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Pressure Load Characteristics of Unsaturated Palm Kernel Shell Stabilized Black Cotton Soil on Basement Complex of Part of South-Western Nigeria

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Abstract: *Black cotton soil, because of its swelling and shrinkage characteristics is a challenge to geotechnical engineers. It is very hard when dry, but losses its strength completely when in wet condition. It exhibits very low bearing capacity, low permeability and high volume change due to the presence of montmorillonite and iolite clay minerals. Modification of black cotton soil by chemical admixtures is a common method for stabilizing the swell-shrink tendency of expansive soils. 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 pit site lies within the coordinates Longitude 7°24'45" and latitude 3°18'34". 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 and was then used to run consolidation tests. The palm kernel shells were broken into pieces passing through 5mm sieve and then substituted for black cotton soil from 0% to 30% at 10% intervals for consolidation and settlement parameters determination while 0% palm kernel shell 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 palm kernel shells to determine the compression and expansion characteristics for the 1-hour soaked samples. From the results, compression behavior is linear meaning, it is directly proportional to time for all the substitutions investigated while for the first 30 seconds, 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.*

Keywords: *Black Cotton Soil, Unsaturated, Consolidation, Palm Kernel Shell.*

Introduction

Expansive soils occupy about 3 % of the world land area and mainly found in Africa, Asia, Australia, and West Indies as well as in vast areas of Russia (Klinkenberg and Higgins, 1972). In Nigeria this soil covers an area of some 104,000 km2 in the Northern eastern fringe (Ola, 1983) of the country including major roads linking the country with neighboring West African countries like Niger, Chad Republic and Cameroun. When the roads are not motorable, this poses a danger to the economy of the region. Tropical black clay otherwise known as Canada‘s swelling clays, India‘s black cotton soil and Kenya black cotton soils can be found all over the world (Chen, 1988). Warren and Kirby (2004) refer to black cotton soils as swelling soils, heaving soils and volume change‖ soils. Sahel (1993) describes expansive clay formations as being favored by the geology, climatic condition and the environment of extreme disintegration, strong hydration and restrained leaching. According to Ola (1983), the Nigerian black cotton soils contain more of the montmorillonite with subsequent manifestation of swelling properties and expansive tendencies. The parent igneous rocks are made up of calcium-rich feldspar and dark minerals which are high in the weathering order and all the constituents are weathered to form amorphous hydrous oxide and under suitable conditions clay minerals develop. The absence of quartz leads to the formation of fine grained plastic soil highly impermeable and easily becomes waterlogged. Other conditions favoring the formation of black cotton soil are evaporation exceeding precipitation, poor leaching, alkaline conditions and retention of magnesium and calcium in the soil (Ola, 1983). Palm kernel wastes produced from small and medium-scale industries pose a serious environmental problem in Nigeria and around the world. A portion of these wastes is used as feed supplements for livestock but most are disposed of by burning in the industry for heating purposes. This practice is an environmental concern and the bye product ash is also a problem which needs to be addressed. Alternative economic disposal methods are necessary and one potential method is to use the wastes as additives to improve soil properties. This research will evaluate the effect of palm kernel shell as an additive to improve black cotton soil. Palm kernel shell has the potential to be used as a partial replacement, leading to reduction in the cost of construction and a convenient means of waste disposal. Thus, the possible use of agricultural wastes (such as palm kernel shell) will considerably reduce the cost of construction and as well as reduce or eliminate the environmental hazards caused by such a waste (Adeniji, 1991; Adepoju, and Olaleye, 2001; Ajaka, 2009; Balogun, 1991; Bairwa et al.. 2013; Bhuyan, 2010; BS 1377, 1990; Chen, 1988; Collins, and Ciesiellski, 1993; Craig, 1987; Eberemu and Sada, 2013; Ibrahim, 1983; Ikeagwuani, 2016;

Klinkenberg, and Higgins, 1972; Morin, 1971; Ibrahim and Ismail, 2012; NBRRI, 1983; Nelson, and Miller, 1992; Ola, 1983; Osinubi, 1995; Osinubi, 1999; Sahel, 1993; Soframine, 1987; Warren and Kirby, 2004).

