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Geotechnical and Geochemical Properties of Lateritic Profile on Migmatite-Gneiss along Ogbomosho-Ilorin Highway, Southwestern Nigeria

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Abstract

Lateritic soils are very important in the construction industries and activities as construction material and foundation support for engineering structures in the tropical regions. This research tends to focus on the influence of position of horizon within the laterite soil profile and the resultant geotechnical and geochemical properties of soils developed over migmatite gneiss rock and also examine their suitability as construction and /or foundation material. A total of twenty three (23) soil samples and two rock samples were obtained from 8 different locations along Ogbomosho – Ilorin Highway, Southwestern Nigeria and considered under this study. The area is underlain by Basement Complex rock and migmatite gneiss is the most widely spread rock type. The laboratory test carried out includes specific gravity, grain size analysis, Atterberg limits (liquid limit, plastic limit, plasticity index and linear shrinkage), Standard proctor test, California Bearing Ratio (CBR), and Shear test. Geochemical analysis for major oxides and thin sectioning of rocks for petrological analysis was also carried out. The oxides are SiO_2, Al_2O_3, Fe_2O_3, K_2O, Na_2O, TiO_2, CaO and MnO while SiO_2, Al_2O_3 and Fe_2O_3 constitute about 70-80 % of the soils chemical composition. Petrology reveal strongly foliated rock that composed of mafic mineral such as biotite, hornblende, and felsic mineral consisting of quartz and feldspar. Quartz, biotite and feldspar constitute about 77% of the minerals with quartz having 40% of the total mineral composition. The position of the horizon within the soil profile was found to have varying influence on the plasticity, moisture density relationship, CBR, and shear strength. This study showed that the influence of the parent rock on engineering properties and the position of the horizon within the lateritic profile determine the engineering properties and behaviour of residual soils.

Keywords: Assessment, Laterite Soil, Migmatite-gneiss, Ogbomosho-Ilorin Highway, Southwestern Nigeria

1. Introduction

Lateritic soils are soils that are composed almost entirely of iron and aluminium oxides; they are usually reddish in colour and are the least soluble product of rock weathering in tropical climates (Plummer et al., 2001, Idris-Nda *et al*., 2010). They are formed in regions of high temperature and abundant rainfall, where the soils are highly leached as common in the tropics (Oke et al., 2009; Nwankwoala *et al*., 2015). Lateritic soils are very important in the construction industries and activities as construction material and foundation support for engineering structures (Nwankwoala and Amadi, 2013; Nwankwoala *et al*., 2014). According to Gidigasu (1976), because of the formation of distinct horizons and varying geochemical compositions within the lateritic soil profile, there is need to study the engineering characteristics of residual soils underlain by parent rocks as given in the migmatite gneiss terrain of Basement Complex which are predominant in the study area.

2. Materials and Methods

2.1 Study Area Description:

The study area is located along Ogbomosho-Ilorin road with Ogbomoso in Oyo State to the south and Ilorin in Kwara State to the north. The 30km road is situated on latitude 8˚ 26′ N (932395.306 m N), 4˚ 24′ E (654129.238 m E) and 8˚ 9′ N (901154.804 m N) and 4˚ 37′ E (678115.796 m E) and was commissioned in 2009 but already showing some signs of failure in some sections. The road trends on NNE – SSW with Ilorin in the north and Ogbomosho to the south (Figure 1). The topography of the study area is slightly undulating with rounded low hills, occasional often elongated ridges indicating the characteristics residue setting of a typical basement terrain with an average height ranging between 180-360m above sea level and average daily temperature greater than 25˚C. The rocks of this Basement Complex include granite gneiss, biotite gneiss, migmatite gneiss, porphyroblastic gneiss, pegmatite and quartz in which migmatite gneiss predominates (Figure 1). The superfacial deposit within the basement complex terrain varies in thickness from 4m to 8m and are mostly clayey loamy topsoil and dark sandy soil, usually less than 2m thick followed by reddish brown laterite soil in most cases.

Twenty three (23) disturbed soil samples were collected from seven different locations along Ogbomosho – Ilorin Highway and labelled appropriately (Plate 1 & 2). The seven sampled profiles and their horizons are shown in Table 1. The collected soil samples from each horizon of the profiles were analyzed at the soil mechanical laboratory of Civil Engineering Department, University of Ilorin, Ilorin. The soil samples were geotechnically tested according to the BS 1377 (1990) procedures. The geochemical analysis of soil samples and thin sectioning of rock samples were done at Nigerian Geological Survey Agency (NGSA) Laboratory, Kaduna.

