Chemical, Physico-chemical and Geotechnical Properties of Lateritic Weathering Profile Derived from Granite Basement

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ABSTRACT

Disturbed and undisturbed soil samples were collected from a trial pit at depths of 0.5, 1.0, 1.5, 2.0, and 2.5 m. Chemical, physico-chemical and index properties tests were carried out on the disturbed samples while in-situ dry density and permeability tests were conducted on the undisturbed samples. California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) tests were carried out on specimens of the soil samples prepared at British Standard Light (BSL) and British Standard Heavy (BSH) compaction energy levels. Evaluation of the variation of chemical, physico-chemical and geotechnical properties of the lateritic weathering profile with depth were made. It was observed that the profile consist of a reddish pisolithic gravelly soil having a thickness of about 0.8 m between a light brownish silty to sandy soil from the top and a reddish fine lateritic soil bellow the horizon. Below this depth however, freshly decomposed granite base rock was encountered. The in-situ and recompacted dry densities as well as the natural and the optimum moisture contents increased to a depth of between 1.0 and 1.5 m after which the values decreased. The CBR and UCS values increased to a maximum of 106 % and 785 kN/m^2 respectively at 1.5 m depth after which the values decreased. Therefore, the chemical, physico-chemical and geotechnical properties of the lateritic weathering profile studied varied with depth and should not be treated as the same.

KEYWORDS: Weathering Profile; Physico-chemical; In-situ Density; Permeability; Unconfined Compressive Strength; California Bearing Ratio.

INTRODUCTION

Residual soils have been defined as soils having sesquioxide content of more than 15 % (Gidigasu, 1971). According to (Madu, 1975), residual soils occur in different forms in Nigeria and throughout tropical Africa. The most common residual soil profile is the lateritic weathering profile. These profiles have been defined as soil profiles in which lateritic horizons exists or are capable of developing under favorable conditions (Gidigasu and Kuma, 1987). The authors have categorized lateritic weathering profile into three major horizons below the humus stained top soil. These are the sesquioxide rich lateritic horizon (some times gravelly and/or hardened in-situ as crust). The second horizon is the mottled zone with evidence of enrichment of sesquioxide sand. The third horizon which overlies the parent rock is referred to as the pallid or leached zone and contains rocks suffering chemical and mineralogical changes, but retaining its physical appearance.

Many soil workers in Nigeria may treat lateritic weathering products and other residual soils as uniform with depth. This is because most works done on the geological study of lateritic weathering profiles in Nigeria are concentrated mainly on their distribution, classification, depth extent, nature and formation (Pugh and King, 1952; Du Preez, 1956; Pullan, 1967; Faniran, 1970; Burke and Durotoye, 1972; Faniran, 1972; Faniran, 1974; Faniran, 1978; Alao, 1983). Much work has also been done on the geotechnical properties of laterites and lateritic soils in Nigeria (Ola, 1978; Ola, 1980a; Ola, 1980b; Ola, 1983), but little has been done on the study of various weathering horizons and the variation of their characteristics with depth.

According to Gidigasu (1987) and Adekoya (1987) lateritic weathering products varies chemically, physico-chemically and geotechnically both vertically and horizontally. This work is therefore aimed at studying the variability with, of chemical, physico-chemical and geotechnical properties of a lateritic weathering profile derived from young granite basement of Minna.

LOCATION, CLIMATE AND GEOLOGY OF THE STUDY AREA

The trial pit studied was located in Bosso campus of Federal University of Technology, Minna, Niger State, Nigeria. The area lies between longitudes 6^0 E and 7^0 E and latitudes 9^0 N and 10^0 N. According to Wright (1989), the residual soil in this area is under laid by a granite basement and is surrounded to the north and south by older basement rocks of the Precambrian to upper Cambrian age and illo-group formation to the north-west. The area is drained by several rivers which are tributaries of river Niger.

Rainfall in this area varies considerably from station to station. The maximum rainfall per year varies from 1000 mm to 1500 mm for different locations.

