Consolidation Parameters and Settlement Potentials of Black Cotton Soil Stabilized Sedimentary Formation of Part of South-Western Nigeria

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Abstract: *Black cotton soils are characterized by their damaging attributes which include erosion, expansion, excessive creep, high compressibility, heaving, subsidence, dispersion and swelling. Problematic soils have some additional unique properties including low bearing capacity, high water absorption, and low permeability, among others. Palm kernel shells are not common material in the construction industry. This is either because they are not available in very large quantities as sand or gravel, or because their use for such has not been encouraged. For some time now, the stakeholders' have been clamoring for the use of local materials in the construction industry to limit the cost of construction. There has therefore been a greater call for the sourcing and development of alternative, non-conventional local construction materials. Therefore there is need to look at the possibility of mitigating the problems of black cotton soils using locally available materials. One of such is palm kernel shells. The black cotton (expansive) soil was obtained from a borrow pit on the* sedimentary formation *at Idogo in Ogun State, South-Western Nigeria. The borrow site lies within the coordinates 6º 50' 6" N and 2º 58' 42" E. The black cotton soils used in the study were collected from depths between 0.3-1.0m below ground level. The palm kernel shell wastes were taken from palm oil producing plant along Ilaro-Owode Road, Ilaro, Ogun State, Nigeria. The quantity of water which was used to obtain optimum moisture content and maximum dry density for black cotton soil (i. e. control, 0%) was determined. This water was then used to run 90% consolidation tests. The palm kernel shells were broken into pieces passing through 5mm sieve and then substituted for black cotton soil from 0% to 50% at 10% intervals while 0% palm kernel shell substitution served as control experiment. In line with BS 1377 (1990) and other relevant codes, consolidation tests were conducted on the saturated and unsaturated composite materials of black cotton on sedimentary formation mixed varying degrees of palm kernel shells for the determination of consolidation parameters and possible settlement potentials. This will help to find a way of incorporating solid palm kernel shells into engineering advantage thereby helping to reduce the nuisance and menace caused by solid palm kernel shell waste in the environment and leading to a more stable environment.*

Keywords: *Sedimentary Formation, Consolidation Parameters, Palm Kernel Shell, Settlement Potentials*

Introduction

One of the factors that have led to the increase in research involving soil type is the strong intention of geotechnical engineers in adopting the soil classification and testing methods developed and recommended for temperate regions in classifying the black cotton soils, soft clay shale, lateritic soils, etc. of the tropics. Temperate region soil classification and testing methods have been reported to have often failed to predict the field performance of soils. This is because the index tests upon which the classifications are based are not always reproducible for soils. Of the various soil types that occur in the tropics and subtropics, black cotton soils, soft clay shale, lateritic soils are the commonest types. The intended use could either be for road or embankment construction, foundation subsoil, clay liners, etc. In the tropics, these soils could be lateritic soils or any other tropical soils (e.g. black cotton soils). In Nigeria and other tropical regions of the world, the most and dominant soil materials available in-situ for the construction of sub base and bases courses for both flexible and rigid pavements are the black cotton soils, soft clay shale, lateritic soils, etc. There are instances where lateritic and black cotton soils may contain substantial amount of clay minerals that its strength and stability cannot be guaranteed under load, especially in the presence of moisture. These soils are also common in many tropical regions where in most cases sourcing for alternative soil may prove economically unwise but rather improve the available soil to meet the desired specifications (Bowles, 1981; Bowles, 1997; Brian, 1980; BS1377, 1990; Chen.1975; Chen, 1995; Craig, 1994; Craig, 1987; Durga and Santosh, 2012; Jones Hockey, 1964; Joseph 1981; Knappett. and Craig, 2012; Kulshreshtha and Vasile, 2002; Rahardjo et al. 2004; Scott, 1963; Skemton and Bjerrum, 1957; Tardy Yves, 1997; Teferra and Leikun, 1999; Tuncer and Lohnes., 1977).

