Investigating Geotechnical Properties of Soils from Mambila Plateau for Sustainable Infrastructural Development

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Abstract

Investigation of geotechnical properties of soils from Mambila Plateau was carried out. Five Standard Penetration Test (SPT) boreholes carried to the depth of 12m each were conducted across a valley, two boreholes each at the opposite sides of the valley and one borehole at the base of the valley. Two significant strata (reddish brown silty soil layer and the grayish weathered rock layer) were observed from the soil samples retrieved from the boreholes except for borehole 3 sited at the base of the valley whose stratum showed relatively thick dark lacustrine deposit followed by yellowish brown sandy soil to terminating depth of 12m. Result of geotechnical properties of the soils relatively high natural moisture contents of between 27.6 and 46.6% for the reddish brown silty soil layer compared with the grayish weathered rock layer. Relatively high values of liquid limit ranging from 42.7 to 75.1% were also recorded at the reddish brown silty soil layer. The range of fines content were also observed to be higher for the reddish brown silty soil layer at between 40.4 and 85.6 compared to the grayish weathered rock layer. From the SPT results, it was deduced that the soil strata becomes stiff at an average depth of 3.0m and denser with depth. The result of the physico-chemical tests showed the soils to be mainly basic with pH ranging from 7.2 to 8.5. Although, no lateritic gravel were observed within the strata, oxides composition of the soils showed silicon-sesquaoxide ratios ($SiO_2/Al_2O_3+Fe_2O_3$) of being generally lower than 1.33, indicating that the soils are lateritic. All these geotechnical properties coupled with the chemical and physico-chemical properties revealed that soil on Mambilla plateau can effectively support engineering structures of significant magnitudes.

Keywords: Foundations; Geotechnical properties; Mambila plateau; Soils

General Introduction

Geotechnical site investigation and estimation of soil characteristics are essential parts of a geotechnical design process, as geotechnical engineers must determine the average values and variability of soil properties (Al-Jabban, 2013). According to Mair and Wood (1987), in-situ testing is becoming increasingly important in geotechnical engineering, as simple strength laboratory tests may not be reliable while more sophisticated laboratory testing can be time consuming and costly. One of such in-situ testing methods is the Standard Penetration Test (SPT). SPT is currently the most popular and economical means of obtaining subsurface information. Bowles (1997) states that, 85–90% of conventional foundation design in north and south America is made using SPT. It is also used to identify soil type and stratigraphy along with being a relative measure of strength (Al-Jabban, 2013).

Mambilla Plateau is one of the places in Nigeria that is well endowed with abundant natural resources. The plateau is endowed with a semi temperate climate that is suitable for agricultural crop production like tea plantation (Kwaga and Fredrick, 2015) and livestock rearing, as well as mineral resources (Oruonye, 2015). Mambila Plateau is the highest highland in Nigeria with average height of about 1600m above sea level (Wikimapia.org, 2011). It is the extension of the Bamenda highlands of Cameroon with some villages situated at about 1850m above sea level (Lenshie and Johnson, 2012). According to physical map of Nigeria (2011), some mountains on the plateau, like Gang mountain has an elevation of about 2419m above sea level. Geologically, the plateau was formed on Basement Complex rocks. Occasional tertiary basalts also exist on the plateau which resulted mainly from trachytic lavas and extensive basalts observed around Nguroje (www.ngrguardiannews.com 2015).

Mambila Plateau is the initial home of the Bantu-speaking peoples (Zeitlyn and Connell, 2003; Griffith, 2007; Martin, 2009), and has been occupying this region for over four hundred years. This region is found in Sardauna Local Government area of Taraba State, Nigeria. According to Lenshie and Johnson (2012), Sardauna Local Government Area lies between latitude 5° 31' and 7° 18' North and longitude 10° 18' and 11° 37' East with an altitude of about 1,850 m above the sea level. Owing to the altitude of this part of the country, it is relatively cool; most days in the dry season, the temperature will reach 20 to 23°C and drop to 16 to 18°C at night, whilst in the wet season these averages fall a couple of degrees to about 14 to13°C. Sardauna Local Government Area is highly saturated by green-lush vegetation (Lenshie and Johnson, 2012).

According to Nigeria Online Tourism Magazine (2011) and Fidelis Mac Leva (2007), the Plateau is about 96 km long and 40 km wide and is bounded by some few escarpments. The plateau, whose surface is characterized by undulating features with occasional streams cutting through the escarpments (Fig.1), covers an area of over 9389 km^2.


