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THE RELATIONSHIP BETWEEN THE GEOLOGY AND THE GEOTECHNICAL PROPERTIES OF ENGINEERING SOILS AROUND AKURE NORTH OF ONDO STATE, SOUTHWESTERN, NIGERIA

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ABSTRACT

Two conterminous occurring brownish to reddish residual soils in the northern environs of Akure, Southwestern Nigeria, which show distinct relationships in their geotechnical properties to their respective lithology have been studied. This research was carried out to determine the influence of geology on the strength parameters of the derived soils. Twenty (23) investigation points were selected based on lithological units for the field test and soil sample collection. In-situ test was performed using Dynamic Cone Penetrometer soundings and laboratory analysis including mineralogy, grain size and Atterberg limits and strength test. The parent rocks are coarse porphyritic granite and fine to medium-grained charnockite. The results classify the Ch as A-7-6 and OGp as A-6. The average maximum dry density of the granite-derived soil is about 2099 Kg/m^3 while that of the charnockite-derived soil is about 1840 Kg/m^3 their average Optimum moisture content was 11% and 19 % respectively The test results show that the differences in physical and engineering properties are conditioned fundamentally by the parent rock, with drainage and other environmental conditions being practically identical. Although the two soils are both usually described as "lateritic", the engineering properties of the soils considered on a comparative basis have established the coarse granite-derived soil as superior.

KEYWORDS: Lithology; Geotechnical Properties; Residual soils; Clay minerals

INTRODUCTION

Geological processes have greatly defined the earth's surface and most importantly the consequential soil's properties. The geological/geotechnical characterization of residual soils helps in knowing and understanding soil mechanic that can cause significant damage to infrastructure, provide data for safe design and also proffers solutions (Jedege, 2004; Bell, 2007). The geotechnical test includes index and strength tests. Index test is performed for soil identification and classification. Classification of soils assists the professionals in apportioning soils to engineering performance classes. According to Afolagboye et al., (2021), professionals use soil group systems to judge soil behaviour and response. Meanwhile, strength tests provide information on structural properties required for engineering design. The northern environs of Akure are defined by two distinct landform features: an inselberg landscape in the North and North-East and a flattish to gently rolling relief in the North-West. Many scholars including Ikubuwaje et al., (2017) and Owoyemi & Adeyemi (2018) have investigated the effect of parent rock factor on the geotechnical properties of lateritic soils in Nigeria. Owoseni et al., (2012) conducted an engineering geological assessment of some lateritic soils derived from three different parent rocks and concluded that the bandedgneiss-derived soils had the least clay-size content, the least linear shrinkage values, and the highest Maximum Dry Density values, making them the best engineering soil group among the three. They also confirmed that in the study, the pedogenic component of parent rock had a substantial impact on the engineering index properties of lateritic soils. Therefore, this research is set to examine the geotechnical properties of residual soils in the study area to further determine the influence of geology on the engineering soils.

MATERIALS AND METHOD

Study Area

The study area is along the Ado - Akure f209 highway defined by 6° 00′N and 7°55′N and longitudes 4°25′E and 5°59′ in Southwestern Nigeria. The elevation is relatively high in some places ranging between 250 m to 700m with a general subtle low relief of 200m to 300m above sea level. Characterized by a humid tropical climate with distinct wet and dry seasons. Annual rainfall reaches a mean value of about 1350mm and 2000mm for the northern and southern parts respectively coupled with high temperatures reaching a peak of about 32^{0}C for the northern part and 24^{0}C for the southern part.

Method of study

An integrated approach was adopted, comprising field mapping, soil sampling, laboratory and field tests. Standard procedures recommended by ASTM D6951/D6951M-09, (2015), were followed for the determination of the geotechnical properties of the soil samples. Soil samples were taken from 23 trial pits at a depth of 1m at 500m intervals for geotechnical analysis. Geotechnical properties determined were grain size, Atterberg limit test, compaction and California Bearing Ratio tests. XRD was used for the mineralogical analysis. In-situ tests: Dynamic Cone Penetrometer soundings (DCP) were carried out in all the investigation points as designated in ASTM D6951/D6951M-09, (2015), at an average interval of 500m. In addition, soil samples were collected at 450mm, 650mm and 950 mm intervals respectively in each test pit to also assess vertical moisture content variations.

