Compression and Expansion Characteristics of Eggshell Powder Stabilized Black Cotton Soil on Basement Complex of Part of South-Western Nigeria

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Abstract: *Black cotton soil is heavy clay soil which varies from clay to loam and it is generally light to dark grey in color. The most important characteristic of the soil is that when dry, it shrinks and is hard like stone and when wet it expands. The uncommon traits of the soil make it hard to construct foundation in such soil. Special method of construction of foundation is needed in such soil. The black cotton (expansive) soil was obtained from a borrow pit on the basement complex at Igbo-Ora in Oyo State, South-Western Nigeria. The borrow site lies within the coordinates Longitude 7 ^{0}24'45" and latitude 3 ^{0}18'34". The black cotton soils used in the study were collected from depths between 0.3-1.0m below ground level. The eggshell wastes were taken from Obasanjo Farms, Ota, 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 consolidation tests. The eggshells were milled into powder and then substituted for black cotton soil from 0% to 30% at 10% intervals for consolidation and settlement parameters determination while 0% eggshell powder substitution served as control experiment. In line with BS 1377 (1990), 90% consolidation tests were conducted on composite materials of black cotton soil mixed with varying degrees of eggshell powder to determine the compression and expansion characteristics for the 24-hour soaked samples. From the results, compression behavior is linear meaning; it is directly proportional to time for all the substitutions investigated while there is no reduction during expansion above 20% substitution while removing the load. The rate and magnitude of expansion is zero for the 30% substitutions investigated. At 30% eggshell powder substitution in black cotton soil, expansion problem would be significantly reduced or completely eliminated.*

Keywords: *Black Cotton Soil, Expansion, Compression, Consolidation, Eggshell Powder.*

Introduction

Black cotton soils are enormously compressible and possess extremely low bearing capacity with shear strength of the soils being extremely low. Black cotton soils are expansive soils and are inorganic clays of high to medium compressibility and make it one of the best satisfactory soils for farming with abundant nutrients and elements suitable for plant growth and agricultural purposes. Farming activities can also be carried out effortlessly because of its texture. These soils are very favorable for growing cotton and have been created from basalt or trap rocks. Of the various factors that affect the swelling behavior of these soils, the fundamental mineralogical composition may be very vital. Most expansive soils are rich in mineral montmorillonite and a few in illite. Black cotton soil is heavy clay soil, varying from clay to loam; it is generally light to dark grey in color. The most important characteristic of the soil is, when dry, it shrinks and is hard like stone. The uncommon traits of the soil make it hard to construct foundation in such soil. Special method of construction of foundation is needed in such soil. It is hard as long as it remains dry, but it loses its stability when wet. On drying, the soil shrinks and cracks very badly. The construction of roads in such soil areas has always presented serious problems, due to the extremely low bearing capacity of the sub-grade when it is wet and extensive swelling during wetting. Due to its expansive character, it increases in volume to the extent of 20% to 30% of original volume and exerts pressure. The upward pressure exerted becomes so high that it tends to lift the foundation upwards. This reverse pressure in the foundation causes cracks in the wall above. The Central Road Research Institute has carried out investigations for several years on the unsatisfactory performance of many road embankments built on Black Cotton soil foundations that have failed to varying degrees. It has been found necessary to pulverize soil clods, place them in layers 20cm to 30cm thick, and compact the embankment properly. Methods for improving the bearing capacity of Black Cotton soil, to ensure pavement stability, include adequate compaction and use of a sand sub-base (Billman, 1976; BS1377, 1990; Chen, 1975; Elinwha and Mohmood, 1986; Egbuniwe, 1982; Faridi and Arabhosseini, 2018; Gundaliya and Oza, 2013; Kameswara, 1998; Kogbe, 1976; Kogbe and Obialo, 1976; Kosun, 1990; Lung et al. 2011; Okonkwo et al. 2012; Omatsola and Adegoke, 1981; Rahaman and Ocan, 1978; Sensale, 2009; Udoeyo et al. 2006)..

