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INFLUENCE OF COARSE-GRAINED SAND ON SHEAR STRENGTH OF LATERITIC SOIL

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ABSTRACT
This research was carried out with an intention to evaluate the effects of coarse grained sand on the shear strength of lateritic soil obtained at 1.0 m depth from a borrow pit located at Goningora, along Kaduna-Abuja high way, Chikun Local Government Area, Kaduna South. The lateritic soil was reconstituted by adding coarse grained sand of 0.075 – 4.75 mm in proportion of 5%, 10%, 15%, 20% and 25% after the sieve analysis conducted on the real sample showed about 54% fines contents. Tests that were performed on both samples dealt with sieve analysis, compaction, shear strength and California bearing ratio. Compaction test results show that optimum moisture contents decreased consistently from 19.7% at 0% to 14.26% at 25% addition of coarse sand contents, while maximum dry density increased progressively from 1.81 g/cm^3 at 0% to 1.94 g/cm^3 at 25% for the constituted samples. For the shear strength parameters ϕ and c, angles of internal friction ϕ and apparent cohesion c revealed that ϕ values increase from 15to 24^0 and c values decrease from 30 to 23 kN/m^2 for both control and reconstituted lateritic samples respectively. Shear strength results improved from 150.15 to 247.82 kN/m^2 and California Bearing Ratio CBR increased from 41.64 to 71.65% for the real and reconstituted samples respectively. Lateritic soils have wide range of shear strength from poor to excellent and pervious to impervious based on the concretionary formations. Therefore, the paper concludes that use of coarse grained sand to reconstitute poorly graded lateritic soil of high percentage of fines content, has significantly improved shear strength for foundation of structures and CBR for sub base of road construction.

Keywords: *Lateritic soil, Coarse grained sand, Reconstituted samples, Shear strength, California Bearing Ratio*

Introduction

During the last decade, the global demand for indigenous laterite soil has continued to increase. This growing demand has generated interest in the use of red tropical soils for road materials especially in the developing countries. Laterites are among the most abundant soils that are developed in the tropics; they form thick blankets near the topsoil horizons in the area. In the execution of construction projects on soils in most tropical countries such as Nigeria, the most naturally occurring and highly abundant soil is the lateritic soils (Ikeagwuani, Nwonu, Eze & Onuoha, 2017). Laterite is a rock deposit principally of sedimentary origin which is known to form due to weathering, and is one of the most readily available raw materials for road construction in Nigeria (Joel & Edeh, 2015).

Therefore, lateritic soils hold great potential with respect to offsetting the cost of construction projects but are of different types based on their environmental and geological formations. Available data on geotechnical characteristics of lateritic soils show that these soils range in performance from excellent to poor for engineering purposes (Lambe & Whitman, 1979). Although in its natural state, the extent of its usefulness in geotechnical engineering application cannot be ascertained (Ikeagwuani et al., 2017). This is as a result of the fact that in geotechnical design, variations prevalent in the natural soil deposit and its properties is among the greatest threats encountered (Vaibhav & Shrikant, 2016). This poses some great challenges in determining the actual behaviour of soils under the action of imposed load. Among the soil properties, it is the shear strength of the soil that determines the ability of the soil to transmit load to the layers beneath. Whereas the maximum dry density (MDD) achieved through compaction gives indication of the strength of the compacted soil (Garber & Hoel, 2014).

Jegede (2000) observed that failures of highway pavements have been common on the Nigerian highway system after his research on “Effect of Soil Properties on Pavement Failures”. He further emphasised that failures on Nigeria highways are generally due to poor geotechnical properties of the underlying soils which constitute the base or subgrade material for the entire road configuration. However, lateritic soil which did not meet the engineering properties requirements such as shear strength, bearing capacity can be stabilized mechanically or chemically by use of admixtures such as lime, bitumen and cement. The growing cost of stabilizing agent and the need for economic utilization of available and sustainable natural construction materials brought initiatives of investigating the influence of coarse sand on shear strength of lateritic soil which contained more fines from its natural source.

Aim

The aim is to investigate influence of coarse-grained sand on the shear strength of lateritic soil.