Background Study

The consolidation of compressible soils is largely of concern to the foundation engineer. Consolidation of poorly compacted soils when loaded with the weight of a foundation is a major geotechnical challenge. Consolidation theory deals with the response of soil systems to imposed load and predicts stresses and displacements of the loaded soil as a function of space and time. This concept is fundamental to the practice of geotechnical engineering where the interaction of soil and water dominates. Consolidation process is even more complex because of the fact that compacted soils are mostly unsaturated. The settlement of structures like embankments, bridge abutments and buildings can produce large displacement, which could be differential and hence produce stresses on the structures over them. This leads to severe cracks and ultimately failure. In engineering practice, reasonably good predictions of a structure's settlement can be made from soil consolidation parameters obtained from the results of carefully run laboratory tests. Black cotton soil is an expansive soil that typically occurs in arid and semi- arid regions of the tropical/temperate zones marked with dry and wet seasons, with low rainfall, poor drainage and exceeding great heat. **Black cotton soil** is a cohesive soil and is considered a difficult or problematic soil for civil engineers, because of their unconventional behavior. **In rainy season black cotton soil swell** due to a higher percentage of **clay and it** swells during the rainy season and cracks in dry season due to shrinkage. The cracks generally are in the range of 100 mm to 150 mm wide and 0.5m to 2m deep. These soils show large volume changes with respect to variation in seasonal moisture content and form part of a major soil group found in South-Western part of Nigeria. They are characterized by high shrinkage and swelling properties. Expansive soils are problematic and normally encountered in foundation engineering designs for highways, embankment, retaining walls backfills, etc. These soils are also found in arid and semi-arid regions of the tropical/temperate zones marked with dry and wet seasons; and with low rainfall, poor drainage and exceedingly great heat. The climatic condition is such that the annual evaporation exceeds precipitation. Expansive soils found in extensive deposits in the North Eastern part of Nigeria referred to as black cotton soils are characteristically dark grey to black soil with high content of clay, usually over 50 % in which montmorillonite is the principal clay mineral (Ola, 1983). Several researches have been carried out on black cotton soil using stabilizers such as lime, cement, bitumen, etc. to improve the strength properties in the past. In the work of Ola (1983), black cotton soil was soaked for 4 days before the test. Little work has been done on the compression and expansion potentials of unsaturated palm kernel shell stabilized black soil on basement complex (Adeniji, 1991; Adepoju, and Olaleye, 2001; Ajaka, 2009; Balogun, 1991; Bairwa et al.. 2013; Bhuyan, 2010; BS 1377, 1990; Chen, 1988; Collins, and Ciesiellski, 1993; Craig, 1987; Eberemu and Sada, 2013; Ibrahim, 1983; Ikeagwuani, 2016; Klinkenberg, and Higgins, 1972; Morin, 1971; Ibrahim and Ismail, 2012; NBRRI, 1983; Nelson, and Miller, 1992; Ola, 1983; Osinubi, 1995; Osinubi, 1999; Sahel, 1993; Soframine, 1987; Warren and Kirby, 2004).

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 pit site lies within the coordinates Longitude 7°24'45" and latitude 3°18'34". 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 (Figures 1 b, c. and d) 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 and was then used to run consolidation tests. The palm kernel shells (Figure 1 d) were broken into pieces passing through 5mm sieve and then substituted for black cotton soil from 0% to 30% at 10% intervals for consolidation and settlement parameters determination while 0% palm kernel shell substitution served as control experiment. In line with BS 1377 (1990) and other relevant codes of practice, 90% consolidation tests were conducted on composite materials of black cotton soil mixed with varying degrees of palm kernel shells to determine the compression and expansion characteristics for the 1-hour soaked samples (Armand et al. (2021); Maail, et al. (2004); Ola, (1983); Craig (1987))

