Investigation of geotechnical properties of soil samples in Isu-Njaba Imo State

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Abstract: The properties of the geotechnical characteristics of soil samples from Isu-Njaba borrow pit was carried out in this study. Ten soil samples from the depth of 3m were taken from the pit at day1, day7 and day14 respectively. The tests carried out on the soil samples include sieve analysis, natural moisture content, Atterberg limit, compaction and California bearing ratio tests in line with standards. From the results, the fine soil content is 4.19%, and the soil samples contain more of sand and gravel and are uniformly graded. Thus the soil is classified as A-2-4 soil in line with AASHTO standard of soil classification. The obtained liquid limit is 38.02%, plastic limit of 27.53% and plasticity index of 10.49%. The results from the test on compaction showed the maximum dry density to be 1.56 Mg/m and optimum moisture content as 14.30%. The values of the California bearing ratio for the non-soaked soil is 20.64%, and 12.63% for the soaked soil. The study showed that the soil samples from Isu-Njaba borrow-pit could be applied as materials for subgrade, sub base and base purposes, as most of the properties meet the specifications of the Federal Ministry of Works and Housing guidelines for road construction.

Keywords: Geotechnical characteristics, Soil, Atterberg limit test, Isu-Njaba

1. Introduction

In the course of construction expansion in structural engineering, some of the frequently faced problems include cracks, pavement break-ups, lines for reservoir, water and sewers, foundations of buildings, roadways, highways, and irrigation systems amongst others. These problems occur because of not understanding the behavior of the soil or lack of information as it concerns the soils’ engineering properties [1]. Investigation on the properties of the geotechnical attributes of the soil is highly needed, because these data are very important in the preliminary designs and in the designs involving building foundations, pavement, and retaining structures for construction projects. Investigation of engineering properties of soil should be done for economical design of sub-structural elements and almost everything we build such as buildings, bridges, dams and others that are in, on or within soils [1]. Sufficient information is necessary for studies on economic and applicability of the anticipated project. Not carrying
out enough geotechnical analysis, interpretation and representation of results wrongly may contribute to inappropriate design and construction delays. This also may cause expensive modifications on constructions, use of inferior materials, environmental pollution, repair and failure of construction works, succeeding legal actions amongst others. Thus in order to get more information on the kind of soil, its attributes, and how it is distributed, investigations are made on the geotechnical qualities of the main soil or neighbouring soils to the site of the proposed structure.

The soil of Adama town is categorized as silt and silty sand in line with Unified Soil Classification System. Almost all the samples of the soil have free swell value of less than 50%. This shows that the soil in the Adama town is non-expansive [2].

The soils of Ambo town are highly plastic. Black and gray soils have higher plasticity index than reddish brown and brown soils. Grain size analysis shows that the predominant proportion of the soils is clay size fraction. The soils in Ambo town are categorized under A-7-5 soils in keeping with AASHTO system of soil classification. It implies that the quality of the soil is poor and would not be suitable for use as grade materials. However during dry season, the consistency of Ambo soils changes from rigid to hard because the unconfined compressive strength (UCS) varies from 112 KPa to 545 KPa [3].

The grain size distribution of Sebeta town indicates majority samples have clay material more than 50%. In line with AASHTO system of soil classification, the soils are classed under group A-7 and A-6, and thus cannot be used as sub grade materials due to the quality is poor [4].

There are both black clay soils and red soils in the town of Adet. The black clay soils are found in the relatively lower elevation and flat lying areas of the town. However, most of the areas in the town are covered with red soils. The free swell values of black clay soils, ranges from 67-100%, which shows that the soils are fairly expansive. Most of the red soils' free swell values are below fifty (50) percent whereas the whole red soil's free swell values ranges from 27-67.5%. The consistency of Adet soils showed medium rigid to hard for the UCS varies from 84 to 442 KPa at natural moisture content of 28-41% [5]. Thus this study is aimed at investigating the engineering attributes (properties) of samples of soils from Isu-Njaba area of Imo State.

2. Materials and methods

Ten soil samples were taken from the depth of 3m. Three soil samples at day1 and day7, while four samples were taken at day 14. The collected soil samples were positioned in weighed containers and properly kept for the needed tests. The following tests were performed on the samples of the soils; sieve analysis, moisture content, Atterberg limit, compaction and California bearing ratio tests.