Figure 1: Undulating surface of Mambila plateau and stream cutting across the valleys

The climate of the plateau is extremely cold compared to other regions of Nigeria. According to (Zainabokino.blogspot.com, 2011) daytime temperatures hardly exceed 25 °C, making it the coolest region in Nigeria. Strong winds prevail during the daytime, and the rainy season lasts from mid-March to end of November. Due to high elevation the plateau experiences temperate weather conditions but on a lower scale because of its location in a tropical environment. Climate on the Mambila Plateau is seasonal with dry season lasting from November to March and rainy season from April to October with a mean annual rainfall of 1780mm (Chapman and Chapman, 2001). Rainy season on the Plateau is always heavy because of the orographic activities which involve movement of moist winds from the South Atlantic Ocean in southern Nigeria and the steep edges and escarpments of the plateau (http://www.onlinenigeria.com). The Plateau is hilly and is characterized by deep gorges. Travelers are constantly passing from one panoramic view to the other. The route to the Plateau and the terrain is widely fascinating because of its scenic beauty, vegetation and landscape which charm various ethnic groups and tourist to the area (Ciroma, 2009; Lenshie and Johnson, 2012).

The valleys in the escarpment of the plateau mostly contain streams and rivers, common among them are the Donga River and Taraba River, with both having their sources from the Mambilla Plateau. The plateau comprises of low grasses with trees being noticeably absent except for some artificial forests planted by German colonialist during the period of German administration of the Cameroons (c. 1906-1915) and some other Nigerian government tree planting programs. The plateau is the only region of Nigeria where tea plant is grown in large quantity even though the sector remains mostly underdeveloped (Kwaga and Fredrick, 2015).

All these factors coupled with the type of vegetation prevalent on the plateau make it to occupy a special space in the mind of Nigerian government as well as the tourist loving individuals all over the world. The Federal Government of Nigeria through the Ministry of Tourism has been scouting seriously for investors to develop the tourism potentials on the Mambilla Plateau and make it viable both economically and socially.

In order to compliment the effort of the Federal Government towards achieving the set goal of developing the Mambilla Plateau, it is therefore pertinent to study the geotechnical properties of the overburden soil covering the basement complex of the plateau which is expected to support the superstructure loads that will be placed on the subsoil during the anticipated development.

Location and Geology of the Studied Area

This study was carried out in one of the valleys on the top of the Mambilla plateau across a stream, which is located at the base of the valley. This valley is situated close to Kakara village at an altitude of about 1,500m above sea level. The area is situated between latitude 06^{0}52’05” and longitude 11^{0}09’55”. The geology of this area, as typical of the Mambilla plateau, is developed on Basement Complex rocks and Tertiary basalts. These complexes are mostly formed by trachytic lavas and extensive basalts, occurring around Nguroje. The plateau is characterized by thick overburden on these complexes.

Generally, the study area is part of Hawal Massif around the Northeastern Basement Complex of Nigeria (Obiefuna and Adamu, 2012). The major rock types in the area include granites, gneisses and migmatites. These rocks have experienced some tectonic deformations, as evidenced by the presence of joints, faults and intrusive bodies such as migmatities and microgranites, dykes and quartz- veins. The granites are Pan-African (450-750 Ma). During this period, granite gneiss and gneissic rocks were produced due to the effects of the tectonic events that took place during the Pan African Orogeny. The effect of denudation had weathered some of the rocks thereby producing alluvium deposits. According to Nur and Kujir (2006), the Gneiss-migmatite rocks have undergone a weathering process that leads to the formation of laterite, gravels, sand, clays and silt materials. The entire area is mostly covered by weathered residual materials (Obiefuna and Adamu, 2012).

Material and Methodology

The materials used in this study were mainly disturbed and undisturbed soil samples collected from the Standard Penetration Test (SPT) boreholes. The soil samples were collected and prepared in accordance with the procedure highlighted in BS 1377 part 1 (1992).

The method used involves conducting two SPT boreholes each on the two slopes (sides) of the studied valley, and one SPT borehole, very close to an existing stream at the base of the valley. These boreholes were taken to depth of 12m or point of SPT refusal. According to Al-Jabban (2013), in many parts of the world, the Standard Penetration Test (SPT) is still considered one of the most common *in-situ* tests to evaluate the strength of soil and often the only *in-situ* test performed during a site investigation. Both disturbed spoon samples and undisturbed tube samples (Fig. 2) were collected at 1.5m depth intervals, down to the 12m depth. Some soil samples were however, lost in the process of collection.

Fig. 2: SPT boring and sample collection in progress

Both the disturbed spoon samples and the undisturbed tube samples were prepared in accordance with the method highlighted in BS 1377 (1992) and transported to the laboratory for tests. Visual inspection showed that the overburden is made up of two distinct layers which are capped by top soil. Soil samples were selected from the two layers for the laboratory tests. The geotechnical properties tests carried out on the disturbed soil samples includes: Natural Moisture Content (NMC), Specific Gravity (G_s), bulk unit weight (γ_b), mechanical sieve analysis, hydrometer analysis, Atterberg limits (Liquid Limit-LL, plastic Limit-PL, and Plasticity Index-PI), permeability (k), and consolidation tests. The permeability (k) results are reported as averages (k_{ave}) for the identified strata, while consolidation test to determine compressive index (c_c) and coefficient of consolidation (c_V) was carried out only on representative samples from the second and third strata. The Physico-chemical tests carried out includes the pH test, organic matter content, carbonate content, cation exchange capacity and hygroscopic moisture content. The chemical tests are aluminum oxide, calcium oxide, iron oxide, silicon oxide, magnesium oxide and sulphate. All these tests are carried out in line with methods highlighted in BS 1377 (1992).