METHODOLOGY

A trial pit was dogged to a depth of 2.5 m during which both disturbed and undisturbed soil samples were collected at depths of 0.5, 1.0, 1.5, 2.0 and 2.5 m. During digging, the soil profile was visually inspected. The disturbed samples were then air dried and chemical property tests including silicon oxide (SiO_2) and aluminum oxide (Al_2O_3) were carried out in soil science laboratory of Federal University of Technology, Minna using gravimetric method. Iron oxide (Fe_2O_3) and potassium oxide (K_2O) tests were conducted in National Research Institute for Chemical Technology (NARICT) Zaria, using the method of atomic absorption spectrometer. All the physico-chemical properties including pH, Cation Exchange Capacity (CEC) and organic matter were tested in Agricultural Research Institute, Ahmadu Bello University, Zaria.

Tests including Natural Moisture Content (NMC), washed sieved analysis, hydrometer analysis, Liquid Limit (LL), Plastic Limit (PL), Linear Shrinkage (LS), Specific Gravity (SG), compaction-British Standard Light (BSL) and British Standard Heavy (BSH) were carried out on each of the sample. Also included are California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) tests whose specimens were prepared at the predetermined Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) at the two energy levels.

All these tests were done in Civil Engineering Laboratory of Federal University of Technology, Minna in accordance with B. S. 1377 (1990) with modifications where necessary.

The undisturbed soil samples on the other hand were used to determine the In-situ Dry Densities (IDD) and coefficient of permeability (k) for all the samples.

RESULTS AND DISCUSSION

Visual Inspection

The weathering profile showed a light blackish top soil 0.2 m thick. This layer is followed by a light brownish silt soil to a depth of about 0.8 m. A reddish, pisolithic-gravelly soil followed to a depth of about 1.3 m after which the reddish soil turned fine with minimal pisolithic gravels to a depth of about 2.1 m. Freshly decomposed granite base rock was encountered beyond this depth to 2.5 m depth. The sketch is shown in fig. 1.

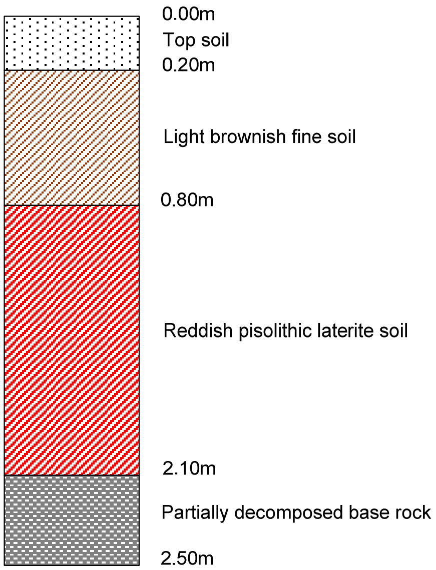

Figure 1: Schematic diagram of the soil profile

The variation of the chemical properties with depth in the lateritic weathering profile is shown in table 1. Generally, it is observed that percentage composition of Al_20_3 is higher, compared to the percentage composition of Fe_20_3. This indicates that the lateritic weathering profile is bauxitic in nature.

The Fe_20_3 content increased from 1.4 % at 0.5m depth to a maximum of 2.50 % at 1.0 m depth after which the values decreased to 0.10 % at 2.5 m depth. The higher percentage composition of Fe_20_3 recorded at 1.0 m depth is probably an indication of more matured laterite at that horizon.

The percentage compositions of potassium oxide are very low. The values range between a minimum of 0.03 % and a maximum of 0.15 %. This is in agreement with finding by Adekoya (1987) who reported very low base content in lateritic weathering profile.