Background Study

Assessment of the suitability of a natural clayey (black cotton) soil is essentially based on laboratory measurements of soil composition, compaction variables and hydraulic conductivity as well as desiccation induced shrinkage and shear strength. However, hydraulic conductivity is taken as the basic parameter for design and for characterizing hydraulic barrier performance and reliability. Results of laboratory hydraulic conductivity (coefficient of permeability, k) tests on compacted specimens are often used to determine compaction criterion for each soil. Such a compaction criterion can, in turn, be used as guide for suitable construction of soil liners and covers in the field. Proper construction operation is judged by the possibility of achieving hydraulic conductivities less than the regulatory maximum of 9m/s for liners and covers of waste containment facilities. In soil mechanics (Joseph 1981; Knappett. and Craig, 2012), consolidation refers to the process by which soil changes volume gradually in response to a change in pressure. This happens because soil is a two-phase material, comprising soil grains and pore fluid, usually groundwater. When soil saturated with water is subject to an increase in pressure, the high volumetric stiffness of water compared to the soil matrix means that the water initially absorbs all the change in pressure without changing volume, creating excess pore water pressure. As water diffuses away from regions of high pressure due to seepage, the soil matrix gradually takes up the pressure change and shrinks in volume. The theoretical framework of consolidation is therefore closely related to the diffusion equation, the concept of effective stress, and hydraulic conductivity. In the narrow sense, "consolidation" refers strictly to this delayed volumetric response to pressure change due to gradual movement of water. Some publications (Joseph 1981; Knappett. and Craig, 2012) also use "consolidation" in the broad sense, to refer to any process by which soil changes volume due to a change in applied pressure. This broader definition encompasses the overall concept of soil compaction, subsidence, heave, swelling and shrinkage which is predominant in black cotton soils. Some types of soil, mainly those rich in organic matter, show significant creep, whereby the soil changes volume slowly at constant effective stress over a longer time-scale than consolidation due to the diffusion of water. To distinguish between the two mechanisms, "primary consolidation" refers to consolidation due to dissipation of excess water pressure, while "secondary consolidation" refers to the creep process (Joseph 1981; Knappett. and Craig, 2012). The effects of consolidation are most conspicuous where a building sits over a layer of soil with low stiffness and low permeability, such as marine clay, leading to large settlement over many years. Types of construction project where consolidation often poses technical risk include land reclamation, the construction of embankments, and tunnel and basement excavation in clay. Geotechnical engineers use oedometers to quantify the effects of consolidation. In an oedometer test, a series of known pressures are applied to soil sample, and the change of sample thickness with time is recorded. This allows the consolidation characteristics of the soil to be quantified in terms of the coefficient of consolidation (Cv), pre-consolidation pressure, hydraulic conductivity (k), compression index, oedometer settlement, etc *(*Bowles, 1981; Bowles, 1997; Brian, 1980; BS1377, 1990; Chen.1975; Chen, 1995; Craig, 1994; Craig, 1987; Durga and Santosh, 2012; Jones Hockey, 1964; Joseph 1981; Knappett. and Craig, 2012; Kulshreshtha and Vasile, 2002; Rahardjo et al. 2004; Scott, 1963; Skemton and Bjerrum, 1957; Tardy Yves, 1997; Teferra and Leikun, 1999; Tuncer and Lohnes., 1977).