Research Objectives

The objectives of this investigation are as follow:

i. Investigate the natural engineering properties of lateritic soil sample.
ii. Determine the effect of coarse grain on shear strength of the natural reconstituted lateritic soil.

Brief Literature

Lateritic Soils

Laterite owes its origin to the Latin word “later” meaning "brick," and was first discussed purely on its field-occurrence (Buchanan, 1807; as cited in Prescott, 1954). The term 'laterite' was first used to describe a ferruginous vesicular unstratified and porous material with yellow ochre due to high iron content occurring in Malabar, India. The freshly dug material was soft enough to be readily cut into brick blocks with an iron instrument but it rapidly hardened on exposure to air and was remarkably resistant to the weathering effect of climate. According to Gidigasu (1980) laterite was recognized as a tropical and sub-tropical weathering product of various crystalline igneous rocks mostly granites sediment deposits and volcanic ash. Lateritic soils are often found in tropical regions which are typical of distinct wet and dry seasons. Another description is a red, porous, claylike soil formed by the leaching of silica-rich components and enrichment of aluminum and iron hydroxides. They are especially common in humid climates. Laterite is a group of highly weathered soils formed by the concentration of hydrated oxides of iron and aluminum (Thagesen, 1996).

Laterites and lateritic soils form a group comprising a wide variety of red, brown, and yellow, fine-grained residual soils of light texture as well as nodular gravels and cemented soils (Lambe & Whitman, 1979). They are characterized by the presence of iron and aluminum oxides or hydroxides, particularly those of iron, which give the colours to the soils. However, there is a pronounced tendency to call all red tropical soils laterite and this has caused a lot of confusion.

One of the most essential engineering properties of laterite is its ability to oppose sliding along inner surface within a mass (Das, 1990). The understanding of the shear strength of a soil is important in the assessment of bearing capacities of foundations, slope stability, retaining structures, roads/dams embankment, tunnel linings and pavement (Georgiannou, Jurland & Hight, 1990).

Shear Strength of lateritic soils.

The shear strength of a soil mass is the internal resistance per unit area that the soil mass can offer to resist failure along any plane inside it (Das, 1990). The action is believed to exist due to interaction of particles brought about by cohesive and frictional forces (Adunoye, 2014). As such, the soil shear strength is measured in terms of cohesion and angle of internal friction of the soil particles. The shear strength of the soil is therefore likely to be affected by any action than can impact on the cementation or interlocking of the soil particles (Ayininuola, Agbede, & Franklin, 2009). When this resistance is exceeded failure occurs.

The law governing the shear failure of soils was first put forward by Coulomb and is given in equation 1.

$$S = C + \sigma tan\phi \qquad (1)$$

Where: S = Shear strength, C = Cohesion, σ = Normal stress and ϕ = Angle of internal friction.

Angle of internal friction could be described as a measure of the ability of a unit of rock or soil to withstand a shear stress. It is the angle (ϕ), measured between the normal force (N) and resultant force (R), that is attained when failure just occurs in response to a shearing stress (S). Determination of shear strength parameters must take place prior to analytical and design procedures in

connection with foundations, retaining walls and earth retaining structures (Bareither, Edil, Benson & Mickelson, 2008).
According to Poulos (1998) strength properties of the soil are affected by soil composition, initial condition, loading condition and its structure. Structure here would include factors like cementation and voids that can affect particle arrangement within the soil (Poulos, 1998). Hence, a method of improving the structure of the soil to augment its strength properties would be the use of admixtures to induce cementation of soil particles and filling of existing voids within the soil mass. Stabilizing agents like lime, tarsand and many others are widely applied in soil stabilization to improve the soil properties.

Soil Classification

Fines in soils consist of silts and clays while coarse component consists of sands and gravels. As described by Unified Soil Classification System (USCS): For engineering use, four ranges of particle sizes are recognized. They are:

i. **Cobbles**: particles with a diameter larger than 75 mm
ii. **Gravel**: particles sizes from 4.75 to 75 mm
iii. **Sand**: particles sizes from 0.075 to 4.75 mm
iv. **Fines**: particles smaller than 0.075 mm (silt and clay).