Results and Discussions

Physical Properties of the Soils

Visual inspection of the soil samples collected from both sides of the slopes showed similarity in strata except that their thickness varies from one position to the other, along the axis (Figure 1). These strata was different from the profile observed on the base of the valley which is characterized by dark clayey muddy deposit to about 3m depth after which sharp sandy deposit was observed to terminating depth of 12m. This trend is expected because of the continue deposit of sand by the running stream and recent lacustrine deposits over years.

The soil from both sides of the slopes shows a thin dark organic top soil followed by reddish brown silty residual soil to grayish silt to sandy weathered rock layer to the terminating depth of 12m. The reddish brown silty residual soil layer has thickness of between 3m to 6.0m. The grayish weathered rock layer is thicker with average thickness of 9.0m. The profile, observed at the base of the valley is completely different from those on the slopes. The profile from the base of the valley showed thick lacustrine deposit (Abdullahi *et al*, 2014) in form of dark soft clay deposit followed by sharp sandy deposit to depth of 12m.

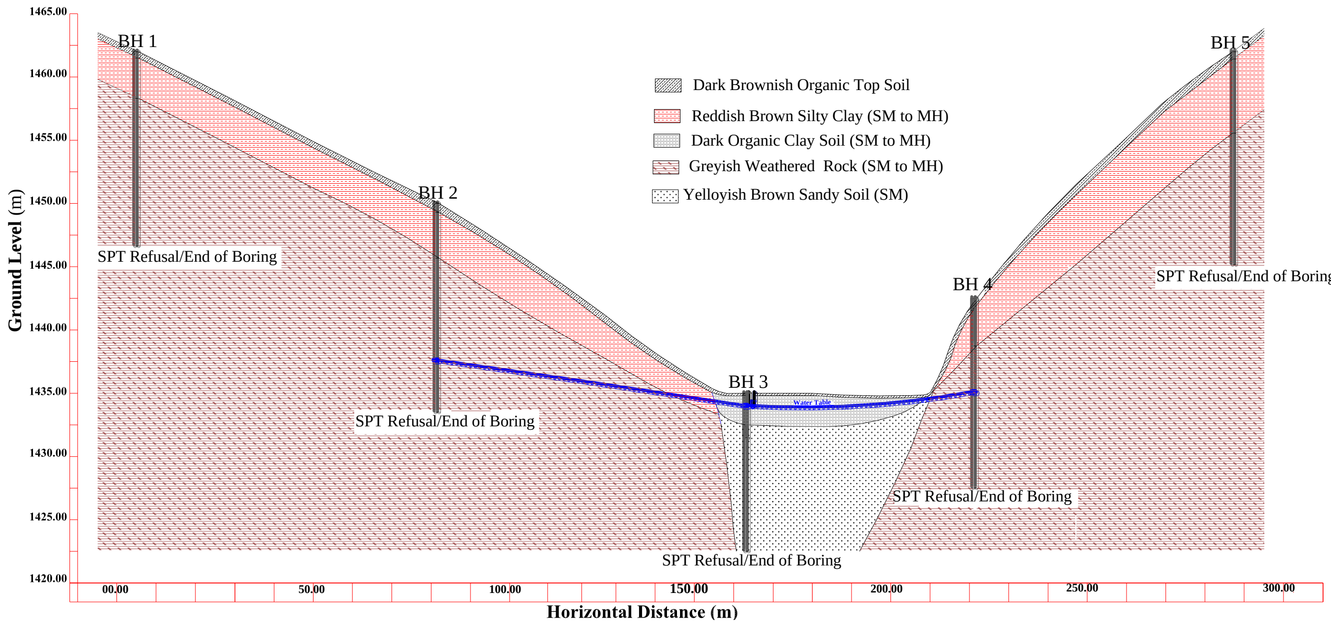

Figure 1: Soil profile across the studied axis

Geotechnical Properties of the Soils

The geotechnical properties the soils studied includes: index properties, compressibility, permeability and in-situ strength obtained from Standard Penetration Tests (SPT). The summary of the index properties are shown on Table 1.