One of the major challenges facing the construction industry is the growing concern over resource depletion. This is because the industry relies heavily on conventional materials such as cement, granite and sand for the production of concrete. The high and increasing cost of these materials has greatly hindered the development of shelter and other infrastructural facilities in developing countries. That has made the search for alternative materials that meet the performance standards of the conventional materials imperative. Effort to produce affordable houses which will impose less environmental stresses and make construction sustainable has necessitated research to the use of alternative materials. Such materials should be locally available and can replace conventional ones used in construction. Furthermore, the materials should be cheap, readily available and contribute to stress reduction on the environment. The necessity of borrowing materials (lateritic soil) for use in the areas where the prevalent soil is not favorable for construction has over the years caused a continuous increase in the cost of borrowing and transporting these materials. Sometimes there is need to stabilize the prevalent soil on site and here the cost of stabilization is determined to a large extent from the optimum quantity of stabilizing agents required for effective stabilization. It is therefore necessary to seek a suitable complementary substitute for the unstable soils which can readily be available and easily upgraded by stabilization (Joseph 1981; Knappett. and Craig, 2012). Palm kernel shell has been used as possible complement for lateritic soil because of its relative abundance and certain physical properties such as low density, high compaction characteristics and strong interlocking property. In addition, palm kernel shells are regarded as waste in this part of the world and are usually burnt. Finding effective use for it will therefore also help to reduce environmental pollution. The main reason to improve soil is either to obtain a suitable physical grading for a poor soil or to improve some other physical characteristics such as the strength, stability or water resistance of the soil. Palm kernel shell which is a by-product of the production of palm oil is yet to be utilized to a great extent as a construction material. It is therefore hoped that, if found structurally adequate in modifying especially black cotton soil, it would offer some advantage such as low density which implies reduction in self-weight of the soil, improved compaction characteristics, swelling and shrinkage of black cotton soil. It has been observed that in the rural areas where unpaved roads are used, there are sometimes difficulties in the easy movement of heavy trucks on these roads. When the drivers are considering access to the farms, these heavy trucks get stuck when loaded with these farm products. Government mostly may not consider the construction of this rural roads simply because it is most expensive and not a major road and also has a less impact to government source of revenue (Bowles, 1981; Bowles, 1997; Brian, 1980; BS1377, 1990; Chen.1975; Chen, 1995; Craig, 1994; Craig, 1987; Durga and Santosh, 2012; Jones Hockey, 1964; Joseph 1981; Knappett. and Craig, 2012; Kulshreshtha and Vasile, 2002; Rahardjo et al. 2004; Scott, 1963; Skemton and Bjerrum, 1957; Tardy Yves, 1997; Teferra and Leikun, 1999; Tuncer and Lohnes., 1977).

Methodology

The black cotton (expansive) soil (Figure 1a) was obtained from a borrow pit on the sedimentary formation at Idogo in Ogun State, South-Western Nigeria. The borrow site lies within the coordinates 6º 50' 6" N and 2º 58' 42" E. The black cotton soils used in the study were collected from depths between 0.3-1.0m below ground level. The palm kernel shell wastes were taken from palm oil producing plant (Figure 1d) along Ilaro-Owode Road, Ilaro, Ogun State, Nigeria. The quantity of water which was used to obtain optimum moisture content and maximum dry density for black cotton soil (i. e. control, 0%) was determined. This water was then used to run 90% consolidation tests. The palm kernel shells (Figure 1d) from palm kernel (Figures 1b and c) were broken into pieces passing through 5mm sieve and then substituted for black cotton soil from 0% to 30% at 10% intervals while 0% palm kernel shell substitution served as control experiment. In line with BS 1377 (1990) and other relevant codes, consolidation tests were conducted on the saturated and unsaturated composite materials of black cotton on sedimentary formation mixed varying degrees of palm kernel shells for the determination of consolidation parameters and possible settlement potentials (Joseph, 1981; Ola, 1983; Craig, 1987; BS 1377, 1990).

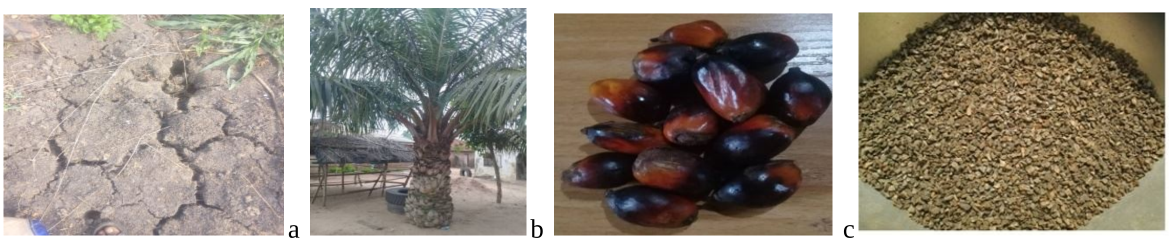
a b c d

Figure 1: (a) Black Cotton (Expansive) Soil (b) Palm Tree (c) Palm Fruits (d) Palm Kernel Shell

Results and Discussion

The results of consolidation parameters and settlement potentials for the saturated and unsaturated samples of various palm kernel shell substitutions ranging from 0% to 50% at 10% intervals (without 30% palm kernel shell substitutions) are presented in Tables 1 to10 respectively. Palm kernel shell substitutions of 0% to 20% is considered to be low dosage substitutions while 40% to 50% substitutions are considered to be high dosage substitutions with 0% serving as control experiment for the two considerations.