Background Study

The Geology of Nigeria is made up of three major geological components namely; Basement Complex, Younger Granites, and Sedimentary Basins. The area covered by the southwestern Nigeria basement complex lies right in the equatorial rain forest region of Africa. The main lithologies include the amphibolites, migmatite gneisses, granites and pegmatites. Other important rock units are the schists, made up of biotite schist, quartzite schist talk-tremolite schist, and the muscovite schists. The crystalline rocks intruded into these schistose rocks. The sedimentary formation of south-western Nigeria is the Dahomey Basin in (now) Republic of Benin. The Dahomey Basin is a combination of inland/coastal/offshore basin that stretches from southeastern Ghana through Togo and the Republic of Benin to southwestern Nigeria. It is separated from the Niger Delta by a subsurface basement high referred to as the Okitipupa Ridge. Based on thickness, black cotton soil is divided into three types namely; **s**hallow black cotton soil, medium black cotton soil and deep black cotton soil. These types of soil form with a thickness of less than 30 cm. It stands in Satpura hills (Madhya Pradesh), Bhandara, Nagpur and Satara (Maharashtra), Bijapur, and Gulbarga areas (Karnataka) in India. This type of soil is desirable for the cultivation of rice, wheat, gram, cotton, etc. **Its** thickness ranges between 30 cm and 100 cm. It encloses a bigger area in Maharashtra, Gujarat, Madhya Pradesh, Tamil Nadu, and Andhra Pradesh in India. Thickness is greater than 1 meter and it encloses huge areas in the lowland zones of Peninsular India with the clay volume ranges between 40% and 60%. Its reaction is alkaline. The soil is fertile and desirable for crops of cotton, sugarcane, rice, citrus fruits, vegetables, etc. **R**eplacement of black cotton soil is also another method of overcoming the problem. This is the easiest technique in which black cotton soil is replaced with some different suitable soil like a combination of moorum and sand with cohesive soil to prevent shrinkage characteristics or water-bound macadam mix and compacted at Optimum Moisture Content. Replace all the black cotton soil up to whatever depth it exists. However, there are two problems over this, one, whether it is economically possible and two, whether it is technically needed. Black cotton soil possesses swelling and shrinkage characteristics up to a specific depth called an active zone. The soil of this region just swells and shrinks. In case, this soil is replaced with different types of convenient soil and the replaced soil is properly compacted, the soil would not have swelling and shrinking characteristics (Billman, 1976; BS1377, 1990; Chen, 1975; Elinwha and Mohmood, 1986; Egbuniwe, 1982; Faridi and Arabhosseini, 2018; Gundaliya and Oza, 2013; Kameswara, 1998; Kogbe, 1976; Kogbe and Obialo, 1976; Kosun, 1990; Lung et al. 2011; Okonkwo et al. 2012; Omatsola and Adegoke, 1981; Rahaman and Ocan, 1978; Sensale, 2009; Udoeyo et al. 2006)..

The technique of soil stabilization is generally adopted in road works. Black cotton soil is extremely notorious for its negative effect on engineering construction as a sub-grade material. The engineering properties of the soil are adversely affected by the extreme poor nature of the soil. One of such properties is the compressibility of the soil. Regrettably, very little emphasis has been placed on this property of the soil. Black cotton soils are susceptible to detrimental volumetric changes with moisture. They are residual deposits formed from lava or trap rocks, occupy mostly the arid and semi-arid regions and also cover a very large area of the world. They are rich in montmorillonite which is extremely responsible for its expansive nature but illite is also present when their parent rock is rich in potash bearing mineral. The soil is problematic for engineering construction. The presence of this montmorillonite, which is highly responsible for the attendant shrink-swell behavior of the soil depending on the amount of available moisture in the soil, is the root cause of the many problems such as pavement failure and excessive settlement associated with the soil. Shrinkage during the dry season often leads to surface cracks that could open up to 50mm or more and several millimeters deep (Billman, 1976; BS1377, 1990; Chen, 1975; Elinwha and Mohmood, 1986; Egbuniwe, 1982; Faridi and Arabhosseini, 2018; Gundaliya and Oza, 2013; Kameswara, 1998; Kogbe, 1976; Kogbe and Obialo, 1976; Kosun, 1990; Lung et al. 2011; Okonkwo et al. 2012; Omatsola and Adegoke, 1981; Rahaman and Ocan, 1978; Sensale, 2009; Udoeyo et al. 2006)..