Soils in the Unified Soil Classification (USC) are classified under three basic soil types. They are as follow;

i. **Coarse-grained soils** (CGS) which contain 50 percent or less of fines;
ii. **Fine-grained soils** (FGS) which contain more than 50 percent fines;
iii. **Highly organic soils** which are peat, humus or swamp soil.

The American Association of State Highway Transportation Officials (AASHTO) described silt-clay as materials more than 35% passing No. 200 Sieve (0.075 mm), while granular materials as 35% or less passing No. 200 sieve (0.075 mm).

MATERIALS AND METHODS

Materials

The materials used for this work are lateritic soil and coarse sand. The lateritic soil is reddish brown and was obtained as disturbed sample at 1.0 m depth in Goningora outskirt, Chikun Local Government Area of Kaduna State at latitude 10° 23' 57", longitude 7°23'49" and about 205 m away from Kaduna – Abuja

high way. The site is used by construction companies as borrow pits for road and other construction purposes.
Figure 1 shows the Google map of the area and the location of the borrow pit as indicated.

Figure 1: Location of borrow pit
Source: Google Map of the Study Area

The coarse sand used was obtained from river Kaduna and were particles in which 35% or less passing through sieve No. 200 (0.075 mm), specifically coarse sand of particle size of 0.075 to 4.75 mm. The collected samples were taken to the soil mechanics laboratory section of the Department of Civil Engineering, Kaduna Polytechnic, where the tests were carried out.

Methods
In this work, the soil tests were carried out according to the Specifications of British Standard (BS) 1377: part 2: (1990). The laboratory tests conducted were as follows:

i. Natural moisture content
ii. Unit weight
iii. Sieve analysis
iv. Shear box
v. Compaction
vi. California Bearing Ration (CBR)

Sieve Analysis.
The method used was “wet method” with the following B.S sieves arrangement; 7, 10, 14, 18, 25, 36, 52, 72, 100, 150 and 200.

Three samples of the original lateritic soil sample were weighed; 500g each, and were soaked in water for 24 hours, were separately washed thoroughly using B.S sieve No. 200 until the water in the soil was clean. The washed samples were oven dried for 24hours, after which they were passed through the sets of sieves of number arrangements and the particle sizes obtained as prescribed in BS 1377.

Compaction Test

Compaction of soil is the process by which the solid particles are packed more closely together by reducing the air void, thereby increasing the dry density of the soil and this is usually done by mechanical means. The compaction method adopted for this research is the standard proctor test using 2.5kg rammer falling through a height of 300 mm. The compaction test was conducted for both natural and the reconstituted soil with 5%, 10%, 15%, 20%, and 25% of coarse sand all in accordance to B.S 1377(1990) part 2.

California Baring Ratio (C.B.R)

The California bearing ratio test (C.B.R Test) is a penetration test developed by California State Highway Department (U.S.A) for evaluating the bearing pressure of sub-grade soil for design of flexible pavement. This test was carried out on natural and reconstituted lateritic soil in un-soaked condition and the result obtained were compared with the curves of standard test to have an idea of strength of sub-grade soil.

Direct Shear Box Test

This test was conducted on remolded samples of both natural and reconstituted ones. To facilitate the remolding processes, samples were compacted at optimum moisture content in a compaction mould. Then specimens for the direct shear test were obtained using the correct cutter provided. Normal loads were applied to each specimen and were sheared across the pre-determined horizontal plane between the two halves of the shear box. Measurements of shear load, shear displacement and normal displacement were recorded. The test was repeated for three identical specimens under different normal loads of 10, 20 and 30 kg respectively. From the results, the shear strength parameters were determined graphically.

ANALYSIS AND PRESENTATION OF RESULTS

The research findings as presented in this paper are based on field and laboratory analyses. The summary of the results obtained are shown in Table 1. The bearing pressures as presented in this study were calculated using the Karl Terzaghi's bearing capacity (equations 2 and 3) as shown below for a borrow pit at 1.0 m depth.