Table 1: Consolidation parameters for the unsaturated sample (control, 0% palm kernel shell substitution)

PRESSURE (ῤ) (KN/M^2)	VOLUME COMPRESSIBILTY(MV) (M^2/ MN)	COMPRESSION INDEX (Cc)	OEDOMETER SETTLEMENT(SOED (MM)	COEFFICIENT OF PERMEABILITY(K) (M/S)
9.8 – 19.6	0.4068	0.019	0.4068	4.396×10^-3
19.6 – 39.2	0	0	0	0
39.2 – 78.5	-0.2045	-0.0132	-1.523	-2.2103×10^-8
78.5 -156.9	0.1356	0.0532	2.022	1.4656×10^-8
156.9 – 313.8	0.0943	0.0731	2.811	1.0192×10^8

Table 2: Consolidation parameters for the saturated sample (control, 0% palm kernel shell substitution)

PRESSURE (KN/M^2)	VOLUME COMPRESSIBILTY (M^2/ MN)	COMPRESSION INDEX Cc	OEDOMETER SETTLEMENT (MM)	COEFFICIENT OF PERMEABILITY (M/S)
9.8-19.6	1.125	0.0731	2.0948	7.019×10^-10
19.6-39.2	1.2936	0.166	4.817	8.068×10^-10
39.2-78.5	1.1813	0.295	8.798	7.370×10^-10
78.5-156.9	0.3753	0.1794	5.598	2.342×10^-10
156.9-313.8	0.2365	0.219	7.0503	1.476×10^-10

Table 3: Consolidation parameters for the unsaturated sample (10% palm kernel shell substitution)

PRESSURE (KN/M^2)	VOLUME COMPRESSIBILTY (M^2/ MN)	COMPRESSION INDEX Cc	OEDOMETER SETTLEMENT (MM)	COEFFICIENT OF PERMEABILITY (M/S)
9.8-19.6	0	0	0	0
19.6-39.2	0	0	0	0
39.2-78.5	0.01987	3.322×10^-3	0.1474	7.0145×10^-11
78.5-156.9	0.06950	0.0233	1.0366	2.4540×10^-10
156.9-313.8	0.10490	0.0697	3.127	3.7032×10^-10

Table 4: Consolidation parameters for the saturated sample (10% palm kernel shell substitution)

PRESSURE (ῤ) (KN/M^2)	VOLUME COMPRESSIBILTY(MV) (M^2/ MN)	COMPRESSION INDEX(Cc)	OEDOMETER SETTLEMENT(SOED (MM)	COEFFICIENT OF PERMEABILITY(K) (M/S)
9.8 – 19.6	4.895	0.212	9.114	2.8202×10^-8
19.6 – 39.2	2.0076	0.166	7.476	1.1567×10^-8
39.2 – 78.5	1.129	0.179	8.408	6.564×10^-9
78.5 -156.9	0.60086	0.183	8.962	3.462×10^-9
156.9 – 313.8	0.3556	0.206	10.601	2.048×10^-9

Table 5: Consolidation parameters for the unsaturated sample (20% palm kernel shell substitution)

PRESSURE (KN/M^2)	VOLUME COMPRESSIBILTY (MV) (M^2/ MN)	COMPRESSION INDEX c	OEDOMETER SETTLEMENT (MM)	COEFFICIENT OF PERMEABILITY (M/S)
9.8-19.6	0.4824	0.0545	0.898	4.603×10^-10
19.6-39.2	0.4862	0.1093	1.8106	4.639×10^-10
39.2-78.5	0.3200	0.1425	2.3383	3.054×10^-10
78.5-156.9	0.2512	0.2212	3.747	2.397×10^-10
156.9-313.8	0.2022	0.3489	6,028	1.929×10^-10