An eggshell is the outer protection of a hard-shelled egg and of some forms of eggs with soft outer coats. Eggshell is the waste material from domestic sources such as hatcheries, bakeries, and home fast food. Eggshell powder is a likely additive material to enhance the strength of soils. In the ever increasing efforts to transform waste to wealth, the efficacy of converting eggshell to useful use becomes a concept worth of embracing. The composition of eggshells implies that the effect of its ash on cement treated materials should be articulated. It is scientifically known that the eggshell is mainly composed of compounds of calcium which is very similar to that of cement. Literature has shown that the eggshell ash primarily contains lime, calcium and protein where it can be used as an alternative raw material in the production of wall tile material, concrete, cement paste and others. Eggshell also contribute to construction industry which is it can be reduce in construction cost and landfill which it gives good performance in properties in concrete and durability of the concrete. Thus, eggshells can be produced a new raw material for development in the construction industry as an additive in the conventional concrete. The construction sector of Nigeria has improved over the years with new ideas in technology and availability of machineries, although development of a nation not only depends on the technology but also depends upon infrastructural development of that nation. A massive quantity of eggshell wastes is produced in 12 months. In the absence of an effective waste disposal, the usage of eggshell for soil improvement will be a welcome development. Therefore, recycling eggshells into the useful product gives good potential benefit on many levels, both for food manufacturers and a much wider construction industry. Eggshell powder could be good replacement in industrial lime because they have similarity in chemical composition. The eggshell can be stabilizing potential of lime on an expansive clay soil. Stabilization is aimed at improving the properties of soil including the increasing the soil density, increase in cohesion, frictional resistance and reduction of plasticity index such as lime, cement and fly ash. So they conclude that eggshell powder can be supplement in lime stabilization. Every year, almost 40,000 metric tons of wastes, including eggshell, are disposed at landfill. Overall, approximately 60% of the waste are collected and disposed in non-sanitary landfills. The remaining 35% were illegally burned or dumped while 5% were dumped into ocean. All the landfill had waste related aesthetic problem, leachate contamination and landfill gas or odour problems. Disposal method such as landfill is not done in the appropriate way which subsequently gives negative effects to the environment. Therefore, ways should be found to utilize the waste (including eggshell) efficiently such as through recycling which is the primary focus of this study (Billman, 1976; BS1377, 1990; Chen, 1975; Elinwha and Mohmood, 1986; Egbuniwe, 1982; Faridi and Arabhosseini, 2018; Gundaliya and Oza, 2013; Kameswara, 1998; Kogbe, 1976; Kogbe and Obialo, 1976; Kosun, 1990; Lung et al. 2011; Okonkwo et al. 2012; Omatsola and Adegoke, 1981; Rahaman and Ocan, 1978; Sensale, 2009; Udoeyo et al. 2006).

Methodology

The black cotton (expansive) soil (Figure 1a) was obtained from a borrow pit on the basement complex at Igbo-Ora in Oyo State, South-Western Nigeria. The borrow site lies within the coordinates Longitude $7^0$24'45" and latitude $3^0$18'34". The black cotton soils used in the study were collected from depths between 0.3-1.0m below ground level. The eggshell wastes in Figures 1 b and c were taken from Obasanjo Farms, Ota, 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 consolidation tests. The eggshells were milled into powder and then substituted for black cotton soil from 0% to 30% at 10% intervals for consolidation and settlement parameters determination while 0% eggshell powder substitution served as control experiment. In line with BS 1377 (1990), 90% consolidation tests were conducted on composite materials of black cotton soil mixed with varying degrees of eggshell powder to determine the compression and expansion characteristics for the 24-hour soaked samples (Ola, (1983); Craig, 1987; BS 1377, 1990).

Figure 1: (a) Black Cotton (Expansive) Soil (b) Eggshell (c) Eggshell Powder

Results and Discussion

The results of dial gauge readings (for maximum pressure of 313.92 kN/m^2) against time (minutes) for various eggshell powder substitutions in black cotton soils ranging from 0% (control experiment) to 30% substitutions are graphically presented in Figures 2 to 9 respectively. From the preliminary results (Figures 2 to 9), similar to palm kernel shell substitutions, compression behavior is linear meaning, it is directly proportional to time for all the substitutions investigated while there is no reduction during expansion at 30% substitution while removing the pressure load. The rate and magnitude of expansion is minimal for all the substitutions investigated.