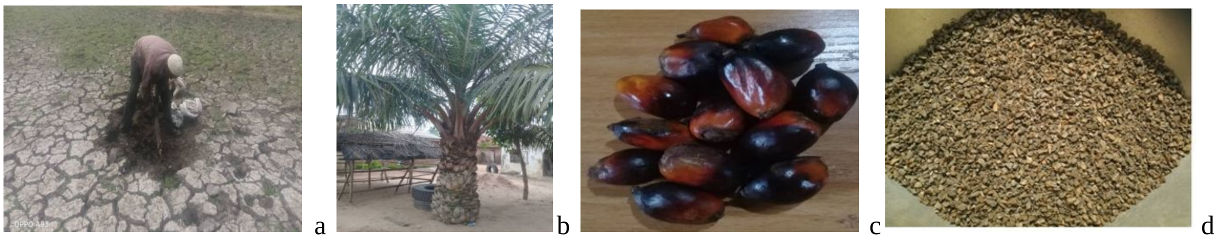

Figure 1: (a) Black Cotton (Expansive) Soil (b) Palm Tree (c) Palm Fruits (d) Palm Kernel Shell

Results and Discussion

The results of dial gauge readings (for maximum pressure of 313.92 kN/m^2) against time (minutes) for various palm kernel shell 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), compression behavior is linear meaning, it is directly proportional to time for all the substitutions investigated and there is no remarkable and noticeable reduction during expansion while removing the pressure load. The rate and magnitude of expansion is minimal for all the substitutions investigated.

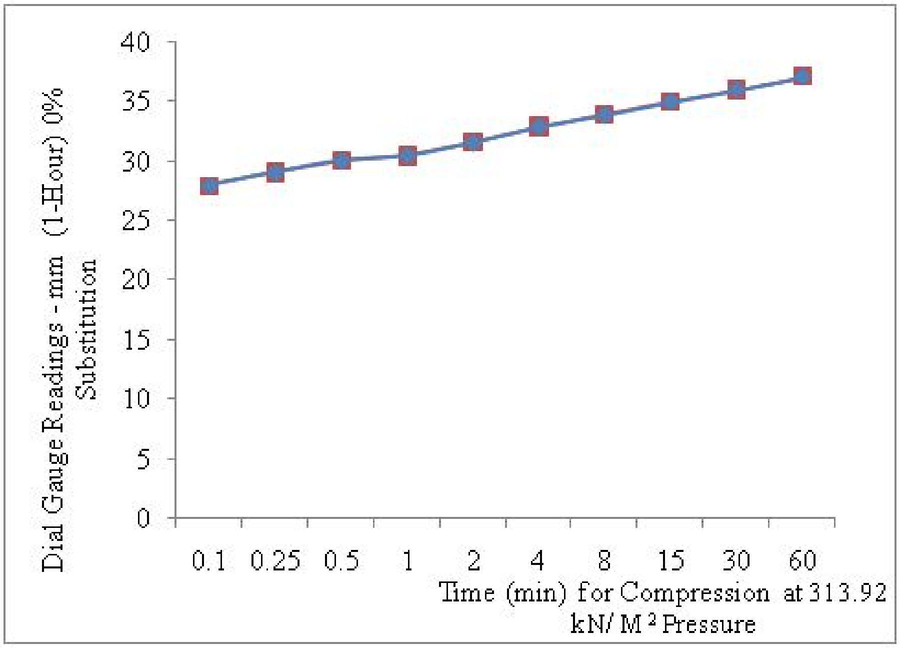

Figure 2: Results of dial gauge reading (mm) against time (min) for 1-hour soaked samples (0% palm kernel shell substitution - compression): Difference in dial gauge reading = 9.1mm