Table 6: Consolidation parameters for the saturated sample (20% palm kernel shell substitution)

PRESSURE (ῤ) (KN/M^2)	VOLUME COMPRESSIBILTY (MV) (M^2/ MN)	COMPRESSION INDEX (Cc)	OEDOMETER SETTLEMENT(SOED (MM)	COEFFICIENT OF PERMEABILITY(K) (M/S)
9.8 – 19.6	3.963	0.3594	7.379	3.3940×10^-9
19.6 – 39.2	1.542	0.269	5.742	1.3206×10^-9
39.2 – 78.5	0.6219	0.210	4.632	5.326×10^-10
78.5 -156.9	0.5662	0.374	8.445	4.849×10^-10
156.9 – 313.8	0.3436	0.434	10.24	2.943×10^-10

Table 7: Consolidation parameters for the unsaturated sample (40% palm kernel shell substitution)

PRESSURE (KN/M^2)	VOLUME COMPRESSIBILTY (M^2/ MN)	COMPRESSION INDEX c	OEDOMETER SETTLEMENT (MM)	COEFFICIENT OF PERMEABILITY (M/S)
9.8-19.6	-0.1491	-0.0066	-0.2776	-3.2858×10^-10
19.6-39.2	-0.1862	-0.0166	-0.6934	-4.1034×10^-10
39.2-78.5	0.0371	0.0066	0.2763	8.176×10^-11
78.5-156.9	0.0927	0.033	1.3826	2.0429×10^-10
156.9-313.8	0.0421	0.0299	1.2550	9.2779×10^-10

Table 8: Consolidation parameters for the saturated sample (40% palm kernel shell substitution)

PRESSURE (ṕ) (KN/M^2)	VOLUME COMPRESSIBILTY (MV) (M^2/ MN)	COMPRESSION INDEX (Cc)	OEDOMETER SETTLEMENT(SOED (MM)	COEFFICIENT OF PERMEABILITY(K) (M/S)
9.8 – 19.6	0.0767	0.003	0.1428	5.0554×10^-11
19.6 – 39.2	0.3074	0.026	1.1447	2.0261×10^-10
39.2 – 78.5	0.3092	0.053	2.3029	2.0379×10^-10
78.5 -156.9	0.4103	0.139	6.1196	2.7043×10^-10
156.9 – 313.8	0.2626	0.172	7.8283	1.7310×10^-10

Table 9: Consolidation parameters for the unsaturated sample (50% palm kernel shell substitution)

PRESSURE (KN/M^2)	VOLUME COMPRESSIBILTY (MV) (M^2/ MN)	COMPRESSION INDEX Cc	OEDOMETER SETTLEMENT (MM)	COEFFICIENT OF PERMEABILITY (M/S)
9.8-19.6	0.8917	0.392	1.66	4.3×10^-9
19.6-39.2	0.41732	0.055	1.55	2.013×10^-9
39.2-78.5	0.3313	0.087	2.48	1.599×10^-9
78.5-156.9	0.1912	0.099	2.85	9.22×10^-10
156.9-313.8	0.1878	0.193	5.599	9.057×10^-10

Table 10: Consolidation parameters for the saturated sample (50% palm kernel shell substitution)

PRESSURE (ṕ) (KN/M^2)	VOLUME COMPRESSIBILTY (MV) (M^2/ MN)	COMPRESSION INDEX (Cc)	OEDOMETER SETTLEMENT(SOED (MM)	COEFFICIENT OF PERMEABILITY(K) (M/S)
9.8 – 19.6	0.6979	0.049	1.299	3.875×10^-9
19.6 – 39.2	0.3256	0.0462	1.213	1.808×10^-9
39.2 – 78.5	0.4137	0.1166	3.081	2.297×10^-9
78.5 -156.9	0.05923	0.033	0.88	3.2884×10^-10
156.9 – 313.8	0.03789	0.042	1.129	2.1039×10^-10