Table 1: Variation of oxide compositions with depth

Depth (m)	Oxides Compositions				
	S_iO_2 (%)	Al_2O_3 (%)	Fe_20_3 (%)	K_20 (%)	$S_iO_2/Al_2O_3+Fe_20_3$
0.5	39.32	38.10	1.40	0.08	1.00
1.0	32.09	36.29	2.50	0.10	0.83
1.5	30.10	39.10	1.80	0.03	0.74
2.0	29.50	38.90	1.35	0.12	0.73
2.5	29.10	38.50	0.10	0.15	0.75

Physico-Chemical Characteristic

The variation of physico-chemical properties of the weathering profile with depth is shown in table 2. The pH of the soil profile increased from 6.5 at 0.5 m depth to a maximum of 7.0 at 2.0 m depth after which the value dropped to 6.8 at 2.5 m depth. This trend is in agreement with Gidigasu (1987) who had reported neutral to acidic medium ($pH \leq 7$) for lateritic soil medium. Organic carbon contents are highest at 0.5 m and 1.5 m depths with values of 0.16 and 0.14 % respectively. These values are very low and hence the characteristics of lateritic weathering profiles. The CEC increased from 4.9 meq/100g at 0.5 m depth to maximum of 11.2 meq/100g at 1.5 m depth. High value of CEC at 1.5 m depth where clay size particle is completely absent is anomalous. High value of organic matter content at that depth is probably responsible for the trend.

The $CaCO_3$ values are also highest (12.5 meg/100g) at 1.5 m depth. Hygroscopic moisture content at 0.3 bar increased from 0.095 at 0.5 m depth to maximum of 0.167 % at 1.5 m depth after which the value decreased to 0.134 % at 2.5 m depth. The highest value of $CaCO_3$, obtained at 1.5 m depth is probably due to substantial amount of organic matter content present at that depth.

Table 2: Variation of physico-chemical properties with depth

Depth (m)	Physico-Chemical Properties							
	pH		Percent Organic Carbon (%)	Cation Exchange Capacity (meq/100g)	Calcium carbonate (meq/100g)	Hygroscopic Moisture Content		
	In H_2O	In 0.01m $CaCl_2$				at 0.3 bar	at 10 bar	at 15 bar
0.5	6.50	6.20	0.16	4.90	10.50	0.095	0.076	0.054
1.0	6.50	6.30	0.04	6.90	11.50	0.144	0.111	0.055
1.5	6.60	6.00	0.14	11.20	12.50	0.167	0.106	0.060
2.0	7.00	6.50	0.10	4.20	11.00	0.164	0.102	0.051
2.5	6.80	6.20	0.04	5.90	12.50	0.134	0.097	0.053

Index Properties

The variation of index properties of the lateritic weathering profile with depth is shown in table 3. The corresponding classification of the soils in accordance with American Association for State Highways and Transportation Officers (AASHTO) is also shown.

Higher percentage of pisolithic gravels (19 %) was recorded at 1.0 m depth. This indicates that laterization is highest at that depth. Similarly, higher percentage of fine was obtained at 1.5 to 2.0 m depth. However, the hydrometer analysis revealed that all fine fractions recorded at depths from 1.5 m to 2.5 m are silt size particles and not clay size particles except at depths of 0.5 m and 1.0 m which contained clay size particles of 8 and 17 % respectively. The highest clay size particles recorded at 1.0 m depth is responsible for the higher shrinkage limit of 7.4 % and plasticity index (PI) of 13.8 % recorded at this depth.

Table 3: Variation of Index Properties with Depth

Depth	Index Properties									
(m)	Percent passing sieve sizes (%)				LL	PL	PI	LS	SG	AASHTO
	2.0 mm	0.425 mm	0.075 mm	0.002 mm	(%)	(%)	(%)	(%)		Classification
0.5	99.1	58.1	30.4	8.0	21.2	13.0	8.2	1.0	2.61	A -2- 4
1.0	81.2	44.5	30.0	17.0	31.8	18.0	13.8	7.4	2.58	A - 2 - 6
1.5	96.8	62.0	43.7	0.0	33.4	22.0	11.4	6.4	2.58	A – 6
2.0	98.2	67.4	44.8	0.0	34.0	25.0	9.0	6.0	2.62	A – 4
2.5	97.4	61.6	37.1	0.0	35.0	28.0	7.0	3.5	2.59	A - 4

