Physiochemical, Mineralogical and Physical Properties of Overburden Over Gneiss Basement Complex in Minna Metropolis, Nigeria

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Abstract. Soil engineers pay very little or no attention to variation in the mineralogical and consequently, the geotechnical properties of overburden with depth on basement complexes, a situation which can lead to sudden failure of civil engineering structures. Soil samples collected at depths ranging from 0.5 m to 4.0 m at 0.5 m intervals, from a trial pit dogged manually to depth of 4.0 m on an overburden over gneiss basement complex, was evaluated for physiochemical, mineralogical and physical properties. This is to determine the variation of these properties with depth within the profile of the strata. Results showed that sodium amphibolite and feldspar, which are both primary minerals dominate the overall profile of the over-burden. Carbon which dominates the lower profile of the strata was observed to alter to gregorite at upper section of the profile. Organic matter contents and cation exchange capacity reduces with increase in depth while lost on ignition and pH were relatively constant with depth. The index properties as well as natural moisture contents increases from 0.5 m to between 1.0 m to 1.5 m depth after which the values reduced to constant values at 3.0 m depth. The grain size analysis shows high composition of sand sized particles with silts of low to non-plasticity. The maximum Dry Density (MDD) values are generally relatively high and increases from 2.262 g/cm^3 at 0.5 m depth to 2.410 g/cm^3 at 4.0 m depth while the Optimum Moisture Content (OMC) reduced from 9.8% at 0.5 m depth to 6.7% at 4.0 m depth.

Keywords: Gneiss basement complex · Mineralogical properties · North Central Nigeria · Physiochemical properties · Physical properties · Overburden soil

1 Introduction

Tropical soils represent the most heavily weathered soils on earth, because the climate is characterized by high temperatures and rainfall patterns promoting extreme alteration of minerals from the parent rock resulting in the formation of new minerals [1]. Soil

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mineralogy plays an important role in forming the character of a soil, such that the key features employed to differentiate soils at the highest level depend on mineralogy [2]. These properties are responsible for all the physical properties of the overburden soils and consequently, the engineering properties of such soils [3]. Mineralogical and physiochemical analysis conducted on overburden soils proves to be useful in understanding the physical properties of these soils and consequently, its engineering properties [4].

Geologists over the years have proved that basement complexes differs from one position to the other over the entire earth crust depending on the rock underlying the complexes. The common basement complexes identified are the Granitic, Gneiss and schist basement complexes. However, the most common of these basement complexes is the granite complex whose overburden has received some level of study [5]. Little studies have been carried out specifically on Schist and Migmatite Gneiss basement complexes. Soil engineers borrow the overburden soil on these complexes for construction of structures or construct heavy structures on the overburden over these complexes without considering possible differences in the physical properties and consequently, the engineering properties of these soils. Ignoring the variability of mineralogical and physiochemical characteristics on these residual weathering profiles with depth is denying the different formation factors of these soils and may lead to misleading results and consequently, serious failure to engineering structures erected on them. This work is therefore, aimed at studying the variation with depth in the physiochemical, mineralogical and the physical properties of the overburden on Migmatite Gneiss complex in Minna metropolis.

2 Location and Geological Setting of the Studied Area

The location of the study area lies within 9° 23’ 01.0”N and 6° 22’ 01.78”E and in geological sheet 184 of Nigerian Geological Sheet which span from Gidankwanu to Kataeregi along Minna-Bida road, Niger State, Nigeria. This sheet has been studied geologically by Olose et al. [6] (Fig. 1).

Some other authors that worked on geology of Nigeria regional sheets includes Ekweme [7], who carried out extensive study on the geochemistry of the schist and metasedimentary phyllites of South-West UGEP, Nigeria. The study revealed that the metasediment contains substantial amount of silica, alumina and Zr but lacking in Nickel. The presence of 0.033% and 0.144% of Titanium oxide and alumina respectively confirms that metasediment in this region originated from bedrocks containing substantial amount of quartz and clay. Dambata and Garba [8] worked on the geochemistry and petrogenesis of the Zuru schist belt of Nigeria. The amphibolite in this region consists mainly of green hornblende, plagioclase and quartz as well as the occurrence of pyroxene, quartz and epidote in small quantity.