Table 1: Summary of Index Properties of the Soils

Layer	Sample	γ_b (kN/m^3)	G_s	NMC	Percent passing sieves (%)				Atterberg limits		USCS
					5.0mm	2.0mm	0.425mm	0.075mm	LL	PI	
Top soil & River deposits	BH2-0.6m	17.6	2.58	26.0	100	99.3	84.5	76.3	54.2	17.7	MH
	BH3-1.5m	18.7	2.60	52.1	100	100	85.6	74.2	46.5	11.5	ML
	BH3-3.0m	19.0	2.44	23.1	100	95.6	56.8	36.0	31.4	8.5	SM
Reddish Brown silty soil layer	BH1-1.5m	18.7	2.61	46.6	100	100	92.4	85.0	60.8	20.0	MH
	BH1-3.0m	18.8	2.57	38.9	100	99.6	92.6	85.6	64.4	22.8	MH
	BH2-1.5m	19.0	2.59	42.2	100	97.8	83.2	78.0	75.1	29.1	MH
	BH2-3.0m	18.9	2.58	37.0	100	93.7	78.1	72.8	63.1	21.7	MH
	BH4-1.5m	19.4	2.51	36.7	100	95.2	68.8	58.2	54.2	15.3	MH
	BH4-3.0m	20.0	2.71	27.6	100	90.4	50.8	40.4	42.7	9.2	SM
	BH5-1.5m	18.6	2.50	31.2	99.8	94.2	68.2	57.9	61.4	19.8	MH
	BH5-3.0m	19.4	2.62	36.5	99.4	92.8	73.8	47.8	65.6	18.1	SM
Grayish weathered rock layer	BH1-6.0m	19.0	2.62	33.2	100	98.2	87.6	80.8	49.8	18.7	ML
	BH1-9.0m	18.6	2.44	29.2	100	97.0	90.1	83.4	50.9	17.0	MH
	BH2-6.0m	19.2	2.70	37.0	100	90.0	61.2	49.2	52.3	11.7	SM
	BH2-9.0m	19.1	2.44	31.3	100	97.4	82.0	71.8	42.9	8.4	ML
	BH2-12m	19.8	2.38	25.4	100	93.7	61.6	40.7	30.1	10.1	SC
	BH4-6.0m	19.5	2.53	24.9	100	96.2	63.2	44.3	36.6	6.8	SM
	BH5-6.0m	19.2	2.56	29.6	98.6	89.8	74.0	41.2	47.0	NP	SM

The results of the index properties showed that the bulk unit weight lies within a narrow ranges of between 18.1 to 20.0kN/m^3 throughout the entire depth of 12m. The dry densities are however, generally low due to relatively high natural moisture contents recorded in some of the soil samples. Relatively high Natural Moisture Contents (NMC) of between 27.6 and 46.6% were recorded for the reddish brown silty soil layer. These values are relatively high compared with reddish lateritic residual soils prevalent in Nigeria. This is probably due to high rainfall prevalent on the plateau coupled with low evapotranspiration. Because of minimal influence of weather on the grayish weathered rock stratum, lower ranges of NMC of between 24.9 and 37.0% were recorded for this stratum.

High liquid limits ranging from 42.7 to 75.1%, coupled with moderately low plasticity index ranging from 9.2 to 29.1%, were recorded for the reddish brown silty soil layer. The high liquid limit is in agreement with the high natural moisture contents recorded on this layer. The low plasticity index is probably an indication of low soil formation activities which is common in temperate regions, a weather condition which exists in the plateau. Lower liquid limit values of between 30.1 and 52.3% are recorded for the grayish weathered rock stratum. This layer is presently undergoing weathering and has not got suitable geological conditions to form substantial clay mineral particles hence the lower Atterberg Limits.

Particle size distribution/hydrometer analysis on the selected soil samples from the identified strata showed predominantly higher silt content compared to the clay contents (Table 2 and Figure 2-3). The reddish silty soil layer recorded silt content ranging from 29.6 to 55.5%. This is probably due to the low active soil formation, predominant in this plateau which can readily results in the formation of clay sized particles. This may be due to temperate-like weathered condition prevalent in the plateau compared to the tropical weather condition in other places of the country. Percentage silt content ranging from 33.8 to 70.6% and percentage clay content ranging from 6.2 to 24.8% were observed in the grayish weathered rock layer. These values are relatively low compared to clay contents of soils from areas in Nigeria with same geological, but different weather conditions. The values of clay content are higher than those obtained by Braga *et al* (2002) from study of Quaternary granitic saprolites from temperate Northwest Portugal, characterized by an average annual rainfall between 1200 and 1600 mm and an average annual temperature between 14.5°C and 17° C. This can be attributed to the temperate-like weathered condition prevalent in this region. Permeability values of the reddish silty soil layer and the grayish weathered rock layer were observed to be within the range of 10^{-7} cm/s.