The sites and their lithological unit are listed below:

(i) Ikere - Iju axis unlies by basic fine to medium grained Charnockite has ten (10) investigation points (ii) Iju - Akure axis unlies by medium to porphyritic granites has ten (10) investigation points.

The coordinates and the altitude of the study area were acquired using the Global Position System (GPS) device used to generate the geomorphology map study area. A total of 141 data comprising 50 and 91 coordinates and altitudes for Ch and OGp respectively were carefully recorded to develop the surface relief map of the studied area.

Geology of the Study Area

The Study area is underlain by rocks of the Precambrian basement complex; Coarse Porphyritic granites and fine to medium-grained Charnockite which vary in type, colour, nature, structure, composition and texture (Figures 1 & 2). The variation in properties of these rocks is primarily due to the effect of various orogenic episodes and deformational episodes on the rocks at different times during their evolutionary history (Odeyemi, 1979). Their intimate association suggests a common time of emplacement as suggested by Olarewaju (1987).

The Charnockitic rock types are believed to be of magmatic origin judging from their unfoliated, massive, homogeneous nature and the cross-cutting contacts. The Coarse Porphyritic granites give rise to the inselberg landscape, and the basic fine to medium-grained Charnockite gives expression to a flattish to gently rolling relief (Figures 1 & 2). In addition, the granite-derived soil is light brown, and coarse, composed in bulk by occasional iron-stone concretions, free quartz and undigested feldspar grains in the upper horizon. On the other hand, the relatively very fine texture of the Charnockite-derived soil is obvious. The dark reddish colour contrasts markedly with the contiguous granite-derived soil (Mesida,1987).

RESULTS AND DISCUSSION

Clay Mineralogy

The determination of the type of clay minerals present and their proportions are fundamental to understanding the engineering performance of the soil (Nazile, 2018). The consistency, water absorption and swelling characteristics of clayey soils are usually better understood if the clay mineralogical contents are known (Mesida, 1987). The result of the mineralogical analysis is presented in Table 1. The granite-derived soil gave peaks indicative of abundant quartz and less feldspar and illite but the Charnockite-derived soil showed less quartz and more feldspar and illite. Furthermore, the occurrence of Vermiculite as the dominant and distinctive pyroxene clay mineral found in Charnokite-derived soil samples not only attests to the differences and influence of the lithology but may also result in the possible disparateness in their respective engineering performance. Meanwhile, the higher proportions of orthoclase feldspar, illite and vermiculite clay minerals in Ch must have resulted in more clay content and a strong affinity for water content. Since Vermiculite exhibits both intercrystalline and intracrystalline swelling properties, it is weakly bonded, so on wetting, moisture enters not only between the crystals but also between the unit layers that comprise the crystals.

It has a high capacity of cation exchange; it ranges from about 100 to 150%. Basal spacing at full capacity of 14.5, specific surface area of 760 and number of water sheets between two layers (Mukherjee, 2013). It is expected that the clay that attracts more water molecules to the surface will have more plasticity Table 2 and Figure 4. The results indicate that Ch-derived residual soils have distinct mineralogical constituents in comparison with the granite-derived residual soils. The major differences in the clay content, clay mineralogical and basic engineering properties of the two soils can be explained by the differences in the lithology and weathering history of the parent rocks.

Textural Analysis

Figures 5a & 5b present some representative grain size distribution curves of each of the derived soils. In comparison, it is interesting to note that the granite, for example, is much coarser than that of the Charnockite-derived soil. The clayey nature of the entire profile of the Charnockite-derived soil is confirmed by the curves. The textural feature of soil is a crucial element in the design of engineering structures (Naresh & Nowatzki, 2006). Gradation of soils affects engineering properties like shear strength, compressibility, etc. The physical strength of cohesive is a function of the decrease in pore spaces, the higher the pore spaces the higher the water orientation power, the higher water adsorption and higher zones of weakness, shear strength, and compressibility properties. High or low pore spaces result from the grading of soils which depend mainly on the lithology and degree of weathering. The Ch fraction distribution curve is mainly gap-graded. Gap-graded soil exhibits poor bearing capacity due to a lack of proper interlock within the soil fabric due to dominance and the absence of a particular grain size fraction. On the other hand, the OGp is mainly well-graded. This class of soil has good workability and compatibility properties due to a well-structured texture that enhances good interlocking between the particles and thus a higher friction angle, than those that are poorly graded. According to Gidigasu (1976) high dry density results from particle size rearrangement in the well-graded soils during compaction.