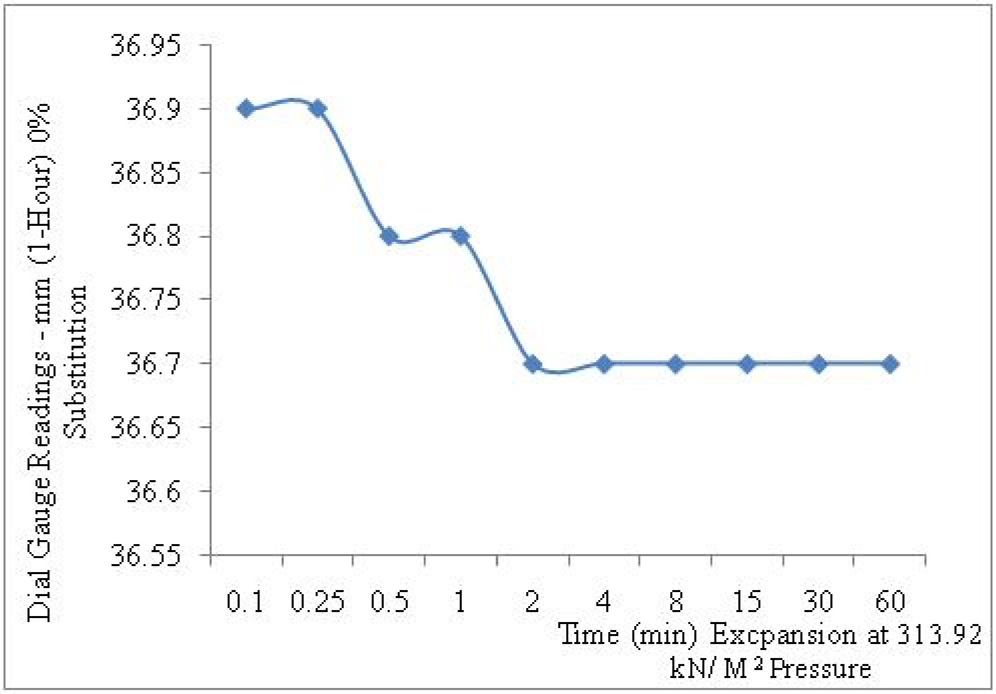

Figure 3: Results of dial gauge reading (mm) against time (min) for 1-hour soaked samples (0% palm kernel shell substitution - expansion): Difference in dial gauge reading = 0.2mm

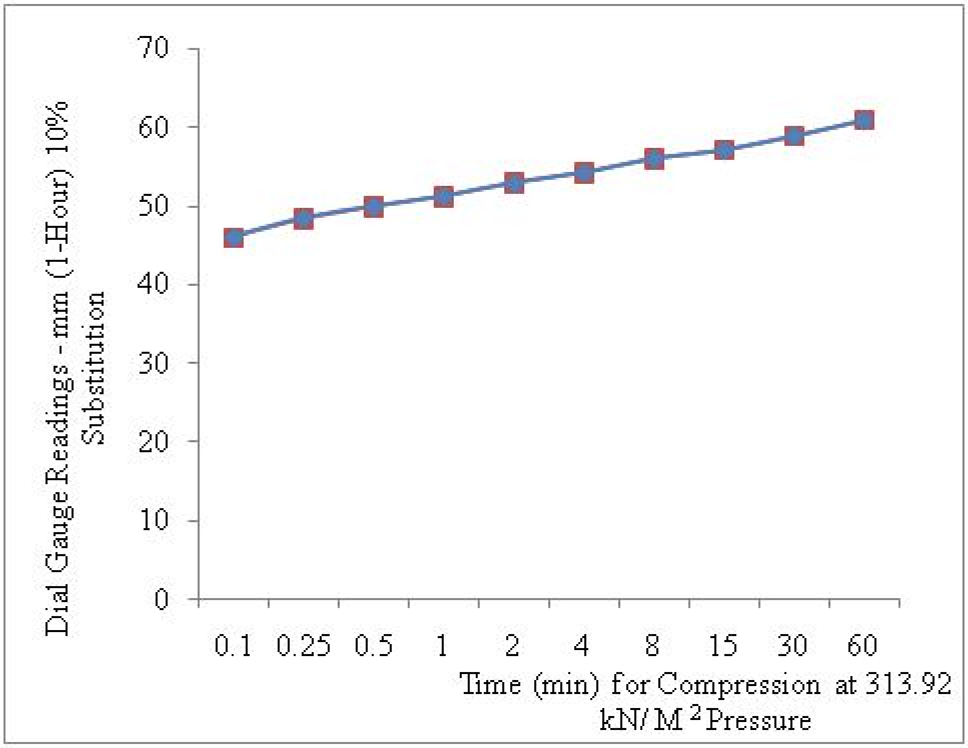

Figure 4: Results of dial gauge reading (mm) against time (min) for 1-hour soaked samples (10% palm kernel shell substitution - compression): Difference in dial gauge reading = 23.9mm