Density Characteristics

The variations of the In-situ Dry Densities (IDD), Maximum Dry Densities (MDD) at BSL and at BSH are shown in fig. 2. The (IDD) values increased from 1.427 Mg/m^3 at 0.5 m depth to a maximum of 1.673 Mg/m^3 at 1.5 m depth after which the value decreased to 1.587 Mg/m^3 at 2.5 m depth. This trend is similar to (MDD) at BSL where the values increased from 1.85 Mg/m^3 at 0.5 m depth to a maximum of 1.930 Mg/m^3 at 1.0 m depth after which the value decreased to 1.825 Mg/m^3 at 2.5 m depth. However, a slight anomaly occurred for MDD at BSH where the value (2.03 Mg/m^3) at 1.0 m depth was a little lower than the value (2.056 Mg/m^3) at 0.5 m depth. This is probably due to higher percentage of clay particles present at 1.0 m depth which will require high water content during compaction against the higher energy level which will require lower water content to achieve the highest dry density. These two conflicting factors are probably responsible for lower MDD at 1.0 m depth compared to that at 0.5 m depth at BSH compaction energy level. Generally, the dry densities increased in the order IDD – MDD-BSL – MDD-BSH. This trend is in agreement with Adekoya (1987).

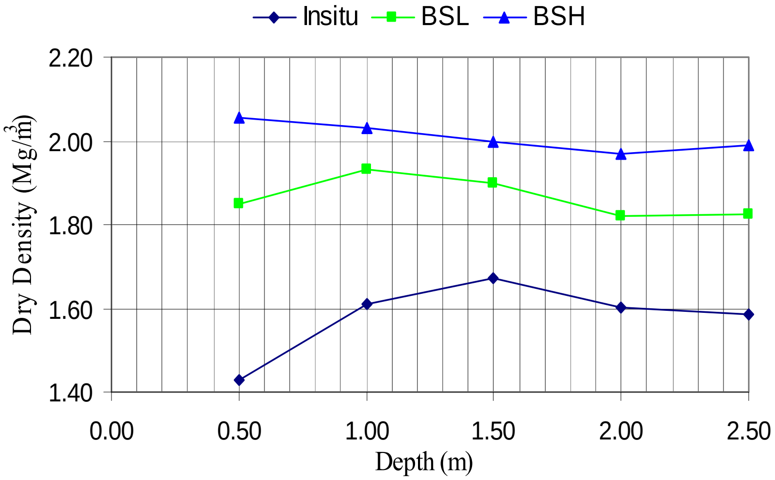

Figure 2: Variation of maximum dry density with depth

Moisture Content

The trend of the NMC, OMC-BSL and OMC-BSH are shown in fig. 3. The NMC increased from 5.5 % at 0.5 m depth to a maximum of 12.5 % at 2.0 m depth after which the value dropped to 9.8 % at 2.5 m depth. The trend probably resulted from surface water infiltration, whose effect is higher at 2.0 m depth. The water table may be far from this depth and its effect was not felt at 2.5 m depth hence a reduction of NMC at that depth.

OMC-BSL has minimum and maximum values of 10 % and 13.4 % respectively while that of OMC-BSH are 8.0 and 9.6 % respectively. Generally, OMC decrease with increase in compaction energy level which is in agreement with Osinubi (1998), Nigerian General Specification (1997) and Osinubi (2000).

