Geotechnical Properties of Foundation Soils in Jos-Bukuru Metropolis, Naraguta (Plateau State), in Relation to Observed Cracks on Buildings in the Area

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ABSTRACT
Collapse of engineering structures such as buildings erected on clayey or expansive soils occur regularly in the study area. Thus, the aim of this study is to evaluate the geotechnical properties of soils of Bukuru Metropolis in relation to building collapse. Eight (8) representative soil samples were collected from various locations in the study area within the Eastern part of Naraguta sheet, 168. Moisture and dry density tests, Atterberg limit tests and particle-size analysis were carried out on the samples. The maximum dry density and the optimum moisture contents of the samples are 19.20kN/m^3 and 19.3% respectively, indicating non-cohesive soils that show uniform settlement when loads are imposed on them. The Coefficient of Uniformity (CU) of the samples computed from particle-size distribution curves ranged from 1.50 to 1.85, indicating poorly graded soils that are not good sub-base materials. The liquid limit (LL), plastic limit (PL) and plasticity index (PI) ranged respectively from 29.5 to 41.3%, 12.2 to 36.4% and 4.10 to 29.1. These values strongly suggest the possibility that swelling clay mineral like montmorillonite may be contained in the soil. On the basis of the results of this study, the soils in the area are expansive in nature and this is responsible for the collapse of buildings observed in the area.

Keywords: *Geotechnical properties, Clayey soil, Expansive soils, Atterberg limits, Building cracks.*

1.0 INTRODUCTION

Soils are very important for geotechnical engineers because the foundations of all civil engineering works are laid on soils. When engineering structures are founded on expansive soils, engineers and geologists are likely to face challenges of structural failures which often result to economic waste. Expansive soils are characterized by clayey minerals such as montmorillonite (smectite) that shrink and swell as it dry or become wet (Ogbuchukwu *et al*., 2019). There are also other clay minerals that may pose problems to engineering structures and these include illite, kaolinite, mica and chlorite. These minerals are formed from weathering of fine grained extrusive igneous rocks and montmorillonite rich mudstones such as shales and mudstones (Gromko, 1974; Harry, 1974).

The mineralogical composition of soils has significant influence on the geotechnical properties such as Atterberg limits, shear strength, swelling potential and bearing capacities (Amadi*et al*., 2012). Expansive soils are problematic because upon swelling and shrinking causes severe impairment to the engineering structure founded on them (Zumrawi and Hamza, 2014).Braja (1996) noted that the major problem of expansive soils, especially the montmorillonite-rich soils are the volume of change and this often results to severe damages of engineering structures.

In the course of field study, features that suggest failures of engineering structures such cracks on walls, over windows and door frames and on floors were observed in the area and are shown in Figures 1 to 4.The durability and economic value of these engineering structures are threatened due to cracks caused probably by expansive soils. According to Owolabi and Aderrinola (2014), these problematic soils are difficult to be used for most engineering constructions due to their swelling and shrinkage nature.

Whereas building failure can occur as a result of geology, most especially, the occurrence of expansive soils, the use of low quality construction materials and non-adherence to building codes can also lead to erection of weak structures that can deform easily and produce cracks on walls. Thus, the aim of this study is to determine the engineering properties of soils in the area in relation to observed cracks on buildings in the area and make appropriate recommendations in line with the findings.

Figure 1: Diagonal cracks

Figure 2: Vertical and diagonal cracks


Figure 3: Vertical cracks


Figure 4: Cracks on floor

2.0 STUDY AREA DESCRIPTION

2.1 Location of Study Area

The study area is part of the Jurassic Younger Granite Ring Complexes and Tertiary basaltic volcanic rocks of North Central Nigeria as found in the Naraguta Sheet 168. The area is located in Sheet 168 N.E. of the Naraguta map, i.e. between latitudes 8°30' and 10°10'N and longitudes 8°20' and 9°30' E as seen in Figure5.