The schist belt of Igara in Southwestern Nigeria was studied by Adepoju and Adekoya [9] to investigate the geochemical characteristic of the area. When the anomalous values obtained for the mean of the geological materials are compared, the result suggests that anomalous values for Au, Hg, U, Cu, Pb, Zn, Th and La shows that these minerals can be explored. There also exists amphibolite and pegmatite in the schist belt. Alabi [10] worked on Environmental impact assessment and geology of granitic rocks of Minna area. The result of the field study carried out by the researcher showed eight granitic masses termed Paiko and Minna Batholiths with height of 350 m above sea level. The geochemistry and geology of Zungeru amphibolite was studied by Agbo [11]. Twelve samples of amphibolite rocks were collected for the study. The result of XRF test showed major oxides including silica, alumina, iron oxide, calcium oxide and magnesium oxides. The geology of Paiko in Niger State of Nigeria which covers part of sheet 185 was extensively studied [12]. The result of the study revealed that the major rocks occupying this region are granitic rocks which can be separated into leucocratic and biotite granites.

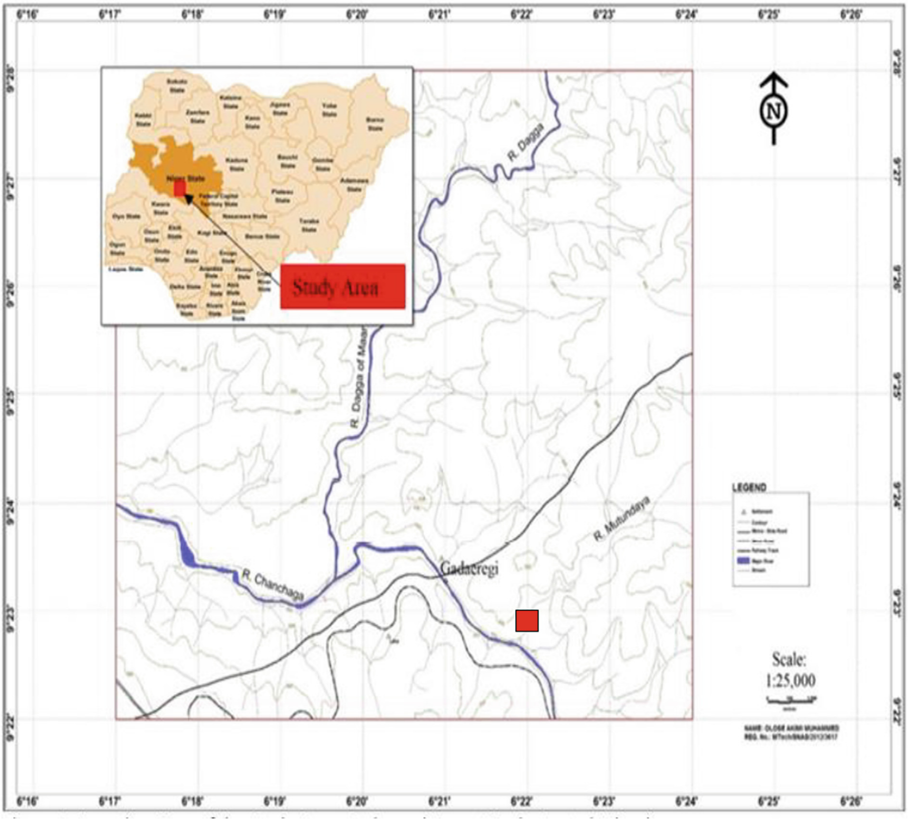

Fig. 1. Map showing the position of test point

The Geophysical study, hydrogeological and geological studies of Niger State was carried out to evolve a ground water development of the region [13]. The result of the studies revealed crystalline and sedimentary rocks existing in the same proportion in the state. The crystalline rocks encountered were mainly granites, gneisses, Migmatite and schists while the sedimentary rocks are clay, shale and sandstone. The basement rocks around Bishewa-Ologoma area was studied in view of knowing the major and trace elements in the rocks [14]. Results from the study showed that there is presence of granite which was interpreted to have been of igneous source with some sedimentary mixtures. Biotite granite, quartz-mica schist and biotite-hornblende granite of this area was observed to be well developed. The geology of the area under consideration which forms part of sheet 184 was studied extensively by Olose et al. [6]. The geochemical properties of amphibolite schist in Gadaeregi area of North Central Nigeria were studied. The paper concluded that the three major theological units predominant in this region are Migmatite-Gneiss, Amphibolite-Schist and Granite rocks. The geochemical and geological characteristics of the rocks on sheet 164 around Kuta town in Niger State, Nigeria were investigated [15]. The study has shown that the studied area is underlain majorly by quartz, phlogopites, paragonite, muscovite, kyanite, kaolinite, topaz and magnetite.

