



Variability of Soil Properties with Horizontal Locations

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ABSTRACT

The index and engineering properties of residual soils at the Nigerian Defence Academy (NDA) Afaka-Mando Kaduna, Nigeria were investigated with the aim of evaluating their variability with horizontal locations. Disturbed soil samples were collected at 0.5 m, 1.0 m and 1.5 m depths from six borrow pits located at 500 m radius around the Civil Engineering department. Results from the laboratory tests range from: 2.40 to 2.64 for specific gravity; 14.96% to 20.05% for natural moisture content; 0.5% to 19.4% for percentage gravel content; 11.1% to 34.1% for percentage sand content; 57.6% to 87.8% for percentage fines content; 39.4% to 44.3% for liquid limits; 24.6% to 30.0% for plastic limits; 1.65 kg/m³ to 1.79 kg/m³ for maximum dry density; 17.36% to 20.94% for optimum moisture content and 159.34 kN/m² to 258.51 kN/m² for unconfined compressive strength. Coefficient of variation was excellent for specific gravity, natural moisture content, consistency limits, compaction parameters and unconfined compressive strength; good for percentage fines fractions only; and poor for gravel fractions and percentage sand fractions. From the research, variations exist in the properties of soil at NDA Kaduna and thus, it can be concluded that soil properties can vary with horizontal locations in an area.

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INTRODUCTION

Primitive man has been narrated to have built his shelter in, of, or on weathered rock whose degree of cementation is reduced by any of or a combination of the various agents, called rock waste or more popular, soil (Laskar *et al.*, 2012). As such, it cannot be out of place for an engineer to say soil is the first engineering material. These soils could be residual when it is deposited at the same location as the parent rock from which it was weathered or transported when moved to a new location by agencies like air, ice, flowing water, wind or other events or forces.

The behavior of many construction materials like wood, concrete and steel can be predicted with a very good confidence. However, this is not the case with soil and interestingly, it is not a total surprise given that the formation and deposition of soils are by different geological processes which are seldom homogeneous and composing of a variety of characteristics. This is evident from Hack (2020) where the geological processes such as chemical, physical and biological

weathering and deposition that birth soil, determine its physical and chemical properties like shape and size of the particles, and mineralogical composition. Breysse *et al.* (2005) maintained that these physio-chemical properties dictate virtually all the engineering properties of the soil. As such, Soils Engineers are tasked with investigating the properties of soil materials and their reactions to imposed conditions as it exists, because major modifications to its physical properties are normally not economically possible to make.

The particles of a soil are seldom identical with other adjacent soil. A soil type is characterized as having the same geologic depositional history which also depends on the parent rock type, its mineral constituents and the climatic regime of the area (Surendra and Sanjeev, 2017; Andavan *et al.*, 2018). Different soils exhibit their properties differently when compared to the adjacent soil with soil strata from long distance (Andavan *et al.*, 2018). Since soil forming factors and differences in human activities dictate the properties of the soil, heterogeneity is surely an inherent quality of soil

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that predicts its complexity and distribution in space (Junior *et al.*, 2006; Abdulfatah *et al.*, 2016). Geotechnical properties (index properties and engineering properties) of soils do not only influence the stability of structures built with or in it, but also influence each other (Ademila, 2016; Surendra and Sanjeev, 2017). Index properties are the properties of soil that help in identification and classification of soil for general engineering purpose (El, 2013; Sule *et al.*, 2021). Even as the occurrence and distribution of soils in nature varies from location to location, index properties of a soil can easily be used to predict its engineering properties (Popescu *et al.*, 2005). It is common practice in some civilizations to estimate soil index properties, like the Particle size distribution, Natural Moisture Content, Specific Gravity, Atterberg's Limits and Relative Density. Based on these, some information about engineering properties such as permeability, compressibility and shear strength can be estimated (Andavan *et al.*, 2018; Adebayo and Balarabe, 2021). This information is essential prior to the construction of any civil engineering work such as roads, buildings, dams, bridges, foundations, etc., and accurate estimations can guarantee safe and economic development of the structures (Adeyeri, 2015). Sometimes, index properties of soil or calculated values of soil parameters used for certain projects are usually assumed as estimates for other projects. This is based on the assumption asserted both for natural soils and for artificial soils that spatial variation of a soil properties is more related to formation process rather than to the physio-chemical details of the soil (Fenton, 1999; Breysse *et al.*, 2005; Larson *et al.*, 2005). Unfortunately, in most developing countries like Nigeria only few stakeholders in the construction industry attempt to investigate the subsoil prior to commencement of construction activities on their projects. This has been reported to be a major cause of failure or collapse of buildings and other massive engineering structures which often cause untold hardship and damage and sometimes even loss of lives and properties (Eze *et al.*, 2017).