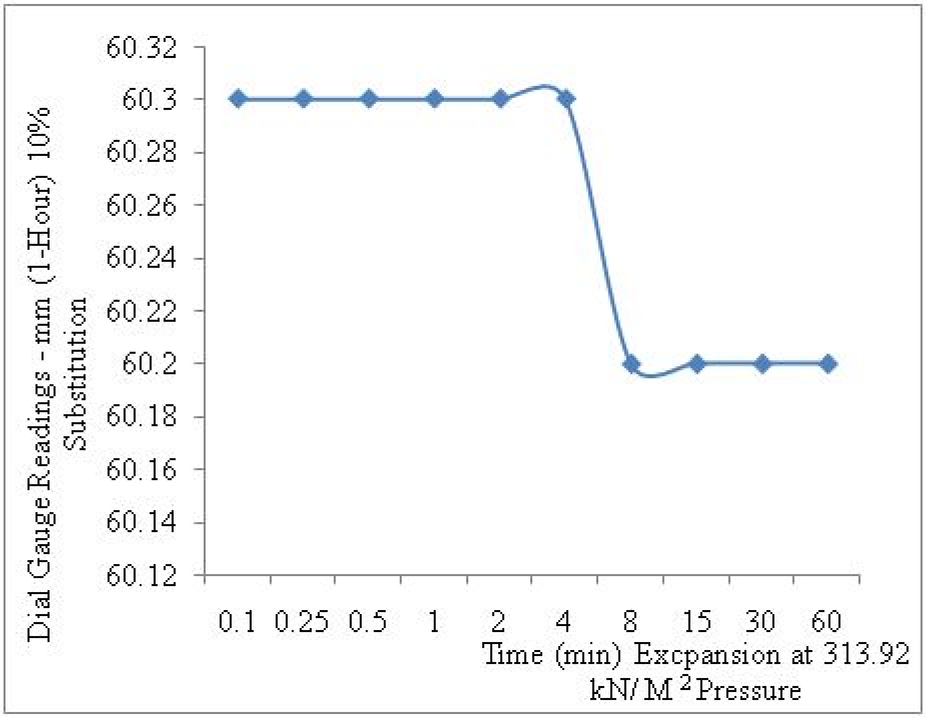

Figure 5: Results of dial gauge reading (mm) against time (min) for 1-hour soaked samples for (10% palm kernel shell substitution - expansion): Difference in dial gauge reading = 0.1mm