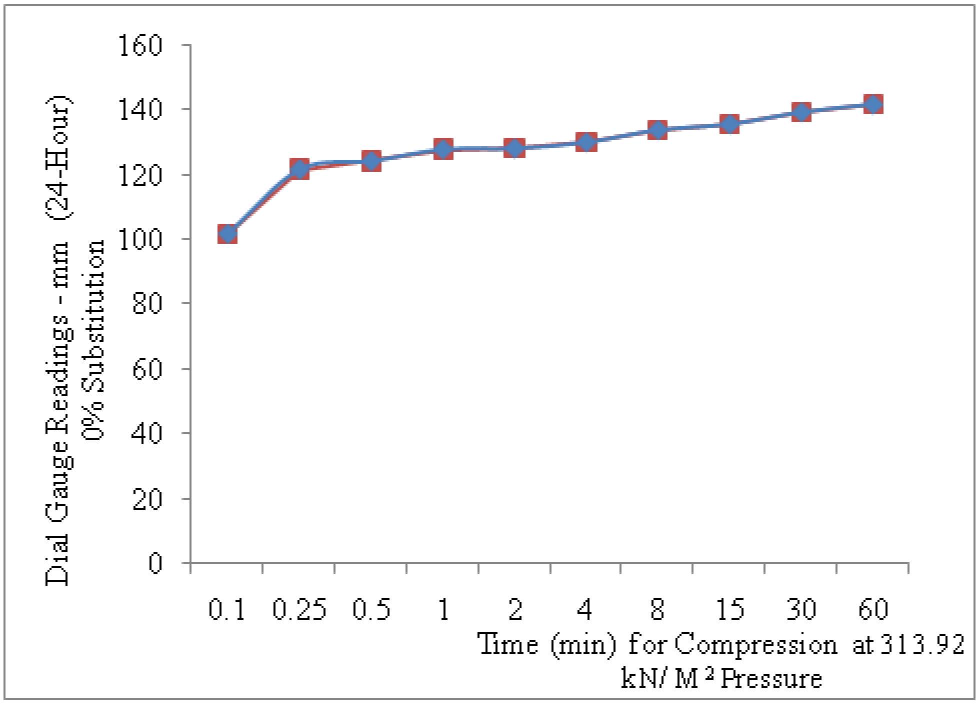

Figure 2: Results of dial gauge reading (mm) against time (min) for 24-hour soaked samples (0% eggshell powder substitution - compression) *:* Difference in Dial Gauge Readings = 40mm

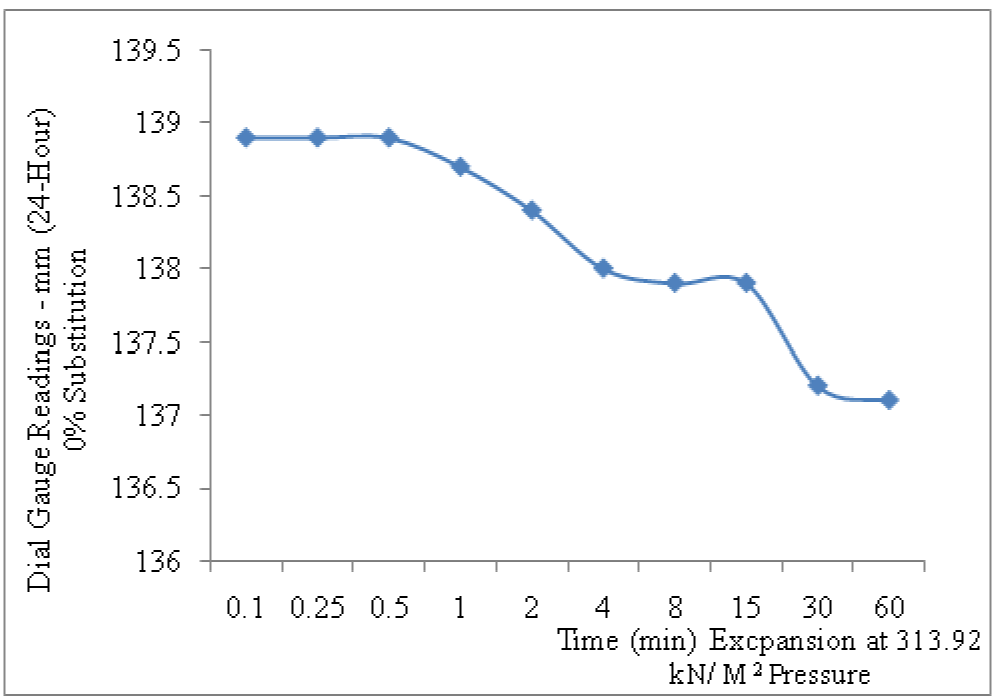

Figure 3: Results of dial gauge reading (mm) against time (min) for 24-hour soaked samples (0% eggshell powder substitution - expansion)*:* Difference in Dial Gauge Readings = 1.8mm

