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# Geotechnical Investigation of Shear Strength and Index Properties of Undisturbed Soil in South-East Nigeria

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***ABSTRACT :*** *This study assessed the shear strength and index properties of undisturbed soil in south-east Nigeria. Soil samples were collected from five different communities in Abia State using the bumper and hand auger equipment and was carefully transported to the laboratory. Triaxial test, atterberg limit test, sieve analysis, moisture content and specific gravity test were performed on these soil samples. The investigation reveals that the moisture content ranges from 11.61%-15.36% having an average of 13.55%, The shear strength of the area explored ranges within 159 kN/$m^2$-333 kN/$m^2$ with an average of 256.8 kN/$m^2$, Liquid limit covers from 2.4%-35.08% with a average value of 25.13%, while the plastic limit ranges from 7.06%-19.08% with a mean value of 14.154%, lastly plasticity index ranges from 1.5% to 28.3% with an average of 10.98%. The highest liquid limit was 35.36%, while the lowest was 14.24%. The lowest plastic limit was 7.06%, while the maximum value was 19.08%. The highest plasticity index was 28.3%, while the lowest was 1.5%. The percentage final on sieve number 200 (0.075mm) is more than 90%. Thi indicate that the soil in the study area is identified as fine grain soil. The soil in the study area is grouped under MH soil group based on Unified Soil Classification System. The result revealed that the maximum shear strength of 333 kN/$m^2$was found in the communities of Obuzor and Imo in Abia State. The moisture content recorded its maximum value at Imo, these findings are important for understanding the engineering properties of soil in the region.*

***KEYWORDS:*** *shear strength, geotechnical properties, foundation, CBR, Atterberg limit*

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## I. INTRODUCTION

In civil engineering, soil is a naturally occurring, loose/weakly cemented/relatively unconsolidated mineral particle, organic or inorganic in character, lying over the bed rock which is formed by weathering of rocks. Soil is formed by different particles such as gravel, rock, sand, silt, clay, loam and humus. Civil engineering structures like buildings, bridge, highway, tunnel, dam, tower, etc. are founded below or on the surface of the earth. For their stability, suitable foundation soil is required. To check the suitability of soil to be used as foundation or as construction materials, its properties are required to be assessed.

The shear strength of soil determines its resistance to deformation by tangential (or shear) stress. Soil that has greater shear strength will have more cohesion between particles, and more friction or interlocking to prevent particles sliding over each other. The shear strength of soil is defined as the maximum shear stress that the soil can sustain before it fails in shear. This can be expressed mathematically as the ratio of the shear stress to the normal stress, also known as the angle of internal friction (ϕ) or the cohesion (c). A commonly used definition of shear strength is the Mohr-Coulomb failure criterion, which states that the shear strength is equal to the sum of the cohesion and the product of the normal stress and the angle of internal friction (Mitchell [1]).

Soil index properties are the properties of soil that help in identification and classification of soil. These are properties of soil that indicate the type and conditions of the soil and provide a relationship to structural properties. Soil index properties are used extensively by engineers to discriminate between the different kinds of soil within a broad category.

The shear strength and index properties of soil are important factors to consider when it comes to civil engineering projects. In south east Nigeria, the soil can be quite diverse, so it's important to understand the unique properties of the soil in that region. This study would serve as reference guide for future engineering projects in the south east region. Shear strength is a measure of how well the soil resists deformation, and index properties are the physical characteristics of the soil that can be measured in the laboratory. These properties can include liquid limit, plastic limit, particle size, and specific gravity. By understanding these properties, engineers can design structures that are safe and efficient. In south east Nigeria, the soils can range from clay to sand, and they may have different levels of organic matter and moisture content. These factors can affect the shear strength and index properties of the soil.

The complex shear strength and index properties of soil in south east Nigeria have led to challenges in engineering design and construction. A better understanding of these properties is needed to improve the safety and efficiency of engineering projects in this region.