OlaOlurun et al. [16] worked on the geochemistry of amphibolite from schist belt of Egbe-Isanlu in south-west Nigeria. Results of the study showed uniformity of minerals in some areas and variation of minerals in some other areas. Tremolite, actinolite, quartz, plagioclase and hornblende are the abundant minerals in the thin shell of the complex.

All these authors considered basement rocks and not the overburden soil on the rocks. The work by Alhaji [5] is one of the early studies that consider the variation of geotechnical properties of overburden on granitic rock with depth. The researcher observed significant variation in geotechnical properties of residual profile on granitic rock with depth. Geotechnical and geological study was also conducted within a gully site along River Bosso in Niger State, Nigeria [17]. Field results showed that granite-Gneiss, granite and schist are the rocks that form the basement complex in this region. The index test results generally revealed high sand content and low plasticity index which was reported to have been the cause of erosion in the soil deposit.

3 Materials and Methodology

The materials used in this study involve disturbed soil samples collected in one trial pit. The trial pit was manually dogged to depth of 4.0 m where manual digging became almost impossible. Disturbed soil samples were collected at depths of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 and 4.0 m. These samples were air-dried and pulverized using the method highlighted in BS 1377 [18]. Representative specimen taken from each of the samples were prepared and sent to iThemba laboratories, Somerset West, 7129, South Africa, for X-ray Diffraction (XRD) tests. The test uses a Bruker AXS D8 X-ray diffractometer system coupled with Cu-Kα radiation of 40 kV and a current of 40 mA. This is to obtain the major minerals contained in the specimens. The physiochemical tests (cation exchange capacity, Calcium carbonate, organic matter, loss on ignition and pH values) were carried out using the method highlighted in BS 1377 [18]. The physical properties of the overburden soils were determined using the method highlighted in BS 1377 [18].

4 Results and Discussion

4.1 Mineralogical Characteristics of the Soil Collected

The mineralogical analysis results for weathering profile on Gneiss Basement Complex are shown in Fig. 2 and Table 1. From the results, four distinct strata are observed: The first lowest stratum from 3.5 to 4.0 m is the closest to the intact base rock and possesses major minerals including quartz, feldspar (albite), amphibole (sodium amphibole) and carbon. The second stratum from 3.0 to 3.5 m consists of all the minerals in the first stratum with introduction of mica (phlogopite and biotite) in the stratum. The third stratum from 2.0 to 3.0 m consists of the same minerals as first stratum except that carbon is completely absent. The fourth stratum ranging from 0.0 to 2.0 m consists of same minerals as in the first stratum except with the introduction of gregoryite and disappearance of carbon. Except for carbon and gregoryite, all these minerals are primary silicate minerals while the secondary silicate minerals (clay minerals) are completely absent. This is an indication of a very poor weathering profile which can lead to absence or minimal plasticity of the overburden soils.

The presence of amphibole mineral spanning through the whole profile agrees with the findings from geological study carried out on sheet 184 [6]. The formation of gregoryite in the fourth and upper stratum is probably due to reaction between carbon that existed in the lower stratum and dissolved oxygen from rain water which leached from the surface through the soil profile to form dissolved carbon dioxide. The carbon dioxide in turn reacts with sodium from sodium amphibolite to form the gregoryite mineral.