Consistency Limits

The result of the consistency property of the two soils is presented in the American Association of State Highway Transportation Officials (AASHTO) plasticity chart for the studied soil samples (Figure 6). The plasticity characteristics of the soils may be interpreted based on their clay size particle content as well as their actual clay mineral content (Mesida, 1987). The Charnockite-derived soil is much more clayey, with higher plasticity tendencies. The dominant kaolinite content of the granite-derived soil has normally imparted limited plasticity to the soil. The higher hydrophilic characteristics of the Vermiculite clay mineral content in the Charnockite-derived soil have enabled the soil to have higher plasticity. According to Casagrande (1947), the plasticity chart can be used to predict the compressibility of clays and silts. From the plasticity chart, the result classifies the Ch as A-7-6 and OGp as A-6. This result agrees with Mesida (1987). The result implies that Ogp samples fall within low plasticity soils and compressibility. Soils within this region are considered as suitable material for engineering construction. Ch samples fall within high plasticity, and compressibility and have high group index values hence not suitable as subgrade soils. This may be attributed to the type of clay minerals and the amount of clay contents which depend on lithological differences.

Moisture/density relationship

The summary of the result of compaction tests on the soil samples is presented in Table 2. The results revealed a similar trend between the laboratory and field tests. The difference in the OMC of the soils can be explained by the presence of different clay minerals in the soil samples. Ch has a higher average field moisture content (FMC) of 19 % and Optimum moisture content (OMC) of 19.79% in comparison to OGp with FMC and OMC of 11% and 11.63% respectively. This may be attributed to the difference in textural properties. Soils having high clay content and active clay minerals will naturally imbibe more water than soils having coarser content and inactive clay minerals to attain maximum compaction. Textural influences on the compaction potential of the two soils are demonstrated in the results. The coarser, fairly well-graded granite-derived soil has been more suited to densification by compaction than the fine-grained, clayey charnockite-derived soil. The average maximum dry density and field dry density of the granite-derived soil are about 2099 Kg/m^3 and 2083 Kg/m^3 while that of the charnockite-derived soil is about 1840 Kg/m^3 and 1929 Kg/m^3 respectively. The higher amount of fines and the actual clay mineral contents in the two soils which are consequential of the geological processes and formation are the basic reasons for these differences in their moisture/density relation.

California Bearing Ratio

The CBR number is used to rate the performance of soils primarily for use as sub-grade course beneath the pavement of roads and airfields. The results of both field and laboratory CBR tests that were conducted are summarized in Table 3. These results show that Ch has the lower CBR values compared to OGp, this is in agreement with the

AASHTO plasticity results in the earlier paragraphy. Soaking or absorption of water usually lowers the CBR values of soils (Gidigasu, 1976). Secondly, the degree of change (reduction) in the CBR values is directly proportional to the amount of moisture content absorption. This may be attributed to the soil's texture and mineralogical compositions. Furthermore, the low CBR values which may be judged as also the bearing capacity are responsible for the manifestation and vast occurrence of the different foundation defects associated with engineering structures.