Due to the lack of reliable data on the shear strength and index properties of soil in the region. This makes it difficult for engineers to accurately design and build structures that can withstand the unique conditions in the south east area. One example of a project that was affected by the shear strength of the soils in south east Nigeria is the third Niger Bridge project. This project involved the construction of a new bridge across the Niger River in the Anambra State, south east Nigeria. The bridge was designed to withstand the high loads that are placed on it by traffic and weather conditions, but the stability of the structure was affected by the poor shear strength of the underlying soils. This led to delays and additional costs for the project.(Sesan and Adebimpe [2])

The studies of the geotechnical properties of Nigeria soil can be traced back to about three to four decades. In the context of soils in south east Nigeria, the shear strength is of particular importance because of the unique conditions found in the region. The soils in south east Nigeria are often lateritic, with a high clay content and a low organic matter content. These soils are often subjected to high rainfall and high temperatures, which can affect their shear strength. Some studies, such as a study by Ejembi and Eno-Abasi [3]), have found that the shear strength of these soils can be affected by factors such as rainfall intensity, drainage conditions, and the depth of the water table. The effect of rainfall intensity on the shear strength of soils in south east Nigeria has been studied in several ressearch, including the one by Ejembi and Eno-Abasi. This study found that when rainfall intensity is high, the soils become saturated and the shear strength decreases. This is because the cohesion between the soil particles decreases as the water content increases. In addition, the high rainfall can lead to erosion and changes in the structure of the soil, which also affects the shear strength.

One study that provides a good overview of the shear strength of soils in south east Nigeria is "Shear Strength Characteristics of Some Soils in South-eastern Nigeria" by Eneh and Ofoegbu [4]. The study uses references from several sources, including Emeakaroha and Uche [5]. These studies provide useful information on the shear strength of different types of soils in south east Nigeria, and can be used to compare and contrast the results of Eneh's study.

Eneh [6] research investigated the shear strength and compressibility of sandy-clay soils from Anambra State in south east Nigeria. The study included both laboratory and field testing. In the laboratory, the soil samples were subjected to consolidated undrained triaxial tests to measure their shear strength. The results showed that the shear strength of the soils was affected by their water content, degree of saturation, and the presence of silt and clay particles. In the field, the soil samples were subjected to oedometer tests to measure their compressibility.

Osoegbu et al. [7] conducted a study on the mechanical properties of tropical soils in the region, and found that the shear strength of clayey soils was up to 2.5 times higher than that of sandy soils. Similarly, Nsofor and Onwubu [8] found that the undrained shear strength of clayey soils was higher than that of sandy soils, and that this difference increased with depth. Ejembi et al. [9] found that soil type has a significant effect on the shear strength of soils in south east Nigeria, with lateritic soils having the highest shear strength.

Many studies have shown that water content has a significant effect on the shear strength of soils in south east Nigeria. For example, a study by Okeke et al. [10] found that increasing the water content of sandy soils in the region decreased their shear strength, while increasing the water content of clayey soils increased their shear strength. The age of the soil is another factor that has been shown to affect its shear strength. This was demonstrated in a study by Nwanegbo et al. [11], which compared the shear strength of newly deposited soils with those that had been exposed to the elements for some time. The study found that the shear strength of newly deposited soils was significantly lower than that of older soils.

This significance of this study is to fill the knowledge gap in the understanding of the shear strength and index properties of soils in the south east Nigeria. This study will contribute to the development of more robust design and construction practices for civil engineering projects in the region, leading to stable and more reliable structures.

## II. MATERIALS AND METHODS

### Materials

Soil samples were extracted from five different locations in Abia State namely; Asa, Imo River, Obuzor, Owaza and Umuohia. These soil samples were extracted with the use of the hand auger and a Shelby tube sampler for undisturbed soil sample. This is a hallow, thin-walled metal tube with a sharp cutting edge that is used to extract a sample of soil that is minimally disturbed. The various soil samples were taken at various depths, 1.0 – 1.5m for each location in Abia State. The geotechnical properties of the soil samples were assessed at the civil engineering laboratory of Rivers State University, Nigeria. Laboratory experiments were restricted to: particle size distribution (PSD), Atterberg limit (LL, PL, and PI), specific gravity, triaxial test and relative density.

**Plate 1. Collection of Undisturbed Soil Sample**

**Methods**

**Experimental Programs**

The computation of the parameters in Table 1 was made on basis of their averages.