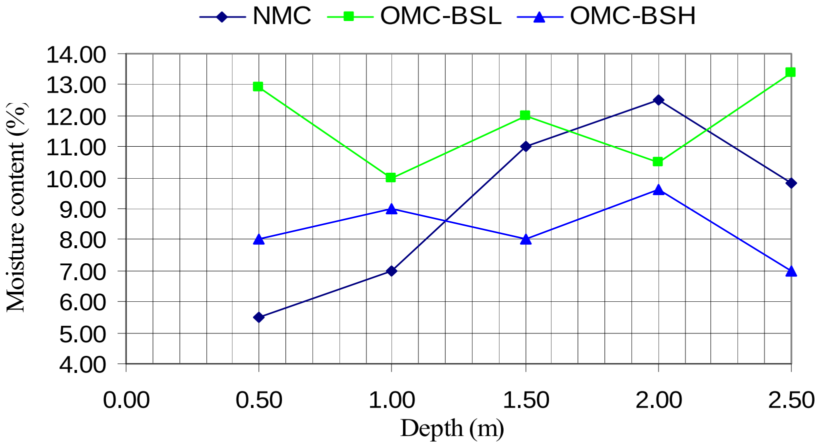

Figure 3: Variation of NMC and OMC with depth

California Bearing Ratio (CBR)

The CBR result reported here were averages taken for the top and bottom CBR values. The trends of the CBR values at the two energy levels are similar (fig. 4).

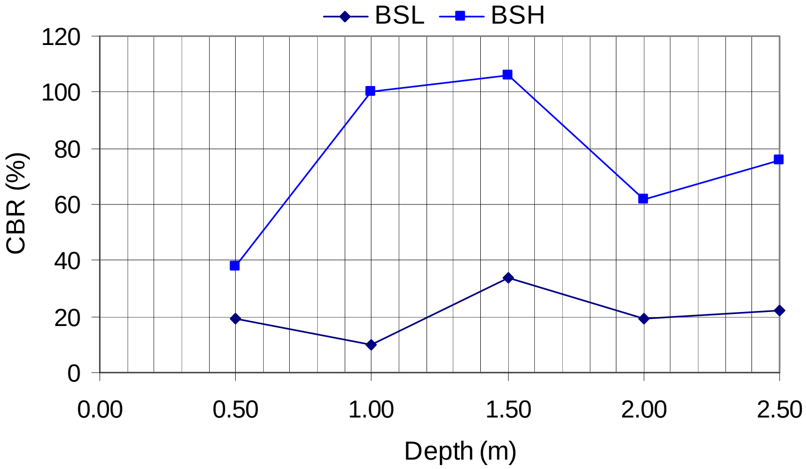

Figure 4: Variation of CBR with depth

At BSL compaction energy level, the CBR dropped from 18 % at 0.5 m depth to 10 % at 1.0 m depth, increased to a maximum of 34 % at 1.5 m depth after which it finally dropped to 22 % at 2.5 m depth. The value increased, for BSH compaction energy level, from 38 % at 0.5 m depth to maximum of 106 % at 1.5 m depth after which the value dropped to 76 % at 2.5 m depth. The initial decrease in CBR at BSL is attributed to higher amount of clay size particles couple with high amount of OMC in the soil matrix at 1.0 m depth which could reduce the stability when load is applied.

Unconfined Compressive Strength (UCS)

The variation of UCS at BSL and BSH with depth is shown in fig. 5. At BSL energy level, the value increased from 94 kN/m^2 at 0.5 m depth to a maximum of 412 kN/m^2 at 1.5 m depth after which the value decreased to 162 kN/m^2 at 2.5 m depth. Similarly, for specimens molded at BSH compaction energy level, the UCS value increased from 101 kN/m^2 at 0.5 m depth to a maximum of 785 kN/m^2 at 1.5 m depth and dropped to 172 kN/m^2 at 2.5 m depth.