3. Results and Discussion

3.1 Petrology

The migmatite gneiss is strongly foliated, composed of mafic minerals such as biotite, hornblende, and felsic minerals of quartz and feldspar. About 77% of the minerals are quartz, biotite and feldspar with quartz having 40% as the most dominating mineral. (Table 2) This compares favourably with the results obtained by Adeyemi and Ogundero (2001), Ige *et al*. (2010).

Table 2: Relative Proportion of Minerals in the Parent Rock

Mineral	Quartz	Biotite	Feldspar	Albite	Microcline	H/blende	Muscovite	Acces. mineral
%	40	25	12	3	6	6	5	3

3.2 Geochemical Studies

The geochemical analysis of two selected profile locations (L3-Aiyede and L6-Gambari) reveal that the major oxides are SiO_2, Al_2O_3, Fe_2O_3, K_2O, Na_2O, TiO_2, CaO and MnO Table 3. Three oxides SiO_2, Al_2O_3, and Fe_2O_3 constitute about 70-80%. The enrichment of Fe_2O_3 in each of the horizon can be attributed to chemical weathering of mafic mineral composition of the parent rock and ferruginization of Fe bearing minerals. Al_2O_3 enrichment increases from the topsoil down the profile with the SiO_2 behaving in similar manner (Table 3). This enrichment of Al_2O_3 can be attributed to the weathering alteration of feldspar to clay mineral (Elueze 2004), causing leaching of Al_2O_3 by infiltrating acid rain/recharge water into the ground. Oxides such as K_2O, Na_2O, MgO, Cao, V_2O_5 are decreasing down the profile due to leaching of the soil. TiO_2 also increases down the profile except in L6 where the value is more at the topsoil.

3.3 Geotechnical Studies

3.3.1 Specific Gravity

The value of specific gravity ranges between 2.50 – 2.74 with an average value of 2.72 (Table 4). According to Wright (1986), the standard range of value of specific gravity of soils lies between 2.6 and 2.80; these values are considered normal. The highest values of 2.74 was obtained at L6SP3 which is B horizon composed of lateritic concretions (hardpan) Plate 1.

3.3.2 Atterberg Consistency Limit

The liquid limit (LL) values range between 40 to 58% with an average of 49%; plastic limits (PL) range between 17 to 27% and plasticity index (PI) is between 17.5 to 35%. The Federal Ministry of Works and Housing (FMWH) recommends LL of 35%, PI of 12% as maximum for subgrade, and LL of 30% and PI of 12% as maximum for sub-base and LL of 30%, PI of 10% as maximum for base course. Plot of PI against LL shows that all samples fall within the CL zone, above A-line which classify the soil as inorganic soil (Figure 2).

3.3.3 Compaction Test

The maximum dry density (MDD) for the soil samples varied between 1.57 and 1.87g/cm^3 at standard proctor compaction energy while the maximum moisture content (OMC) range between 11.0 and 16.5% (Table 4). According to O'Flaherty (1979), Adeyemi and Ogundero (2001), Ogunsanwo (1988); MDD usually range between 1.76 and 2.16 mg/m^3 and OMC 8 – 15% for sandy clays which the gradation analysis of the soils confirmed. The decrease in MDD values of C horizons 1.68 (L1SP1) and 1.57 (L6SP4) while increase in OMC value in C horizons L1SP2 and L6SP4 are due high percentage of clay content in the mottled zone. However the values generally fall within the recommendation of previous researcher for purpose of fills in dams, building, and base course in road and liner in landfill.

3.3.4 California Bearing Ratio

All compacted samples show some differences in their soaked and unsoaked CBR values ranging between 17 and 66% for soaked and 42 and 74% for unsoaked. Federal Ministry of Works and Housing recommends for road works less than or equal to 10% for subgrade, 30% for sub-base and 80% for base course soil respectively. Thus, all the samples satisfy the condition for subgrade and sub-base material for road construction.

3.3.5 Shear Test

The angle of friction (ϕ) range between 22 - 32°, while the cohesion (C) range between 10 - 30KN/m^2. According to the Unified Soil Classification System (USCS) the results obtained from the shear box test can be use to classify the soils based on angle of internal friction. A soil having angle internal friction less than 20° are classified as soft, between 20 - 35° are classified as hard and above or greater than 35° are classified as stiff. The shear box test shows that the soils are of high strength (Table 4) as they compare favourably with values of other authors Ogunsanwo (1989), Alao (1983)