**Table 1. Experimental Parameters**

| Experiments | Parameters | Standard |
|---|---|---|
| Sieve Analysis | Particle Size Distribution | BS 1377-2: 1990 |
| Atterberg Limit Tests | Liquid Limit, Plastic Limit and Plasticity Index | BS 1377-2: 1990 |
| Specific gravity | Dry density and the water content | BS 1377-2: 1990 |
| Triaxial Test | Cohesion, angle of frictional resistance | BS 1377-7:1990 |
| Relative Density | Grains Size Distribution, Degree of compaction and Moisture Content | BS 1377-6: 1990 |

**Sieve Analysis**

Sieve analysis was performed in order to determine the soil particle size distribution. Representative sample of approximately 300g was used for the test after washing and oven-dried. The samples were washed using the BS 200 sieve and the fraction retained on the sieve was air dried and used for the sieve analysis. The sieving was done by mechanical method using an automatic shaker and a set of sieves.

**Plate 2. Set of sieves used**

**Atterberg Limit Test**

For the determination of liquid limit, the soil sample passing through 425 µm sieve, weighing 30g was mixed with water to form a thick homogeneous paste. The paste was collected inside the Casangrade's apparatus cup with a grove created and the number of blows to close it was Similarly, for plastic limit determination, the soil sample weighing 30g was taken from the material passing the 425 µm test sieve and then mixed with water till it became homogenous and plastic to be shaped to ball. The ball of soil was rolled on a glass plate until the thread cracks at approximately 3 mm diameter. The 3 mm diameter sample was placed in the oven at 105°C to determine the plastic limit.

### Specific Gravity
The specific gravity examination was carried out on the clay soils, and the findings were documented. Specific gravity is the ratio of the mass in air of a given volume of soil particle to the mass in air of an equal volume of de-aired distilled water.

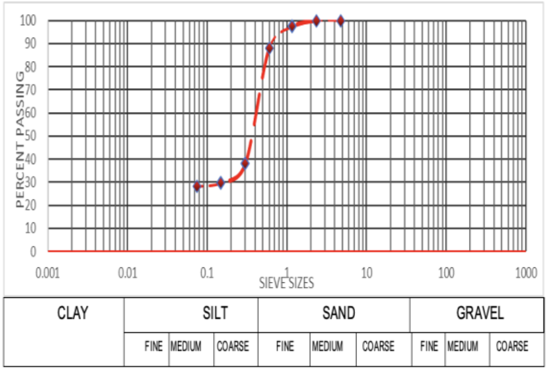
### Triaxial Test
The triaxial test was used to determine the undrained shear strength of the soil. This test is a method of measuring the strength of a material by applying a confining pressure and an axial load to a cylindrical specimen. The confining pressure is the pressure applied to the sides of the specimen, and the axial load is the pressure applied to the top of the specimen. The triaxial test is commonly used in soil mechanics to measure the shear strength of a soil under various conditions.

## III. RESULTS AND DISCUSSION
The results obtained from the various laboratory tests are presented and discussed under the relevant subheadings that follow.

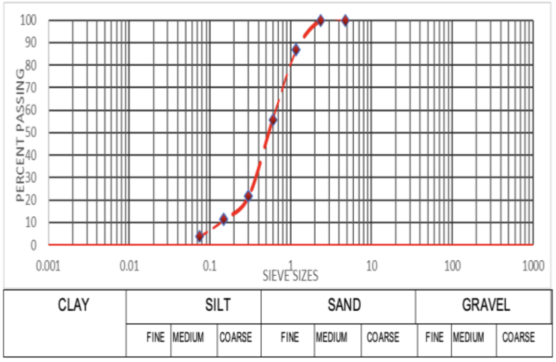
### Sieve Analysis
The sieve analysis results and particle size distribution graph of samples and are shown in Table 3 and Figure 1a-d respectively.