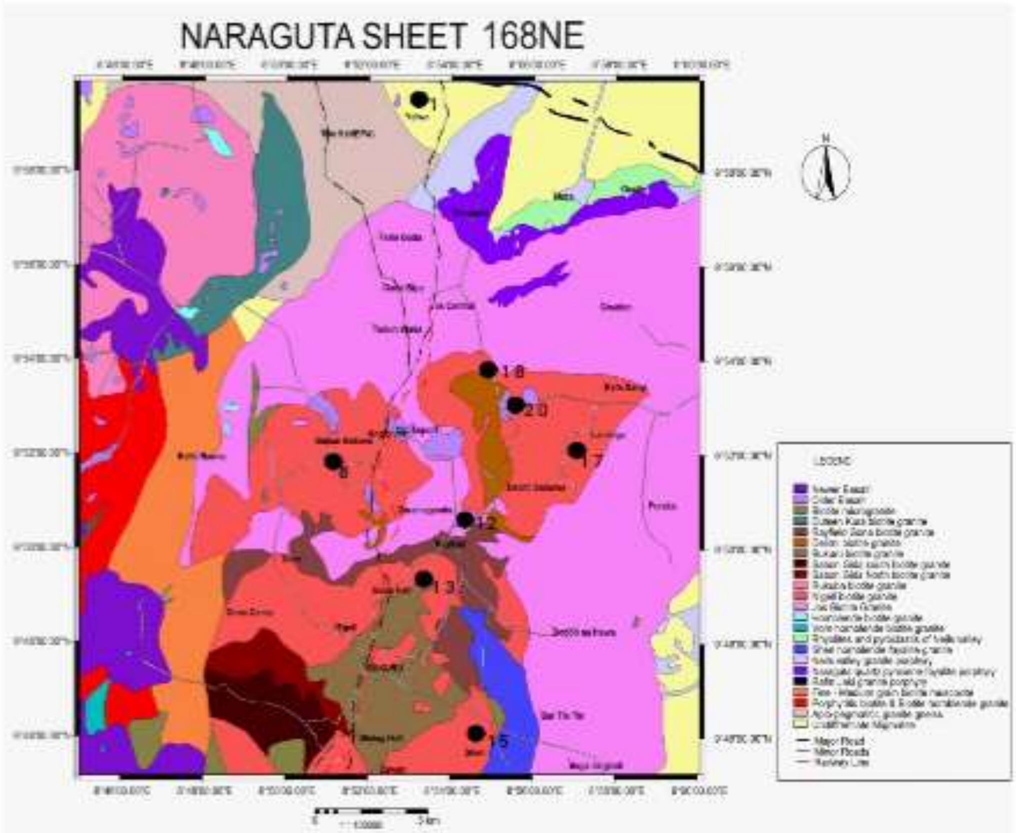

Fig. 5: Geologic map of the study area (after Macleod and Berridge, 1971).

2.2 Geological Setting and Sequence

The geology of the study area falls within the Jos-Bukuru Complex which is predominantly of biotite - granite type as exhaustively studied by Macleod and Berridge (1971). The geology of the Jos Plateau is made-up of the Precambrian Basement migmatite-gneiss-quartzite complex which underlies about half of the entire State and in some places, has been intruded by Precambrian to the late Paleozoic Pan-African granite (Older Granite), diorite, charnockite etc. Intrusives in these Basement Complex rocks are the Jurassic anorogenic alkali Younger Granites. In association with the Younger Granites are volcanic rocks such as basalts and rhyolites that overlie or cross-cut this formation as well as the Basement rocks.

The geological sequence of the Jos Plateau consists of almost entirely plutonic and volcanic rocks that belong to the four major groups while the sediments are restricted to river alluvium. This sequence can be seen as presented in the Table 1.

