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Full Length Research Paper

Assessment of the Engineering Significance of Geo-Materials Derived from a Borrow Pit at Ugwu Orlu, South-East Nigeria

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ABSTRACT

For soils to be suitable for engineering works, they must meet existing requirements for index properties in addition to certain strength criteria. Typically, specifications limit these properties to some threshold values which in most cases are project specific. The objective of this study is to evaluate properties (such as moisture content, particle size distribution, Atterberg limits, California bearing ratio and compaction characteristics) of soils derived from Ugwu, Orlu borrow pit with a view to providing sufficient data for engineers, planners, designers and contractors who might wish to utilise the materials for diverse construction purposes. Three soil samples were collected and tested. The soil has grain size ranging from 0.075mm to 2.00mm; average natural moisture content of 6.83% and mean plasticity Index of 9.5%. The soil is classified as CL according to USCS classification system since the samples plot slightly above "A" line and within the CL zone in the plasticity chart. The average liquid limit (LL) is 26%. The compaction characteristics shows that the OMC for the three samples ranges from12.3 to 13% and MDD ranges from 1.9 to 1.96 mg/m³. California Bearing Ratio (CBR) values are low ranging from 4.25 to 4.50% for the soaked and 7.13 to 10.29% for the unsoaked; hence cannot withstand excessive loading. Although the soil will not exhibit significant rheological properties, that is swelling up with increase in water content or shrinking with decrease in water content, and this property makes it suitable for engineering works because it will not cause cracking to foundations and structures due to heaving.

Keywords: Construction work, Engineering properties, Geo-materials, Plasticity, Soil

INTRODUCTION

Naturally occurring deposits of the earth's crust are classified by geologists and engineers into **"soil"** and **"rock"**(Coduto, 2007) with the division based on strength, related physical properties and use (Singh, 2004). Establishing the difference is difficult, because of the very significant transition zone in which rock is changing to soil or in which a soil formation has acquired rock-like properties, or various other conditions. In general terms they may be defined as follows; In engineering sense, a rock is considered to be a "hard, durable material that cannot be excavated without blasting" (Coduto, 2007), a definition based on strength and durability, while soil, is defined as a loose, unconsolidated aggregation of mineral particles that can be easily separated by hand pressure or agitation in water (Johnson and DeGraff, 1988) and that can be excavated without blasting (West, 1995). Geologically, a rock is "any naturally formed aggregate or mass of mineral matter, whether or not coherent, constituting an essential and appreciable part of the earth's crust", (American Geological Institute, 1976) while, soils are the end products of mechanical and or chemical weathering of rocks. Soils are classified as coarse-grained (sands and gravels) and fine-grained soils (silts and clays) on the basis of particle size whereas rocks are divided into igneous, sedimentary, and metamorphic based on their origin (Hunt, 2007). The geo-materials are the natural materials and have very complex structure. According to Karl Von Terzaghi (1936) *"Unfortunately, soils are made by nature and not by man, and the products of nature are always complex"*. The complexity of soils arises from the fact that it is formed from weathering of rocks, and the behaviour of soils is a legacy of natural processes, from origin to the actual state (Lancellotta, 2009). With the population explosion, increasing tempo of industrialization and agricultural growth, the demands for soil have increased beyond our perception. One of the most rapid uses of soils is for engineering purposes such as construction of roads, buildings, dams and so on, hence, the need for the evaluation of the suitability of the soil material for engineering purposes. This involves the determination of soil properties. The various properties of soil are grouped under two headings: index properties and engineering properties. The three engineering properties of soils are permeability, compressibility and shear strength. Index properties are those soil properties which are mainly used in identification and classification of soils and help the geotechnical engineer in predicting the suitability of soils as foundation and construction material (Ramamurthy and Sitharam, 2005). They include; specific gravity of soil particles, particle size distribution, consistency (Atterberg) limits and density index. The fundamental behaviour of the geo-materials depends on their permeability, compressibility and shear strength characteristics. Laboratory test were employed for obtaining these properties. The accuracy of the results depends on the quality of the sample and the sampling technique applied. The conventional laboratory test are often time consuming, cost intensive, and require sophisticated equipment and skilled personnel in the lab as well as interpretation. The study area is a growing economic town because of its strategic position as a link town. The rapid development of the area has increased demands for soil for building construction, road construction and other engineering purposes. This research will provide geo-technical data for engineers, planners, designers and contractors who may require soil in the area for use as engineering materials as well as developing a clear vision for new researchers.