**Table 3. Sieve Analysis**

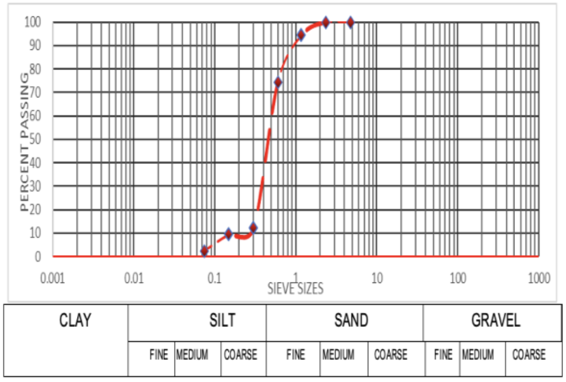
| PARTICLE SIZE DISTRIBUTION | | | | |
|---|---|---|---|---|
| SAMPLE DESCRIPTION | reddish brown to medium grain loose soil | | DATE | October, 2023 |
| LOCATION | ASA | | | |
| WEIGHT OF DRY SAMPLE | 215.6 | g | | |
| W.T. SAMPLE BEFORE WASHING | 300 | g | | |
| SIEVE SIZES (mm) | MASS RETAINED | PERCENTAGE ON SIEVE | CUMULATIVE PERCENTAGE RETAINED | PERCENTAGE PASSING |
| 4.75 | 0.00 | 0.00 | 0.00 | 100 |
| 2.36 | 0.00 | 0.00 | 0.00 | 100 |
| 1.18 | 7.90 | 2.63 | 2.63 | 97 |
| 0.600 | 28.40 | 9.47 | 12.10 | 88 |
| 0.300 | 150.00 | 50.00 | 62.10 | 38 |
| 0.150 | 24.60 | 8.20 | 70.30 | 30 |
| 0.075 | 4.70 | 1.57 | 71.87 | 28 |
| PAN | 0.00 | 0.00 | 0.00 | 0 |
| TOTAL MASS RETAINED | 215.6 | g | | |



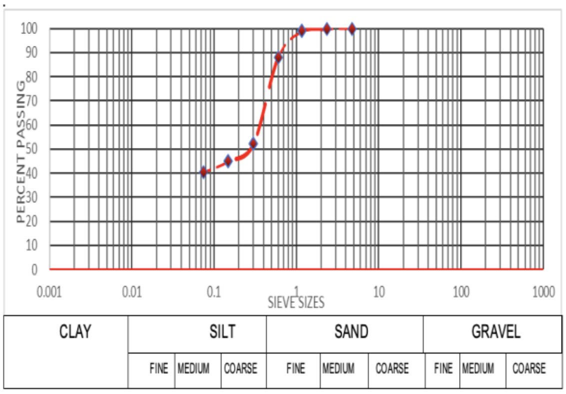

**(a) Asa**




**(b) Obuzor BH4**




**(c) Umwoho**




**(d) Owaza**

**Figures 1(a)-(d). Particle size distribution graphs of some samples**

The weights of soil samples from five locations, Obuzor BH4, Asa, Imo BH2, Umwoho, and Owaza after washing were 298.5g, 215.6g, 288.7g, 292.9g, and 180g respectively. The percentage of finer on sieve number 200 (0.075mm) is more than 90%. This indicates that the soils in the study area are classified as fine-grained soils. The soils in the study area are grouped under MH soil group based on Unified Soil Classification systems.

**Atterberg Limits**

The comprehensive summary result of Atterberg limit testis shown in Table 4.

**Table 4. Results of Atterberg Limit Analyses of the Five Studied S oils**

| Location | Liquid Limit LL (%) | Plastic Limit PL (%) | Plasticity Index PI (%) |
|---|---|---|---|
| Owaza | 19.55 | 13.79 | 5.8 |
| Asa | 31.61 | 19.08 | 12.5 |
| Umwoha | 35.36 | 7.06 | 28.3 |
| Imo BH2 | 24.90 | 18.10 | 6.8 |
| Obuzor BH4 | 14.24 | 12.74 | 1.5 |

Results obtained from the test show that liquid limit (LL) ranges from 14.24% to 35.36%, the plastic limit (PL) ranges from 7.06% to 19.08%, while the plasticity index (PI) is between 1.5% and 28.3%. This result also defines the cohesive characteristics of the soil samples, in this regard, soils that are more cohesive in nature tend to absorb and retain moisture in their pores, causing a decrease in shear resistance. From the liquid limit result obtained, Obuzor BH4 is more stable compared to other locations. The Federal Ministry of Works and Housing for road construction works and housing recommends liquid limit of 50% (maximum) for subbase and base materials and according to the AASHTO soil classification system used as a guide in the classification of soil and soil- aggregate mixture for highway construction, the soil samples fall within the A7 group, subgroup A-7-6 group of soil classification. Therefore, all the soil samples explored in South East Nigeria are not suitable for subbase and base materials for road construction without adequate soil improvements (stabilization). Overall, the soils can be classified as clay with low plasticity.

**Specific Gravity**

As defined in ASTM D854-58, specific gravity is the ratio of mass in air of a given volume of soil particle to the mass in air of an equal volume of de-aired distilled water. The specific gravity value for soil particles is a useful parameter needed for all calculations involving void ratio, porosity or the degree of saturation. Figure 2 shows the specific gravity of the different soil locations.