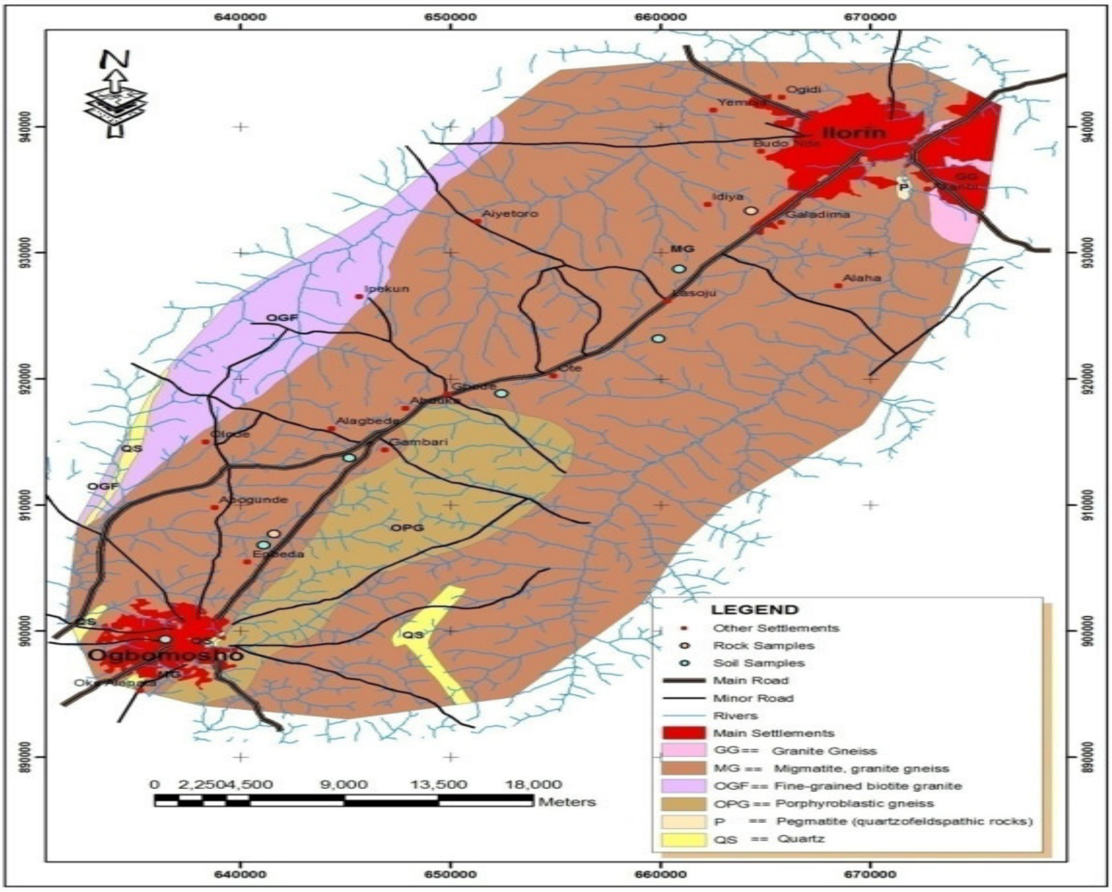

Figure 1: Geology and Drainage Pattern

Plate 1and 2: Typical Matured Laterite Profiles Along Road Cuts (L6SP3 & L1SP1)

Table: 1 Sample Localities and Profile Horizons

Profile S/No	Symbols for Horizon	Location	Coordinate	Depth from top (m)
1.	L1SP1	Eiyenkorin Bridge	N 08^{0}35’ 0” E 04 45’ 2”	0.54
	L1SP2			0.68
2.	L2SP1	Araromi	N 08^{0}41’ 6” E 04^0 16’ 6”	0.52
	L2SP2			1.22
	L2SP3			1.64
	L2SP4			1.72
3.	L3SP1	Aiyede	N 08^{0}31’ 1” E 04^{0}38’ 4”	0.65
	L3SP2			1.36
	L3SP3			2.56
	L3SP4			3.34
	L3SP5			4.20
4.	L4SP1	Otte	N 8^{0}31’ 1” E04^{0}38’4”	0.64
	L4SP2			1.78
	L4SP3			2.59
	L4SP4			2.64
5.	L5SP1	Abduka	N08^0 40’ 0” E0 4^{0}46’ 1”	0.88
	L5SP2			0.94
	L5SP3			2.20
6.	L6SP1	Gambari	N08^{0}26’ 5” E04^{0}31’ 8”	0.72
	L6SP2			0.86
	L6SP3			1.68
7.	L7SP1	LAUTECH R/ABOUT	N08^{0}13’ 5” E04 23’ 8”	0.65
	L7SP2			0.95
	L7SP3			1.44