THE STUDY AREA

The study area is in the northern part of Imo state, south-east Nigeria. It lies within latitude 5°50´N- 5°56´N and longitude 7°02´E - 7°06´E. It shares a common boundary with Anambra state in the north-west, Okigwe to the east and Owerri in the south. Orlu is a growing economic town because of its strategic position as a link town. There are access roads that link the study area with its neighbouring towns. One of these roads connects the area with Owerri via Mbaitoli. Another connects it with Isiekenesi and Awo-Idemili. Ihite-Owerre, Urualla, Obinugwu and Ogberuru are also linked to the study area. The study area is in the humid tropical rainforest belt of Nigeria. The prevalent climatic condition is marked by two main regimes: the rainy and the dry seasons. The rainy season is from (April to October) and this season is associated with the prevalent moisture-laden south-west trade wind from the Atlantic Ocean. This wet season is also characterized by double maximum rainfall during which the first peak occurs in July. Due to vagaries of weather, the August break sometimes occurs in July or early September. The dry season starts in November when the dry continental North-east wind blows from the Mediterranean Sea across the Sahara desert and down to the southern part of Nigeria. The mean annual rainfall is between 2,000mm and 2,250mm while mean daily temperature ranges from 20°C during the rainy season to about 33^0c in the dry season. The mean annual temperature is between 26.5 and 27.3^0c while relative humidity lies between 65 and 75%. Evapo-transpiration in the area is above 1,450mm/year (National Root Crop Research Institute, 2010). Humidity is usually low and clouds are absent, during the dry season. The effect of the harsh north-east wind, also called Harmattan, is felt within the period. The natural vegetation in greater part of the area had been replaced by derived savannah grassland interspersed with oil palm trees, crops such as cashew, mango and pear and other shrubs. However, most of the vegetation has been removed due to human activities such as farming and construction of civil structures. The people of the area are of Igbo origin and their main language is Igbo. Their major occupations include farming and trading.

GEOLOGICAL SETTING OF THE STUDY AREA

The study area is dominated by three different geologic units viz: Benin, Ogwashi-Asaba and Ameki Formations (Figure 2). The Benin Formation is the youngest Formation outcropping in the study area. The name Benin Formation was reinstated by Reyment (1965) for the formation known as "Coastal Plain Sands" (Avbovbo, 1978). It consists mainly of yellow and white sands, sandstone and gravel with clays occurring in lenses (Reyment, 1965). The sands and sandstones are coarse to fine partly unconsolidated (Avbovbo, 1978). The sediments represent upper deltaic plain deposits. The environment of deposition is partly marine, partly deltaic, partly estuarine, partly lagoonal and fluvio-lacustrine (Reyment, 1965). The Benin Formation is composed mainly of high resistant fresh water-bearing continental sands and gravels with clay and shale intercalations (Onyeagocha, 1980). The formation which dips South-westwards starts as a thin edge layer at its contact with the Ogwashi-Asaba Formation in the northern part of the area and thickens southwards to about 100 m in Owerri area (Reyment, 1965). The sandy

Table 1. The stratigraphic succession of the area (Edited from Uma and Egboka, 1985)

	AGE	FORMATION	LITHOLOGY
	Miocene - Recent	Benin Formation	Medium to coarse grained, poorly consolidated with clay lenses and stringers
	Oligocene – Miocene	Ogwashi – Asaba Formation	Unconsolidated sand with lignite seams at various layers
Tertiary	Eocene	Ameki Formation	Grey clayey sandstone and sandy clay stone

