Geotechnical Properties and Classification of Some Soils Formed on Shale in Imo State, Nigeria

Adaobi.U.Onyechere[1], Emmanuel U. Onweremadu[2], Ignatius C. Onyechere[3]
[1,2]*Department of Soil Science and Technology, Federal University of Technology Owerri, Nigeria.*
[3]*Department of Civil Engineering, Federal University of Technology Owerri, Nigeria.*

***Abstract*- The study investigated geotechnical properties of soils along with other soil's properties and classified soils derived from Imo Clay Shale. Free soil survey technique was used in siting profile pits. The Ultimate Bearing Capacity was estimated from the Shear Strength values, using the ten soil samples from the two profile pits investigated. The objectives of this study was to utilize these geotechnical properties to classify soils of this region and to measure the degree of variation among soil properties. Results revealed the presence of gravel (19%-53%,). The Liquid Limit (56.6-65%) was higher than the Plastic Limit (21.0%-22.5%). Plasticity Index was between 35.6%-43.3%, Optimum Moisture Content 20%-34%, Maximum Dry Density 1.32%-1.50%, COLE 0.32-0.16, Volumetric Shrinkage 56.1-130.0, Shear Strength 72.32KN/m^2-80KN/m^2, Angle of Internal Friction 16.1^0-20.3^0, Cohesion 21.0KN/m^2-14KN/m^2 and Ultimate Bearing Capacity 303KN/m^2-326KN/m^2 was observed in soils analyzed. The soils were classified as VerticHapludult and TypicHapludult.**

Keywords- Geotechnical, lithologic, shale, bearing capacity, soils.

I. INTRODUCTION

The basic knowledge of the geology, the surrounding environment and the associated problems has been a major interest of study among scientists. This is important because if no secure and environmental friendly measures associated with development are carried out, several environmental problems are expected to occur ([12], [9], [15], [34]). Among all the factors that control the formation of soil, lithologic or parent material appears to exert the most dominating influence on soil properties when compared to other pedological factors ([20], [7], [5], [6]). The production of important information needed for planning and for initiating necessary environmental management programme to reduce potential negative effects is very crucial for sound environmental sustainability ([34]).Geotechnical information are expedient in making sure that the effects of projects on the environment and natural resources are properly estimated and adverse effects on them moderated where necessary ([22]).

Shale displays a wide spectrum of geotechnical behaviour and has often been a cause for concern on environmental and geotechnical issues and thus shale, most often, is regarded as problem materials ([2]). These problems possessed by shales in shaley terrains of the world are, in most cases, being influenced by mineralogy, especially the sedimentary attributes, predominant clay mineral type(s) ([33], [24], [14]) as well as the climate and physiography of the area under consideration ([17]).

II. MATERIALS AND METHODS

A: Study Area

The study was carefully carried out at two different locations which are underlain by the lithologic material, shale in Imo State, Nigeria. A reconnaissance study was first of all carried out followed by soil samples collections from areas underlain with the lithologic material with the help of geology map. Free survey technique was used for sampling at the sites. The study sites and profile pits were georeferenced with a hand held Global Positioning System (GPS) receiver. The coordinate of the first location was 5^{0}47.830'N, 7^{0}17.55'E with elevation of 107m and gentle slope feature, the second location has a coordinate of 5^{0}47.073'N, 7^{0}14.917'E with elevation 106m and a gentle slope feature. A profile pit was dug at each location and described in line with to FAO guidelines for soil description ([18])and soils sampled according to the genetic horizons from the bottom layer to the topmost layer and criteria for delineation include softness, presence of root, colour and presence of macro fauna.

B: Laboratory Analyses

The soil samples collected were first of all air dried and pulverized in order to reduce the effect of clods. Then samples for grain size analysis and shear strength determination were separated out. Soils for compaction test were sieved with 4.75 mm sieve. Soil samples for Atterberg limits were sieved with 425µm sieve and 2mm sieve was use to sieve the rest for other soil routine analysis. Routine analytical methods was used to determine the physical and chemical properties of the soil samples. The geotechnical properties of soil analyzed included compaction characteristics, grain size distribution analysis, shear strength characteristics, ultimate bearing capacity, Atterberg limits, COLE and volumetric shrinkage. The wet density and the dry density of the soils were determined with the help of Protor Mould and Rammer. Compaction was effected in three layers, each being given 25 blows. The soil samples were passed through sieves of various sizes and the grains of soils retained in each sieve were weighed. The fines where determined using Hydrometer method. Shear Strength, angle of internal friction and the cohesion were determined by the method of shear box test ASTM D2487-11 (2000) specifications. The general bearing capacity equation applied in the study was that given by Terzaghi and Meyerhof ([14]). Atterberg limits were determined using Cassagrande method and plasticity index (PI) was calculated as liquid limit minus plastic limit ([19]) in accordance to clause 4.5 and 5.3 part 2 of BS 1377 and BS 1990, respectively. The coefficient of linear extensibility (COLE) was calculated as described by ([31)**.** Volumetric shrinkage (VS) was calculated from the COLE.