TABLE 1: SUMMARY OF RESULTS FOR LATERITIC SOIL SAMPLES

Coarse-grained sand (%)	0%	5%	10%	15%	20%	25%
Percentage passing sieve No.200 (%)	54.01	50.64	47.73	44.21	42.53	39.27
Optimum Moisture Content (OMC) (%)	19.70	17.65	16.33	15.94	14.53	14.26
Maximum Dry Density (MDD) (g/cm^3)	1.81	1.83	1.85	1.89	1.91	1.94
Angle of internal friction (ϕ) (^{o})	15	17	19	21	22	24
Apparent cohesion (C) (kN/m^2)	30	29	27	26	25	23
Unit weight (γ) (kN/m^2)	18.53	19.54	19.84	19.92	20.21	20.73
California Bearing Ratio (CBR) (%)	41.64	53.73	59.73	62.84	68.53	71.65
Average safe Bearing Capacity (kN/m^2)	157.94	179.24	198.13	226.87	240.54	272.50

Source: *Authors' laboratory work (2019)*

Assuming width of the footing 1 m = 1000 mm and water table is well below foundation level. Net allowable bearing capacity is calculated as follows:

$$q_{net} = CN_C + \gamma D(N_q - 1) + 0.5\gamma B N_\gamma \quad (2)$$

$$q_s = \frac{q_{net}}{f} \quad (3)$$

Where: Nc, Nγ and Nq = Karl Terzaghi's bearing capacity coefficients.

Nc = 11, Nγ = 3.9 and Nq = 1.2

B = Breath of foundation and = 1.0 m

D = Depth of foundation and = 1.0 m

C = Cohesion and = 30 kN/m^2

ϕ = Angle of internal friction and = 15^0

γ = Unit weight of soil and = 18.53 kN/m^2

$$q_{net} = (30 \times 11) + 18.53 \times 1(1.2 - 1) + 0.5 \times 18.53 \times 1 \times 3.9$$

$$q_{net} = 369.84\ kN/m^2$$

$$q_s = \frac{q_{net}}{f} = \frac{369.84}{2.5} = 147.94 kN/m^2$$

Bearing capacity values and other tests results are presented in Table 1.