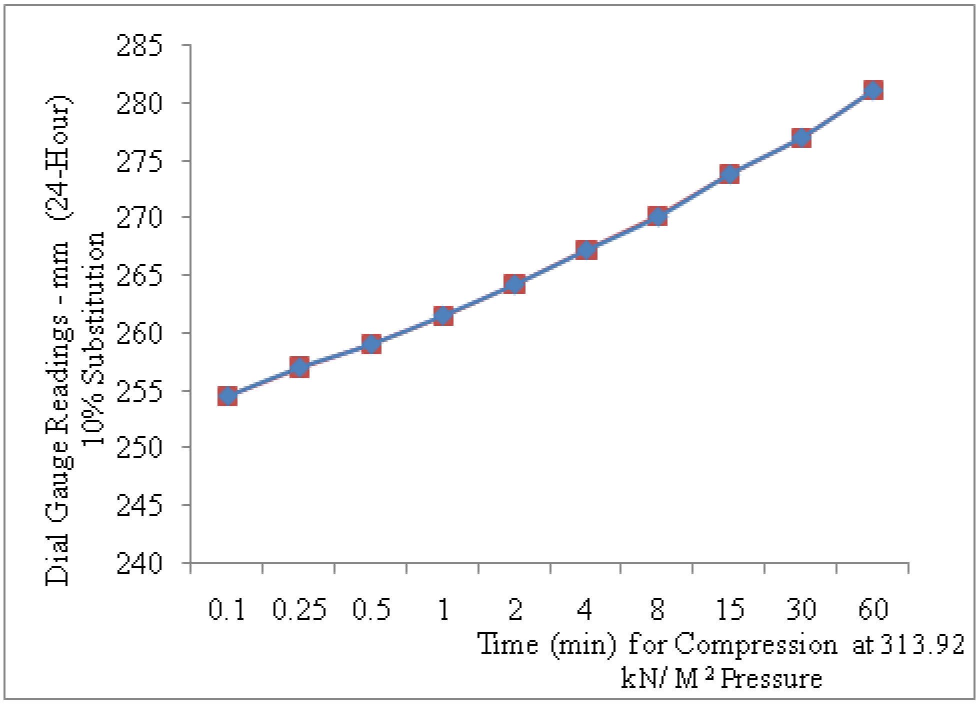

Figure 4: Results of dial gauge reading (mm) against time (min) for 24-hour soaked samples (10% eggshell powder substitution - compression)*:* Difference in Dial Gauge Readings = 26,6mm

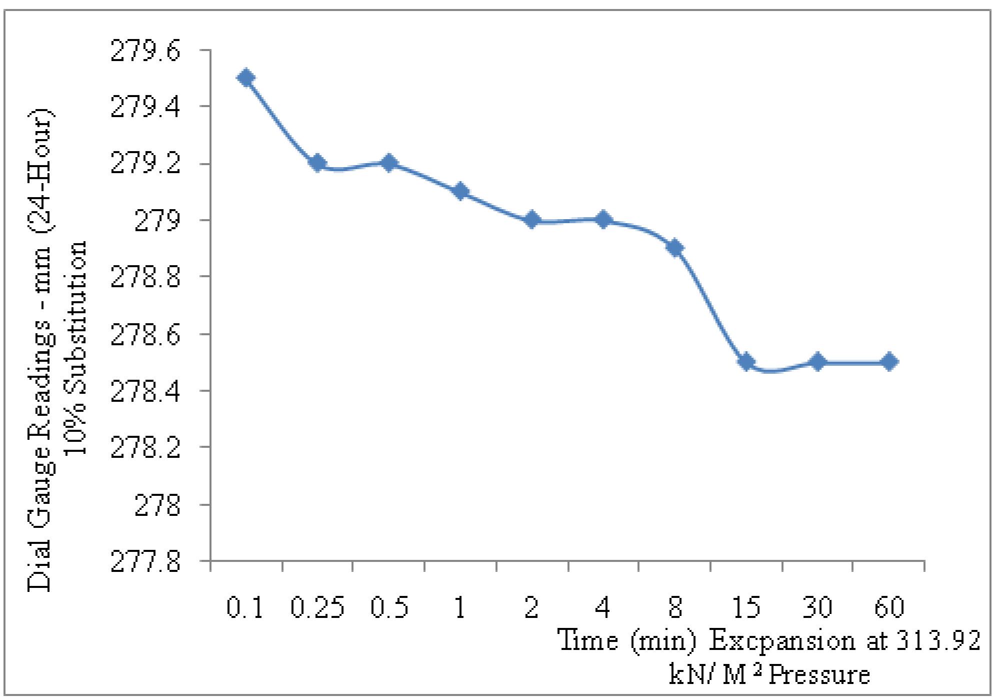

Figure 5: Results of dial gauge reading (mm) against time (min) for 24--hour soaked samples (10% eggshell powder substitution - expansion)*:* Difference in Dial Gauge Readings = 1mm