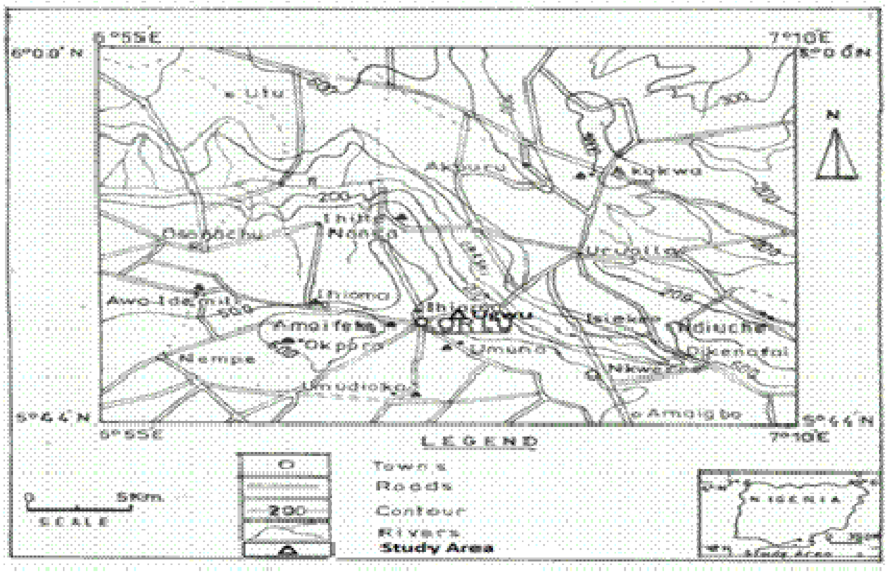


Figure 1. Location map of the study area

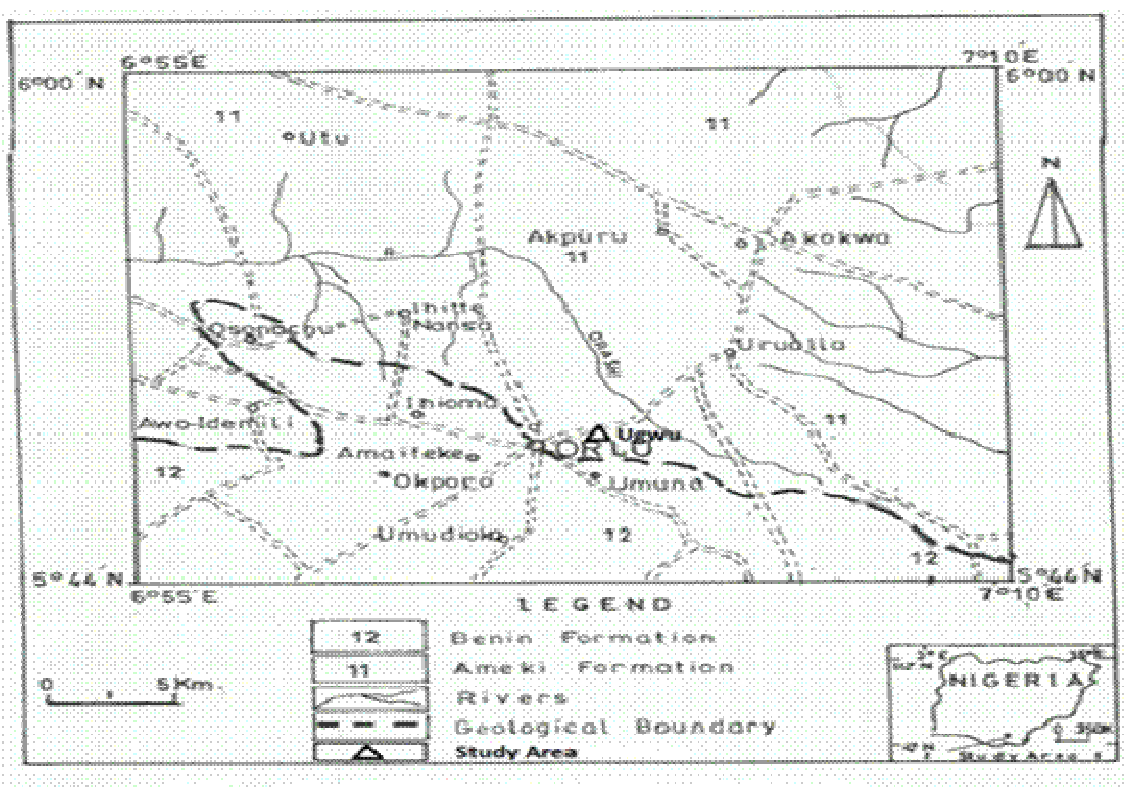


Figure 2. Geological map of the study area

Table 2. Summary of Geotechnical Results of the soil samples

Sample No.	GEOTECHNICAL PARAMETERS											
	%Fines (%)	Coefficient of Curvature (Cc)	Coefficient of Uniformity (Cu)	Moisture Content (%)	Bulk density (mg/m^3)	LL (%)	PL (%)	PI (%)	MDD (mg/m^3)	OMC (%)	CBR	
											Soaked	Unsoaked
A	12.77	3.81	21.25	10.3	1.92	27.3	16.7	10.6	1.90	13.0	4.25	9.73
B	23.68	0.45	7.94	6.6	2.16	25.8	16.5	9.3	1.96	12.3	4.41	7.13
C	1.57	1.21	6.39	3.6	2.02	24.8	16.3	8.5	1.96	12.3	4.50	10.29