DISCUSSION OF RESULTS

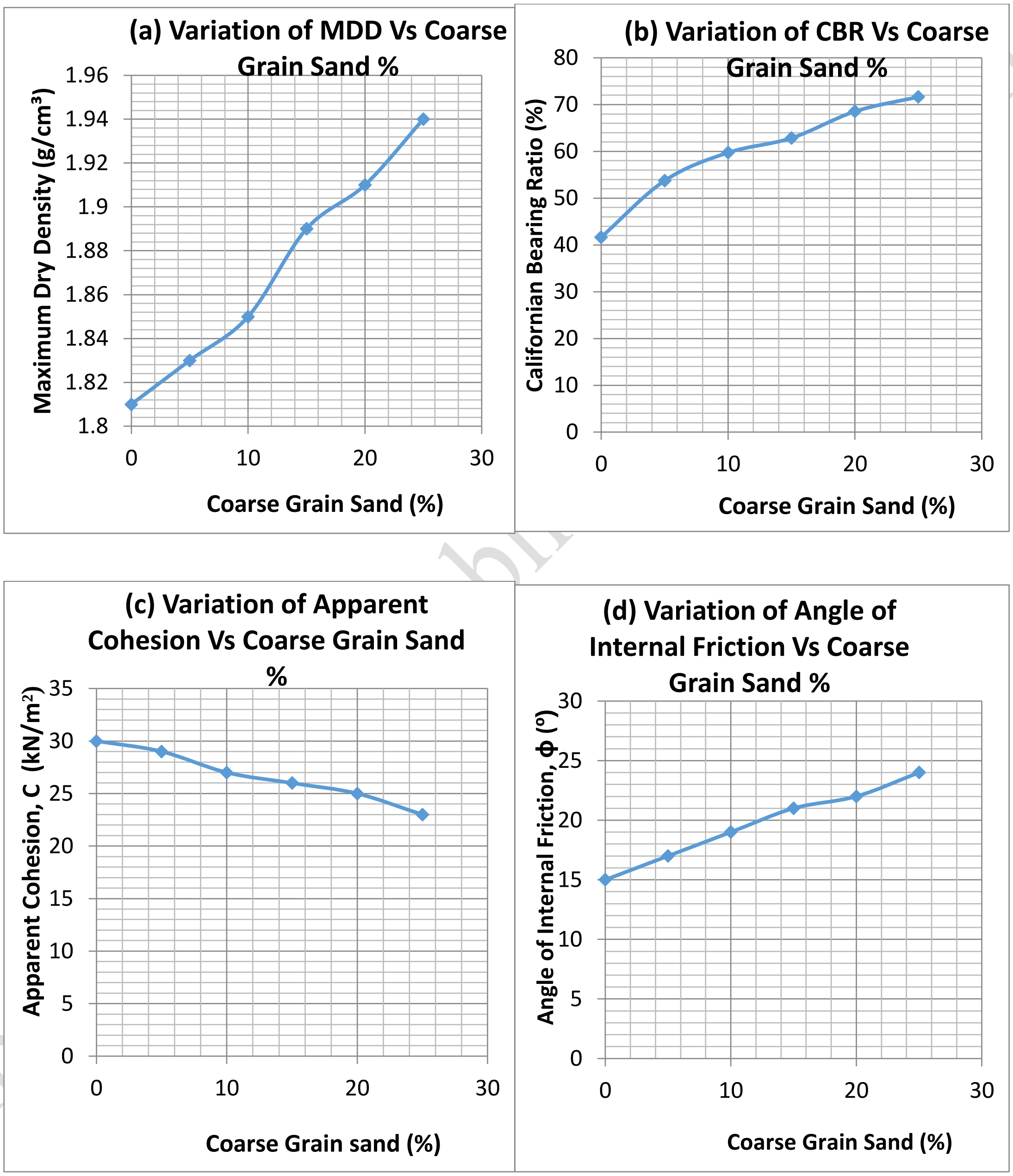

Figure 2: Influence of (a) MDD with increase in coarse grain soil (b) CBR with increase in coarse grain soil (c) Apparent cohesion with increase in coarse grain soil (d) Angle of internal friction with increase in coarse grain soil