Table 1: Geological Sequence of the Plateau (Ochonogor, 1984; Macleod et al., 1971)

Quaternary	New Basalt	Lava flows and Volcanic cones
Tertiary Quaternary	Alluvium	

Lower Tertiary	Older Basalt	Lava flows (now largely decomposed/weathered), overlying alluvium (formerly termed fluvio-volcanic series)
Jurassic	Younger Granites	Granites, Porphyry and Rhyolites
Precambrian to Lower Paleozoic	Crystalline Basement	Migmatites, Gneisses and Pan-African Older Granites

3.0 MATERIALS AND METHODS

3.1 Sample Collection

About eight representative samples were collected. In each sampling point, soil sample was collected at depths of 0.5m and 1.0m, mixed and packed in polyethene bags for laboratory analysis.

3.2 Laboratory Tests

In line with the intent of the study, geotechnical tests were carried out on the samples in the laboratory. These include moisture content test, Atterberg limits and particle-size analysis. The geotechnical tests were performed in accordance with the British Standard Institution, BS 1377 (1990) and American Standards for Testing Materials(ASTM 2008a and ASTM 2008b) at the quality control laboratory of In-depth Engineering Limited, 17 Waziri Crescent, G.R.A., Kaduna. The activity of clay was computed from the relation:

$$A_C = \frac{PI}{\%Clay}$$

where:
A_C = activity of clay;
PI = plasticity index; and
% Clay = clay fraction.

4.0 RESULTS AND DISCUSSION

4.1 Moisture content/dry density

The moisture content of a given soil is the ratio of mass of water to the mass of solids in the soil. It has much to say about the soil type, as clay soils absorb water and retain more water than sandy soil because sandy soils are more porous and permeable. The moisture content of the soils ranged from 3.9 to 15.9% and are within the permissible limit of 5 to 15% (Weltman and Head, 1983) whereas the dry density of the samples ranged from 6.90kN/m^3 to 19.20kN/m^3.

Table 2: Summary of geotechnical parameters of soils in the area

S/N	Samples	Moisture Content $(100W_m/W_d)\%$	Dry Density (kN/m^3). Ib/cu.ft	Depth (m)	LL (%)	PL (%)	PI
1	POT D	6.5	17.85	1.5	37.7	17.6	20.1
2	POT 8U	9.8	17.30	1.5	35.9	20.1	12.2
3	POT 12D	11.0	17.5	1.0	41.3	12.2	29.1
4	POT 13U	3.9	19.20	1.5	29.5	13.6	15.9
5	POT 15D	15.9	6.90	1.5	31.5	21.9	9.60
6	POT 17D	9.3	18.22	1.5	32.2	17.2	15.0
7	POT 18D	12.1	16.77	1.5	40.5	36.4	4.10
8	POT 20D	9.8	-	1.5	36.0	18.4	17.6

4.2 Sieve analysis/grain-size distribution

The results of the sieve analysis showed that the soils are mainly clayey soils. The grain-size distribution curve is presented in Figure 6. Coefficient of Uniformity (CU) and activity of clay were computed using the particle-size distribution curve. The values obtained ranged from 1.50 to 1.85 and 0.35 to 0.85 respectively.