Note: LL= Liquid Limit, PL= Plastic Limit, PI= Plasticity Index, MDD= Maximum Dry Density, OMC= Optimum Moisture Content, CBR= California Bearing Ratio.

unit which constitutes about 95% of the rock in the area is composed of over 96% of quartz (Onyeagocha, 1980). The Ogwashi-Asaba Formation underlies the Benin Formation and occupies the Northern part of the area. It was referred to as Lignite series (Onyeagocha, 1980). It consists of alternated unconsolidated sandstones with sandy clays and lignite seams. The Ameki-Formation underlies the Ogwashi- Asaba Formation, consisting of deltaic sands and shallow marine clastics. Two main lithological divisions have been recognised: a lower with fine to coarse sandstones with intercalation of calcareous shale and thin shelly limestone, limestone modules; and an upper with coarse cross bedded sandstones bands of fine grey-green sandstone and sandy clay (Whiteman, 1982).

The stratigraphic succession of the area is summarized in Table 1 above;

METHOD OF STUDY

The methods of study employed in the investigation include: desk studies, field work and laboratory investigations. The desk study was carried out before the field work. All relevant literatures, imagery and archival records of the study area were studied and analysed. The field work was initiated with a reconnaissance survey of the area. Observation of the geographical features, exposed sand units along gullies, streams, valleys, erosional surfaces and outcrops were made and features noted. The geologic mapping involves the location of outcrop, obtaining the dip, strike and bearing. Descriptions of the outcrop in terms of lithology, colour, texture and structural type were carried out in the field. The co-ordinate of each of the sampling stations in Universal Traversal Mercator (UTM) was recorded with the aid of the “GARMIN 76CSx” personnel navigation geographic position system (GPS) unit. Geotechnical measurement of insitu soil materials were carried out to ascertain their engineering properties. Three unweathered (fresh) soil samples were collected at designated locations within the site and labelled A, B and C as shown in Figure1 above. The natural moisture content of the samples collected from the field was determined in the laboratory within a period of 24 hours after collection. This was followed by air drying of the samples by spreading them out on trays in a fairly warm room for four days. Large soil particles (clods) in the samples were broken with a wooden mallet. Care was taken not to crush the individual particles. The entire laboratory tests were carried out in accordance with standard procedures, such as those recommended by the American Society for Test and Material (ASTM) or British Standard B.S. 1377 (BSI, 1975) for all the soil samples collected using well calibrated apparatus/equipment. The investigations of soil in the laboratory and the values required for calculation have led to the development of special equipment and procedure (Cheng and Jack, 1990). The tests conducted on the three different soil samples include: Atterberg limits: P-Index (Plasticity Index), L-Limit (Liquid Limit), Particle size Analysis (Hydrometer test), Moisture content, California Bearing Ratio (CBR) and Compaction Test. The particle size distribution curve is used for classification of soil, determining the coefficient of permeability, provides an index to the shear strength. Soil moisture content, shows the change or variation in the soil characteristics; compaction is done to improve the engineering properties of soil, it generally increases the shear strength of the soil,