Specific Gravity (Gs) of Composite Material

The specific gravity of a given material is defined as the ratio of the weight of a given volume of material to the weight of an equal volume of distilled water. Specific gravity of soil is important in hydrometer analysis, weight volume related calculations, etc. It is often found that the specific gravity of the materials making up the soil particles are close to the value for quartz, that is, Gs approximately equal 2.65. For all the common soil forming minerals, the specific gravity is in the range of 2.5 and 2.8. Gs could be used to calculate the density or unit weight of the solid particles. But for a composite material such as laterite mixed with varying degrees of plastic pellets, specific gravity could have different values. The standard specific gravity of a lateritic soil ranges from 2.60 to 3.40 but that of black cotton soil is less/lower than 2.6 (Rahardjo et al. 2004; Ola, 1983; Craig, 1994; Knappett and Craig, 2012; Chen, 1995). The reduced and low specific gravity of composite material which resulted in reduced unit weight of black cotton soil mixed with palm kernel shell as compared to the soil alone (0%) is an attractive property for its use in geotechnical applications.

Initial Void Ratio and Final Void Ratio

The void ratio is the ratio of the volume of voids in a soil to volume of solids. The initial and final void ratios for the composite materials of black cotton soil mixed with varying degrees of palm kernel shells are obtained from Equations 1, 2 and 3)

$$e_1 = G_s M_c \qquad \text{Equation 1}$$

where e_1 is the final void ratio, G_s is the specific gravity of each substitution of the composite material and M_c is the moisture content of the soil after test

$$e_0 = e_1 + \Delta e \qquad \text{Equation 2}$$

where e_0 is the initial void ratio and Δe is the change in void ratio

$$\frac{\Delta e}{\Delta H} = \frac{1 + \Delta e + e_1}{H_0} \qquad \text{Equation 3}$$

where ΔH is the change in height of soil sample and H_0 is the initial height of soil specimen. Soil is a three phase material which consists of solid particles making up the soil skeleton and voids which may be full of water if it is saturated, may be full of air if it is dry, or may be partially saturated. Using volumes is not very convenient in most calculations, and an alternative measure that is used in most calculations is the void ratio, e (Ola, 1983; Chen, 1995).

Compression Index, Cc

Compression index is the slope of straight part of (e-log – P) curve, and it relates to the amount of anticipated consolidation settlements that a stratum will experience when introduced to loads that are greater than that experienced in the past. Compression index is an important parameter used in geotechnical engineering. A lower value of comprehension index shows that the material is not easily compressible. The Cc values are obtained from Equation 4.

$$C_c = \frac{e_1 - e_2}{\log\left(\frac{P_2}{P_1}\right)} \qquad \text{Equation 4}$$

where Cc is the Compression index and P_1 and P_2 are pressures from (e-log P) graph. Since the lower the Cc, the less compressible the composite material at high palm kernel shells dosage, compression index and coefficient of volume compressibility are closely related and they are key parameters in determining the expected settlement of a foundation or embankment. The subsequent and consistence increase or decrease in Cc value is normal as it indicate a faster rate of consolidation, which is due to increase in the palm kernel shells substitution. The increase can also be explained from the perspective of soil texture; the changes in the texture of the soil as a result of addition of palm kernel shells which also accounts for increased permeability and corresponding increase in Cv (Craig, 1994; Knappett and Craig, 2012; Chen, 1995). The variation of compression index with palm kernel shells substitution shows that the compression index is influenced by the particle state of soil fabric which is controlled by the moisture content and the rate at which the void ratio of the soil changes under the applied load. Soils having high water content contain more void and as a result of this the particle are dispersed. Also, compression index of a sample of soil are different under varying water content.