2.1 Sieve analysis
To understand the distribution of the sizes of the soil particles, sieve analysis was done, in line with BS 1377 [6] method. 700g of sample that has been dried in the oven was discharged into a set of sieves and placed on the sieve shaker. Later on, the set of sieves was taken out and the weights of the quantities remaining on the different sieves were taken. The weight of soil retained in percentage and weight of soil that passed in percentage were calculated using equations (1) and (2) [7]:

\[
\text{\% weight of soil retained} = \left( \frac{\text{weight retained}}{\text{Initial weight}} \right) \times 100\% \quad (1)
\]

\[
\text{\% of soil passing} = 100 - \text{\% weight retained} \quad (2)
\]

The results are plotted in a semi-logarithmic graph identified as the particle size distribution curve.
2.2 Test for moisture content
The natural moisture content analysis was done in line with BS 1377 [6] method. A tiny quantity of the sample of the soil was placed on a weighed container and then kept for drying in the oven for a temperature of 105°C for a period of 24 hrs. Then the sample that was dried in the oven was brought out to cool. Thereafter, moisture content was calculated using equation (3) [7]:

\[
\text{Moisture content} = \frac{M_2 - M_3}{M_2 - M_1} \times 100\%
\]  

(3)

where \(M_1\) gives the weight of the container, \(M_2\) gives the weight of the soil before oven drying, \(M_3\) gives the weight of the soil after oven drying.

2.3 Test for Atterberg limit
The liquid limit was determined using the ASTM D423 [8] method. To carry out the test on liquid limit, 300g of the sample of the soil that went through sieve No. 40 was carefully blended with water, in a clay dish. Water is repeatedly added to the soil mixture, and steadily stirred, kneaded and chopped using a spatula. When a homogenous mixture was produced, a small quantity of the mixture was forced down into a cup and cautiously positioned with a spatula while avoiding air entrapment. Later the moisture content was plotted in respect to the number of blows and the moisture content at 25 blows gives the liquid limit. Also the plastic limit and the shrinkage limit tests were performed using the BS 1377 [6] standard procedures.

2.4 Test for compaction
The test for compaction was conducted using BS 1377 [6] method. The maximum dry density was carried out by varying the content of moisture and about 3 kg of the soil sample was used. Three equal layers of compacted soil samples and each of the layers was subjected to 27 blows, which were shared evenly on top of every layer. Then the collar was taken away and the sample that was compacted was stabilized using a straight rim. The mould that contains the sample that was stabilized was brought to a weight of 1g. A little sample was removed from the soil that was compacted with the aim of finding out the moisture content. In the bid to find out the moisture content, similar practice was undertaken again. Later, a graph of dry densities was plotted against the individual moisture contents, and thus the maximum dry density (MDD) and the optimum moisture content (OMC) were deduced from the plot.

2.5 Test for California bearing ratio
The BS 1377 [6] method was followed in performing the test for California bearing ratio (CBR). The sample of soil about 6 kg was carefully blended with moisture at their particular optimum moisture contents. The compaction of the soil sample was done and placed in a mould with dimensions (10 x 10 x 10 cm), in five layers. Every layer was compacted by 62 blows using a 4.5 kg rammer. From the CBR test, an indirect measurement of the resistance of the soil to shear under monitored conditions of density and moisture content would be achieved. The ratio of the amount of load needed to penetrate to a particular depth in a compacted sample at given density and moisture content, to the standard load needed to obtain similar depth penetration on a standard crushed stone sample, gives the CBR. This can be mathematically expressed using equation (4):

\[
\text{CBR} = \frac{\text{Test load on the sample}}{\text{standard load on the crushed stone}} \times 100
\]  

(4)

3. Results and discussions
The sieve analysis was carried out to find out the distribution of the grain size of the soil. The result from the sieve analysis is shown in Figure 1 and the clay content of the soil sample is 4.19%. This fits into the
Federal Ministry of Works and Housing (FMWH) [9] specification, which directs that the content of clay for materials used for sub-grade, sub-base and base purposes going through No. 200 BS Test sieve or 0.075 mm should be less than or equal to 35%. This is to ensure that the amount of clay in the small is not too much so as to enhance the mechanical stability of the soil [10]. The soil sample studied belongs to the class of A-2-4 and SW soils in accordance with AASHTO and USCS standards for classifications of soils respectively, which implies that the soil contains more of sand and gravel. The coefficient of uniformity ($C_u$) is 2.61, and the coefficient of curvature ($C_c$) obtained is 1.01. This classifies the soil as a uniformly (or poorly) graded sandy soil [11].

![Figure 1. Distribution of the particle size of the soil samples](image)

The properties of the geotechnical characteristics of the soil sample are presented in Table 1. From Table 1, the obtained natural moisture content is 3.45%. The reduced moisture content of the soil sample would enhance the shear strength of the soil and thus makes it fitting for use in construction of roads. There is an implication also that there would be no interaction of moisture between the sub grade, sub base and base rocks, thus keeping the soil intact [12].