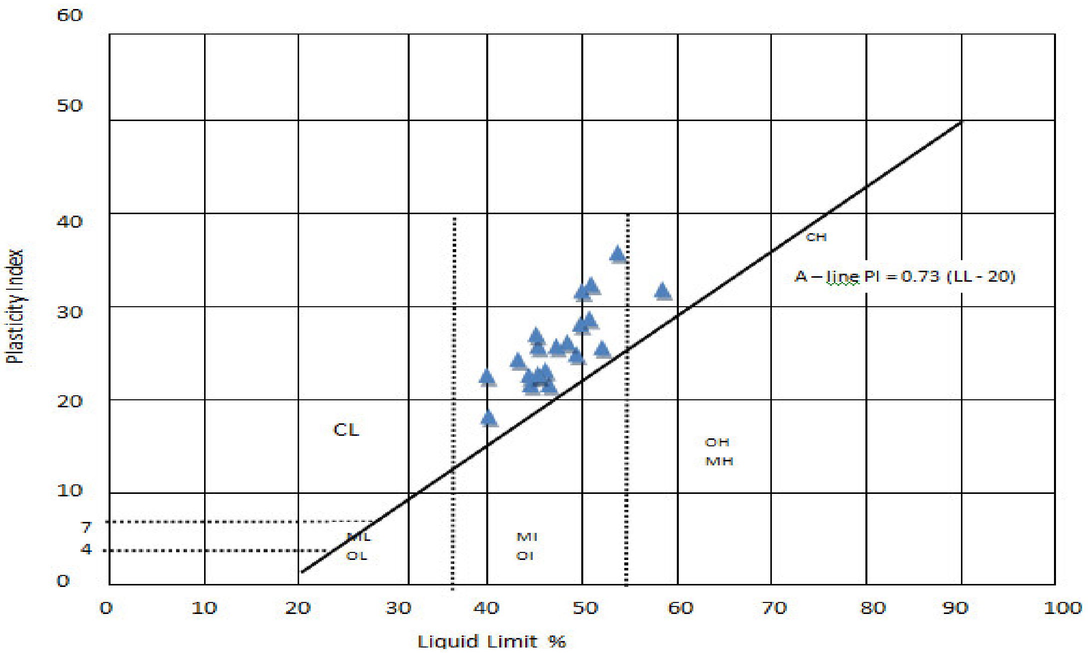

Figure 2: Plasticity Chart

4. Conclusion

The study was to assess the influence of parent rock on soil engineering characteristics of soil horizons of lateritic profiles derived from migmatite gneiss. The A horizon which is the top soil and C horizon which is the mottled zone of the profile overlying the parent rock revealed low values in bulk density (1.44 and 1.48; location L7SP1 and L3SP4), high natural moisture content 17.7% (L1SP1), high porosity of 63.6% (L2SP1). Low SG, CBR, and angle of friction of 45^0, 42^0, and 46^0 L1SP1 and L2SP1, L3SP5 are also associated with A and C horizons. Since horizon A is normally scraped, evacuated and often stacked for slope grazing; road cuts intercepting the C Horizons during cut and fill procedures in road construction should be given special attention as sub-grade to road pavement.

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Table: 3Geochemical Analysis Results

Sample No.	**SiO_2**	**Al_2O_3**	**K_2O**	**Na_2O**	**MgO**	**TiO_2**	**CaO**	**V_2O_5**	**Cr_2O_5**	**MnO**	**Fe_2O_5**	**CuO**	**BaO**	**Eu_2O_3**
LOC3 SP1	50.80	16.60	4.15	1.02	0.30	1.55	0.1	0.081	0.033	0.03	20.27	0.02	0.32	0.15
LOC3 SP2	52.40	16.40	2.50	1.09	0.48	1.19	0.1	0.077	0.057	0.046	17.14	0.02	0.25	0.17
LOC3 SP3	51.40	18.10	2.30	0.93	0.11	2.08	0.71	0.092	0.029	0.01	18.13	0.02	0.25	0.17
LOC3 SP4	39.50	13.00	0.41	0.15	0.04	1.13	0.22	0.13	0.051	0.15	33.72	0.036	0.17	0.29
LOC3 SP5	67.50	15.30	2.73	1.13	0.89	0.61	2.50	0.028	0.012	0.036	6.280	0.01	0.22	0.094
LOC6 SP2	85.40	0.33	0.76	0.45	0.35	2.64	0.46	0.095	0.015	0.19	6.429	-	-	0.99
LOC6 SP3	43.10	13.00	0.85	0.022	0.013	1.49	0.24	0.12	0.044	0.068	27.83	0.03	0.20	0.25
LOC6 SP4	42.10	20.10	0.61	0.06	0.03	2.02	0.36	0.11	0.027	0.03	23.23	0.037	-	0.22