CONCLUSIONS AND RECOMMENDATIONS

This study gave insight into the influence of geology on the geotechnical characteristics of residual soils. The study area was underlain mainly by charnockites and granites, variations in textural and compositional properties of these rocks result in variations in their weathered products. The occurrence of vermiculite and higher illite found in charnockite-derived soils only distinguished its engineering properties from that of granite ones. Vermiculite which exhibits similar properties as montmorillonite adversely affect the geotechnical properties of the charnockite-derived soils. The major differences in the physical, clay mineralogical and basic engineering properties of the two soils examined in this study can be explained by the differences in the lithology and weathering history of the parent rocks. The slope conditions, colour and texture of the two soils are practically different so few engineers would fail to suspect the differences in the engineering properties of the soils. The lithology factor is essential in soil classification and evaluation, and should always be regarded as basically important and useful by engineers. In this way, the relation of the ubiquitous lateritic soils to their local geology would be better understood and elucidated. This would also facilitate appropriate comparative interpretations of the results of investigations in similar or dissimilar geological and climatic environments. The construction of the engineering geological maps in residual soil terrains would also be greatly aided.

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Table 1: Mineralogical Compositions

Mineral	OGp	Charnockite
Quartz	64.3	45.5
Kaolinite	11.7	11.8
Illite	3.4	7.6
Montmorillonite	-	-
Vermiculite	-	12
Clinochlore	6.7	4.3
Orthoclase	5.3	9.6
Osumilite	3	1.5
Garnet	2.9	6.4

Table 2: Compaction test results for study soil samples

	Samples	(OMC) (%)		MDD (kg/m^3)		FMC (%)		FDD (kg/m^3)	
Lithology	IPs	Range	Average	Range	Average	Range	Average	Range	Average
Ch	11	16 - 24	19	1585 - 2024	1840	15 - 25	19.79	1775 - 2219	1929
OGp	12	9 - 14	11	1684 - 2386	2099	7.9 -15.36	11.63	1856 - 2207	2083

Where: IPs is investigation points, OMC is Optimal moisture content, FMC is field moisture content, MDD is maximum dry density, FDD is field dry density

Table 3: California Bearing Ratio for both field and laboratory

	Samples	FMC (%)		CBR Lab		CBR Field	
Lithology	Total	Range	Ave	Range	Ave	Range	Ave
Ch	11	15 -25	19 - 79	1 - 5	3	3.5 - 20	12
OGp	12	7.9 -1 5.36	11.63	5 - 78	30	13 - 48	40

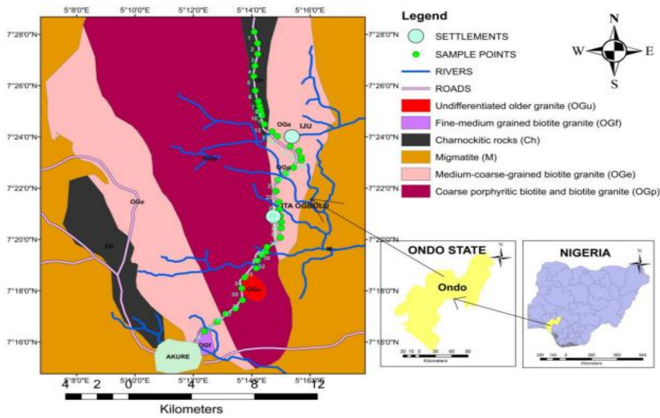

Figure 1. Geological map of the study area (modified after Olarewaju, 1987)

Figure 2. showing the granite section

Figure 3. showing the Charnockite section

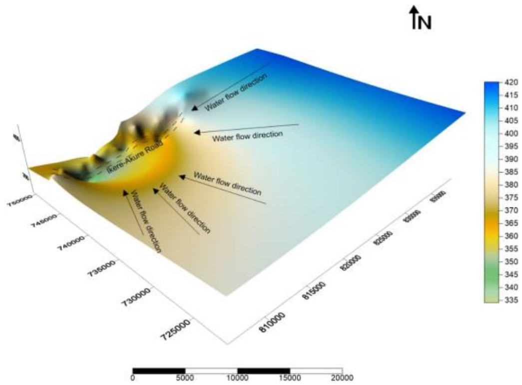

Figure 4a. Geological model of the study area.