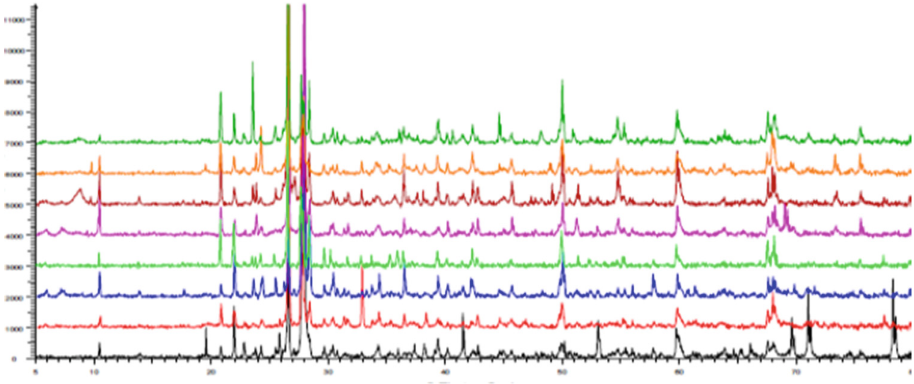

Fig. 2. X-ray Diffractogram for Gneiss basement

4.2 Physiochemical Properties of the Soils

The physiochemical properties determined from the soils are the cation exchange capacity, organic matter content, pH and loss on ignition. Their variation with depth of the weathering profile is presented in Fig. 3. The cation exchange capacity was observed to decrease from 77.0 at 0.5 m depth to 52.0 cmol/kg at 2.5 m depth after which the values increased to 67.0 cmol/kg at 4.0 m depth. These values are generally low compared to values obtained with clay soils. This is an indication that secondary minerals are minimal in the overburden soil on this basement complex. The organic matter decreased from 0.45% at 0.5 m depth to 0.34% at 3.0 m depth after which the values increased to 0.68% at 4.0 m depth. This trend is in agreement with literature where organic matter was observed to reduce with depth. The later increase must have resulted from the presence of carbon at the lower part of the profile. The pH was observed to be relatively constant at neutral to basic with value of between 7.15 to 7.77. The loss on ignition shows similar trend with organic matter content. The values reduced from 7.2% at 0.5 m depth to 3.8% at 4.0 m depth. These values are generally low and indicate low availability of fine soils.

4.3 Physical Properties of the Soils

Variation of natural moisture content, liquid limit and plasticity index with depth of the weathering profile is presented in Fig. 5. The natural moisture content increased from 9.7% at 0.5 m depth to maximum of 13.8% at 1.5 m depth after which the values reduced to 8.3% at 3.0 m depth and thereafter the values reduced to constant values of 7.6%. This trend is in agreement with Alhaji [5] who attributed this trend to residual profiles where water table is relatively far from the base of the excavation pit and the surface water percolating from the ground surface has its maximum accumulation at depth of 1.5 m. The trend for liquid limit and plasticity index is similar to that of natural moisture content except that the maximum values of liquid limit and plasticity index occurs at 1.0 m depth. This indicates that, even though rate of weathering is observed to me minimal within the profile, the highest weathering stratum must have occurred at depth of 1.0 m.

The grain size analysis (Fig. 5) shows high composition of sand size particles and silt of low to non-plasticity. This grain analysis is a clear indication of lack of clay soils from secondary minerals which would have resulted in to higher plasticity. The grain size analysis curves showed that the curve is capped at the top by soil at 1.0 m depth and covered from the bottom by soil at 3.0 m depth. The soils beyond 3.0 m depths showed increase in grading probably because of inclusion of freshly weathered rocks (Fig. 4).

The trend of the maximum dry densities with depth (Fig. 6) showed increase from 2.262 g/cm^3 at 0.5 m depth to 2.41 g/cm^3 at 4.0 m depth. These values are generally high

Table 1. The mineralogical composition of Gneiss basement with depth

Depth (m)	Mineral name	Chemical formula
0.5	Quartz Albite (Plagioclase feldspar) Magnesioarfvedsonite (Na-amphibole) Gregoryite (Carbonate)	SiO_2 $KO.2NaO.8AlSi_3O_8$ $Na_3(Mg,Fe)_5Si_8O_{22}(OH)_2$ Na_2CO_3
1.0	Quartz Albite (Plagioclase feldspar) Magnesioarfvedsonite (Na-amphibole) Arfvedsonite (Na-amphibole) Gregoryite (Carbonate)	SiO_2 $KO.2NaO.8AlSi_3O_8$ $Na_3(Mg,Fe)_5Si_8O_{22}(OH)_2$ $(Na,K)_2.6Fe_5(Si,Al)_8O_{22}(OH)_2$ Na_2CO_3
1.5	Quartz Albite (Plagioclase feldspar) Magnesioarfvedsonite (Na-amphibole) Arfvedsonite (Na-amphibole) Gregoryite (Carbonate) Hydrobiotite (Mica)	SiO_2 $KO.2Na0.8AlSi_3O_8$ $Na_3(Mg,Fe)_5Si_8O_{22}(OH)_2$ $Na,K)_2.6Fe_5(Si,Al)_8O_{22}(OH)_2$ Na_2CO_3 $K(Mg,Fe)_9(Si,Al)_8O_{20}(OH)_4.4H_2O$
2.0	Quartz Albite (Plagioclase feldspar) Magnesioarfvedsonite (Na-amphibole)	SiO_2 $KO.2NaO.8AlSi_3O_8$ $Na_3(Mg,Fe)_5Si_8O_{22}(OH)_2$
2.5	Quartz Albite (Plagioclase feldspar) Magnesioarfvedsonite (Na-amphibole)	SiO_2 $K0.2NaO.8AlSi_3O_8$ $Na_3(Mg,Fe)_5Si_8O_{22}(OH)_2$