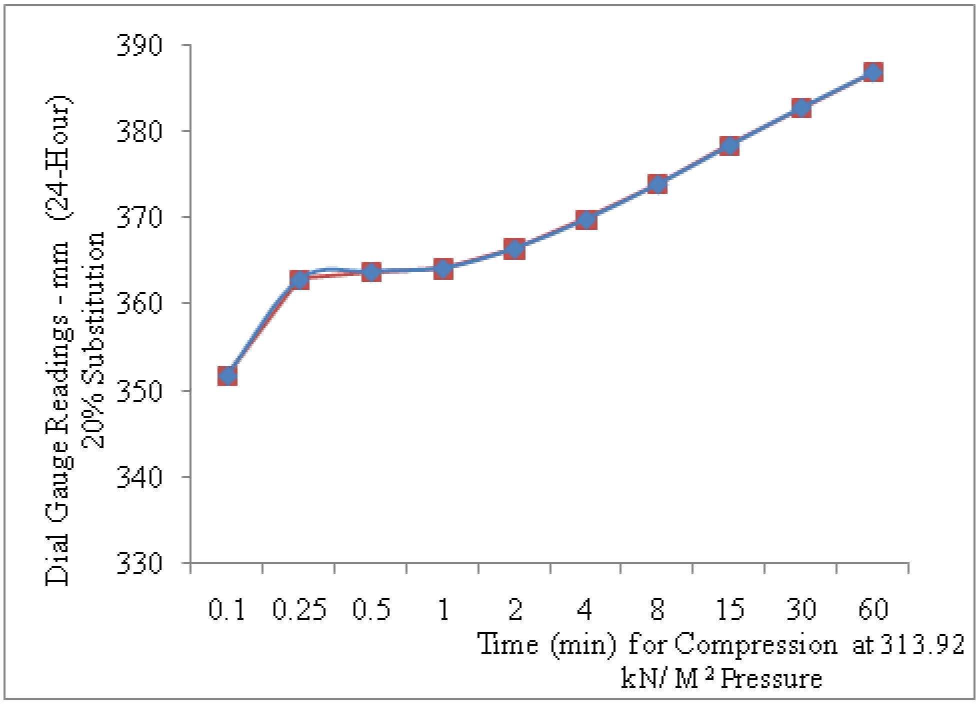

Figure 6: Results of dial gauge reading (mm) against time (min) for 24-hour soaked samples (20% eggshell powder substitution - compression)*:* Difference in Dial Gauge Readings = 35,2mm

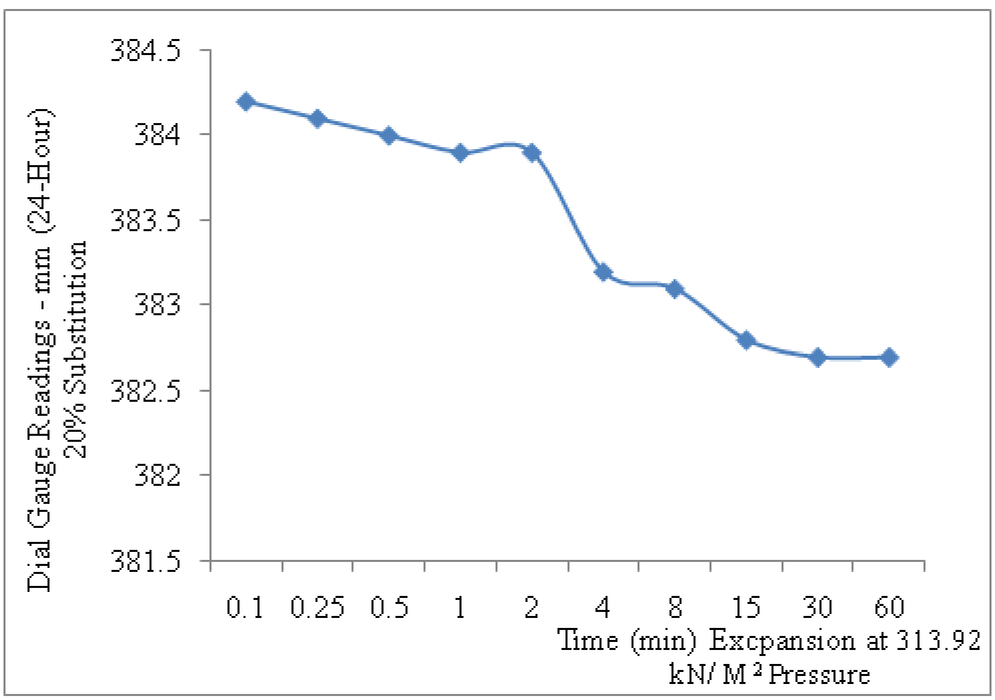

Figure 7: Results of dial gauge reading (mm) against time (min) for 24--hour soaked samples (20% eggshell powder substitution - expansion)*:* Difference in Dial Gauge Readings = 1.5mm