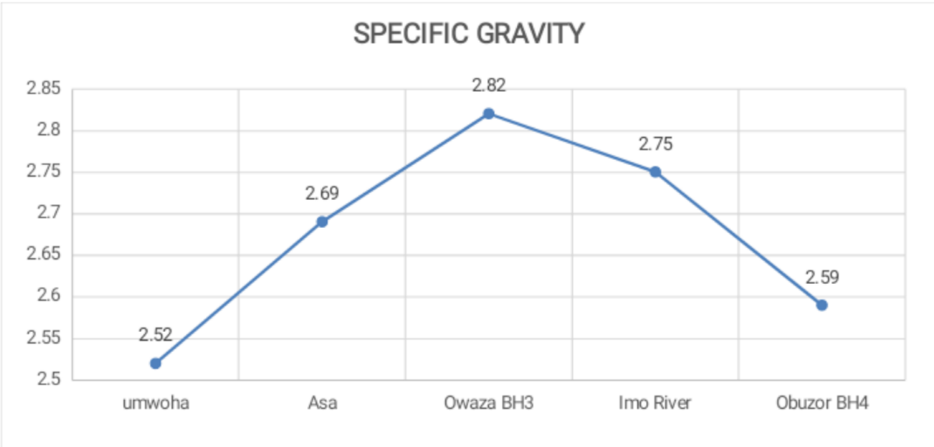



**Figure 2: Graph showing the specific gravity of the different locations**

From Figure 2, it is seen that the specific gravity of the sample locations ranges between 2.5 and 2.9.

**Moisture Content**

Table 5 shows the natural moisture content of the different soil locations.

**Table 5. Natural moisture content of the different soil locations**

| Location | Moisture Content (%) |
|---|---|
| Umwoha | 13.57 |
| Asa | 13.41 |
| Owaza | 15.36 |
| Imo BH2 | 11.61 |
| Obuzor BH4 | 13.8 |

From the proctor compaction tests of all soil samples (Table 5), the moisture content ranges from 11.61% to 15.36%. Owaza has the highest water content of 15.36% while Imo has the least water content of 11.61%. The range of values that may be anticipated for optimum moisture content (OMC) may fall between 20-30%.

**Triaxial Test**

Table 6 shows the triaxial test results of soil samples from five locations in South East Nigeria. This test was done in accordance to BS 1377(7):1990 ASTM D4767.

**Table 6. Triaxial Test Results of Different Locations in South East Nigeria**

| Location | Cohesion | Friction Angle | Shear Stress $kN/m^2$ |
|---|---|---|---|
| Umwoha | 100 | 10.48 | 159 |
| Asa | 110 | 9.93 | 172 |
| Owaza | 115 | 19.03 | 287 |
| Imo | 120 | 20.80 | 333 |
| Obuzor | 120 | 20.81 | 333 |

From Table 6, Imo and Obuzor have the highest cohesion (120 $kN/m^2$) followed by Owaza (115 $kN/m^2$) and Asa (110 $kN/m^2$). The lowest cohesion is observed in Umwoha (100 $kN/m^2$). Obuzor has the highest friction angle (20.81°) followed by Imo (20.80°) and Owaza (19.03°). The lowest friction angle is observed in Asa (9.93°). Shear stress is the stress that tends to cause a layer of material to slide relative to the layer below it. Imo and Obuzor have the highest shear stress (333 $kN/m^2$) followed by Owaza (287 $kN/m^2$) and Asa (172 $kN/m^2$). The lowest shear stress is observed in Umwoha (159 $kN/m^2$).

## IV. CONCLUSION

The geotechnical properties of soils (subsoil) in South East Nigeria have been assessed in compliance with the BS1377 (1990) laboratory procedure for the determination of basic soil properties. The comparative analysis of all five soil samples explored showed that the soils can be classified as clay with low plasticity. If the shear strength of any location is less than 100 $kN/m^2$, soil stabilization will be required. For Umuoha location, the shear strength is 159 $kN/m^2$, which is suitable for construction projects. For Asa location, the shear strength of 172 $kN/m^2$ does not require soil stabilization. For Owaza location, the shear strength of 287 $kN/m^2$ is suitable for construction projects. Imo River and Obuzor location have shear strengths above 100 $kN/m^2$ and do not require all stabilization.

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