The complexity in most engineering structures is conspicuous in the physical appearance of the built structures. Two structures can be built from the same design, by the same engineer using the same materials and technology, very often in the same locality

and sometimes sharing perimeter fences. Whether all or some of the stated conditions hold, two structures most often are not entirely the same as the similarity in structures is not entirely indicated by its appearance as built alone but by the constituent materials and methods adopted in constructing them as well as the foundation types and soils supporting the structures. The properties of soil in an area can vary inherently, from measurement or from model representation of the soil both horizontally and vertically but not randomly in space (DeGroot and Baecher, 1993; Baecher and Christian, 2003; Elkateb *et al.*, 2003; Kasama *et al.*, 2012; Abdulfatah *et al.*, 2016; Sule *et al.*, 2021). The less variation at closely neighboring points than at widely spaced points explains why second moment statistics alone are not enough to characterize uncertainty in geotechnical parameters (Jones *et al.*, 2002; Uzielli *et al.*, 2007). As such, it becomes imperative to carefully and completely investigate the properties of soil on a proposed project site before decisions on the type of structures to be constructed are made (Griffiths and Fenton, 2001; Agapetus, 2010).

Geostatistics alongside classical statistics have been reportedly used by engineers to describe spatial patterns in soil behavior and to predict the values of soil properties at unsampled locations by a set of statistical tools (Junior *et al.*, 2006). Existing statistical analysis in geotechnical projects which uses univariate and bivariate analyses does not account for the spatial variability present in the soil properties. In earlier studies conducted by researchers using conventional statistics, the measured soil property values on the field were typically described by a normal distribution (Hammah and Curran 2006; White *et al.*, 2008). However, this distribution did not offer any information on which zones were likely to have high values and which zones had low values. Like in Abdulfatah *et al.* (2016) where soil samples collected at 1m and 1.5m depths from five pits 500 m apart were analyzed for their properties in order to check variation with depths across the study area. Measure of dispersion, "Range", was used to analyse the results obtained and it showed variation between 18.8% and 100%. This necessitated the requirement for detailed soil investigation at any site around the sampled pits. Also, in Sule *et al.* (2021) disturbed soils at depth 1m from



four pits along Jos-Makurdi road in Nigeria were investigated for their index properties, the results were analysed by direct comparison of values for the tests conducted on soils from the pits to show locations with better properties.

Coefficient of variation which is obtained by dividing the samples' standard deviation by the samples' mean provides a concise measure of the relative dispersion of data around the central tendency estimator. For simplicity reason, the coefficient of variation is commonly used in geotechnical variability analyses. The advantages are that it is dimensionless and provides a more physically meaningful measure of dispersion relative to the mean. They are thought to be independent of the geological age of the soil and allows use of literature values with some confidence even at sites for which little or no data may be available (Phoon and Kulhawy, 1999). As a rule of thumb, Harr (1987) maintained that coefficients of variation below 10% are considered to be "low", between 15% and 30%; "moderate", and greater than 30%; "high". According to the ACI (1965) the coefficient of variation less than 10% is termed "Excellent", between 10% and 15% is termed "Good" and between 15% and 20% is "Satisfactory" and greater than 20% is termed "Poor".