Table 2: Composition, permeability and consolidation characteristics of the soils

Layer	Sample	Gravel	Sand	Silt	Clay	k_{ave} (cm/s)	C_c	C_v (m^2/min)
	BH3-1.5m	0	24.8	56.9	18.3	8.77×10^{-4}		
	BH3-3.0m	0	64.0	26.8	9.2			
Reddish Brown silty soil layer	BH1-1.5m	0	15.0	55.5	29.5	8.26×10^{-7}		
	BH1-3.0m	0	14.4	49.6	36.0			
	BH2-1.5m	0	22.0	50.6	27.4			
	BH2-3.0m	0	27.2	46.9	25.9			
	BH4-1.5m	0	41.8	43.9	14.3			
	BH4-3.0m	0	59.6	29.6	10.8		0.148	1.98×10^{-5}
	BH5-1.5m	0.2	41.9	43.2	14.7		0.169	1.71×10^{-5}
	BH5-3.0m							
Grayish weathered rock layer	BH1-6.0m	0	19.2	56.0	24.8	7.30×10^{-7}	0.241	1.34×10^{-5}
	BH1-9.0m	0	16.6	70.6	12.8		0.234	1.19×10^{-5}
	BH2-6.0m	0	50.8	42.3	6.9		0.211	2.05×10^{-5}
	BH2-9.0m	0	28.2	65.6	6.2		0.116	1.52×10^{-5}
	BH2-12m							
	BH4-6.0m	0	55.7	33.8	10.5			
	BH5-6.0m							

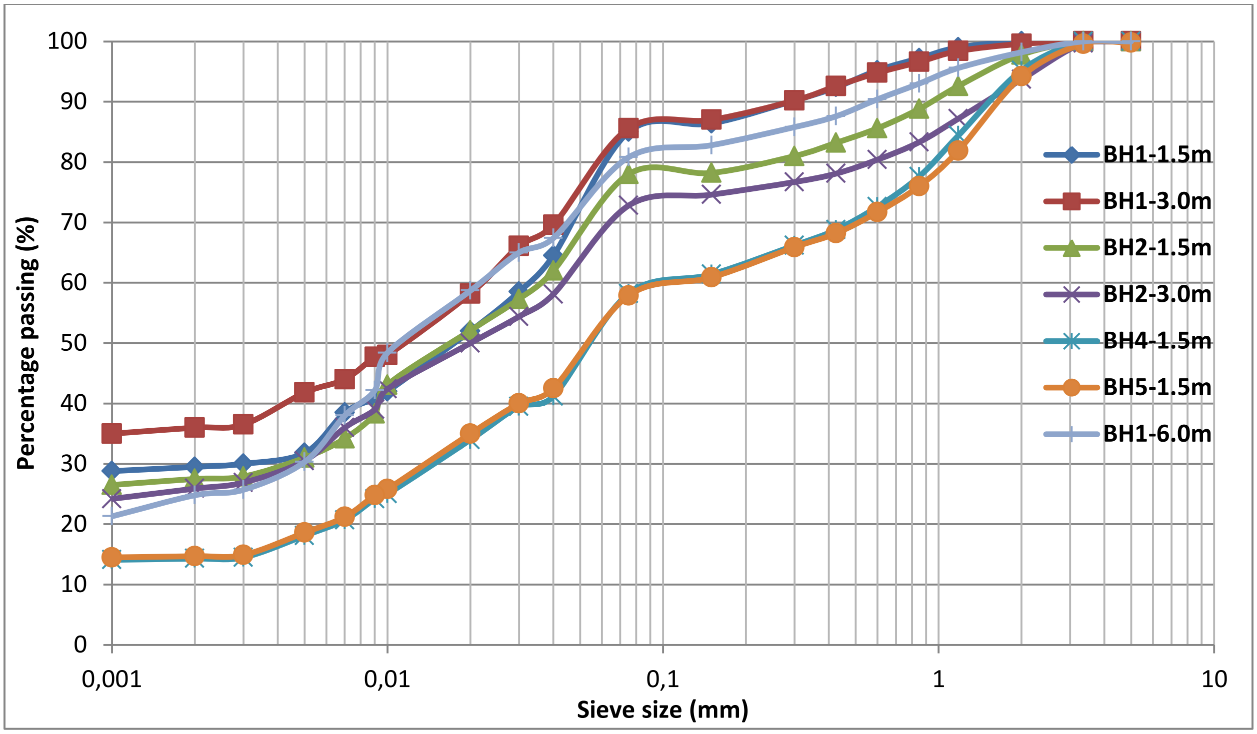

Figure 2: Particle side distribution curves for soils from brownish silty soil layer