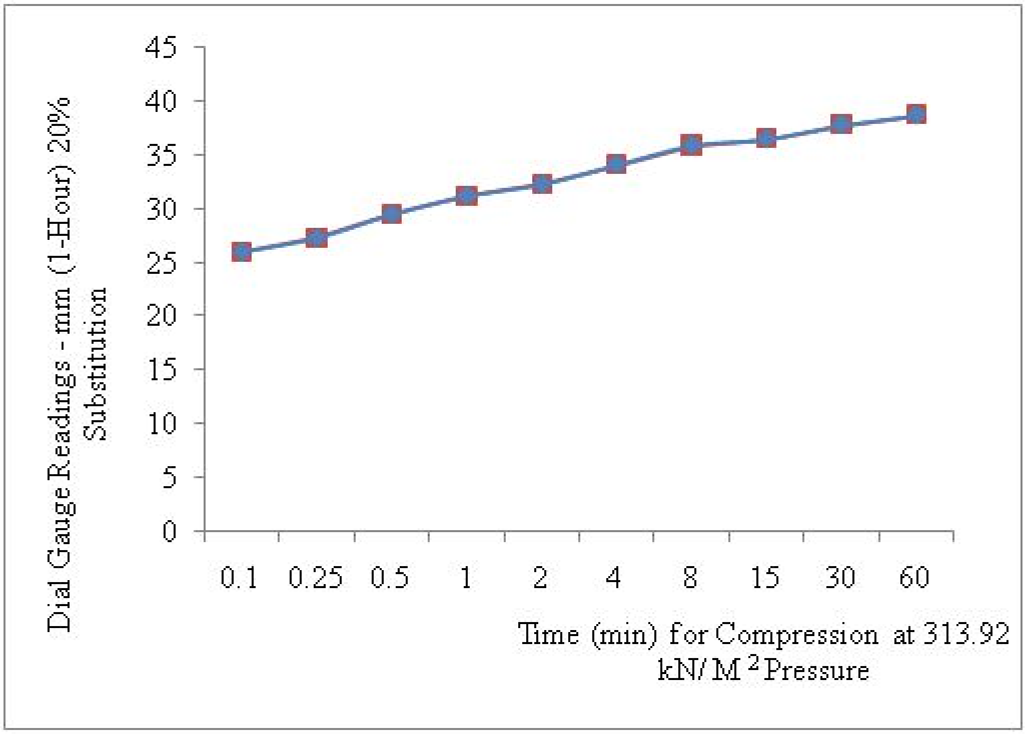

Figure 6: Results of dial gauge reading (mm) against time (min) for 1-hour soaked samples (20% palm kernel shell substitution - compression): Difference in dial gauge reading = 12.7mm

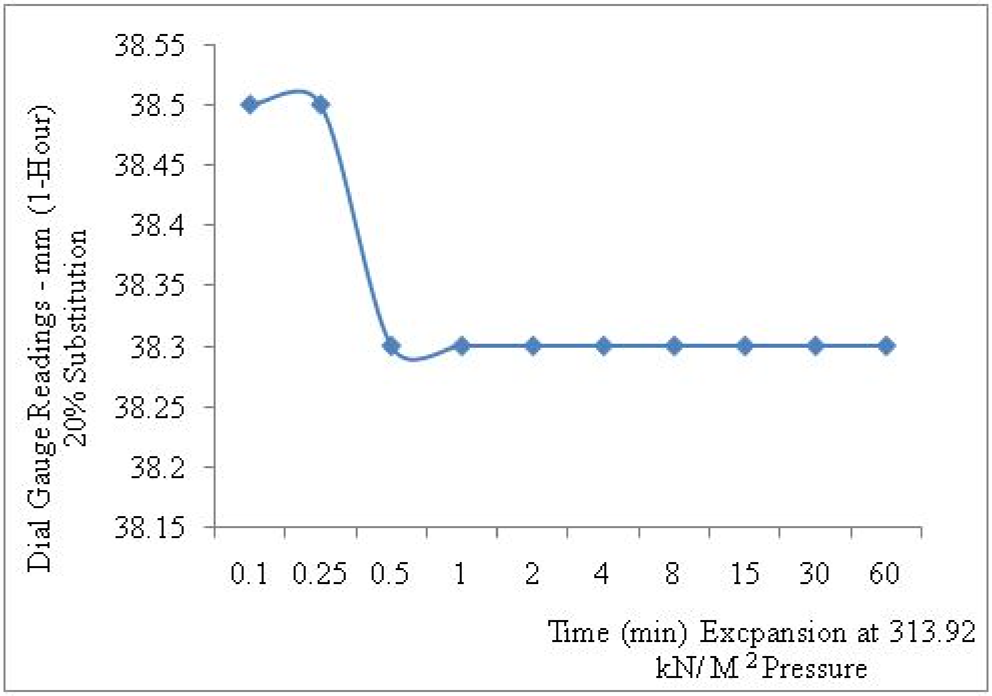

Figure 7: Results of dial gauge reading (mm) against time (min) for 1-hour soaked samples (20% palm kernel shell substitution - expansion): Difference in dial gauge reading = 0.2mm