Figure 3. Overview of the Ugwu Orlu Borrow pit

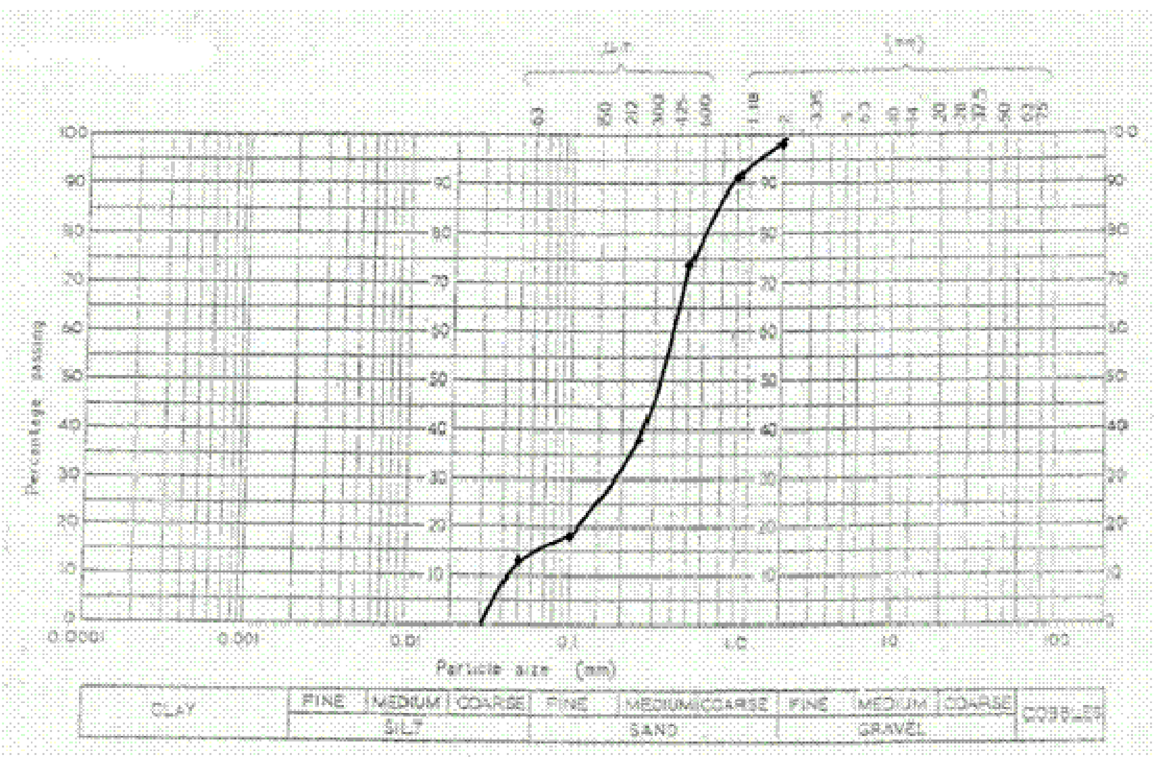
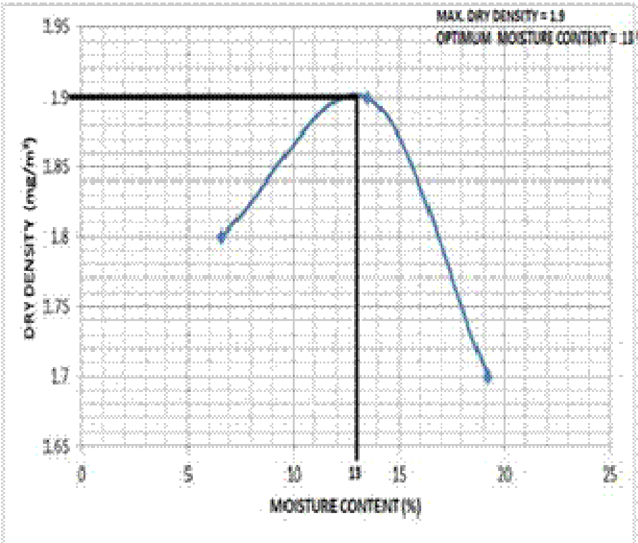


Figure 4. Typical Grading curve for the studied borrow soil

and hence the stability and bearing capacity. It is also useful in reducing the compressibility and permeability of the soil. The Atterberg limits show the consistency of the soil, i.e. the degree of cohesion between particles of the soil at given moisture content. CBR is primarily intended for, but not limited to evaluating the strength of cohesive materials having maximum particle size less than 19mm (AASHTO, 2000). It helps to obtain the strength of the sub grade soil.