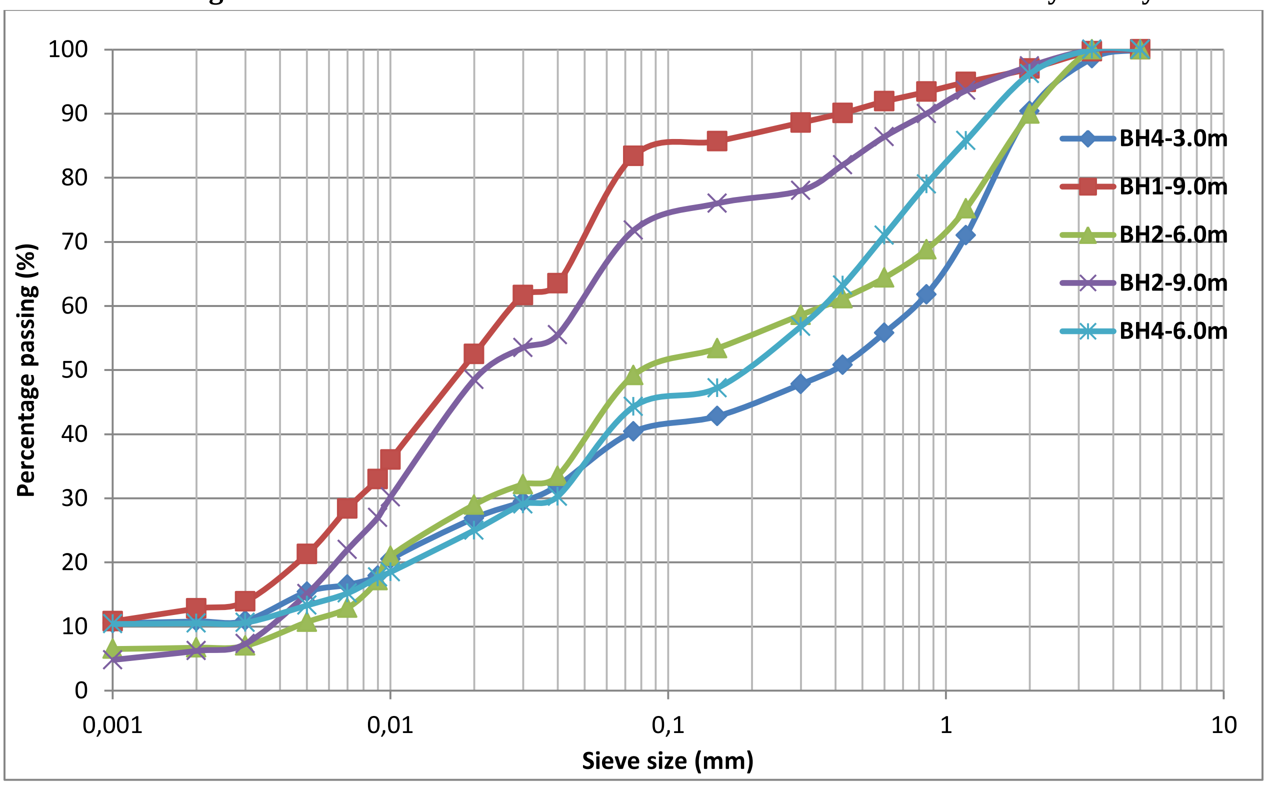

Figure 3: Particle side distribution curves for soils from grayish weathered rock layer

Figure 4 shows one dimensional consolidation test plots for some of the soil samples. The compression indices showed low ranges of between 0.148 and 0.169 on the reddish brown silt soil layer compared with the moderate values of between 0.159 and 0.241 observed on the grayish weathered rock layer. This is an indication of low magnitude of settlement to be expected on the two layers.