(*continued*)

Table 1. (*continued*)

Depth (m)	Mineral name	Chemical formula
3.0	Quartz Albite (Plagioclase feldspar) Arfvedsonite (Na-amphibole) Phlogopite (Mica) Biotite (Mica) Carbon (Carbon)	SiO_2 $KO.2NaO.8AlSi_3O_8$ $(Na,K)_2.6Fe_5(Si,Al)_8O_{22}(OH)_2$ $KMg_3(Si_3Al)O_{10}(OH)_2$ $KMg_3(Si_3Al)O_{10}(OH)_2$ C
3.5	Quartz Albite (Plagioclase feldspar) Arfvedsonite (Na-amphibole) Carbon (Carbon)	SiO_2 $KO.2Na0.8AlSi_3O_8$ $(Na,K)_2.6Fe_5(Si,Al)_8O_{22}(OH)_2$ C
4.0	Quartz Albite (Plagioclase feldspar) Arfvedsonite (Na-amphibole) Carbon (Carbon)	SiO_2 $KO.2NaO.8AlSi_3O_8$ $(Na,K)_2.6Fe_5(Si,Al)_8O_{22}(OH)_2$ C

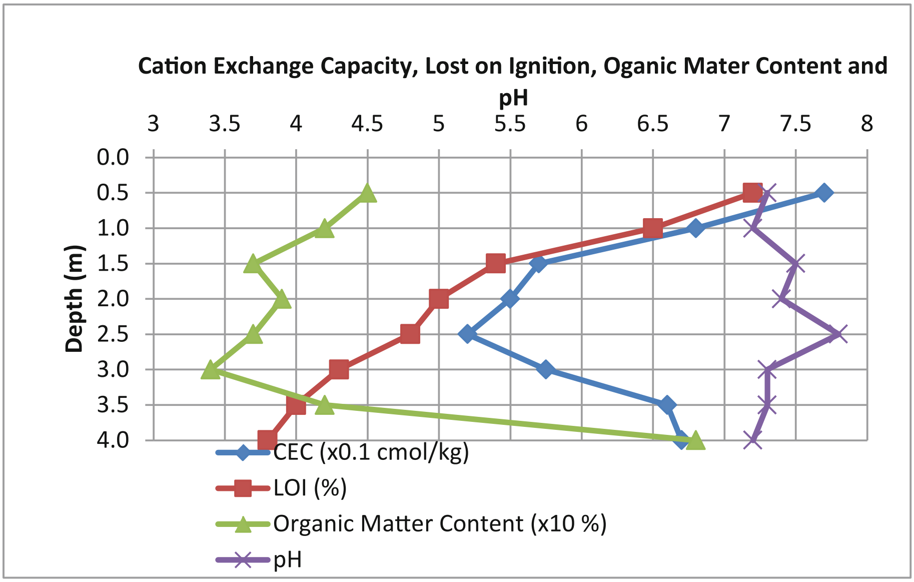

Fig. 3. Variation of physiochemical properties with depth

compared to other values in literature. This trend suggests that magnitude of weathering reduces with depth within this residual profile which postulates that, primary minerals increases with increase in depth and consequently, the MDD increase with depth in the profile. Conversely, the optimum moisture content (Fig. 7) reduces with increase in depth, a trend which is in agreement with literature.

The trend of specific gravity with depth is shown on Fig. 8. The trend showed decrease in specific gravity from 2.77 at 0.5 m depth to 2.58 at 2.0 m depth after which the values increases to 2.71 at 4.0 m depth.