III. RESULTS AND DISCUSSIONS

Results

Results of the morphological properties, physical properties, chemical and geotechnical properties of the soils studied were shown in Tables I, II, III and IV.

TABLE I: MORPHOLOGICAL PROPERTIES OF SOILS STUDIED

Pedon ID	**Depth (cm)**	**Horizon**	**Moist Colour**	**Textural Class**	**Structure**	**Consistency**	**Mottle**
				Imo clay shale (Amuro)			
A1	**0-10**	A	2.5YR$^4/_1$	Sandy clay	1graf	Firm	-
A2	**10-31**	AB	5YR$^5/_6$	Sandy clay	2sbkf	Firm	-
A3	**31-65**	BA	2.5YR$^7/_2$	Clay	2msf	v.firm	present
A4	**65-98**	Bg_1	2.5YR$^8/_4$	Clay loam	2msf	e.firm	present
A5	**98-150**	Bg_2	10R$^7/_1$	Sandy Clay loam	2msf	e.firm	present
				Imo clay shale(Umuna)			
U1	**0-8**	A	2.5YR$^{2.5}/_2$	Loamy sand	1crm	Friable	-
U2	**8-26**	AB	5YR$^4/_4$	Sandy loam	2bkm	Firm	-
U3	**26-60**	Bt_1	7.5YR$^4/_6$	Sandy clay loam	3sbk	v.firm	-
U4	**60-87**	Bt_2	7.5YR$^5/_6$	Sandy clay loam	3sbk	v.firm	-
U5	**87-110**	Bt_3	7.5YR$^5/_6$	Sandy clay loam	3sbk	v.firm	-

Structure; 0- structureless, 1- weak, 2- moderate, 3- strong, gr- granular, cr- crumb, bk- blocky, ms- massive, f- fine, m- medium, c- coarse. Consistency; v- very, e- extremely.

TABLE II: PHYSICAL PROPERTIES OF SOILS UNDERLAIN BY SHALE

Pedon ID	Depth (cm)	Horizon	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)	Silt:Clay Ratio	Textural Class	Moisture Content (g/kg)	Porosity (g/kg)	Bulk density (Mg/m^3)
					Amuro					
A1	0-10	A	560.8	80	359.2	0.22	Sandy clay	297	615	1.02
A2	10-31	AB	476.8	100	433.2	0.23	Sandy clay	160	589	1.09
A3	31-65	BA	416.8	140	443.2	0.31	Clay	326	577	1.12
A4	65-98	Bg_1	440.8	160	399.2	0.4	Clay loam	331	574	1.13
A5	98-150	Bg_2	500.8	160	339.2	0.47	Sandy Clay loam	353	513	1.29
		Mean	**479.2**	**128**	**394.8**	**0.33**		**293.4**	**573.6**	**1.13**
		CV	**11.7**	**28.4**	**11.5**	**32.9**		**26.3**	**65.4**	**8.8**
		CV Ranking	*	**	*	**		**	***	*
					Umuna					
U1	0-8	A	840.8	40	119.2	0.33	Loamy sand	174	542	1.21
U2	8-26	AB	740.8	100	159.2	0.63	Sandy loam	156	479	1.38
U3	26-60	Bt_1	640.8	100	259.2	0.38	Sandy clay loam	191	467	1.41
U4	60-87	Bt_2	656.8	80	263.2	0.3	Sandy clay loam	217	449	1.46
U5	87-110	Bt_3	580.8	100	319.2	0.31	Sandy clay loam	242	464	1.42
		Mean	**692**	**84**	**224**	**0.39**		**196**	**480.2**	**1.38**
		CV	**14.4**	**31.0**	**36.7**	**35.3**		**17.4**	**7.5**	**7.0**
		CV Ranking	*	**	**	***		**	*	*

Legend: CV-Coefficient of Variation, *- Low variation, **- Medium Variation, ***- High Variation