Owoyemi and Adeyemi (2017) studied the index and engineering properties of two residual lateritic soils 15m apart underlain by different bed rocks (Sandstone and Migmatite-gneiss) forming the subgrade of a failed section of a flexible highway pavement between Ilorin and Mokwa in North-Central Nigeria. Variations in the test results from sixty-four samples collected in a grid pattern at 5m interval by coefficient of variation showed soils on sandstone varying more than those on Migmatite-gneiss. Oyedirin and Durojaiye (2011) also investigated the variability in the geotechnical properties of some residual clay soils from Southwestern Nigeria by exploring eight samples from two test pits at 30m apart at depths of 0.5m to 2.0m. Laboratory tests results on the samples were analysed using T-test and coefficient of variation. T-test analysis showed significant differences only in the maximum dry density while coefficient of variation showed variation of 16.16% for percentage clay fractions only, which by T-test does not vary. Kasama *et al.* (2012) in a similar work with Navin and Filz (2005) showed that higher

strength is feasible when grounds are treated with cement and coefficient of variation of 14% to 99% can exist when core samples obtained from a series of construction projects cured in the field are tested for their unconfined compressive strength. Kulhawy *et al.* (1991) showed that coefficient of variation between 9-13% can exist in natural moisture content, 3-19% can exist in liquid limit, 7-17% can exist in plastic limit and 16-61% can exist in undrained shear strength of soils located at different depth of a soil profile.

As at now, in terms of structures, Nigerian Defence Academy (NDA) Afaka-Mando Kaduna, in Northwestern Nigeria is not fully developed. As such, there is need for new and diverse structures to accommodate the expected population growth. Generally speaking, site specific soil tests are compulsory before any structure is designed or constructed. However, general idea of the physical properties of soil at different locations for a given depth at NDA Afaka, can serve as a useful guide and pointers to engineers and NDA managements in deciding the type of structures to be constructed at a given depth of a particular area. This work aims at investigating the variability of soil properties with horizontal locations at NDA Afaka-Mando Kaduna.

MATERIALS AND METHODS

The study conducted at the Nigerian Defence Academy Afaka-Mando Kaduna, Nigeria located at latitude 10°36'45.09" N and longitude 7°22'38.97" E involved the usage of many materials and equipment in field collection of samples and determining the index and engineering properties of the collected samples with the ultimate aim of determining the variations in the properties of the samples.

Materials

The materials used in this work include;

1. *Soil Samples*: Soil samples obtained at and around the Civil Engineering department of the Nigerian Defence Academy Afaka-Mando Kaduna, Nigeria were used for this work.
2. *Global Positioning System (GPS)*: GPS camera compass S8 application installed on Tecno LD7 Android mobile phone was used to take coordinates and elevations of the sampled points used in this work.



Methods

The following methods were used in this study:
 Sample Collection

Disturbed soil samples were collected in March 2021 when the rainy season was just beginning, in a grid scheme field observation from six (6) borrow pit points located at 500 m radius around the Civil Engineering department of Nigerian Defence Academy Afaka-Mando Kaduna, Nigeria. Three samples were collected using diggers, shovel and trowel from each borrow pits at 0.5m, 1.0m and 1.5m depths (total of 18 samples). The samples were pulverized and collected into polythene bags to preserve their moisture content. They were immediately taken to the Civil Engineering laboratory at NDA Afaka where their properties were investigated.

Sample Characterization

In order to classify and identify the samples collected at the various depths (D) of the borrow pits, the following tests were conducted on them according to the provisions of BS 1377 (1990): The specific gravity (Gs), the natural moisture content (w), particle size distribution; PSD (Percentage Gravel; %G,

Percentage Sand; %S and Percentage Fines; %F), the consistency limits (liquid limit; LL and Plastic limit; PL), compaction parameters (Maximum Dry Density; MDD and Optimum Moisture Content; OMC) and the unconfined compressive strength (UCS).

Samples Classification and Variation

The results of the laboratory tests conducted on the samples at the various depths were used to classify them according to USCS (1985) and AASHTO (1986). Averages (AVG), Standard Deviations (STD), Coefficient of variations (COV) and one factor analysis of variance (ANOVA) were carried out on the results values using Microsoft Excel 2016 to show the magnitude of variations between the values and prove the hypothesis (H₀): that at 5% significance level, no significant differences in the result values of the investigated soil property or parameter with horizontal location in the study area respectively.

RESULTS AND DISCUSSIONS

The results and analysis of all the laboratory experiments carried out on the samples are summarized into tables and discussed.