Coefficient of Volume Compressibility, Mv

This refers to decrease in volume per unit volume of soil per unit increase in effective stress. It can be expressed in terms of void ratio of specimen thickness. It is an important parameter in estimating the primary consolidation settlement of a soil (Craig, 1994; Knappett and Craig, 2012; Chen, 1995). The values of coefficient of volume compressibility, Mv are obtained from Equation 5.

$$M_v = \frac{1}{H_1} \cdot \frac{H_1 - H_2}{P_2 - P_1} \quad \text{or} \quad \frac{1}{1 + e} \cdot \frac{e_1 - e_2}{P_2 - P_1} \qquad \text{Equation 5}$$

where Mv is the coefficient of volume compressibility, H_1 and H_2 are heights of soil samples under pressure P_1 and P_2 respectively. For the maximum applied pressure investigated, coefficient of volume compressibility, Mv, practically reduce as the percentage palm kernel shell substitutions increases even though there is variation in the results. The compressibility of the black cotton soil depends on the void ratio, if the voids in a soil sample are much, its potential for volume changes will be high. $M_V$value also depends on the stress range over which it is calculated, this implies that the compressibility of soil at shallow depth is not the same as that of greater depth. In geotechnics, M_V is used to estimate the settlement (Equation 6) of soil.

$$S_c = M_V \Delta p H \qquad \text{Equation 6}$$

where S_c is the consolidation settlements. The compressibility discussed in this work is that which is due to the expulsion of excess pore water from soil grain. Material of high compressibility may be used as shock absorber for burying underground flexible pipe. These values are still within the range of low compressibility and that the addition of palm kernel shells has not greatly increase the compressibility.

Coefficient of Consolidation, Cv
The coefficient of consolidation, Cv (Equation 7) is a parameter used to describe the rate at which the consolidation process proceeds and it relates to how long it will take for an amount of consolidation to take place (Craig, 2004; Bowels, 1981; 1997) The parameter is governed by the amount of water squeezed out and the rate at which water flows out.

$$C_v = \frac{0.196\, d^2}{T_{50}} \quad \text{Equation 7}$$

where C_v coefficient of consolidation, d is the length of the drainage path and T_{50} is the time for 50% consolidation. The initial slow and steady increase may be due to the rate at which the water flows out which is affected by the black cotton soil-particle interaction and the orientation of the palm kernel shells. If the palm kernel shells lie flat (horizontally) it may delay the vertical movement of water (permeability). The coefficient of consolidation as explained earlier is a parameter used to describe the rate at which the consolidation process proceed and it relates to how long it will take for an amount of consolidation to take place (Bowles 1984). It is well known that the coefficient of consolidation is a parameter that indicates the rate of compression of a saturated soil undergoing compression, which in turn directly depends on the hydraulic conductivity of the soil medium undergoing compression (Craig, 2004; Bowels, 1981; 1997). The parameter is governed by the amount of water squeezed out and the rate at which water flows out. Consolidation and the accompany settlement takes a longer duration especially in soft clays or silty clay present in the areas of coastal region, land areas having predominantly clay soils (i. e. black cotton soil) are often waterlogged due to their lower permeability. C_V is inversely proportional to the time taken for consolidation provided a length of drainage path is constant (Craig, 1994; Knappett and Craig, 2012; Chen, 1995).

Coefficient of permeability, K
The coefficient of permeability values are obtained from Equation 8.

$$K = M_v C_v \gamma_w \quad \text{Equation 8}$$

where K is the coefficient of permeability, γ_w is the unit weight of water and other parameters already defined. The initial gradual increase in the rate at which the water flows out is affected by the soil-palm kernel shells particle interaction and the orientation of the palm kernel shells. If the palm kernel shells lie flat it may delay the vertical movement of water which will eventually decrease the permeability. The coefficient of permeability of a soil is an important property of soils as it describes the rate at which water moves through a soil. It is an indication of the volume of void present in a given sample of soil and it affects the rate of consolidation in soil. Although the values of coefficient of permeability obtain from the oedometer test is generally lesser than the in-situ value. This is due to the compaction of the soil which causes particle re-arrangement and alteration to the macro-fabric of the soil. The macro-fabric of clay is not represented accurately in a small oedometer specimen and the permeability of such specimen will be lower than the mass permeability. When soil is loaded practically, pore water pressure will develop, the excess pore water pressure dissipates with time and water leaves the soil, resulting in volume changes and consolidation settlement. This process takes time, and the rate of settlement decreases over time. Hence, the amount of settlement which occurs in a given time depends on the permeability of soil, length of drainage path and compressibility of soil. The higher the permeability of the soil, the faster water will be able to flow out of the soil, and the quicker the settlement occur. Moreover, the expulsion of water from soil causes increase in effective stress of the soil because there is a transfer of energy from water to the grain as the water moves away. The rate at which the settlement occurs depends upon the rate at which water is expelled from the soil and this depends upon the total head gradient and the permeability of the soil (Craig, 2004; Bowels, 1981; 1997). Coefficient of permeability is directly proportional to the coefficient of consolidation provided the coefficient of volume compressibility is kept constant. An increase in the coefficient of permeability results to a corresponding increment in the rate of the coefficient of consolidation. The result of the permeability of soils sample from an oedometer gives the rate at which water seeps out of saturated sample under constant steady pressure.