TABLE III: CHEMICAL PROPERTIES OF SOIL

Pedon ID	Depth (cm)	pH (H_20)	O.C	O.M	Total N	Avai. P	Al^{3+}	H^+	TEA	Ca	Mg	Na	K	TEB	ECEC	Al Sat	BS
				(g/kg)		(mg/kg)					(CMol/Kg)					(g/Kg)	
								AMURO									
A1	0-10	6.3	1.81	3.12	0.156	12.88	1.12	0.72	1.84	2.00	1.20	0.08	1.5	4.78	6.62	16.9	72.2
A2	10-31	6.4	1.31	2.26	0.113	15.61	6.72	2.40	9.12	2.10	1.46	0.15	0.1	3.81	12.93	51.9	29.5
A3	31-65	6.4	1.13	1.95	0.098	13.79	7.12	2.12	9.24	1.60	0.50	0.19	0.7	2.99	12.23	58.2	24.4
A4	65-98	6.8	0.93	1.60	0.080	12.60	1.92	6.92	8.84	2.24	1.44	0.18	0.9	4.76	13.60	14.1	35.0
A5	98-150	6.9	0.93	1.60	0.080	13.93	12.0	0.76	12.84	2.35	1.56	0.32	1.2	5.43	18.27	65.6	29.7
	Mean	**6.56**	**1.22**	**2.1**	**0.1**	**13.8**	**5.8**	**2.6**	**8.4**	**2.1**	**1.2**	**0.18**	**0.9**	**4.35**	**12.7**	**41.3**	**38.2**
	CV	**4.1**	**29.8**	**29.9**	**29.8**	**8.6**	**76.7**	**98.3**	**47.8**	**14.0**	**34.9**	**47.5**	**60.3**	**22.0**	**32.6**	**58.3**	**50.8**
	Ranking	*	**	**	**	*	***	***	***	*	**	***	***	**	**	***	***
								UMUNA									
U1	0-8	6.5	1.25	2.16	0.108	13.09	0.40	0.92	1.32	0.46	0.21	0.08	1.1	5.43	6.75	5.9	80.0
U2	8-26	6.2	1.09	1.88	0.094	12.74	2.00	1.52	3.52	1.15	1.73	0.10	0.6	3.58	7.10	28.2	50.4
U3	26-60	6.5	0.87	1.50	0.075	13.93	3.92	0.48	4.40	1.01	0.59	0.05	1.3	2.95	7.35	53.3	40.1
U4	60-87	6.6	0.85	1.47	0.074	11.76	0.72	1.08	1.80	0.37	0.30	0.09	2.4	3.16	4.96	14.5	61.6
U5	87-110	6.6	0.81	1.40	0.070	7.84	3.64	1.25	12.84	0.94	0.50	0.10	1.1	2.64	7.53	48.3	35.1
	Mean	**6.5**	**0.97**	**1.7**	**0.08**	**11.9**	**2.2**	**1.1**	**3.2**	**0.79**	**0.67**	**0.08**	**1.3**	**3.6**	**6.7**	**30.0**	**53.4**
	CV	**2.5**	**19.3**	**19.4**	**19.3**	**20.1**	**75.8**	**40.7**	**49.4**	**44.3**	**92.1**	**24.7**	**51.3**	**31.1**	**15.3**	**68.9**	**33.7**
	Ranking	*	**	**	**	**	***	***	***	***	***	**	***	**	**	***	**

O.C- organic carbon, O.M- organic matter, N-nitrogen, P-phosphorus, TEA-Total Exchangeable Acidity, TEB- Total Exchangeable Base, ECEC- Effective Cation Exchangeable Capacity, BS-Base Saturation, Al Sat- Aluminium Saturation.

TABLE IV: GEOTECHNICAL PROPERTIES OF SOIL

Geotechnical Properties.	**Site Locations**	
	Amuro	**Umuna**
Liquid Limit(%)	65.5	56.6
Plastic Limit(%)	22.5	21
Plasticity Index(%)	43.3	35.6
Linear Shrinkage(%)	24	14
Maximum Dry Density(Mg/m^3)	1.32	1.5
Optimum Moisture Content(%)	34	20
Grain Size Distribution		
Sand(%)	16	48
Clay(%)	20	22
Silt(%)	11	11
Gravel(%)	53	19
COLE	0.32	0.16
Volumetric Shrinkage	130	56.1
Shear Strength (KN/m^2)	72.32	80
Angle of Internal Friction	16.1	20.3
Cohesion (KN/m^2)	21	14
Ultimate Bearing Capacity(KN/m^2)	303	326

COLE- Coefficient of Linear Extensibility

Results Discussions.