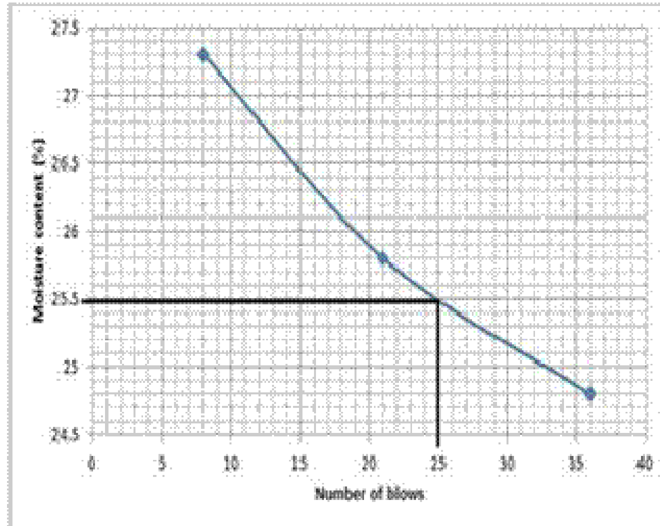
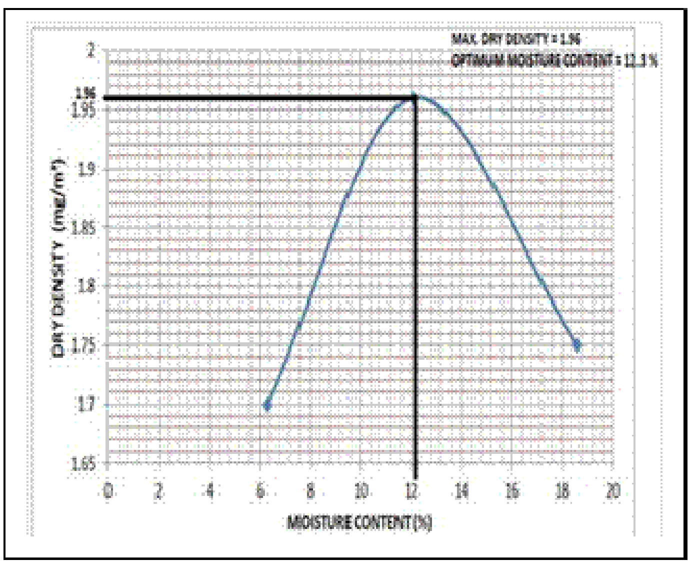


Figure 5. Typical Flow curve of the area

Figure 6. Compaction curve for Sample A



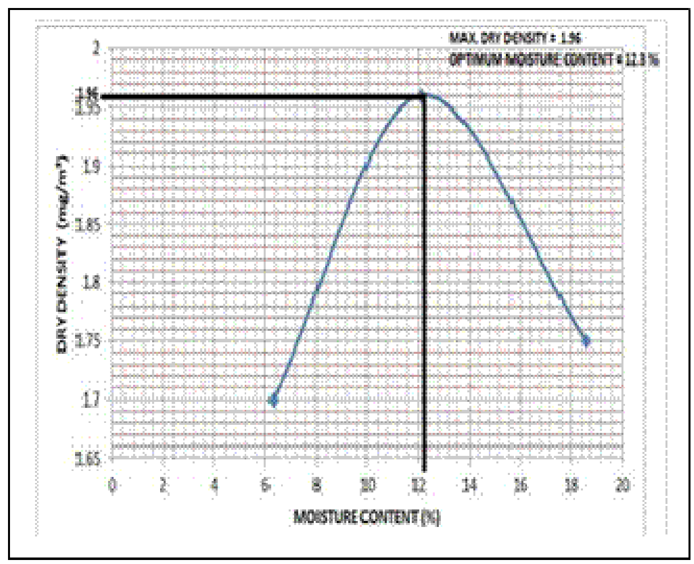


Figure 7. Compaction curve for Sample B

Figure 8. Compaction curve for Sample C

RESULTS PRESENTATION AND DICUSSION

The result of the geotechnical analysis carried out on the three soil samples collected from the study area is presented in Table 2 above.