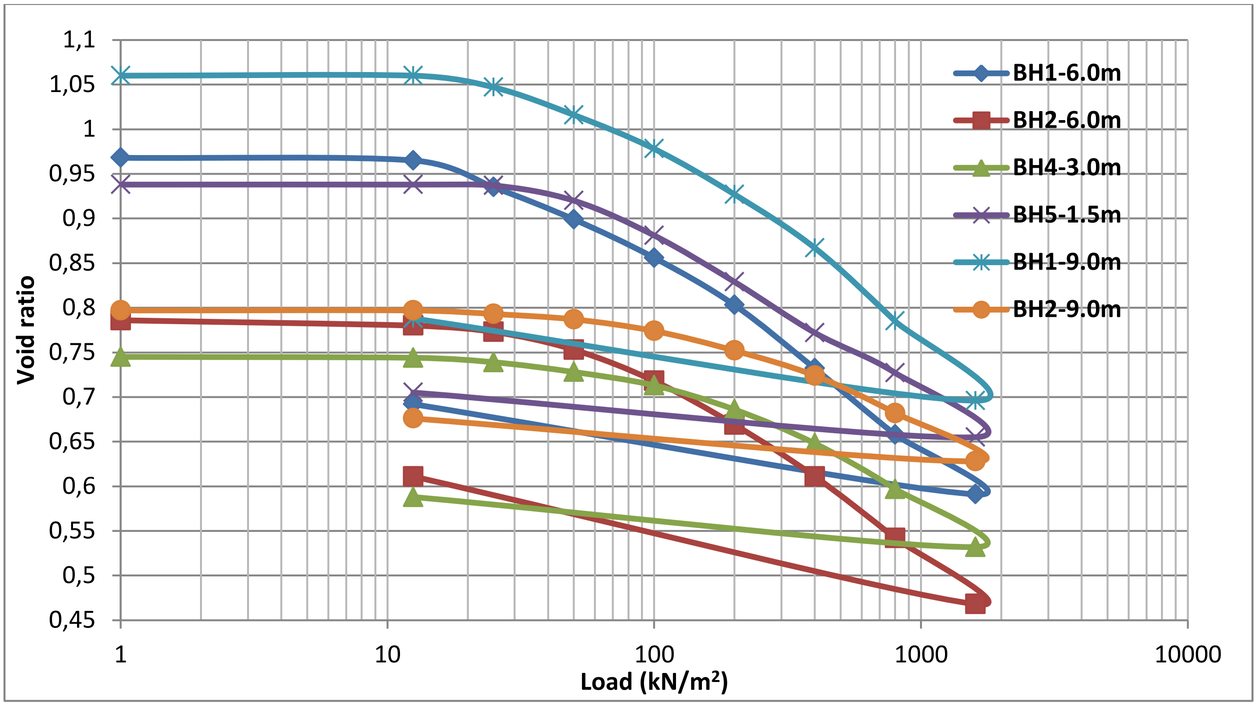

Figure 4: Consolidation plots for some of the soil samples

Standard Penetration Test (SPT)

This test defines the in-situ strength of the sub-soil strata, down to the 12m depth studied. The result of the test is shown in Figure 5. The result revealed similar trend for BH1, BH2, BH4 and BH5 which showed strength increasing gently from the top to 6.0m depth after which the increase becomes higher to 9.0m depth. After 9.0m depth, the values became constant down to 12m depth. Variation of strength with depth at BH3, however, deviates from this common trend probably because it was sighted at the base of the valley close to a stream. The first 3m

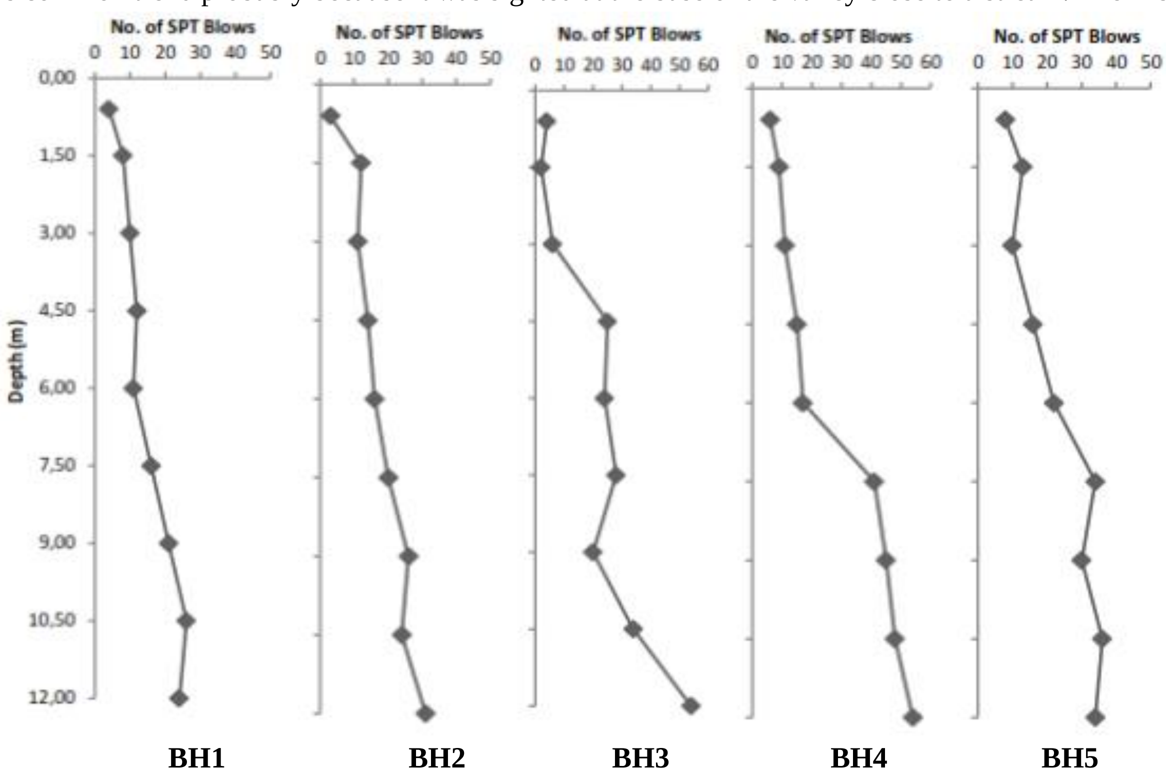

Figure 5: Standard Penetration Test (SPT) Results for the Five Boreholes

thickness showed very low SPT values due to the soft lacustrine organic clay deposit on this stratum. The values increased due to the relatively dense sand deposit observed below the organic clay stratum. The low SPT value recorded locally at 9.0m depth may be as a result of pocket of loose sand at this depth. The values increased highly after 9.0m down to 12.0m depth.