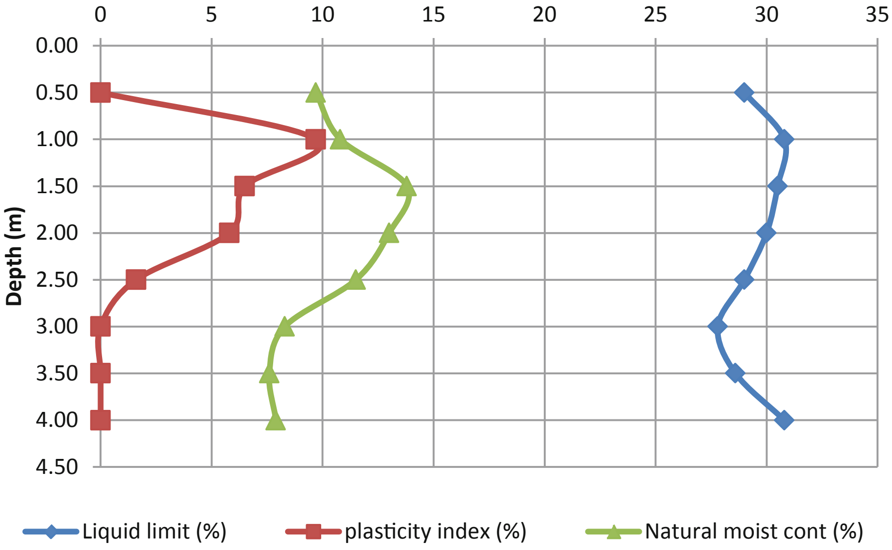

Fig. 4. Variation of Atterberg limit and NMC with depth

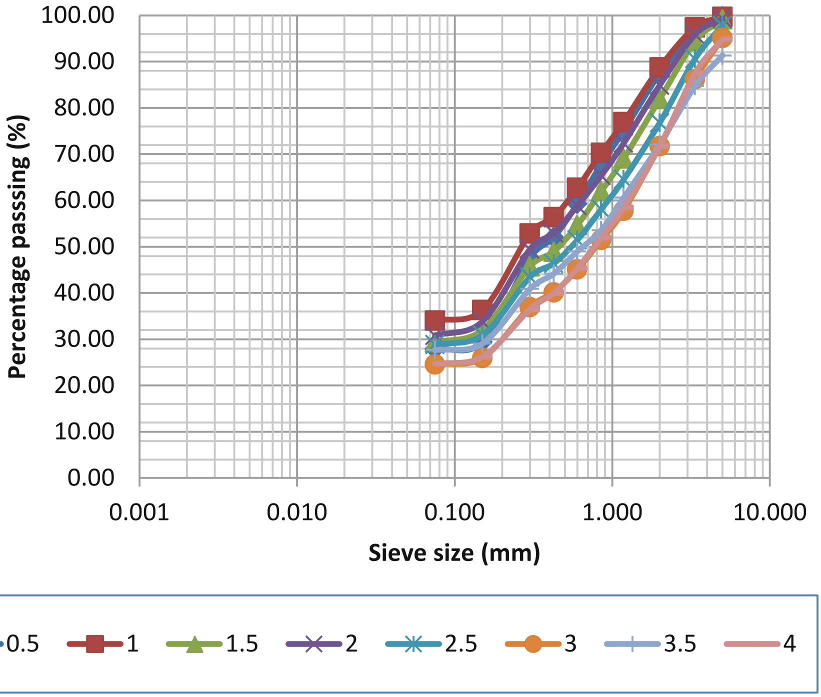

Fig. 5. Grain size analysis of soils within the profile

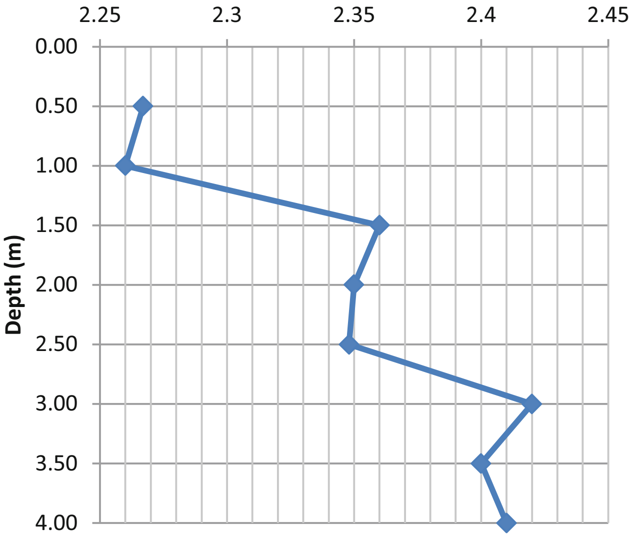

Fig. 6. Variation of Maximum Dry Density with depth

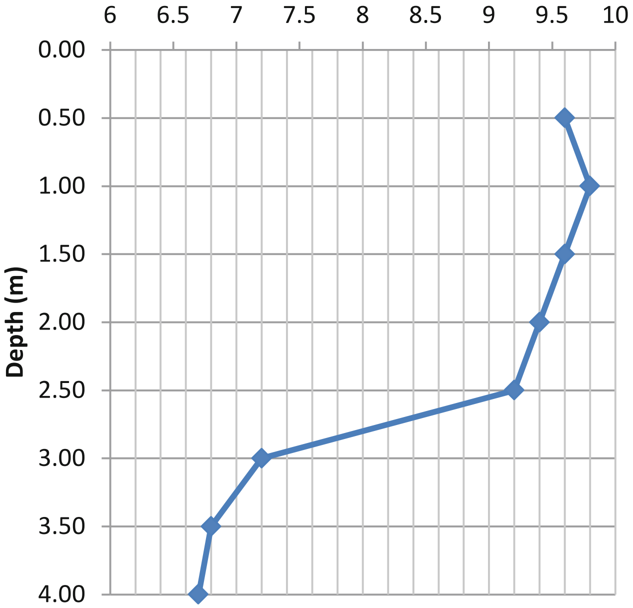

Fig. 7. Variation of Optimum Moisture Content with depth

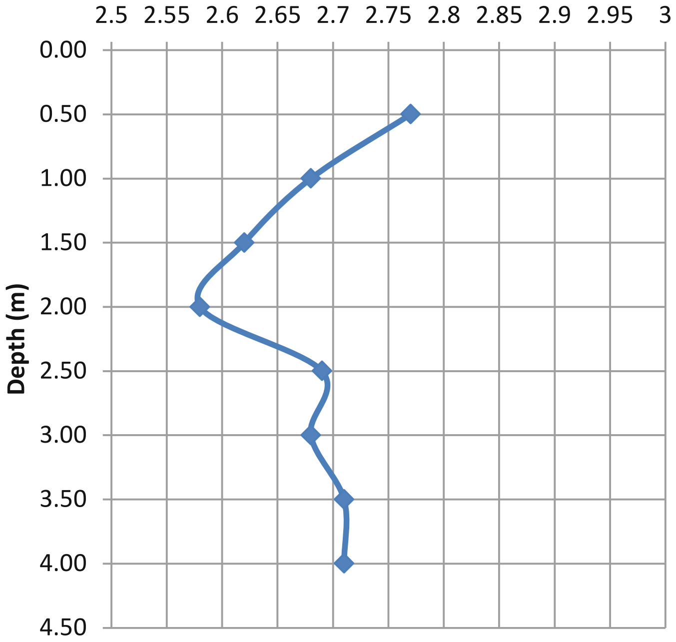

Fig. 8. Variation of specific gravity with depth

5 Conclusion

The mineralogical characteristics of overburden soil on gneiss basement complex with depth consist basically of amphibolite and feldspar within the entire profile with little alteration of carbon element contained at lower stratum of the profile to gregorite at upper stratum.

The natural moisture content as well as the Atterberg limits increases to between 1.0 to 1.5 m depth after which the values reduced to a constant value at 3.0 m depth.

The result of the grain size analysis coupled with the Atterberg limits classified most of the soil within the profile as silty sand (SM) based on Unified Soil Classification test. The general grain size distribution curves is capped on the top by soil at 1.0 m depth and covered at the base by soils from 3.0 m depth. Beyond 3.0 m depth, the grading began to increase again.

The MDD values were observed to be relatively high and increases from 2.262 g/cm^3 at 0.5 m depth to 2.410 g/cm^3 at 4.0 m depth while the OMC reduced from 9.8% at 0.5 m depth to 6.7% at 4.0 m depth.

From all the forgoing conclusions, structures sited on this basement complex are not susceptible to catastrophic collapse resulting from foundation failure.

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