Results obtained from natural moisture content determination for the three samples as shown in Table 2 reveal that the moisture content of earth materials from the borrow pit ranges from 3.6% to 10.3%, with an average of 6.83%. This low natural moisture content implies that the soil loses moisture easily in its natural state. From the results of grain size analysis for three samples, the values range from 0.075mm to 2.00mm. From the plot of percentage passing against grain size, it shows that the soil is well graded ranging from fine, medium to coarse (Figure 4). The uniformity coefficient of the particles is greater than 6 (Cu for sample A is 21.25, 7.94 for sample B and 6.39 for sample C) and the coefficient of curvature of the particles is greater than 0 and less than 4 (i.e.0<Cc<4); Cc for sample a is 3.81, for sample B is 0.45 and it is 1.21 for sample C; it may therefore be appropriately described as well-graded sand

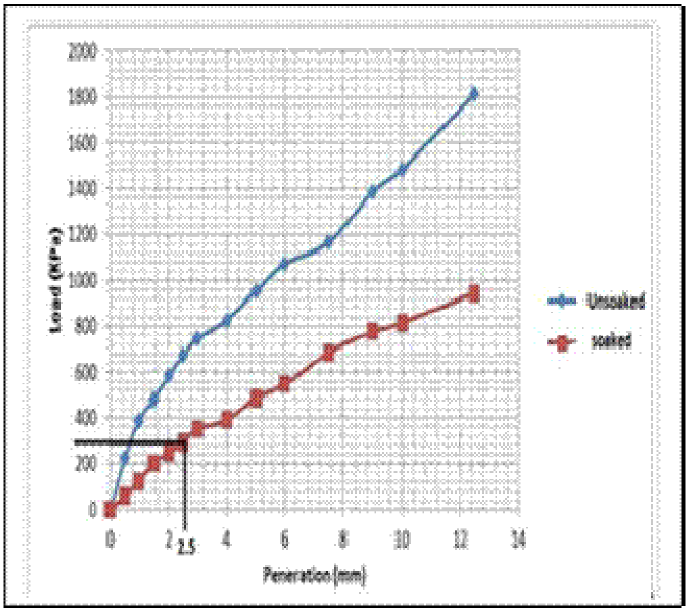


Figure 9. Plot of Load against Penetration for CBR (Sample A)

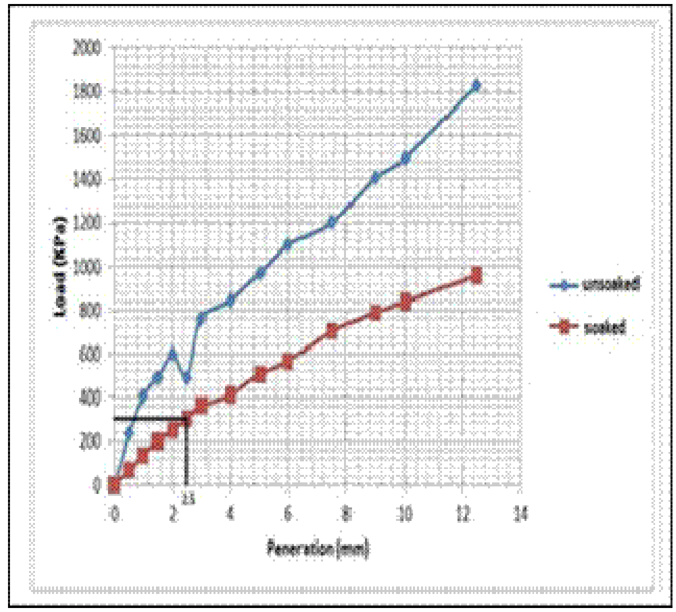


Figure 10. Plot of Load against Penetration for CBR (Sample B)

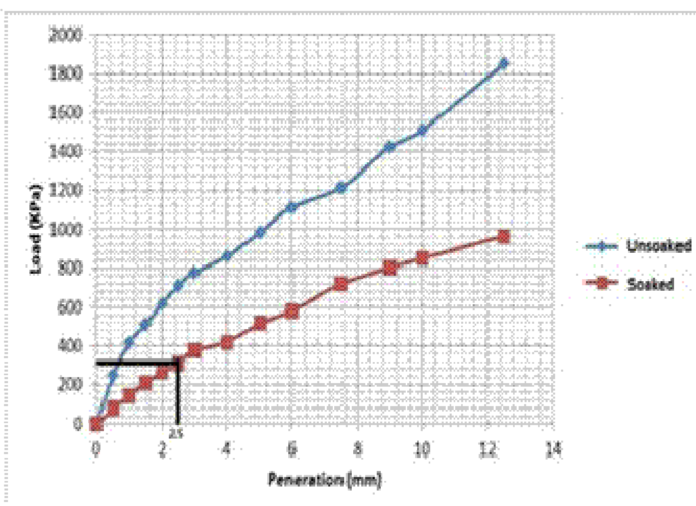


Figure 11. Plot of Load against Penetration for CBR (Sample C)