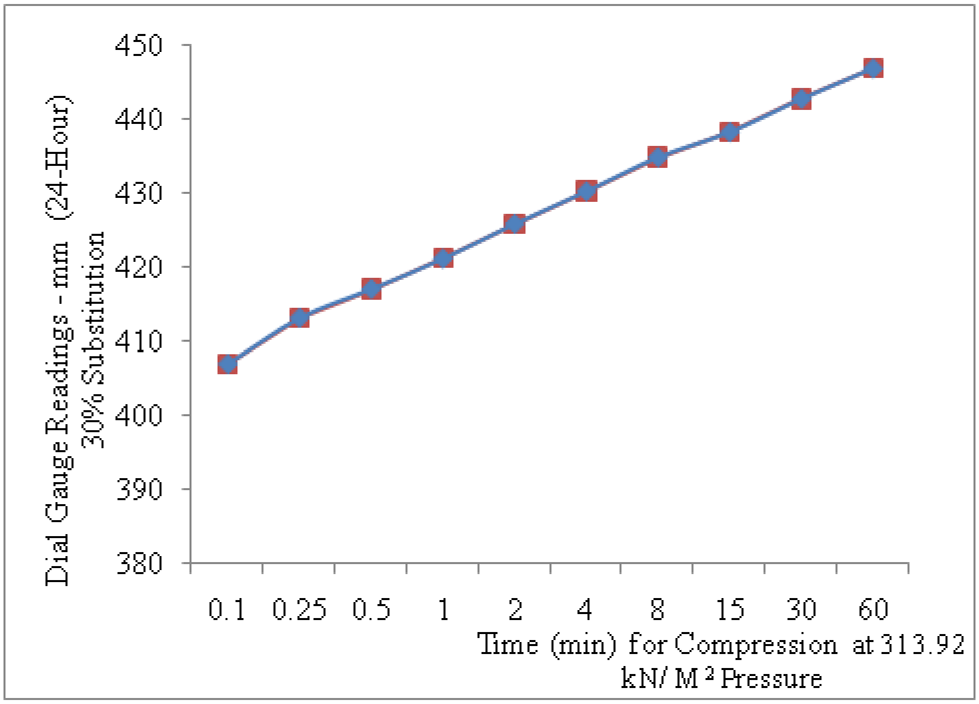

Figure 8: Results of dial gauge reading (mm) against time (min) for 24-hour soaked samples (30% eggshell powder substitution - compression)*:* Difference in Dial Gauge Readings = 39.9mm

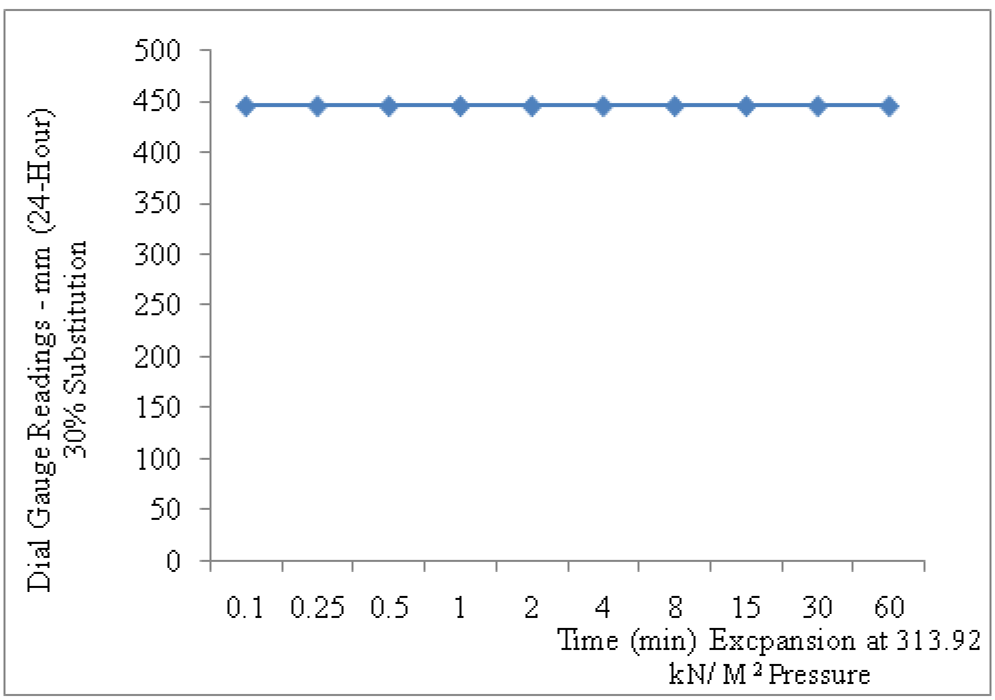

Figure 9: Results of dial gauge reading (mm) against time (min) for 24--hour soaked samples (30% eggshell powder substitution - expansion)*::* Difference in Dial Gauge Readings = 0mm

From the preliminary results, the difference in dial gauge readings shown in Figure 2 is 40mm for compression while the difference in dial gauge readings shown in Figure 3 is 1.8mm for expansion, In addition to this; the difference in dial gauge readings shown in Figure 4 is 26,6mm for compression while the difference in dial gauge readings shown in Figure 5 is 1mm for expansion. Furthermore, the difference in dial gauge readings shown in Figure 6 is 35,2mm for compression while the difference in dial gauge readings shown in Figure 7 is 1.5mm for expansion. Finally the difference in dial gauge readings shown Figure 8 is