Table 1. GPS Location Details of Sampled Points

Designation	Physical Feature	Latitude	Longitude	Elevation
A	Civil Engineering	10°36'52.243"N	7°22'25.436"E	619.8m
B	Officers' Quarters	10°36'35.076"N	7°22'32.586"E	608.4m
C	Training Ground	10°36'46.212"N	7°22'16.152"E	640.1m
D	Cadets Mess	10°36'59.551"N	7°22'17.981"E	653.9m
E	Fire Service	10°36'46.975"N	7°22'37.277"E	621.1m
F	PG school Site	10°36'59.570"N	7°22'39.149"E	639.9m

Table 2. Variation of Properties with Depths at the Sampled Points

D (m)	Point	Gs	W (%)	PSD			Consistency (%)		Compaction		UCS (kN/m ²)	AASHTO
				%G	%S	%F	LL	PL	OMC (%)	MDD (kg/m ³)		
	A	2.64	14.98	0.6	28.9	70.5	42.3	29.9	19.31	1.69	198.3	A-7-6
	B	2.54	16.11	1	26.7	72.3	44.3	29.7	18.22	1.68	220.95	A-7-6
	C	2.57	17.01	1.1	11.1	87.8	41.1	28.8	19.01	1.67	258.51	A-7-6
0.5	D	2.43	16.9	6.1	13.2	80.7	40.9	29.4	20.15	1.68	232.56	A-7-6
	E	2.4	18.52	19.4	23.0	57.6	42.1	29.2	20.94	1.68	212.83	A-7-6
	F	2.49	16.54	0.8	28.1	71.1	40.9	28.7	20.04	1.66	226.73	A-7-6
	AVG	2.51	16.68	4.83	21.8	73.3	41.9	29.3	19.61	1.68	224.98	A-7-6



	ST.D	0.09	1.16	7.44	7.80	10.3	1.31	0.47	0.96	0.01	20.30	
	COV	3.57	6.98	154	35.7	14.0	3.12	1.61	4.91	0.62	9.02	
1.0	A	2.6	15.01	0.5	21.7	77.8	42.5	29.0	17.54	1.7	190.44	A-7-6
	B	2.6	17.43	3.1	34.1	62.8	39.9	28.1	17.65	1.79	236.45	A-7-6
	C	2.59	16.44	0.5	15.1	84.4	43.0	27.2	19.39	1.68	218.28	A-7-6
	D	2.45	17.67	6.0	14.3	79.7	41.1	28.9	20.14	1.69	210.35	A-7-6
	E	2.44	19.56	15.7	24.9	59.4	43.0	30.0	20.65	1.66	201.55	A-7-5
	F	2.5	16.34	1.4	27.3	71.3	39.4	27.2	19.79	1.74	207.95	A-7-6
	AVG	2.53	17.08	4.53	22.9	72.6	41.5	28.4	19.19	1.71	210.84	A-7-6
	ST.D	0.08	1.54	5.85	7.55	9.89	1.60	1.12	1.31	0.05	15.64	
	COV	3.00	9.02	129	33.0	13.6	3.85	3.93	6.80	2.77	7.42	
1.5	A	2.61	17.37	0.8	26.8	72.4	42.0	29.9	17.36	1.69	159.39	A-7-6
	B	2.55	17.88	2.1	23.9	74.0	43.2	29.4	18.52	1.71	188.29	A-7-6
	C	2.61	18.34	1.2	14.0	84.8	43.7	24.6	19.79	1.65	203.1	A-7-6
	D	2.52	17.92	5.4	16.6	78.0	41.5	29.9	20.17	1.68	206.34	A-7-6
	E	2.48	20.05	18.1	23.6	58.3	41.5	29.9	20.29	1.66	198.9	A-7-6
	F	2.46	19.51	2.0	24.1	73.9	42.5	29.6	20.04	1.67	193.34	A-7-6
	AVG	2.54	18.51	4.93	21.5	73.6	42.4	28.9	19.36	1.68	191.56	A-7-6
	ST.D	0.06	1.04	6.65	5.01	8.72	0.92	2.12	1.17	0.02	17.05	
	COV	2.51	5.64	135	23.3	11.9	2.16	7.34	6.06	1.29	8.90	