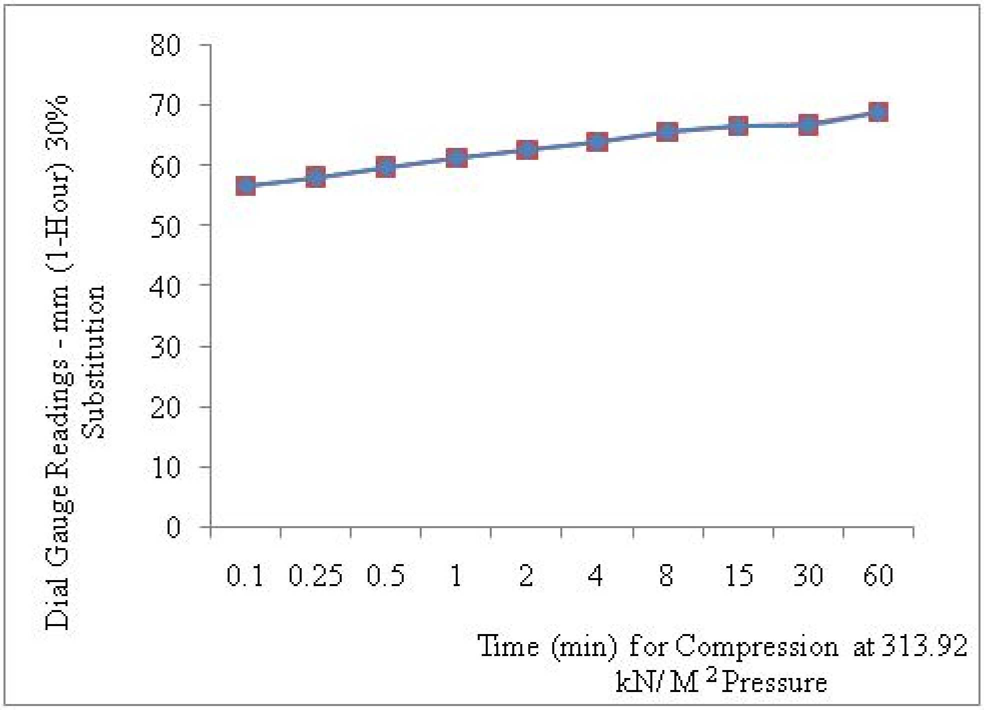

Figure 8: Results of dial gauge reading (mm) against time (min) for 1-hour soaked samples (30% palm kernel shell substitution - compression): Difference in dial gauge reading = 12.2mm