39.9mm for compression and the difference in dial gauge readings shown in Figure 9 is 0mm for expansion. From the these preliminary results, for 30% eggshell powder substitution in black cotton soil on basement complex, no expansion was observed after removing the pressure load while for the eggshell powder substitution less than 30%, the expansion is low compared to compression when pressure load is applied. Important constitutive relationship of geo mechanics (soils) explains how stress and strain are related in terms of stress equilibrium and how stress displacement effects ensure compatibility, assuming linear to elastic behavior taking boundary condition (force and displacement) into consideration. In the case of linear elastic behavior (model) of soil, the two (2) elastic constants are enough for the analysis of such material; elastic modulus E Poison's ratio v. In another development, soil behaves nonlinear with stress within yield limit. Direction of incremental stress and incremental strain coincide, which is for homogeneous, isotropic, low stress material that is independent of stress level. For the B-linear model of constitutive relationship of soil, these are divided into two namely elastic perfectly plastic and rigid perfectly plastic. In addition to this, there is linear elastic linear hardening model which is followed by linear elastic nonlinear hardening that takes care of volumetric change. In the case of nonlinear behavior, non permanent behavior is more realistic behavior with parameters depending on stress and/or strain level (tangential increment). Isotropic assumption is valid to ensure two parameters from Elastic modulus E, poison's ratio v, K as well as G with K and G being preferred. Other models of constitutive relationship of soils are non linear elastic nonlinear hardening, K-G model, hyperbolic model, small strain stiffness model and finally, elasto-plastic behavior. In the case of elasto-plastic behavior, it has to do with loading and off-loading, load and reload, permanent setting and/or permanent deformation which are predominant in consolidation tests. Eggshell powder has played this role after off-loading during consolidation test. That is why the difference in dial gauge reading is zero (0) for 30% eggshell powder substitution in black cotton soil. In this case, knowledge of stress-strain relationship beyond yielding is important to understand failure and stress-strain relationship is not unique beyond yielding. Strain at a point not only depends on stress level but also the loading history which is the concept of normally consolidated, over consolidation, dense or loose state of soil materials. In a related development, the typically adopted constitutive relations of soils are elastic, elasto-plastic, or visco-plastic and in the case accidental explosion, whether surface or underground accidental explosion, the initial response is the most important. It involve some plastic deformation that takes place within the vicinity of the explosion and as a result of this one could take the soil i.e. ground media to be an elasto-plastic material. Beyond this, the soil can be taken as an elastic material at certain distance from the explosion. Visco-elastic soils exhibit elastic behavior upon loading followed by a slow and continuous increase of strain at a decreasing rate. Most soils are homogenous, isotropic and anisotropic (i.e. soils with different hydraulic properties in different directions) and in most studies, it is considered as linear elastic, homogeneous, isotropic material. For such material, only two elastic constants are needed to study the geo mechanics/behavior of such body. These can be the usual elastic constants (the Young's modulus, E and Poisson's ratio,ν) or the Lame's constants λ and μ (Billman, 1976; BS1377, 1990; Chen, 1975; Elinwha and Mohmood, 1986; Egbuniwe, 1982; Faridi and Arabhosseini, 2018; Gundaliya and Oza, 2013; Kameswara, 1998; Kogbe, 1976; Kogbe and Obialo, 1976; Kosun, 1990; Lung et al. 2011; Okonkwo et al. 2012; Omatsola and Adegoke, 1981; Rahaman and Ocan, 1978; Sensale, 2009; Udoeyo et al. 2006).

Conclusion

Compression and expansion characteristics and behavior of stabilized black cotton soil on basement complex has been investigated. From the preliminary results, compression behavior is directly proportional to time for all the substitutions of eggshell powder investigated but there is no remarkable and noticeable reduction during expansion while removing the load. The rate and magnitude of expansion is minimal for all the substitutions investigated but at 30% eggshell powder substitution, expansion is zero when removing the pressure load. Efforts are still on-going to determine the relevant consolidation parameters and settlement indices of stabilized black cotton soil on basemen complex as well as sedimentary formation. The materials used for stabilization of these black cotton soils are palm kernel shell and eggshell powder.

Acknowledgement

The author acknowledges the contributions of OLOEOKO-OBA Abdulwaheed, BAMISAYE Ayodele, OGUNJIMI Wale, ADEGBESIN Ayodeji, ADEWUNMI Francis and FALOLA Ebenezer as well as Aro, M. O. for technical assistance in the Geotechnical and Material Laboratories of the Federal Polytechnic Ilaro, Ogun State, Nigeria. Special thanks to Teejay O. Allinson Nigeria Enterprises, Ikate, Surulere, Lagos with palm kernel oil factory located at Olorunsomo, Sabo, Ilaro, Ogun State, Nigeria.

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