Table 3. Summary of Single Factor ANOVA on Result Values

S/NO.	DATA	F CALCULATED	F CRITICAL	HYPOTHESIS STATUS
1	Gs	0.291554	3.68232	REJECT H ₀
2	W (%)	3.481308	3.68232	REJECT H ₀
3	%G	0.005829	3.68232	REJECT H ₀
4	%S	0.067384	3.68232	REJECT H ₀
5	%F	0.017666	3.68232	REJECT H ₀
6	LL (%)	0.712019	3.68232	REJECT H ₀
7	PL (%)	0.570965	3.68232	REJECT H ₀
8	OMC (%)	0.199086	3.68232	REJECT H ₀
9	MDD (kg/m ³)	2.369668	3.68232	REJECT H ₀
10	UCS (kN/m ²)	5.346787	3.68232	ACCEPT H ₀



Specific Gravity (Gs)

The results of the specific gravity from Table 2 show variations with horizontal location at a given depth in the study area. The values range from 2.40 to 2.64, 2.44 to 2.6 and 2.46 to 2.61 at depths 0.5 m, 1.0 m and 1.5 m with low/excellent coefficient of variations; 3.57%, 3.00% and 2.51% respectively (Harr, 1987; ACI, 1965). This implies that a value within this range can be assumed for soils at their respective depths below the ground surface and not more than 500 m from any of the sampled points. Statistically, from Table 3 there is no evidence to accept the hypothesis; at 5% significance level, there is no significant difference in the specific gravity of soils with horizontal location in the study area since F calculated was lower than F critical. This shows that the soil at different locations tested are constituted of different materials makeup.

Natural Moisture Content (W)

The results of the natural moisture content from Table 2 show variations with horizontal location at the given depth in the study area. The values range from 14.96% to 18.52%, 15.01% to 19.56% and 17.37% to 20.05% at depths 0.5 m, 1.0 m and 1.5 m with a low/Excellent coefficient of variations; 6.98%, 9.02% and 5.64% respectively (Harr, 1987; ACI, 1965). This variation agrees with Abdulfatah *et al.* (2016) and Kulhawy *et al.* (1991) and implies that a value within the range obtained for the natural moisture content may be used for soils at their respective depths below the ground surface and not more than 500 m from any of the sampled points. Statistically, from Table 3 there is no enough evidence to accept the hypothesis; at 5% significance level, there is no significant difference in the natural moisture content of soils with horizontal location in the study area since F calculated was lower than F critical. This variation could be attributed to the topography of the area and closeness to water body as locations at lower elevations and close to the stream at NDA Afaka have higher natural moisture content than those at higher elevations or far from water bodies.

Particle Size Distribution

The results of the particle size distribution (%G, %S and %F) from Table 2 show variations with horizontal location at a

given depth in the study area. The values at depths 0.5 m, 1.0 m and 1.5 m respectively range from 0.6% to 19.4%, 0.5% to 15.4% and 0.8% to 18.1% for gravel fractions (%G), 11.1% to 28.9%, 14.3% to 34.1% and 14.0% to 26.8% for sand fractions (%S) and 57.6% to 87.8%, 59.4% to 84.4% and 58.3% to 84.8% for fines fractions (%F) with their coefficient of variations; 154%, 129% and 135% respectively (high/poor), 35.7%, 33.0% and 23.3% respectively (high/poor) and 14.0%, 13.6% and 11.9% respectively (good) respectively (Harr, 1987; ACI, 1965). Agreeing with Abdulfatah *et al.* (2016) and Kulhawy *et al.* (1991), a value within the range for the gravel fractions cannot be assumed for soils at their respective depths below the ground surface and within 500 m from any of the sampled points. Those for sands and fines may and can be used respectively. Statistically, from Table 3 there is no evidence to accept the hypothesis; at 5% significance level, there is no significant difference in the gravel, sand and fines fractions of the soils with horizontal location in the study area since Fs calculated were lower than Fs critical for all the fractions. This also shows that because of the different degrees of weathering at different elevations in the study area, soils of similar proportions of different sizes of grains exist at a given depth for different locations in the study area.