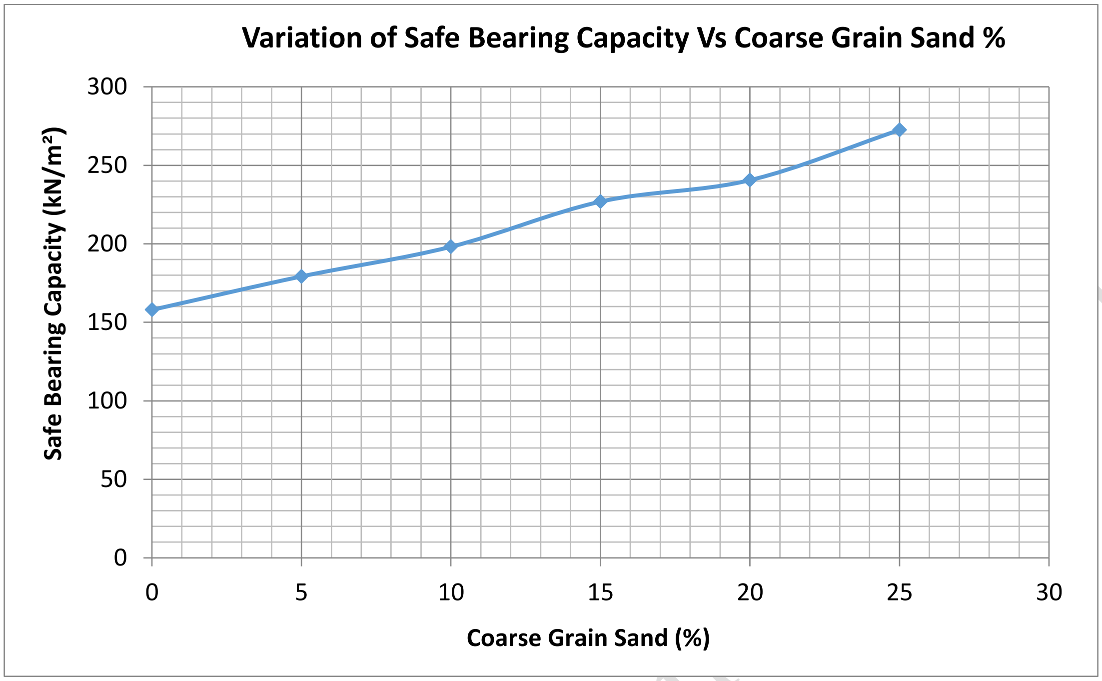

Figure 3: Variation of average safe bearing capacity with increase in coarse-grained sand

The sub-soil at the site is mainly brownish lateritic fine-grained soil at1.0 m deep below the ordinary ground level. The ground was relatively soft during excavation of the trial pits and no static ground water was encountered in the borrow pits explored.

Table 1 gives a summary of results in this research. Sieve analysis result showed that more than 35% passed through sieve No 200 (0.075 mm) hence the lateritic soil of 0% coarse sand is fine-grained materials and therefore poorly graded for it to attain a realistic CBR or bearing capacity values for sub-base. OMC decreased consistently from 19.7% at 0% coarse sand to 14.26% at 25% addition of coarse sand contents, while MDD increased progressively from 1.81 g/cm^3 for the lateritic soil used as control to 1.94 g/cm^3 for the constituted samples of 5% to 25% coarse sand as shown in Figure 2(a). The CBR values range from 41.64% to 71.65% at 0% and 25% respectively as indicated on variation graphs in Figure 2(b). The significant increase in CBR may be due to addition of coarse sand to the control material.

In the results of shear strength parameters (c and ϕ), ϕ values range between 15^o (for 0% coarse sand) and 24^0 (for 25% coarse sand), the increase is probably due to reduction in fines. While c values decreased from 30 kN/m^2 to 23 kN/m^2 at 0% and 25% respectively and may be as a result of increase in coarse contents as indicated in Figure 2 (c) and (d). The analytic bearing capacity computations revealed that the bearing pressure of the natural lateritic soil has minimum value of 157.94 kN/m^2 and the reconstituted soil ranges between 179.24 kN/m^2 (for 5% coarse sand) and maximum value of 272.50 kN/m^2 (for 25% coarse sand). The results show progressive increase in the bearing pressure of the reconstituted lateritic soil by changing its gradation using coarse sand as presented in Figure 3.

Conclusion

From the findings of this research, the sub-soil at the site is mainly brownish fine grained lateritic soil at 1.0 m deep below the ordinary ground level because it contained more than half (54%) fines contents and may not be suitable for road construction and airfields. Maximum dry density of the soil sample increased progressively from 1.81 g/cm^3 for the lateritic soil used as control to 1.94 g/cm^3 for the constituted material at 5% to 25% and these improvements have justified the addition of coarse grained sand to the parent material. The angle of internal friction generally increased with the addition of coarse grained sand with decrease in cohesion thereby causing significant improvement in shear strength and California Bearing Ratio (CBR) in the range of 157.94 to 272.50 kNm^2 and 41.64 to 71.65% respectively. Therefore, coarse-grained sand may be used to improve gradation of laterites with overwhelming fines content, hence a well graded laterite is expected to have fines, medium and coarse grains in its particles size distributions.

Recommendations

The recommendations as contained in this paper are based on the interpretation of the field and laboratory analyses carried out.

i. Based on the significant improvements on the engineering properties, such as bearing capacity/California Bearing Ratio of the reconstituted lateritic soil, coarse sand may be used as admixture to lateritic soil with high fines percentage.
ii. It is advisable that construction companies handling projects on roads, airfields, earth dams, and high rise buildings should endeavour to

adequately conduct soil tests with thorough analyses on samples collected from borrow pits and site for foundation structures.

iii. Further laboratory test be conducted to determine what percentage increase would affect negatively the adequate cohesion required for proper bonding between soil particles.

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