for the different parameters have also been established. These equations depicts the linear relationships which exists between the properties of soils from both pits and can be used to estimate the different properties considering the sampling distance.

Statistical T-test showed no significant difference exists between the soils obtained from pit "A" and pit "B" in terms of specific gravity, liquid limit, plastic limit, plasticity index, linear shrinkage, % clay size fraction, amount of fines, unconfined compressive strength and optimum moisture content. However the maximum dry density of the soils from both pits differed significantly.

Furthermore strong positive correlation coefficient of 0.8242, 0.8761 and 0.8462 was respectively observed between the soils from both pits for the % clay size fraction, unconfined compressive strength and maximum dry density.

Although most of the parameters examined showed insignificant difference for soils from the pits, the equations generated provide an option in the estimation of properties considering the close sampling distance. However the importance of detailed and thorough sampling of soils cannot be ignored.

TABLE 6. RESULTS OF STATISTICAL ANALYSIS AND RELATIONSHIPS

PARAMETER	T-TEST (NATURE OF DIFFERENCE)	CORRELATION COEFFICIENT (r)	COEFFICIENT OF VARIATION (%)	LINEAR REGRESSION EQUATION
SPECIFIC GRAVITY	INSIGNIFICANT	-0.4708	2.12	$y = -3.1x + 11.17$
LIQUID LIMIT	INSIGNIFICANT	-0.6694	2.56	$y = -3.63x + 226.14$
PLASTIC LIMIT	INSIGNIFICANT	-0.8618	0.88	$y = -1.96x + 59.71$
PLASTICITY INDEX	INSIGNIFICANT	0.2688	3.75	$y = 2.50x - 45$
LINEAR SHRINKAGE	INSIGNIFICANT	-0.4870	3.37	$y = -0.74x + 19.80$
% CLAY SIZE FRACTION	INSIGNIFICANT	0.8242	16.16	$y = 0.67x + 9.17$
AMOUNT OF FINES	INSIGNIFICANT	-0.0651	5.70	$y = -0.08x + 69.02$
UNCONFINED COMPRESSIVE STRENGTH	INSIGNIFICANT	0.8761	6.73	$y = 0.73x + 3.53$
OPTIMUM MOISTURE CONTENT	INSIGNIFICANT	-0.6033	6.43	$y = -1.90x + 51.49$
MAXIMUM DRY DENSITY	SIGNIFICANT	0.8462	1.56	$y = 0.57x + 818.74$

5 CONCLUSIONS

Investigations on the variability of the geotechnical properties of some residual clay soils in terms of sampling distance have helped in arriving at the followng conclusions;

The soils are generally well graded with no noticeable trend with depth common to the pits. The average amount of fines 59.50 and 64.50% indicative of soils with poor engineering properties since the amount of fines are greater than 50%. However the soils from pit "B" exhibit a higher degree of laterization considering their specific gravity.

Casagrande chart classification of all the soils indicate they are not organic with medium to high plasticity and hence compressibility, and are of the same geologic origin. The average values of plasticity index, liquid and plastic limits are higher for soils from pit "A" with the soils from the pit expected to exhibit high swelling potential.

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