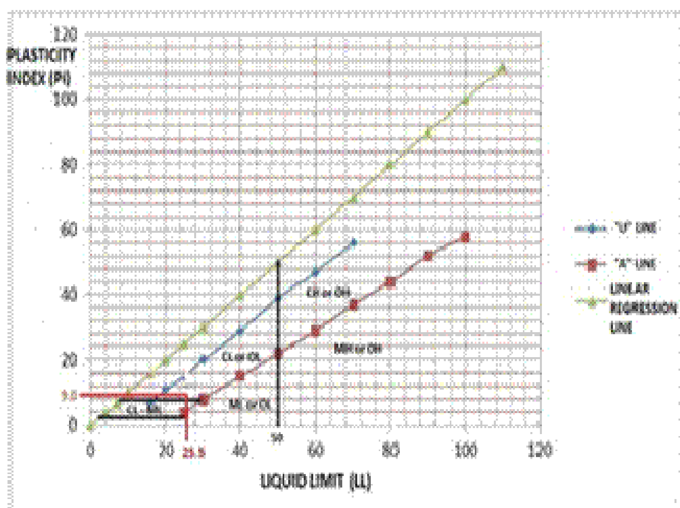


Figure 12. Plot of Plasticity index against Liquid Limit (Casagrande Chart)

according to Unified Soil Classification System (USCS). Well graded sands generally have high shear strength, as pore spaces decrease, density increases and the amount of air and water held in the soil also decreases thus increasing the soil strength. From Table 2, the average plastic limit value is 16.5%, mean Liquid limit of 26% (Figure 5) and hence mean plasticity index value of 9.5%. Using Unified Soil Classification System (USCS), the plot of plasticity Index against liquid limit falls above "A" line (Figure 12), indicating inorganic clays of low plasticity (CL). This implies that the soil will not exhibit significant rheological properties i.e. swelling up with increase in water content and shrinking with decrease in water content, and this property makes it suitable for engineering works because it will not cause cracking to foundations and structures

The values for Optimum Moisture Content (OMC) range from 12.3 to 13% and their Maximum Dry Density (MDD) values range from 1.9 to 1.96mg/m³ (Figures 6, 7 and 8). The CBR values for soaked and unsoaked samples were determined and shown in Figures 9, 10 and 11. The CBR values are low ranging from 4.25 to 4.50% for the soaked and 7.13 to 10.29% for the unsoaked; hence cannot withstand excessive loading.

CONCLUSION

The geotechnical property of soil plays a vital role in any engineering project such as buildings, roads, bridges or earthen structures like dams and embankment. These projects use soil as an engineering material in terms of its ability to carry the loads and support the structures safely. The analysis of soil properties provides sufficient data to the engineer towards ensuring an economical design for the type of soil to be used in terms of its stability, durability, strength and workability. The soil underlying the Ugwu Orlu borrow pit is probably the best from a foundation standpoint (B-20, USCS), but in some cases, the soils may be soft and wet and with its low bearing capacity, there could be fairly large settlements under excessive load. The settlement can be controlled by increasing its thickness. It shows well graded soil which generally could be said to have high shear strength sequel to limited pore spaces. Furthermore, the soil is slightly compressible and gives fair to good compaction with sheep-foot roller; this property makes it unsuitable for use as sub-base and base course in road construction. Undesirable compressibility or expansion characteristics may be reduced by distributing the load through a greater thickness of overlying material. This is adequately handled by the CBR method of design for flexible pavements. The soil also indicates inorganic clay content with low plasticity. This implies that the soil will not exhibit significant rheological properties i.e. swelling up with increase in water content and shrinking with decrease in water content, and this property makes it suitable for engineering purpose because it will not cause cracking to foundations due to heaving. Finally, it may be used in core sections of embankments to retard the flow of water to control seepage. Where it is important that seepage will not emerge on the downstream slope or the possibility of drawdown exists on upstream slopes, more pervious materials are usually placed on the outer slopes. It is also best adapted for embankment construction; the soils are impervious and fairly stable. The stability can be increased by treatment with fly ash or pozzolans, cement, lime or a mixture of any two of them.

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