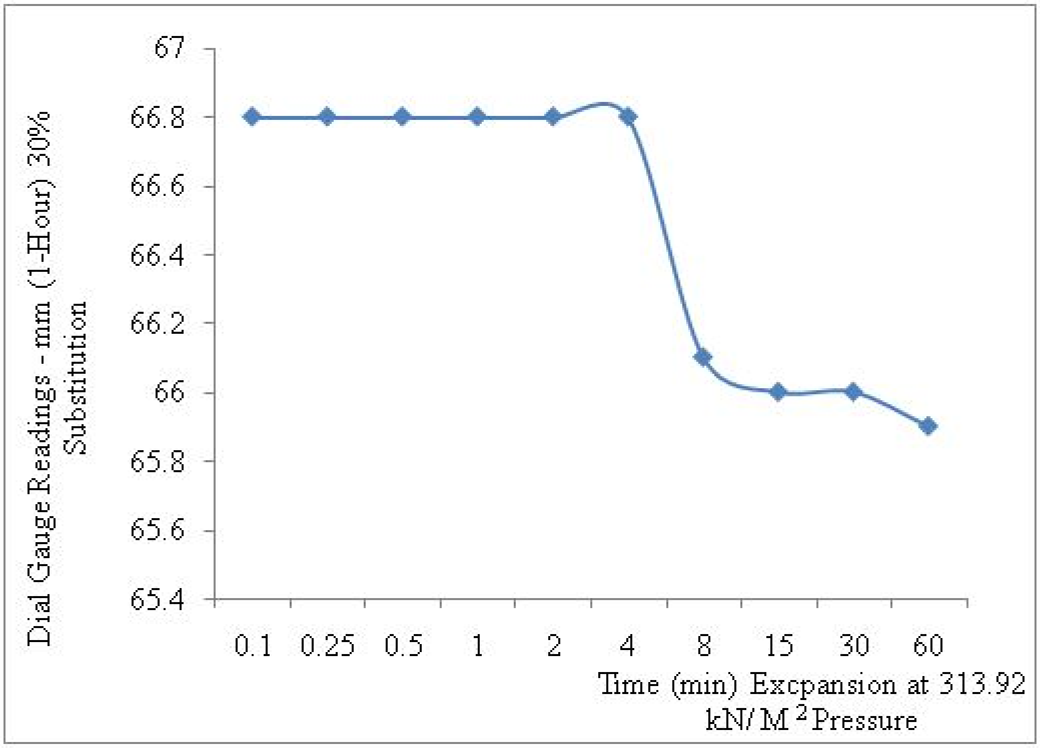

Figure 9: Results of dial gauge reading (mm) against time (min) for 1-hour soaked samples (30% palm kernel shell substitution - expansion): Difference in dial gauge reading = 0.9mm

Figure 2 shows the results of dial gauge readings (mm) against time (min) for 1-hour soaked sample of 0% palm kernel shell substitution (compression), the increase in dial gauge readings for the period of 0.1 to 60 min is minimum (9.1mm) due to the fact that the soil is not fully saturated. In addition, Figure 3 shows the results of dial gauge readings (mm) against time (min) for 1-hour soaked sample of 0% palm kernel shell substitution (expansion). In this case, there is no significant changes in the dial gauge readings due to low moisture content present in the soil, this occur due to the presence of montimorillonite minerals in the soil. Furthermore, Figures 4 and 5 shows the results of dial gauge readings (mm) against time (min) for 1-hour soaked sample of 10% palm kernel shell substitution for both compression and expansion respectively. In the results, Figure 4 shows that there is increase in dial gauge reading (23.9mm) compared to Figure 2 (9.1mm), this is due to 10% palm kernel shell substitution in the black cotton soil which also contributed to its properties while Figure 5 shows no significant value in its expansion. In addition to this, Figures 6 and 7 shows the variation of both the compression and expansion characteristics of the soil respectively. The results obtained for both compression and expansion of 1-hour soaked indicates that there is initial increase in the dial gauge reading value of 20% PKS substitution before the progressive reduction in the dial gauge reading value. The initial increase at 10% PKS could be attributed to the presence of free lime (CaO) in palm kernel shell. Palm kernel shell content increases the cementitious relationship that was hitherto built up initially and began to fade away which does affect the expansion value leading to the drop noticeable in the compression value for 1-hour soaked. Furthermore, Figures 8 and 9 shows the results of dial gauge readings (mm) against time (min) for 1-hour soaked sample of 30% palm kernel shell substitution for both compression and expansion respectively. The results in Figure 8 continue to show reduction in dial gauge readings due to increase in palm kernel shell substitution while in Figure 9, expansion value reduce drastically compared to other results due to very low water absorption rate in palm kernel shell. The compaction characteristics shows increase in compression from 9.1mm to 23.9mm for 10% palm kernel shell substitution but later reduces to 12.7mm and 12.2mm for 20%, and 30% palm kernel shell substitution respectively. Swelling pressure increased with up to 0.9mm with the addition of 30% palm kernel shell substitution (Adeniji, 1991; Adepoju, and Olaleye, 2001; Ajaka, 2009; Balogun, 1991; Bairwa et al.. 2013; Bhuyan, 2010; BS 1377, 1990; Chen, 1988; Collins, and Ciesiellski, 1993; Craig, 1987; Eberemu and Sada, 2013; Ibrahim, 1983; Ikeagwuani, 2016; Klinkenberg, and Higgins, 1972; Morin, 1971; Ibrahim and Ismail, 2012; NBRRI, 1983; Nelson, and Miller, 1992; Ola, 1983; Osinubi, 1995; Osinubi, 1999; Sahel, 1993; Soframine, 1987; Warren and Kirby, 2004).

Conclusion

Compression and expansion characteristics as well as behavior of unsaturated black cotton soil on basement complex have been investigated. From the preliminary results, compression behavior is directly proportional to time for all the substitutions investigated and 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. 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.

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