A: Soil Morphological Properties

Results of the morphological properties of the soils studied were shown in Table I.The soils in the study sites were characterized with the presence of dark colour at the surface

In soils at Umuna they are reddish brown to strong brown in colour and while those at Amuro are dark reddish brown at surface horizon with grey mottles in the subsurface horizon. These structural developments of soils form from shale were likely to be as a result of the clay content of the soils. The consistency of the soils ranged from firm to extremely firm

B: Physical properties

Sand-sized particles dominated other primary particles in the study sites. Sand fraction generally decreased down the profile while clay contents had irregular distribution, but were observed to increase with depth. [16] described this as clay migration by lessivage to produce the process of illuviation.Texture varied between sandy clay, clay, clay loam, loamy sand, sandy loam and sandy clay loam in soils. Texture has a deep influence on so many soil properties and italso affects the suitability of a soil for most uses [10].

Bulk densities of the soils increased with soil depth primarily due to less organic matter existing in the sub-surface horizons. The highest bulk densities values were found in the deepest horizons with corresponding low organic matter. [4] stated that low soil organic matter was responsible for increased bulk density in cultivated soils of Southeastern Nigeria. Several other authors have reported the significant influence of organic matter on soil bulk density ([3], [28]). Moreover, results of bulk densities obtain were less than the critical limits for root restriction (1.75 – 1.85 gcm^{-3}).Moisture content increased as depth increased and porosity declined down the profile due to the clay content which enters into the soil pores and blocks them thereby reducing the total porosity. As bulk density increases, the porosity decreases.

C: Chemical Properties

Selected chemical properties of the soils studied are presented in Table III. pH range of 5.6 to 6.5 provides the most satisfactory plant nutrient levels for most crops. Generally, organic carbon contents which translate into organic matter content decreased down the profile in all the pits. Higher proportion of organic matter was observed in the surface horizons of the soils studied. This could be due to the fact that most of the organic residues are incorporated or deposited on the soil surface. High quantity of organic matter reported in the surface soils could be explained by their dark colour and low bulk density of these horizons. Organic matter has been reported to have significant positive influence on soil pH, cation exchange capacity, colour, buffering capacity, base saturation and water holding capacity [4] and effective cation exchange capacity [25]. Total nitrogen ranging from 0.07g/kg to 0.15g/kg were obtained across the soils studied. When compared with the critical level of 2% (20 gkg-1) reported by [13] in soils of southeastern Nigeria, total nitrogen across the studied soils were rated low.

The values of the available P contents of the soils were rated low as values falls between the critical levels of 10 – 16 $mgkg^{-1}$[1]. Low level of available P may be due to removal through sedimentation ([23], [30]). Exchangeable calcium was noticed to be higher in the surface soil layers than in subsoil. The surface soil layers were muchmore richer in nutrient than the subsoils as commonly observed in soils of the tropics ([29], [21]).

D: Geotechnical Properties of Soil

Results of geotechnical properties are presented in Table IV.According to the ranking of compressibility using liquid limit by [31], the study site showed high compressibility (LL > 50%). [10] noted that high porosity of clay floccules and the flake-like shape of clay particles give clayey soils much greater compressibility. This is to say that clayey soils do not make excellent soil to bear foundation. The soils of the study sites also showed Plasticity index (PI) above 50%. Soils with plasticity index above 50% have high swelling potentials [26]. Linear Shrinkage was observed to be > 8% which showed critical degree of expansion [6b]. The grain size distribution showed the presence of gravel (53% in Amuro and 19% in Umuna) in soils of the study area. The presence of this rock fragment probably showed that shale, to an extent,is resistant to forces of weathering. The Coefficient of Linear Extensibility (COLE) observed in soils had COLE > 0.09, which falls within very severe Shrink-Swell hazard rating by [31]. This shrink and swell action can easily crack foundation, cause even heavy retaining walls to collapse, and also the soil becomes extremely sticky and difficult to work when they are wet [10]. Volumetric shrinkage was also very high (>30) in the soils [31].

Soils formed had shear strength of 72.32KN/m^2 – 80KN/m^2. The strength of soil describes the ultimate state of stress that it can sustain before it fails. Cohesion is the resistance due to forces tending to hold the soil particle together in a solid mass [31]. This is evident in the soils of the study area. The bearing capacity of soil determines the nature and type of foundation required to set up any structure.

E: Soil classification

Soils from Amuro were classified using USDA soil taxonomy as VerticHapludult, under World Reference Base (WRB),asVerticCambisols because of cambic horizon starting within 50cm from soil surface. Soil at Umuna were classified as TypicHapludult using USDA soil taxonomy and HaplicNitisols (WRB)

Unified Soil Classification

Soil at Amuro is classified as Coarse-Grained because > 50% was retained on sieve No 200with group symbol GC (Clayey Gravel). Soil at Umuna was classified as Coarse-Grained because > 50% was retained on sieve No 200 with group symbol SC (Clayey Sands).

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