Consistency Limits

The results of the consistency limits (LL and PL) from Table 2 show variation with horizontal location at a given depth in the study area. The values at depths 0.5m, 1.0m and 1.5m respectively range from 40.9% to 44.3%, 39.4% to 43.0% and 41.5% to 43.7% for liquid limit (LL) and 28.7% to 29.9%, 27.2% to 30.0% and 24.6% to 29.9% for plastic limit (PL) with their coefficient of variations agreeing with Kulhawy *et al.* (1991); 3.12%, 3.85% and 2.16% respectively (low/excellent) for LL and 1.61%, 3.93% and 7.34% respectively (low/excellent) for PL (Harr, 1987; ACI, 1965). Comparing well with Kulhawy *et al.* (1991) and Abdulfatah *et al.* (2016) this implies that a value within the range for both parameters can be assumed for soils at their respective depths below the ground surface and not more than 500 m from any of the sampled points. Statistically, surprisingly from Table 3 there is no enough evidence to



accept the hypothesis; at 5% significance level, there is no significant difference in the consistency limits of the soils with horizontal location in the study area since F_s calculated were lower than F_s critical for both parameters. This could mean be attributed to the variations in the elevations of the different locations of sample points or proximity to water bodies which reduces the effects of drawdown of the water table.

Compaction Parameters

The results of the compaction parameters (OMC and MDD) from Table 2 show variations with horizontal location at a given depth in the study area. The values range from 18.22% to 20.94%, 17.54% to 20.65% and 17.36% to 20.29% for optimum moisture content (OMC) and 1.66kg/m³ to 1.69kg/m³, 1.66kg/m³ to 1.79kg/m³ and 1.65kg/m³ to 1.71kg/m³ for maximum dry density (MDD) with their coefficient of variations; 4.91%, 6.80 and 6.06% respectively (low/excellent) for OMC and 0.62%, 2.77 and 1.29% respectively (low/excellent) for MDD (Harr, 1987; ACI, 1965). This implies that a value within the ranges for both parameters can be assumed for soils at their respective depths below the ground surface and not more than 500 m from any of the sampled points. Statistically, from Table 3 there is no enough evidence to accept the hypothesis; at 5% significance level, there is no significant difference in the compaction parameters of the soils with horizontal location in the study area since F_s calculated were lower than F_s critical for both parameters.

Unconfined Compressive Strength (UCS)

The results of the unconfined compressive strength from Table 2 show variations with horizontal location at a given depth in the study area. The values range from 198.3kN/m² to 258.51kN/m², 190.44kN/m² to 236.45kN/m² and 159.39kN/m² to 206.34kN/m² with low/excellent coefficient of variations; 9.02%, 7.42 and 8.90% respectively (Harr, 1987; ACI, 1965). However, this low coefficient of variation which does not agree completely with Kulhawy *et al.* (1991) where undrained shear strength was investigated, suggests that a value within the range obtained for the UCS can be used for soils at their respective depths below the ground surface and not more than 500 m from any of the sampled points. Statistically from Table 3, there is

enough evidence to accept the hypothesis; at 5% significance level, there is no significant difference in the UCS of soils with horizontal location in the study area since F calculated was higher than F critical. From the results, the UCS was observed to be averagely the same at a given depth in the different locations of the study area. This could be due to the similarity in the laterization process of the soils in the area.

CONCLUSIONS

The variations in the specific gravity, natural moisture content, particle size distribution, consistency limits, compaction parameters and unconfined compressive strength of residual soils at NDA Afaka-Mando Kaduna, Nigeria with horizontal locations were investigated and the results presented, analyzed and discussed.

From the study, it was concluded from the research that the soils in the sampled area at NDA Afaka-Mando Kaduna, Nigeria are generally clayey sand with little gravel. These soils are not suitable as sub-base materials but can be fairly used as subgrade materials in areas not subjected to frost action. The particle size distribution varies significantly with horizontal locations at NDA Afaka-Mando. The specific gravity, natural moisture content, liquid limits, plastic limits, optimum moisture content, maximum dry densities and the unconfined compressive strengths do not vary significantly with horizontal locations at NDA Afaka-Mando.

It is recommended that soil properties at a location within NDA Afaka-Mando and at depth not exceeding 1.5m can be predicted from all the index properties except particle size distribution investigated for a soil in a neighboring location not exceeding 500 m away.

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