This indicate that shallow foundations can be placed at average depth of 3.0m since the SPT values below this depth showed that the clay deposit is stiff (Bowles, 1997). Foundation shafts into this soil will mobilize strength from the depth of 3.0m which will increase down to 12m depth.

Chemical and Physico-Chemical Properties

The chemical and physico-chemical properties of the soils are shown on Table 3. The pH of the soil indicate 7.2 for the top soil/river deposits, 8.5 for both reddish brown silty soil and Grayish weathered rock layers. These values are not in agreement with the results obtained by Gidigasu (1972) and Gidigasu (1987) which showed lateritic soils to be neutral to acidic. The organic matter contents (OMC) are generally low for all the soil strata, which is characteristic of lateritic weathering profiles. Although, no lateritic gravel were observed within the strata, oxides composition of the soils showed silicon-sesquaoxide ratios ($SiO_2/Al_2O_3+Fe_2O_3$) of being generally lower than 1.33, indicating that the soils are lateritic (Ola, 1983; Alhassan, 2006). Generally, it was observed that percentage composition of Al_2O_3 is lower, compared to those of Fe_2O_3. This indicates that the lateritic weathering profile is non-bauxitic in nature (Mustapha and Alhassan, 2012). Sulphate content of the soils range between 40 and 48, which are lower, compared to the maximum values recommended in BS EN 1008 (2002).

Table 3: Summary of chemical and physico-chemical properties

Layer	Sample	Oxide Compositions								Physico-Chemical Compositions				
		SiO^2	CaO	Al_2O_3	Fe_2O_3	MgO	SO_3	LOI	Silicon-sesquaoxide ratio	pH	OMC	HMC	Mg	P
Top soil & River deposits	BH2-0.6													
	BH3-1.5	4.1	63.5	4.8	1.7	3.1	46	11.9	0.63	7.2	0.086	6.0	1.5	4.3
	BH3-3.0													
Reddish Brown silty soil layer	BH1-1.5													
	BH1-3.0	4.1	62.1	4.7	2.2	3.6	48	4.0	0.59	8.5	0.086	8.7	1.5	3.82
	BH2-1.5													
	BH2-3.0													
	BH4-1.5	4.3	62.6	4.5	1.9	3.6	40	2.7	0.67	8.5	0.120	8.1	1.5	4.25
	BH4-3.0													
	BH5-1.5													
	BH5-3.0													
Grayish weathered rock layer	BH1-6.0													
	BH1-9.0	4.0	62.0	4.7	2.2	3.8	48	3.9	0.58	8.5	0.034	8.0	1.5	4.41
	BH2-6.0													
	BH2-9.0													
	BH2-12													
	BH4-6.0	4.8	64.8	5.0	2.0	3.1	46	7.6	0.69	8.1	0.086	8.2	1.2	3.8
	BH5-6.0													

Conclusion

Investigation of geotechnical properties of soils from Mambila Plateau was carried out, using Standard Penetration Test (SPT) and samples collected from the SPT boreholes, carried to the depth of 12m. From the retrieved soil samples, two significant soil strata (reddish brown silty soil and grayish weathered rock layers) were observed except for the third borehole, which was located at the base of the valley whose stratum showed relatively thick dark lacustrine deposit at the top. Geotechnical properties of the soils showed relatively high natural moisture contents of between 27.6 and 46.6% for the reddish brown silty soil layer compared with the grayish weathered rock layer. Relatively high values of liquid limit ranging from 42.7 to 75.1% were also recorded at the reddish brown silty soil layer. Fines content were also observed to be higher for the reddish brown silty soil layer at between 40.4 and 85.6 compared to the grayish weathered rock layer. From the SPT results, it was deduced that the soil strata becomes stiff at an average depth of 3.0m and denser with depth. The result of the physico-chemical tests showed the soils to be mainly basic with pH ranging from 7.2 to 8.5. Oxides composition of the soils showed silicon-sesquaoxide ($SiO_2/Al_2O_3+Fe_2O_3$) ratios generally lower than 1.33, indicating that the soils are lateritic. These properties are indication of relatively high strength, capable of supporting engineering structures of significant magnitudes.

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