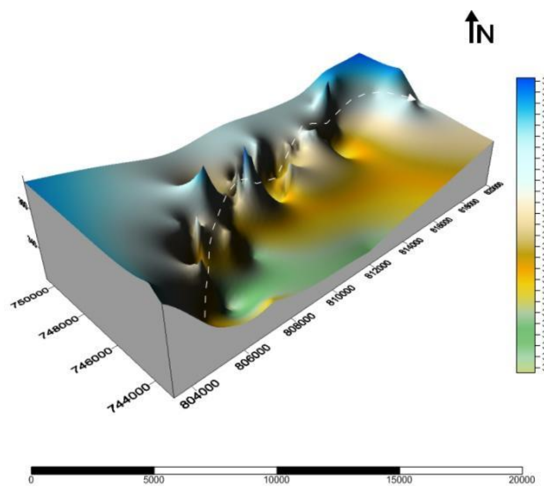

Figure 4b. Geological mode of the study area (showing granite section)

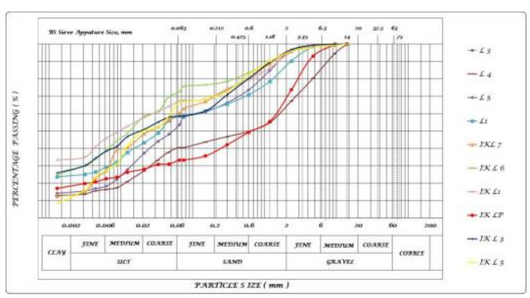

Figure 5a. Distribution Curve for Ch

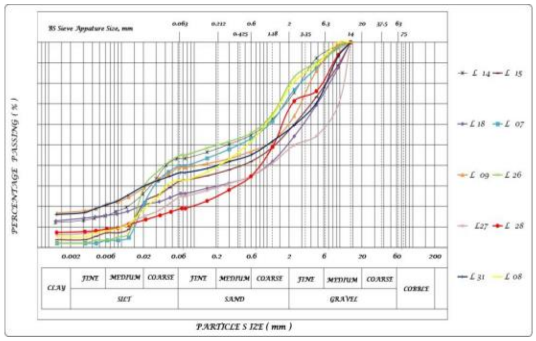

Figure 5b. Distribution Curve for OGp

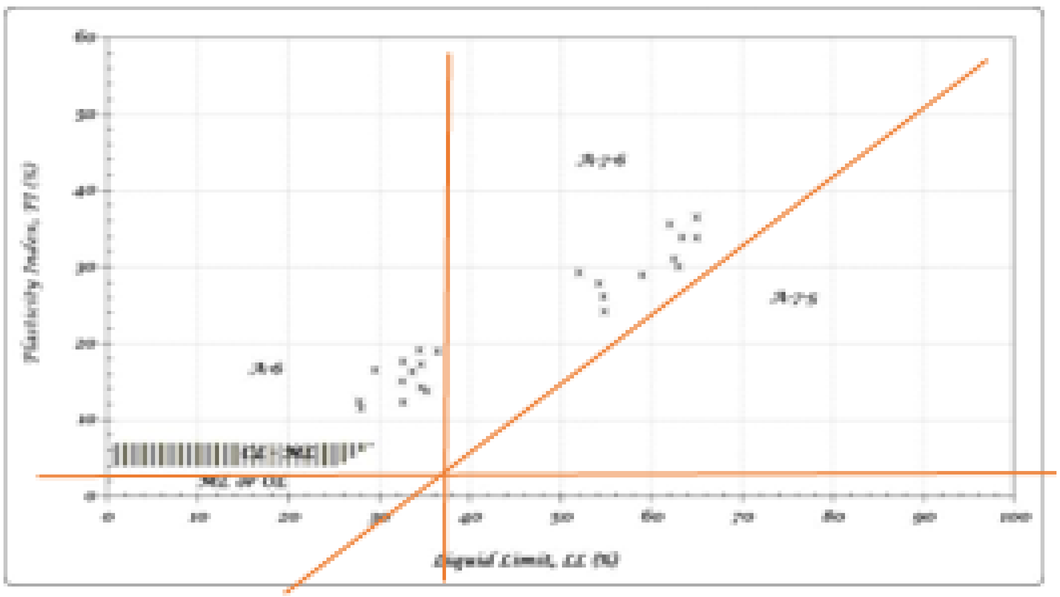

Figure 6. AASHTO plasticity chart for the studied soil samples.