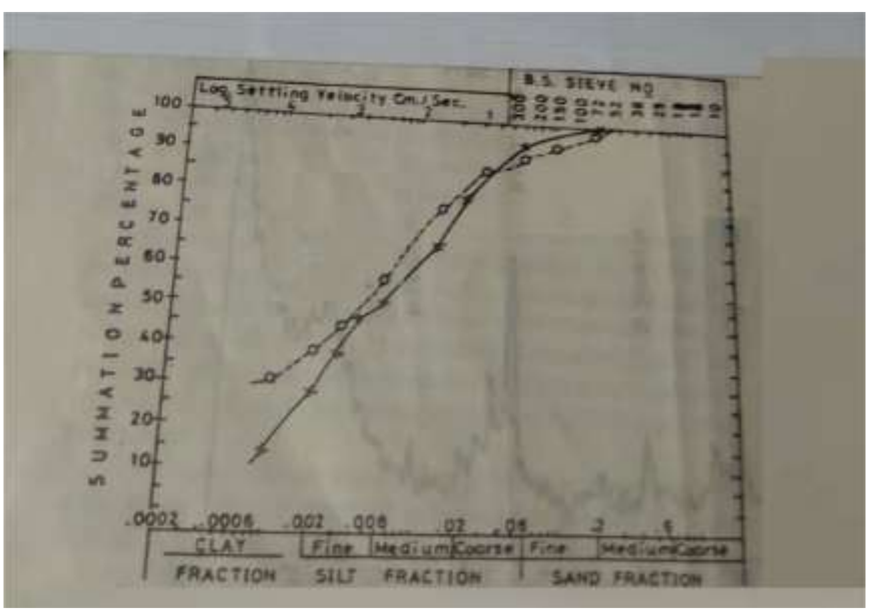

Fig. 6: Particle-size distribution curve of the samples

4.3 Atterberg limittests

The summary of the Atterberg limit tests carried out on the soil samples are shown in Table 2. The calculated liquid and plastic limits were within 29.5 to 41.3% and 12.2 to 36.4% respectively whereas the plasticity index ranged from 4.10 to 29.1.

4.4 DISCUSSION

4.4.1 Moisture content

The moisture content of the soils which ranged from 3.9 to 15.9% (see Table 2) could be described as low and suggest high transmissivity and low affinity for moisture characteristic of non-cohesive soils that lack substantial amount of silt/clays. In that the moisture contents are not natural as they were not measured in the field, it is likely that higher values suggesting fines and clayey materials, would have been obtained if the natural moisture content were determined.
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4.4.2 Compaction characteristics

The dry density of the soils which ranged from 6.90kN/m^3 to 19.20kN/m^{3}depicts the soils as non-cohesive soils that are known to show uniform settlement when loads are imposed on them.

4.4.3 Particle-size distribution curves

The particle-size distribution curve forms the basis for determining whether a soil sample is poorly or well graded. The result of the sieve analysis carried out on the soil samples indicated that the soils are majorly clayey soils and poorly graded. Thus, the soils in the area are cohesive and expansive in nature.

The Coefficient of Uniformity (CU) of the samples computed from particle-size distribution curves ranged from 1.50 to 1.85, indicating also, poorly graded soils that are not good sub-base materials. The poorly graded nature of the soils suggests that they are expansive soils and would be mechanically unstable to perform satisfactorily as sub-base materials.

4.4.4 Activity of clay

Activity of clay is a geotechnical parameter that is used to estimate the swelling potential of soils. It is the measure of the contribution of clay minerals to soil plasticity. According to Skempton (1953) classification, values less than 0.75 indicate low activity whereas values in the range of 0.75 to 1.25 depict medium activity. Values greater than 1.25 indicate high activity.

The activity of clay determined from particle-size distribution curve of the samples ranged from 0.35 to 0.85. In line with Skempton (1953) classification, the swelling potential of the soil samples is of low to medium activity.

4.4.5 Atterberg limits

Atterberg limit is an important test in environment and foundation studies and gives an indication of the consistency limits of soils (Maduabuchi and Obikara, 2019). In line with Ola (1981), PI of less than 15 is low, 15 to 25 is medium whereas 25 to 35 is high. On this basis, with the exception of POT8U, POT 15D and POT 18D, all other samples have medium to high plasticity index. Liquid limit less than 35 is low while values of 35 to 50 are moderate (Holtz and Gibbs, 1956). This classification shows that POT 13U, POT 15D and POT 17D have low liquid limit whereas other samples have medium liquid limit.

The plasticity index of 12 to 29.1% and liquid limits of 40.5 to 41.3% (see Table 2) strongly suggest the possibility that swelling clay mineral like montmorillonite may be contained in the soil. Low values of liquid limit and plasticity index in the soils, and as observed in some samples are indications that the constituent clay mineral is the non-swelling kaolinite (Ehujuo *et al*., 2017).

In line with the plasticity index and liquid limits which indicate clayey soils, the plasticity chart (Figure 7) has all the points plotted above the A-line, which is a major requirement for classification of soils as clayey material using the plasticity chart.