The results of the Atterberg test carried out as presented in Table 1, showed that the soil samples studied have average liquid limit of 38.02%, average plastic limit of 27.53% and average plasticity index of 10.49%. According to the plasticity chart of Casagrande [13], soils that have liquid limits less than 30% are said to depict low plasticity and compressibility, those that have liquid limits amid 30% and 50% show medium plasticity, while as the soils having liquid limits that are above 50% are said to display high plasticity and compressibility. Thus this soil sample displays medium plasticity. Moreover, the Federal Ministry of Works and Housing [9] has specified that the liquid limit for sub grade materials should be maximum of 40%, maximum of 35% for sub base, and maximum of 30% for base materials. Also that the plasticity index should be maximum of 20% for sub grade, maximum of 16% for sub base and maximum of 13% for base materials [7]. Comparing the results obtained from this study to the FMWH [9] guidelines, the liquid limit obtained showed that the soil may not have stretchy clayey materials and would be good for sub grade since it is below 40%, but would be poorly suitable or sub base and base materials [7]. However, obtained plasticity index of 10.49% from the study meets the specification of FMWH [9] for application as materials for sub grade, sub base and base purposes. The increase in the plasticity index more than the required value may lead to decreased permeability and increase in soil’s compressibility, which can in turn cause the soil to be easily flooded and water logged [14].

The result of the test on linear shrinkage test is presented in Table 1. The linear shrinkage shows how the soil expands or swells during wet or dry seasons [15]. For this study, the linear shrinkage is 8.10% which fairly satisfies the recommendation by FMWH [9] that the linear shrinkage of soils for sub grade
materials should be at maximum of 8%. Thus the soil studied would be fairly fit to be used as material for sub grade purposes, for its expansion would be as required.

From the test on compaction, the maximum dry density (MDD) and optimum moisture content (OMC) were obtained as 1.56 Mg/m$^3$ and 14.30% respectively as presented in Table 1. It has been reported that soils with increased maximum dry density and reduced optimum moisture content values are most appropriate for sub grade and sub base purposes [16, 17]. FMWH [9], specified that for sub grade and sub base materials that the MDD should be ≤ 1.7 Mg/m$^3$ and OMC should be < 18%. The soil sample in this study met this specification and would be fitting for application as sub grade and sub base materials.

To determine the capacity of the soil to bear loads, the California bearing ratio (CBR) was investigated on the samples of soils for unsoaked and soaked conditions and the results are included in Table 1. The FMWH [9] specifications for unsoaked soil is ≤ 10% for sub grade, ≤ 30% for sub base, and ≤ 80% for base materials. It could be seen that the value of the CBR of the investigated unsoaked sample of soil (20.64%) showed that the soil would be best fit to be applied as sub grade and sub base materials, and also can be utilized as base materials. However the CBR of the soil sample reduced after soaking for 24 hours, which implied that if the soil becomes water logged, its capacity to bear loads or its strength would be reduced.

### Table 1. Properties of the geotechnical characteristics of the soil.

| Parameters                                      | Quantities |
|-------------------------------------------------|------------|
| Percentage passing BS Sieve No 200 (%)          | 4.19       |
| Average moisture content (%)                    | 3.45       |
| Liquid limit (%)                                | 38.02      |
| Plastic limit (%)                               | 27.53      |
| Plasticity index (%)                            | 10.49      |
| Linear shrinkage (%)                            | 8.10       |
| AASHTO Class                                    | SW         |
| USCS                                            | A-2-4      |
| Maximum Dry Density (Mg/m$^3$)                  | 1.56       |
| Optimum Moisture Content (%)                    | 14.30      |
| California Bearing Ratio (unsoaked) (%)         | 20.64      |
| California Bearing Ratio (after 24 hour soaking) (%) | 12.63    |

### 4. Conclusion

The properties of the geotechnical characteristics of soils from Isu-Njaba borrow pit was investigated in line with established standards. The results indicated that the sample of soil investigated is a uniformly graded sandy soil having the percentage passing less than 35%. Low values of natural moisture content, maximum dry density and optimum moisture content were obtained from the results. Also, the values of the plasticity results and CBR results for the non-soaked soil samples showed that the Isu-Njaba borrow-pit soils would be suitable for application as sub grade, sub base and base materials for the construction of roads. In addition, the results from this study can offer preliminary information needed for the planning and infrastructural development of Isu-Njaba Imo State in future.

This study has shown that the soil in the Isu-Njaba area is underlain predominantly by sandy soil (fine and medium sands). The soil is a uniformly graded sandy soil, and has desired properties needed as a construction material without or less improvement in its properties. Therefore, the soil would be apt for use as materials for sub-grade material in the construction of roads. Also, results of this study gives preliminary information required for future planning and infrastructural development of Isu-Njaba in Imo State.
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