Oedometer settlement, Soed
Oedometer settlement values are obtained from Equation 9. Oedometer settlement is the vertical displacement of a sample of soil in an odometer test and it gives or predicts the amount of consolidation expected in the field.

$$S_{oed} = M_v \Delta P\, H \qquad \text{Equation 9}$$

where S_{oed} oedometer settlement, ΔP is the change in pressure and H is the initial height of specimen. For the maximum applied pressure investigated for the control, saturated samples settles more than unsaturated samples while for low dosage of 10% and 20%, saturated samples experience more settlement compared to unsaturated samples. Oedometer results can be modified using Equation 10 to get the value of consolidation settlement that will occur to an embankment.

$$S_c = \mu S_{oed} \qquad \text{Equation 10}$$

where S_C is the consolidation settlement while μ is settlement coefficient for footings obtained from Scott (1963) reproduced by Craig (1994) and Knappett and Craig (2012) which can be expressed as.

$$\mu = A + (I - A)\alpha \qquad \text{Equation 11}$$

where A is the pore pressure coefficient, μ can be derived from a chart depending on the shape of foundation. Values of μ are typically within 0.4 – 0.7 for lightly over consolidated clay and 0.6 – 1.0 for normally consolidated clay. Soed is the laboratory value while Sc is the result in practice. Oedometer settlement is a value derived from a one dimensional, oedometer test which is used to calculate the expected consolidation settlement of a layer of soil beneath a foundation. Skempton and Bjerrum (1957) in Craig (1994) proposed that the effect of lateral strain be neglected in the calculation of consolidation settlements. This enables the oedometer test to be maintained as the basis of the method. Although this may attract error of up to 20%, this is because oedometer settlement is related to pre-consolidation pressure. It should be noted that the results in this study are for a 19 mm soil specimen. The increase in oedometer settlement is as a result of having higher moisture content before loading. This is due to the composite material getting saturated very faster and an initial expansion (heaving) of the sample before loading. When loads are applied, the material compresses at higher rate than when it is ordinary soil sample. The settlement takes place in lesser time. Hence helping to reduce the consolidation/gradual settlement, moreover the mixture of palm kernel shells with black cotton soil tends to make the soil to lose some of its index properties, and the soil behave like sand such that the settlement become immediate. Settlement observations have indicated that the rate of settlement of full scale structure are generally much greater than those predicated using values of Cv obtained from oedometer test on small specimen. Rowe has shown that such discrepancies are due to the influences of the clay macro-fabric on drainage behavior (Craig, 1994; Knappett and Craig, 2012; Chen, 1995).

Conclusion

Stabilization fulfils a number of objectives that are necessary to achieve a lasting structure from locally available soil. This research work will be of great necessity and importance to the geotechnical engineer as it will help to find a way of incorporating solid palm kernel shells into engineering advantage thereby helping to reduce the nuisance and menace caused by solid palm kernel shell waste in the environment and leading to a more stable environment where black cotton soil is predominant. It will also aid in boosting the economy of the nation by reducing the amount of money spent on the disposal and maintenance of palm kernel wastes. It will also be an eye opener to the manufacturing engineer prompting them into the manufacturing of palm kernel shell breaking machines; this will leads to more jobs in the sector. Efforts are still ongoing to determine other relevant geotechnical properties of palm kernel shell stabilized sedimentary formation.

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