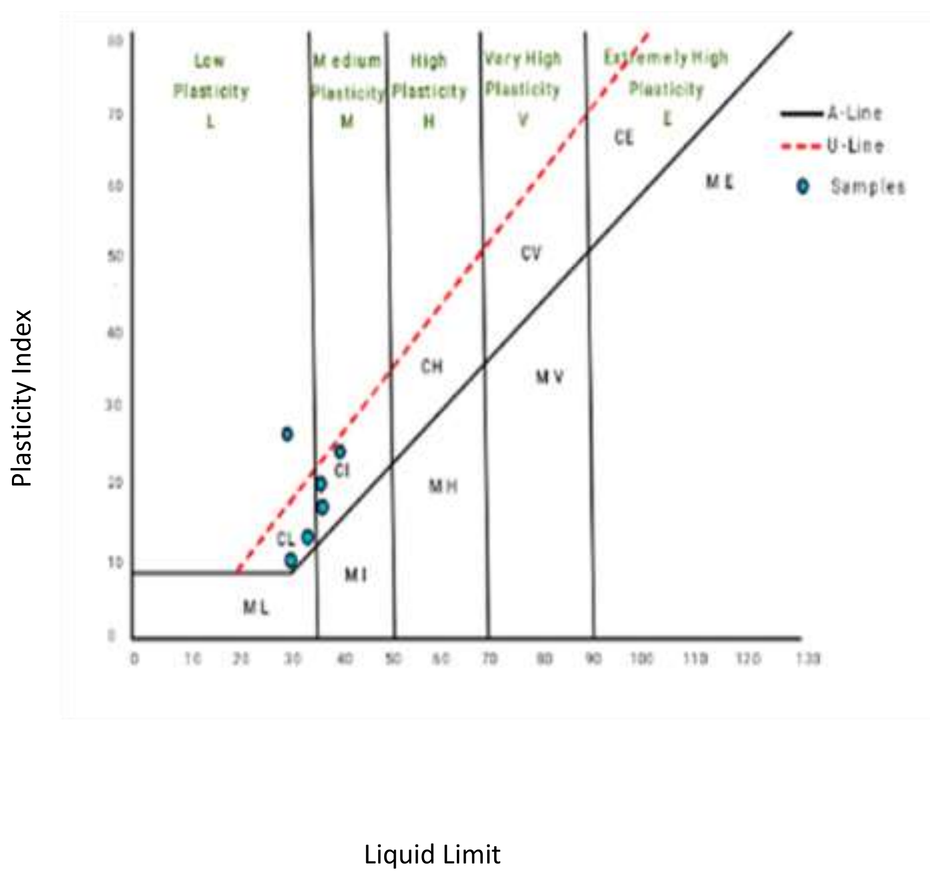

Fig. 7: Casagrande plasticity chart of the soil samples

The results of the Atterberg limit tests complemented by other geotechnical tests carried out on the samples show that the soils are expansive in nature and hence, buildings erected on them may crack vertically and/or diagonally as the clayey soils swell and shrink. A typical example of building failures that are likely to occur in the area as a result of expansive soils are shown in Figure 7.

Fig. 7: Typical cracks caused by expansive soils on buildings at Bende, Southeastern Nigeria(adapted from Okoro *et al.*, 2019).

5.0 CONCLUSION AND RECOMMENDATIONS

The results of the particle-size analysis indicate that the soils are mainly clayey soils. The Coefficient of Uniformity (CU) of the samples computed from particle-size distribution curves also indicate poorly graded soils that are not good sub-base materials.

The Plasticity index shows medium to high plasticity for most of the samples, indicating the possibility that swelling clay mineral like montmorillonite may be contained in the soil. On this basis, and taking into account, the activity of clay of the samples, the soils in the area are expansive in nature and this is responsible for the collapse of buildings observed in the area.

We recommend that the soils in the area be subjected to X-ray diffraction analysis in order to identify the constituent clay minerals. This will be very useful in determining appropriate soil stabilization measures to be adopted for building construction in the area.

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