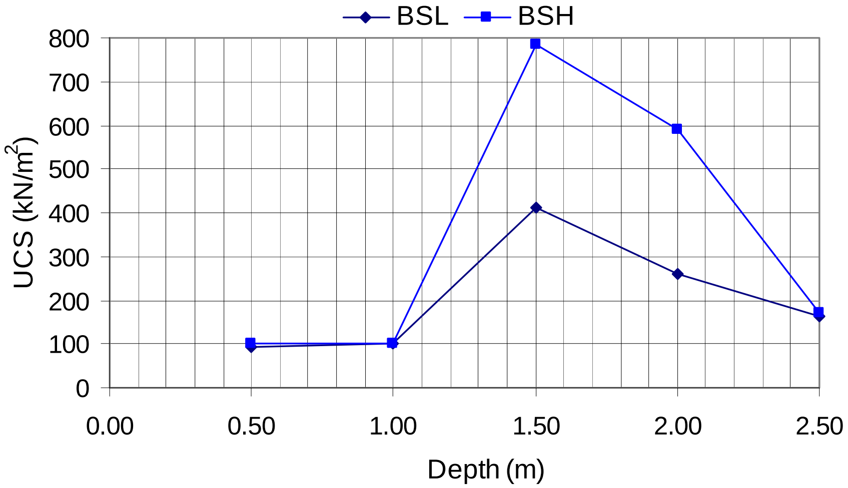

Figure 5: Variation of UCS with depth

Permeability Characteristics

Permeability test was performed on in-situ soil samples collected at the five layers during excavation. The trend of the coefficient of permeability (k) with depth shows decrease from 7.44x10^{-3} cm/s at 0.5 m depth to 4.36x10^{-3} cm/s at 2.0 m depth and increased thereafter to 5.45x10^{-3} cm/s at 2.5 m depth (fig. 6). The first decrease in the trend of coefficient of permeability values is probably due to pressure from the upper horizons on the subsequent lower horizons. The abrupt increase recorded at 2.5 m depth may be due to the presence of semi-decomposed parent rocks at that layer whose structure is loose compared to the upper layers.

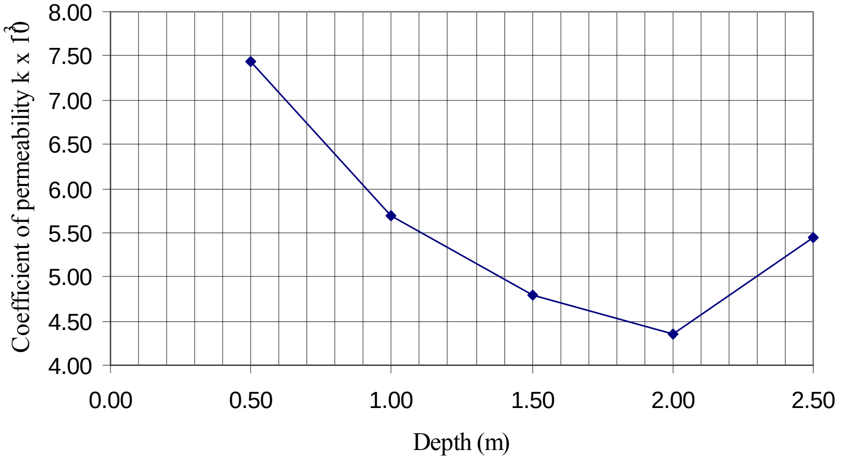

Figure 6: Variation of coefficient of permeability with depth

CONCLUSIONS

In conclusion, the result of the chemical composition of the lateritic weathering profile showed higher values of aluminum oxide content compared to the iron oxide contents. This shows that the laterite is bauxitic in nature. Also going by the definition of laterite using silicon-sesqueoxide ratio, all soil samples in the five horizons are laterite indicative. Physico-chemical properties like $CaCo_3$ and organic matter content are very low, similar to the characteristics of laterites studied in other regions. The pH values were acidic to neutral.

Texturally, the profile consist of a reddish, pisolithic gravelly soil having a thickness of about 0.8 m, between a light brownish silty to sandy soil from the top and a reddish fine lateritic soil bellow the horizon. Beyond this depth however, freshly decomposed granite base rock was encountered. The in-situ and re-compacted dry densities as well as the natural and optimum moisture contents increased to a depth of between 1.0 and 1.5 m after which the values decreased. Also, the CBR and UCS values at the two compaction energy levels increased to 106 % and 785 kN/m^2 respectively at the depth of 1.5 m, after which the values decreased. Going by Nigerian General Specification (1997), the soil at this depth can be used as base coarse material for low trafficked road bases. More so, the chemical, physico-chemical and geotechnical properties of the lateritic weathering profile in Minna varies with depth and should not be treated as the same.

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