Table: 4Summary of Laboratory Test Results

Sample	Nw (%)	Bulk Density (g/cm^3	Dry Density (g/cm^3	E	Porosity (%)	S(%)	S.G (Gs)	Cc	Cu	LL (%)	PL (%)	PI (%)	LS (%)	MDD (g/cm^3)	OMC (%)	CBR (%) Unsoaked	CBR (%) Soaked	ϕ	C
L1SP1	17.7	1.54	1.31	0.978	49.4	46.9	2.59	6.8	1.5	50	22	27.9	13	17	14	45	24	22	30
L1SP2	16.8	1.55	1.33	0.950	48.7	49.4	2.56	6.2	0.9	54	19	35	14	1.68	16	42	20	24	20
L2SP1	9.3	1.77	1.62	0.636	63.6	40.9	2.65	4.0	0.7				4.4	1.87	11	62	47	32	10
L2SP2	9.9	1.63	1.48	0.799	44.4	33.1	2.67	2.4	0.7	53	27	26	9.4	1.78	14	57	42	30	15
L2SP3	8.2	1.62	1.5	0.759	43.2	28.1	2.64	3.5	1.0	49	24	25.3	8.2	1.78	14	56	38	31	20
L2SP4	7.2	1.60	1.49	0.748	42.8	25.1	2.6	2.9	1.0				3.3	1.8	13	59	44	30	10
L3SP1	9.8	1.69	1.54	0.702	41.2	36.6	2.62	3.5	1.5	51	23	28.1	9.8	1.8	14	53	25	28	10
L3SP2	11.5	1.76	1.58	0.695	41.0	43.6	2.67	5.5	1.3	50	18	31.9	11	1.82	14	51	35	30	30
L3SP3	17	1.62	1.38	0.828	45.3	52.2	2.53	3.3	1.2	58	25	32.2	14	1.71	16	51	27	24	20
L3SP4	3.1	1.44	1.40	0.949	48.6	9.4	2.72	9.4	1.7	44	22	22.2	5.0	1.84	13	54	47	27	30
L3SP5	7.6	1.58	1.47	0.803	44.5	25.0	2.64	2.9	1.5	46	25	21.5	6.6	1.89	13	46	24	30	10
L4SP1	11.8	1.54	1.38	0.823	45.1	35.2	2.52	2.4	1.5	43	20	22.9	5.5	1.78	15	61	31	24	20
L4SP2	12.8	1.58	1.40	0.847	45.8	39.0	2.59	3.2	1.3	40	22	17.7	5.4	1.76	15	65	27	25	30
L4SP3	10.9	1.58	1.42	0.791	44.2	35.1	2.55	2.4	1.5	46	22	23.2	6.0	1.74	15	59	21	26	20
L4SP4	14.2	1.58	1.39	0.803	44.5	42.5	2.50	3.3	1.2	44	22	22.2	5.4	1.75	15	57	17	26	30
L5SP1	6.6	1.64	1.54	0.943	48.5	20.5	2.69	5.3	1.3				3.3	1.78	17	71	52	27	20
L5SP2	5.6	1.58	1.50	0.849	45.9	25.5	2.65	6.0	1.1				3.3	1.65	15	66	46	27	25
L5SP3	3.2	1.56	1.51	0.809	44.7	29.7	2.74	6.7	0.8	43	17	26	5.6	1.82	13	74	53	31	10
L5SP4	11.9	1.54	1.37	0.866	46.4	22.3	2.66	5.8	1.3	51	18	33.4	11	1.57	16	65	42	23	20
L6SP1	7.2	1.48	1.38	0.931	48.2	18.5	2.56	4.4	2.1	45	21	23.6	11	1.73	14	65	61	23	30
L6SP2	8.2	1.53	1.41	0.819	48.0	26.5	2.50	4.1	1.6	48	21	23.6	11	1.78	14	66	66	28	20
L6SP3	9.3	1.57	1.43	0.743	42.6	23.7	2.59	3.5	0.9	48	25	22.4	9.9	1.73	14	65	58	23	20
L7SP1	7.4	1.50	1.40	0.773	43.5	19.6	2.61	4.6	1.2	44	20	23.5	8.2	1.82	14	74	61	27	20
L7SP2	6.5	1.46	1.37	0.815	44.9	10.6	2.65	2.4	1.5	40	18	22	8.6	1.80	12	73	65	28	25